THE IMPACT OF CLIMATE CHANGE ON SUBTIDAL AND INTERTIDAL BENTHIC SPECIES IN SCOTLAND

Report to Scottish Natural Heritage from the Marine Biological Association of the UK

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THE IMPACT OF CLIMATE CHANGE ON SUBTIDAL AND INTERTIDAL BENTHIC SPECIES IN SCOTLAND

ABSTRACT

Keywords: Climate change; seabed wildlife; species distribution.

1. SNH require to know what impact climate change might currently be having and what effect it might have in the future on seabed wildlife around the coast of Scotland.

2. The marine flora and fauna of Scottish waters, excluding bacteria, non-lichenous fungi, viruses and Protista includes in the order of 8,500 species. About 230 of the 263 seabed biotopes catalogued from around the British Isles are recorded from Scottish waters.

3. Occurrence and distribution of species in Scotland is ultimately determined by seawater temperatures with many species reaching their northern or southern geographical limits in Scotland. Other factors that are important in determining species distributions include the direction of prevailing currents northwards along the west coast and offshore islands and the 'quality' of water on the west coast which seems to favour survival of some species usually associated with the south-west of the British Isles. Biogeographical differences around Scotland are increased by the greater cooling of water during winter in the North Sea.

4. The most recent predictions suggest that, by 2100, average air temperatures may be between 2 and 4°C higher than at present and seawater temperatures may be as much as 2°C higher than in 2000. The rise of inshore seawater temperature may be higher than the oceanic average. In addition to increased air and seawater temperatures, increased storminess and alterations in major current patterns may occur as a result of climate change.

5. Important factors to take into account when identifying likely changes in distribution as a result of warming are the reproductive biology of species, the presence of physical or hydrographic barriers to the spread of species, the importance of water quality, and the possible over-riding importance of local conditions to survival of species. At present, despite evidence of warming in both air and sea temperatures in Scotland in recent years, we cannot point unequivocally to changes in abundance or distribution of seabed species that can be ascribed to climate change around the Scottish coast.

6. The rate of geographical extension or reduction of distributional extent or change in the abundance of species at existing locations in response to increases in temperature are likely to be determined by a range of factors that are represented in a 'key' and decision tree.

7. One hundred and twenty nine species and 30 biotopes are identified as likely to be representative of the changes which may occur in distribution and abundance of species and biotopes in seabed habitats around Scotland as a result of any increased air and sea temperatures over the next 100 years. Distributional and other relevant information is given for 63 species expanded for 23 of those species to provide examples of likely changes in distribution and abundance for scenarios of a rise in seawater temperature of one and two degrees centigrade. Distributional and other relevant information including a description of likely change is given for 21 biotopes which are included in Biodiversity Action Plans or are likely to be modified in composition and/or distribution as a result of any increased air and sea temperatures over the next 100 years.

8. Overall, it is expected that a warming of air and seawater temperatures will result in increased diversity of seabed marine life in Scotland with adverse effects limited mainly to declines in abundance or loss of a small number of northern species. Changes to a minority of biotopes might occur in the long term but they include some that are 'special' to Scotland including maerl and horse mussel beds.

9. Targeted surveys are required now to establish baselines and wider recording schemes focussed on conspicuous easily identified indicator species should be initiated.

THE IMPACT OF CLIMATE CHANGE ON SUBTIDAL AND INTERTIDAL BENTHIC SPECIES IN SCOTLAND

1. INTRODUCTION

1.1 Species and biotopes in Scotland

Based on the collation of species numbers included in Davison (1996), the marine flora of Scotland, excluding bacteria, lichens, non-lichenous fungi and viruses, includes about 2,400 species of which about 800 are benthic algae. The marine fauna of Scotland, excluding Protista, Insecta and Aves includes about 6,090 species of which about 4,500 are benthic species. The wide range of habitats present in Scotland, encompass about 230 of the 263 separate seabed biotopes currently catalogued around the British Isles (derived from the list of biotopes in Connor *et al.*, 1997 a&b). Many of those species and biotopes are widely distributed in the north-east Atlantic, but some species are especially abundant or only found in Scotland in Great Britain. There are no seabed species believed to be endemic to Scotland.

1.2 Current climate – seawater temperatures

The seawater temperature range, both bottom and surface temperatures for summer and winter, for the British Isles are shown in Figure 1. The western coasts are greatly affected by the warm water of the North-East Atlantic Drift. However, the enclosed nature of both the North and Irish Seas means that winter temperatures are much colder than on the open Atlantic coast, although local warming can occur in the summer. Water temperature is of greatest importance in determining the distribution of species although air temperature and the amount of direct sunlight are important for littoral communities.

1.3 Past climates

Climate change is a feature of the history of the earth. Studies of seabed deposits reveal large-scale and long-term changes in species that characterise particular temperature regimes. Climate change including seawater temperature rise may be rapid (see Figure 2). ‘Rapid’ in climate change terms can mean, for instance, that, at the end of the last glaciation, it took almost four centuries for sea surface temperature in the north-east Atlantic to rise by 10 °C (Bard *et al*., 1987). During interglacial periods, climate may still change suddenly (within less than a century) (see, for instance McManus *et al*., 1994; Broecker, 1997; Adkins *et al*., 1997). Written history is much shorter than the geological record but significant changes in air and seawater temperatures have been recorded in the past thousand years or so based on various texts and observations. For instance, Lamb (1977) uses various sources of information including direct temperature readings and fisheries records to conclude that, in about the past 150 years, seawater temperature in the north Atlantic might have risen by about 0.5 to 1.0 °C. Rises in temperatures can be quite rapid; for instance, off southern Iceland the rise between 1910-1919 and 1940-1949 was 2.1°C. Sometimes those changes take place over only a few years or decades but last for centuries. Much further back (between about 800 and 1300 AD), it seems that there was a period when seawater temperatures in the north Atlantic were warmer than today. Some evidence, such as the occurrence of cod off Greenland (cod require water temperatures above 2°C), does suggest higher temperatures than in recent times but other evidence is more circumstantial. The following, which relates to a Viking settlement in southwest Greenland in the years between 985 and 1000 AD, is copied from Lamb (1988):

“*Of one of the leading original settlers, a cousin of Erik the Red, named Thorkel Farserk, who settled at Hvalseyjarfjord, it is related that: ‘He was extremely strong. Erik the Red once visited him. As he wished to entertain his cousin well, but had no serviceable boat at hand, he had to swim out to Hvalsey to fetch a full-grown sheep, and carry it home … it was a distance of well over 2 miles’ …. 10°C would be a fair estimate of the lowest temperature at which a person not specifically trained in long-distance swimming could swim 2 miles, and even then he would have to be fat. …. As the average temperature in the fjords of that*

Figure 1: Recent mean seawater temperatures around Britain for summer (top) and winter (bottom). (From Hiscock, 1998, re-drawn from Lee & Ramster, 1981.).

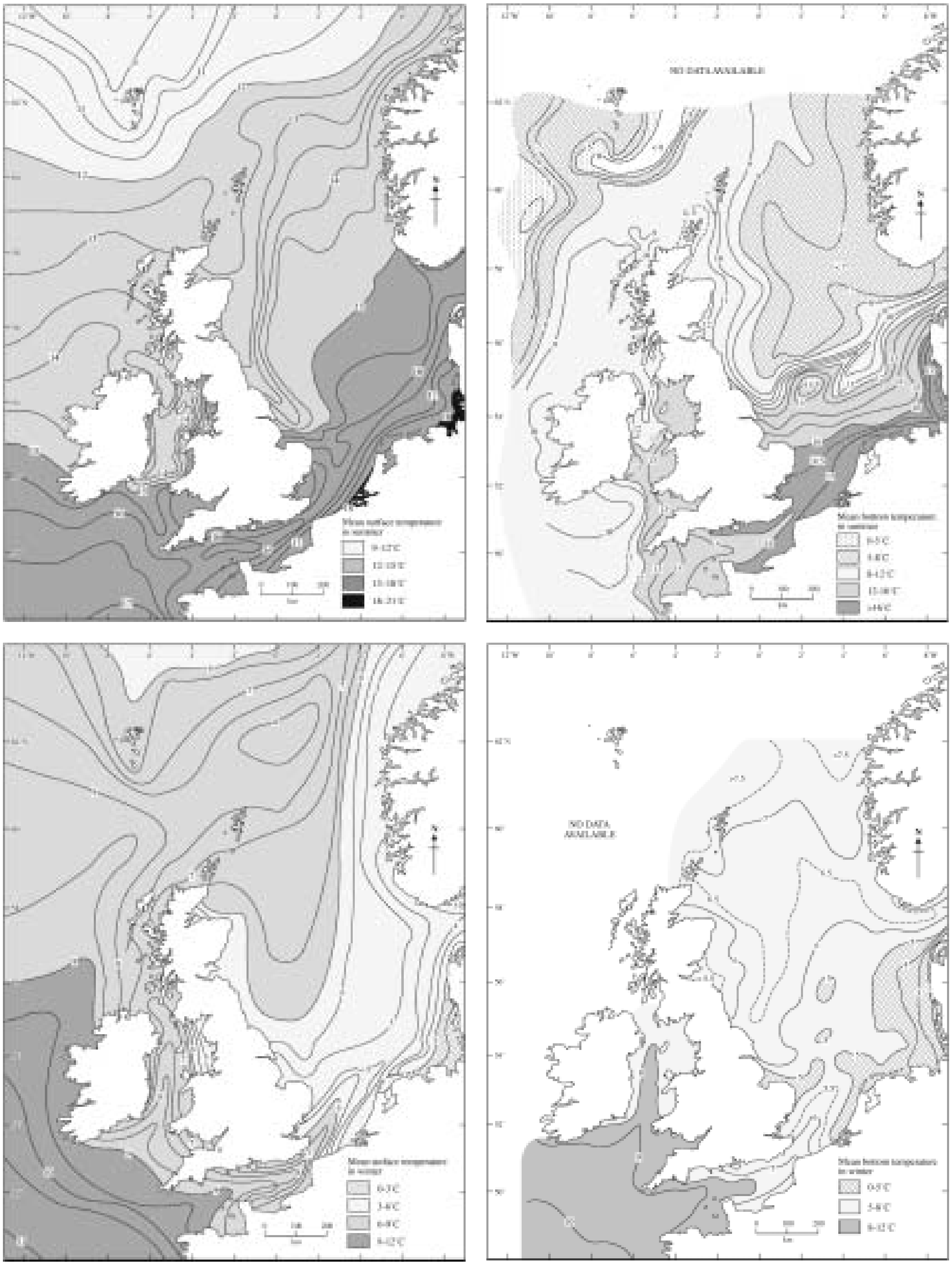
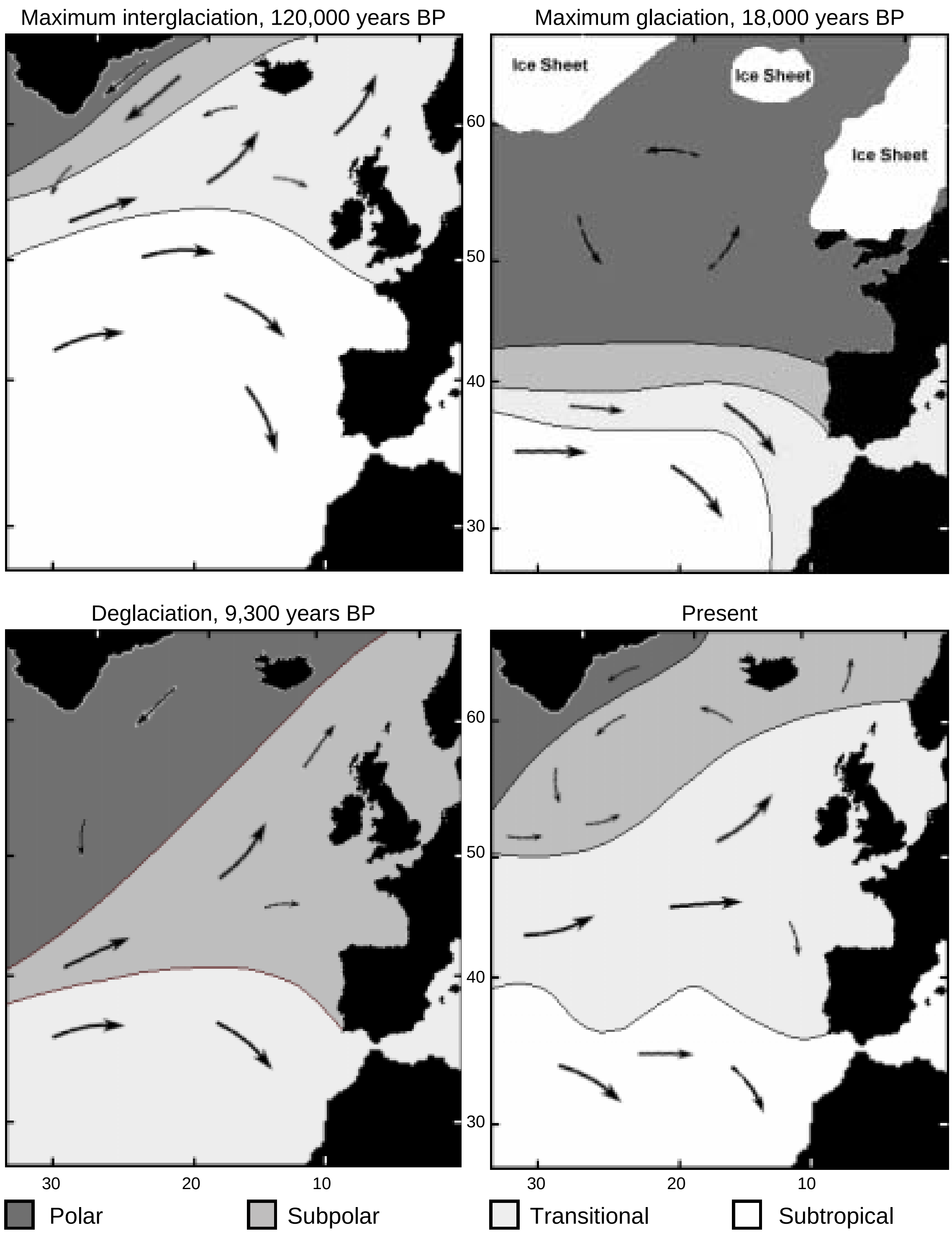


Figure 2: Long-term change. Oceanographic and palaeoceanographic maps of the northeast Atlantic depicting inferred surface currents and ecologic water masses. (After Ruddiman & McIntyre, 1976.).



coast in August in the warm years around 1950 were +3°C to +6°C, it seems that the water must have been at least 4°C warmer in the years concerned in Viking times."

Clearly such stories may exaggerate the physical prowess of the Vikings but it is a useful indicator of different conditions.

1.4 Recent changes in climate

Figure 3: Global surface temperatures (combined land, air & sea temperatures) from 1840 to 1999. (From: http://www.meto.govt.uk/sec5/CR_div/GlobeTemp.) © Crown Copyright.

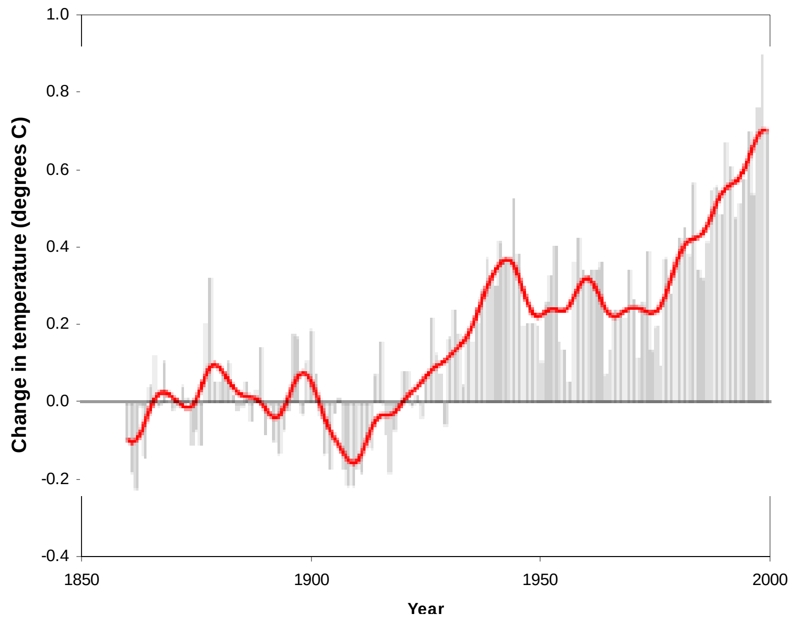
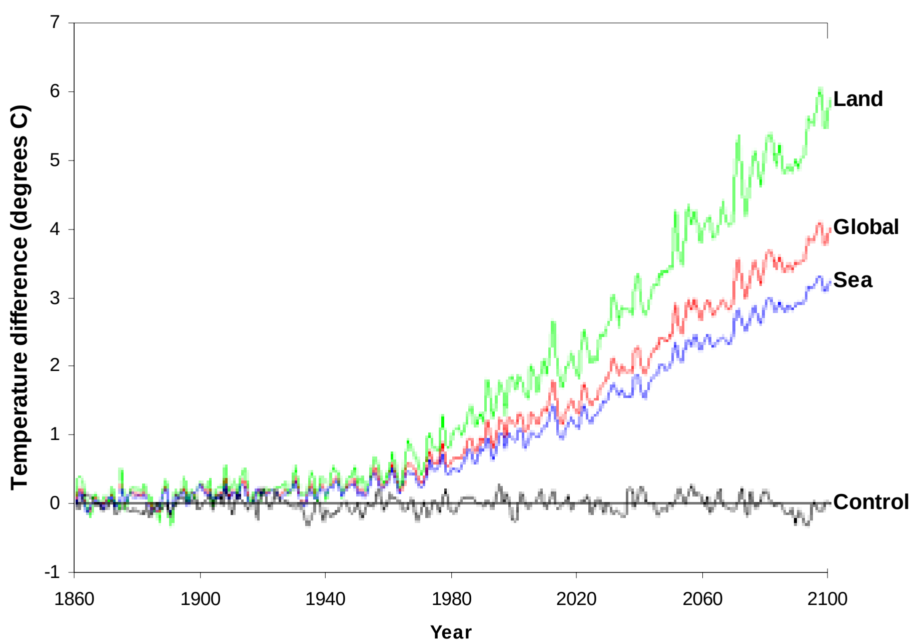


Figure 4: Global temperature rise due to increase in greenhouse gases. Predicted changes in (from upper to lower lines) land, global, sea and 'unperturbed'. (From: http://www.meto.govt.uk/sec5/CR_div/Brochure98/index.html.) © Crown Copyright.



Evidence is now increasing that human activities are influencing climate change and that change includes significant warming of the atmosphere with inevitable consequences on seawater temperature.

The most recent predictions and historical precedents suggest that it is most likely that Scottish inshore waters will be subject to a progressive increase in seawater temperatures over the next few years. By 2100, average air temperatures may be between 2 and 4°C higher than at present; sea level may have risen by 50 cm (www.doc.mmu.ac.uk/aric/ace/online_info/gcc) and seawater temperatures may be as much as 2°C higher than in 2000 (www.meto.govt.uk/sec5/CR_div/Brochure98/index.html; Wood *et al*.1999) However, coastal water temperatures in Scotland have already risen by about 1°C between 1970 and 1998 (Turrell, 1999) and it may be that, in enclosed waters especially, the rise of inshore seawater temperature may be higher than the oceanic average.

All of the evidence currently available suggests that seawater temperatures in inshore waters will:

- continue to show significant short term variations with the possibility of maximum and minimum sea surface temperatures in any one year being 2 °C above or below the average at the time, but
- there will be a trend towards higher average temperatures which, even in the most rapid change scenarios, would be unlikely to result in a long-term increase in average temperature of sea surface temperatures of more than 2 °C over the next 50 years, and
- enclosed waters with restricted exchange to the open sea may warm to a greater extent than average conditions in the open sea and especially if summer air temperatures are significantly warmer than at present.

Predictions of likely seawater temperature rise are much more sparse than for air temperatures but the work of Wood *et al.* (1999) seems to indicate that an increase in temperature of about 3°C between 1858-69 to 2089-99 around Scotland may occur. However, since the temperature of Scottish inshore waters has risen by about 1°C between 1970 and 1998 (Turrell, 1999), temperature rise in those inshore waters might be higher than for the north-east Atlantic generally.

Any true long-term change is likely to be obscured initially by short-term changes driven (for instance) by the decadal but irregular cycle of the North Atlantic Oscillation (Hurrell, 1995), the 11-year cycle of sunspot activity (Southward *et al.*, 1975), or by longer-term fluctuations such as the Russell cycle (Russell, 1973; Flushing & Dickson, 1976; Southward, 1980).

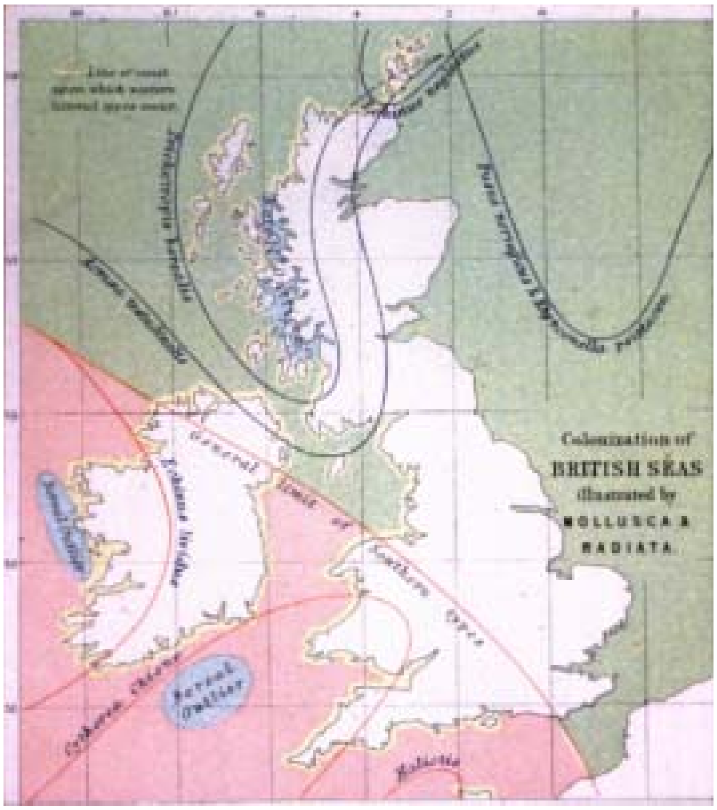
Uncertainties abound – not least the possibility that melting polar ice may resulting in 'switching-off' or at least slowing of the 'Atlantic conveyor belt' which draws warm water northwards along the western seaboard of Europe. Even if changes in seawater temperatures lag behind those on land or are modified by changes in current patterns, intertidal organisms will be influenced by air temperatures and sunlight regimes during emersion.

1.5 Establishing recent effects of climate change in north-east Atlantic waters – finding baselines

The distribution of marine species has been studied for a long time in Britain, although the term 'biogeography' has been in regular use only for the past 60 years. The distribution of marine life was put on a scientific basis by Edward Forbes, during the first half of the 19th century. Forbes was of Scottish descent, brought up in the Isle of Man, and was a competent field worker and taxonomist who also became an expert in geology and palaeontology as head of the Geological Survey. He was appointed to the Chair of Natural

Figure 5: Biogeographical characteristics of the coast of the British Isles including the range limits of some species. From Forbes (1858).

The "Line of coast upon which western littoral types occur" extends along the outer west coast and the north coast of Scotland and includes all of Orkney. Current nomenclature is: Acmaea testudinalis = Tectura testudinalis (a limpet); Cytherea chione = Callista chione (a bivalve); Echinus lividus = Paracentrotius lividus (purple sea urchin); Fusus norvegicus = Volutopsis norwegicus (a snail); Haliotis = Haliotis tuberculata (the ormer); Rhynconella psittacea = Hemithiris psittacea (a snail); Trichotropis borealis (a snail); Echinus neglectus = Strongylocentrotus droebachiensis (a sea urchin).



History in Edinburgh in 1854, but died the same year. His ideas of distribution, including fossils, are given in the first report of the Geological Survey (Forbes, 1848), but his detailed maps of marine life were published posthumously (Forbes, 1858; Forbes and Godwin-Austen, 1859). Figure 5, reproduced from Forbes (1858) is an inset into a larger map of the world, showing the distribution of key species around the British Isles. Forbes recognized an east/west divide in the British Isles. The fauna of the west coasts of Britain, from the Isle of Wight around to the Orkney Islands, includes what Forbes calls "western elements", mostly species of warm water or southern character. In contrast, the eastern coasts of Britain have a more northern character. The British Isles coincide with a boundary between cold-water, northern forms and warmer water, southern species. However, the situation was, and still is, complicated by the occurrence of what Forbes called "outliers". For example "boreal outliers" are cold water species that he showed as present in deeper waters of the western Scottish sea lochs, off Galway and in the western Celtic Sea. Warmer water or "Lusitanian outliers" were shown in the western English Channel. Forbes drew a line across the British Isles, roughly from Beachy Head to Donegal, noted as the general northern and eastern limit of southern types. He also depicted the limited distribution of the warm-water sea urchin *Paracentrotus* (as *Echinus) lividus*, apparently restricted then to the coast of Ireland from south-west Cork to Donegal Bay. We may note that there were no Scottish records of this sea urchin at the time.

The interpretation provided by Forbes is of special importance when considering the effect of climate change on shallow water and intertidal life of Scottish waters. There is the contrast between the eastern and western coasts, and while the outer islands and western coasts include southern species, the deeper western lochs also hold species typical of colder, more northern waters. These boreal outliers might be regarded as relicts of the period when the last ice age was abating and the climate warming. The question is whether these northern species can maintain themselves if further warming occurs, as discussed in later sections of this report.

After the establishment of marine laboratories around Britain in the 1880s, the staff and visitors to these places collaborated in drawing up comprehensive lists of the fauna and flora, as for example at Plymouth, Port Erin, Millport and Cullercoats. Some lists did not get beyond local archives but others have been published as books (Marine Biological Association, 1957; Bruce *et al.*, 1963; Foster-Smith, 2000) and others appeared as occasional publications at various levels of higher taxa (e.g. Wilkie, 1989). These works provide us with valuable detailed baseline data for restricted localities that can then be used to check and improve some of the wider ranging biogeographical surveys.

Further studies of distribution of marine life along British coasts were made in the 1920s, 1930s and 1950s (Fischer-Piette, 1936; Russell, 1935; Moore & Kitching 1938; Crisp & Southward 1958, summarised in Lewis, 1964). Most of these authors were concerned to identify the environmental factors controlling the distributions, including climate and water movements. Field ecological studies of this type became less popular after the 1960s, when it was easier to obtain support for laboratory studies of processes and systems. There was a short revival of interest in distribution in the late 1960s, following disastrous oil-spills, when it became urgent to establish baseline information on British shores (Powell *et al.*, 1979, 1980a, 1980b; Crisp *et al*. 1981). Afterwards, laboratory studies again became ascendent. In the last decade, interest in distribution has been re-kindled to help conserve biodiversity (various reports from the Marine Nature Conservation Review of Great Britain listed in www.jncc.gov.uk/corporate) and to follow the likely consequences of climate change (Southward & Boalch, 1994). A parallel line of investigation of coastal marine life has been the study of its zonation and the factors that structure the community, including biotic interactions as well as abiotic factors. As examples we can cite Lewis (1964) and his later collaborators (references in Moore & Seed, 1985) who studied, among other things, recruitment and who added to our knowledge of geographical distribution. Then there is the school at Port Erin, principally concerned with biotic interactions (references in Rafaelli & Hawkins, 1996), but who were also interested in distribution.

Lewis and co-workers (Lewis, 1964; Lewis *et al.*, 1982; Bowman & Lewis, 1986; Kendall & Lewis, 1986; Lewis, 1986; Kendall, 1987; Kendall *et al.*, 1987; Lewis, 1996, 1999) have undertaken various studies of species which reach or are near their northern limits in Scotland, particularly *Gibbula umbilicalis*, *Chthamalus* spp. and *Patella ulyssiponensis* (*P. aspera*). They provided clear evidence that both the extreme limits and population structure and abundance towards these limits are set by recruitment processes including reproductive output, larval survival and early juvenile survival post-settlement. More recently Lewis (1996, 1999) has eloquently argued the case for use of the study of reproduction and recruitment as a means of monitoring climate change. The detailed published work spanning the 1970s and 1980s will provide an excellent baseline to judge changes with global warming, especially for *G. umbilicalis*. We anticipate these populations will expand as recruitment becomes more regular. There are also many unpublished data for this group that are of value and need to be accessed and archived (M. Kendall, pers. comm.).

Although only a small amount of survey work was published, fortunately there are considerable archives of the results of investigations of Scottish rocky shores from 1953 to

1962. The period from 1962 to 1980 saw a decline in sea temperatures, coinciding with increases in cold water species of plankton and fish in the English Channel (Southward *et al.* 1995). Hence care is needed in interpreting unpublished data on distribution of intertidal and shallow water benthos during this period.

The symposium volume on the Islands of Scotland (Baxter & Usher, 1994), gives a general picture of Scottish inshore marine life and the need for conservation. In that volume Sole Cava *et al.* (1994) take note of the isolating effect of islands upon the genetic make up of marine animals with reduced dispersal, and this must add to the complexity of distribution of marine life in Scottish west coast waters. Animals with a planktonic larval stage may still have difficulties in spreading across sea barriers, even such a short distance as from South Wales to Ireland, a barrier not yet crossed by two southern species - the barnacle *Balanus perforatus* and the limpet *Patella depressa* (Crisp & Southward 1953). Furthermore, the Irish Sea differs environmentally from the more wave-beaten western coasts of Ireland and Scotland, and a species spreading northwards from south-west England might have to colonise Ireland first (e.g. *Chthamalus stellatus* is absent from Northern Irish Sea Basin, Crisp *et al.*, 1981).

Recent observations have been made of changes that might be the result of climatic change. The southern topshell *G. umbilicalis* has increased in abundance greatly within Strangford Lough in Northern Ireland in recent years whilst the northern tortoiseshell limpet *Tectura testudinalis* cannot now be found at the entrance to the lough or on the open coast of the Ards Peninsula in Northern Ireland (J. Nunn, pers. comm.). Similarly, *T. tessulata* has not been readily seen in recent years on the south coast of the Isle of Man (S.J. Hawkins, own observations), where it was previously quite common.

An important feature of the Scottish coast is the contrast between the wave-beaten outer shores and offshore islands and the sheltered habitat of the lochs. As in other regions with long fjords, notably Norway, British Columbia and Alaska, the outer shores are dominated by southern elements, together with a few Arctic or Boreal forms that favour strong wave-beaten habitats. For example, the warm water barnacle, *C. stellatus,* is the only chthamaloid on North Rona; it is a species of wave-beaten headlands on the mainland coast where it may outnumber *Chthamalus montagui*, a species better adapted to embayed conditions. In contrast, the boreo-arctic barnacle, *Semibalanus balanoides* flourishes inside the long mainland sea lochs and is similarly distributed inside the Alaskan fjords. Many of these cold water species appear to be better adapted than the southern types to endure the seasonally varying lower salinities that they may experience inside the lochs/fjords. However, the western coasts of Orkney, the outer Hebrides and Ireland from Donegal to Kerry carry populations of *Fucus distichus anceps,* a boreal alga that prefers extreme wave action. There are other exceptions; some enclosed sea lochs such as Loch Sween, become stratified, like Norwegian '*pollens*' and the intertidal zone may show the southern species, *C. montagui* outnumbering the cold water species *S. balanoides*, in the upper midlittoral.

Catches or sightings of species of fish normally found south of the area where they are reported are frequently considered to be harbingers of climate change. Invertebrate species and algae are much less reported although, for instance, catches of the mantis shrimp, *Squilla desmaresti* in the English Channel in 1999 and its discovery in Cardigan Bay (R. Holt, pers. comm.) caused some excitement (although records of the species in the Channel extend back to 1900). In Scotland, the identification of the southern species of feather star prawn *Hippolyte prideauxiana* at Loch Carron (S. Scott, pers. comm.) may be a chance observation of a long-term presence or may reflect some effect of climate change encouraging larval survival and settlement.

Attempts at a synthesis of distribution of shallow water life have been mostly regionally based (e.g. Fischer Piette, 1936; Crisp & Southward, 1958; for the English Channel coasts: Southward & Crisp, 1954 for Ireland) or else restricted to one or few species (e.g. Moore & Kitching, 1939 for *Chthamalus*; Powell, 1957 for *Fucus distichus*). These last two contributions do deal with Scotland, but have gaps in coverage while treating particular regions in detail. To improve the situation for Scotland, D.J. Crisp and A.J. Southward carried out low budget field surveys of rocky shores from 1953 to 1962, with the help of small grants from the Royal Society. Data from these surveys were supplied to other authors, for example to J.R. Lewis, who published maps of distribution of certain species around the British Isles in his book on rocky shores and made a national synthesis (Lewis, 1964). Other publications taking data from the surveys were Crisp *et al.* (1981) and Southward *et al*. (1995). Unfortunately, compilers of other works on distribution have not been able to make use of these unpublished data, and some authors seem to have passed over the local fauna lists as well, giving erroneous pictures of certain species.

Since there was a cool period in Britain between 1962 and 1980, we should restrict ourselves to the records before 1963 as a baseline and then carry out fresh surveys in the future to determine if distributions have changed. Data from the cool period can be expected to show declines in warm water species and increases in boreal species, such as detected in the plankton and fish in the English Channel (Southward, 1980; Southward *et al.* 1995). There is a problem that there was only a small amount of quantitative estimation in the cool period. For example, many of the biodiversity surveys were and are qualitative or semi-quantitative in their approach.

The Crisp and Southward archives for Scottish localities do contain repeat counts of certain species after 1962, but these are for a few places only and need careful assessment and comparison with the data for south-west England. Annual surveys of certain species were made at up to 40 localities around south-west England from 1955 to 1987, and a few stations have been continued to date. These show definite changes in the intertidal fauna during the cool period, comparable to those seen in plankton and fish. The Crisp and Southward data for Scotland offer some comparisons between 1953/62 and the 1970s/1980s, but there are too few records in the later period to offer statistical proof of change. To detect future changes in Scottish waters we need to set up a network of reasonably accessible stations, enough in number to provide sound statistics, where selected species can be enumerated each year. Much could be done photographically if advantage was taken of new digital technology, providing not only non-intrusive sampling but also a permanent record.

Some specific examples of changes or likely changes in distribution are described in greater detail in Appendix 1.

All-in-all, there are few comprehensive baselines from which to assess change in distribution and abundance of seabed marine species in recent times, and obtaining validated records is a problem. The results of the extensive Marine Nature Conservation Review surveys available on MERMAID (Marine Environmental Resource Monitoring And Information Database) (www.jncc.gov.uk/mermaid/) give a good indication of the distribution of many conspicuous mainly epibenthic species, but some records that are illustrated require checking and validation.

There are authentic early (sixteenth century) accounts of the marine flora of the North Sea from Thanet, Kent in the herballs of Gerard (1597) and Johnson & Gerard (1633). These allow a glimpse of the marine flora at that time, and cite *Fucus serratus*, *Fucus vesiculosus*, *Halidrys siliquosa*, *Laminaria digitata*, *Laminaria saccharina*, *Corallina officinalis*, *Palmaria palmata* and *Ulva lactuca*, species which form the principal vegetational features on the chalk foreshore today. Their continued presence suggests stability in inshore water temperatures over the past 400 years; however, the warm-water brown alga *Padina pavonica* was recorded from Thanet in the nineteenth century. *P. pavonica* reaches its northern distributional limit in southwestern England but occasionally occurs to the north and east (Price *et al*., 1979). Its sporadic occurrence on Thanet may be because it is at the limit of its environmental tolerance and therefore susceptible to small fluctuations in environmental conditions. The spread of *P. pavonica* beyond its generally accepted boundaries could also be an indication of raised temperatures (climate change).

Although such long-term information is not available for the marine flora of Scotland, there are reliable, comprehensive accounts for the nineteenth century which provide a baseline for comparison. These indicate, for example in the Edinburgh area of the Firth of Forth, changes (loss) in the main vegetational features (biotopes) and algal diversity generally; literature accounts and museum records reveal a formerly much richer and luxuriant marine flora compared with that of today (Wilkinson & Tittley, 1979; Wilkinson *et al*., 1988). These changes probably relate to a deterioration in water quality (due to discharge of polluting substances and consequent increased load of particulate matter) than to inshore water temperatures. Another example is for the Orkney Islands; two areas in particular (Skaill Bay and Kirkwall) have a good recorded history with extensive records from Traill in the 1880s and herbarium specimens at the Natural History Museum from the 1830s. The results of field surveys were also undertaken in1973 and recently in 1998/9 suggest little change at Kirkwall in the last 26 years but show that many species may have been lost since the 19^{th} century (Wilkinson *et al*., 2000). This could be ascribed to large scale coastal reclamation at Kirkwall about 100 years ago. At Skaill Bay, in contrast, species loss has not occurred suggesting stability in marine algal assemblages over the past two centuries despite increased inshore sea temperatures (see above).

1.6 Evidence for effects of change in species due to seawater warming elsewhere

Responses of benthic species to increases (or decreases) in seawater temperatures over long periods are sparse. Barry *et al.* (1995) report significant increases in the density of southern intertidal species and decreases in abundance of northern species at Monterey, California during the period from 1932 to 1993. During that period, mean summer maximum air temperatures increased by about 2.2 °C and shoreline seawater temperatures by about 0.75 °C (Sagarin *et al.*, 1999).

There is far more evidence for fisheries with switches in species being recorded for sardine and anchovy which may be linked to temperature either directly or indirectly due to changes in oceanographic regime including upwelling (Cushing, 1975). Fluctuations in recruitment and hence abundance of a variety of stocks have also been linked to climate (Cushing, 1975). Cushing & Dickson (1976) have summarized climate-related biological trends in north-east Atlantic waters up to 1975. Planktonic changes have also been recorded following the analysis of long term data from continuous plankton recorders (Aebischer *et al.*, 1990).

2. SPECIES AND BIOTOPES TO BE RESEARCHED

2.1 Species and biotopes included in statutes, directives and Biodiversity Action Plans

All of the inshore seabed species and biotopes that occur in or near Scottish waters and that are specifically identified for protection under legislation including directives or for which Biodiversity Action Plans have been prepared are included in Appendix 2 and 3. However, the ‘habitats’ included in the Habitats Directive can encompass most rock and many sediment biotopes present in Scotland and are not therefore included in the review.

2.2 Species and biotopes with a restricted distribution in Scotland

Appendix 4 gives the ‘long-list’ of species with good distributional records that were first considered (and which others might consider) to have climatically restricted distributions in or near Scotland. The Appendix also includes reasons, where relevant, for exclusion from the final short-list of representative or important species for detailed research. Table 1 shows those species which have northern or southern centres of distribution. The northern species are expected to decrease in abundance, have a more restricted range or even become extinct in some cases in Scotland. The southern species have been divided into:

1. those that at present are not found in Scotland, but are expected to spread there due to climate change, and
2. those species that are already recorded in Scotland and are expected to extend their range or increase in abundance due to global warming.

Table 1: Northern and southern species with good distributional records that are considered to have climatically restricted distributions in or near Scotland.

** = Species recommended for establishment of current distribution and abundance and to be considered in schemes for monitoring change. Further information on each species is given in Appendix 4. (Names follow Howson & Picton, 1997 except for* Pentapora fascialis *(Pallas)).*

Southern species not currently recorded in Scotland but which may spread to Scotland	**Southern species currently recorded in Scotland whose extent of distribution or abundance might increase**		**Northern species which may either decrease in abundance and extent or disappear from Scotland**
*Ciocalypta penicillus **	*Axinella dissimilis **	*Crassostrea virginica*	*Thuiaria thuja **
Haliclona angulata	*Hemimycale columella*	*Cerastoderma glaucum*	*Swiftia pallida **
Gymnangium montagui	*Phorbas fictitius*	*Gari depressa*	*Bolocera tuediae*
*Eunicella verrucosa **	*Haliclona cinerea*	*Pentapora fascialis **	*Phellia gausapata **
Aiptasia mutabilis	*Haliclona fistulosa*	*Asterina gibbosa*	*Lithodes maia*
*Balanus perforatus **	*Haliclona simulans*	*Paracentrotus lividus **	*Tonicella marmorea*
*Maja squinado **	*Alcyonium glomeratum **	*Holothuria forskali **	*Margarites helicinus*
*Osilinus lineatus **	*Anemonia viridis **	*Centrolabrus exoletus*	*Tectura testudinalis **
*Patella depressa **	*Aulactinia verrucosa*	*Crenilabrus melops*	*Onoba aculeus*
Crepidula fornicata	*Corynactis viridis*	*Ctenolabrus rupestris **	*Colus islandicus*
Tritonia nilsodheri	*Sabellaria alveolata*	*Labrus mixtus **	*Akera bullata*
Solen marginatus	*Chthamalus montagui **	*Thorogobius ephippiatus*	*Limaria hians*
Phallusia mammillata	*Chthamalus stellatus **	*Scinaia trigona*	*Anomia ephippium*
Scinaia furcellata	*Hippolyte huntii*	*Asparagopsis armata*	*Thyasira gouldii*
Chondracanthus acicularis	*Palinurus elephas **	*Bonnemaisonia hamifera*	*Leptometra celtica*
*Stenogramme interrupta **	*Polybius henslowi*	*Naccaria wiggii*	*Leptasterias muelleri*
Laminaria ochroleuca	*Ebalia tumefacta*	*Jania rubens*	*Semibalanus balanoides **
*Bifurcaria bifurcata **	*Corystes cassivelaunus*	*Lithothamnion corallioides*	*Lithodes maia **
*Cystoseira baccata **	*Liocarcinus arcuatus*	*Mesophyllum lichenoides*	*Strongylocentotus*
Cystoseira foeniculaceus	*Liocarcinus corrugatus*	*Calliblepharis ciliata*	*droebachiensis **
	Goneplax rhomboides	*Kallymenia reniformis*	*Cucumaria frondosa **
	Pilumnus hirtellus	*Rhodymenia delicatula*	*Styela gelatinosa **
	Xantho incisus	*Rhodymenia holmesii*	*Lumpenus lumpretaeformis*
	Xantho pilipes	*Rhodymenia pseudopalmata*	*Zoarces viviparus*
	Tricolia pullus	*Halurus equisetifolius*	*Lithothamnion glaciale **
	*Gibbula umbilicalis **	*Sphondylothamnion multifidum*	*Phymatolithon calcareum*
	*Patella ulyssiponensis **	*Drachiella heterocarpa*	*Callophyllis cristata*
	Bittium reticulatum	*Drachiella spectabilis*	*Odonthalia dentata **
	Cerithiopsis tubercularis	*Stilophora tenella*	*Sphacelaria arctica*
	Melaraphe neritoides	*Halopteris filicina*	*Sphacelaria mirabilis*
	Calyptraea chinensis	*Dictyopteris membranacea**	*Sphacelaria plumosa*
	Clathrus clathrus	*Taonia atomaria **	*Chorda tomentosa*
	Ocenebra erinacea	*Carpomitra costata **	*Ascophyllum nodosum mackii*
	Acteon tornatilis	*Cystoseira tamariscifolia*	*Fucus distichus distichus **
	Pleurobranchus membranaceus	*Codium adhaerens**	*Fucus evanescens*
	Atrina fragilis	*Codium tomentosum*	

Table 2 gives the 'long-list' of biotopes with good distributional records that were first considered (and which others might consider) to have climatically restricted distributions in or near Scotland. Appendix 5 provides more detailed information and includes reasons, where relevant, for exclusion from the short-list of representative or important biotopes for detailed research.

*Table 2. Biotopes with good distributional records that are considered to have climatically restricted distributions in or near Scotland and that might be affected by climate change. * = Biotopes for which more detailed information is given in Appendix 6.*

Biotopes found only or predominantly in Scotland in Great Britain		**Biotopes found predominantly south of Scotland in Great Britain**	
Code	Name	Code	Name
ELR.FR.Fdis*	*Fucus distichus* and *Fucus spiralis* f. *nana* on extremely exposed upper shore rock.	ELR.MB.Bpat .Cht*	*Chthamalus* spp. on exposed upper eulittoral rock.
SLR.FX.AscX .mac*	*Ascophyllum nodosum* ecad. *mackii* beds on extremely sheltered mid eulittoral mixed substrata.	MLR.Sab .Salv*	*Sabellaria alveolata* reefs on sand-abraded eulittoral rock.
ECR.BS.Hbow Eud*	*Halichondria bowerbanki*, *Eudendrium arbusculum* and *Eucratea loricata* on reduced salinity tide-swept circalittoral mixed substrata.	LR.Rkp.Par	*Paracentrotus lividus* in shallow eulittoral rockpools.
ECR.Efa .CCParCar*	Coralline crusts, *Parasmittina trispinosa*, *Caryophyllia smithii*, *Haliclona viscosa*, polyclinids and sparse *Corynactis viridis* on very exposed circalittoral rock.	LR.Rkp.FK .Sar	*Sargassum muticum* in eulittoral rockpools.
MCR.Xfa. ErSSwi*	Erect sponges and *Swiftia pallida* on slightly tide-swept moderately exposed circalittoral rock.	LR.Rkp.Cor*	*Corallina officinalis* and coralline crusts in shallow eulittoral rockpools. [1]
ECR.Alc ECR.AlcC ECR.Alc.MaS	*Alcyonium digitatum* dominated biotopes.	MCR.Xfa. ErSEun	Erect sponges, *Eunicella verrucosa* and *Pentapora foliacea.*
ECR.BS .HbowEud	*Halichondria bowerbanki*, *Eudendrium arbusculum* and *Eucratea loricata* on reduced salinity tide-swept circalittoral mixed substrata.		
MCR.M.ModT* SCR.Mod* CMX.ModMx* CMX.ModHo	*Modiolus* dominated biotopes.	CMX.SspiMx*	*Sabellaria spinulosa* and *Polydora* spp. on stable circalittoral mixed sediment.
IGS.Mrl.Phy*	*Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand		

IGS.Mrl.Lgla*	*Lithothamnion glaciale* maerl beds in tide-swept variable salinity infralittoral gravel.	
IMX.MrlMx .Lcor*	*Lithothamnion corallioides* maerl beds on infralittoral muddy gravel.	
IGS.FaG .HalEdw*	*Halcampa chrysanthellum* and *Edwardsia timida* on sublittoral clean stone gravel.	
IMS.Sgr.Rup*	*Ruppia maritima* in reduced salinity infralittoral muddy sand.	
CMS.Ser*	*Serpula vermicularis* reefs on very sheltered circalittoral muddy sand.	
CMU.SpMeg .Fun*	Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral soft mud.	

[1] Sub-biotopes especially

Additionally, some biotopes already present in Scotland but neither predominantly northern or southern may change as a result of climate change (CMU.Beg*: *Beggiatoa* spp. on anoxic sublittoral mud).

2.3 Selecting species and biotopes to be included in assessment

Only those species and biotopes likely to change significantly as a result of climate change around Scotland have been included in library research. Seabed species and biotopes for library research have been further identified using the following criteria:

1. species (i.e. northern species) that reach the southern limits of their range in Scotland;
2. species (i.e. southern species) that reach the northern limits of their range in Scotland or in nearby Ireland, England and/or Wales;
3. species and biotopes included in UK Biodiversity Action Plans and that occur in or near Scotland;
4. species and biotopes listed in directives and conventions;
5. species and biotopes that are particularly abundant or only found in Scottish waters in the UK;
6. species where a significant proportion of the world population occurs in Scottish waters;
7. biotopes that presently only occur further south than Scotland but that might extend to Scottish waters as a result of climate change;
8. species that may be representative, through their reproductive biology, abundance and distribution, of a suite of similar species.

3. LITERATURE REVIEW - CURRENT DISTRIBUTIONS

3.1 The sources and nature of distributional records

Most sources of information about distribution of species (usually identification guides or monographs about taxonomic groups) are generalised descriptions. Some, for instance, distributional atlases for molluscs (Seaward, 1982, 1990, 1993) and decapod Crustacea (Clark, 1986) provide maps within large sea areas which are unhelpful for indicating geographical extent of distribution. Where texts give specific geographical locations for species, they have proved invaluable. Unpublished data collected by A.J. Southward and D.J. Crisp in the late 1950's and early 1960's (at the end of the last warm period) have been collated for the current study and used in mapping distributions of species. Some site-specific records required for the present study are held in unpublished databases that we have not accessed. However, many records have been brought together in the Marine Nature Conservation Review (MNCR) database (MacDonald & Mills, 1996). The results of MNCR and other surveys included on the MNCR database are now available on the Internet on MERMAID (Marine Environment Research, Mapping And Information Database) (www.jncc.gov.uk/mermaid) which has been used in this review. However, some records on this database require confirmation as errors may have been made in identification or entry into the database. Valuable sources of information on the distribution of algae which have been used in this study are the review of algal distributions in Scotland by Maggs (1986) and the atlas of 100 species from the British Phycological Society recording scheme (Norton, 1985). South and Tittley (1986) identify that, of the 1200 species of benthic algae listed for the North Atlantic, 423 species are recorded from Scotland excluding Shetland and 274 are recorded from Shetland. Sixteen of these Shetland species are not recorded from the rest of Scotland although 13 of them are recorded from England. Therefore there are three species which have their only British records in Shetland. France is the most species-rich area of the north Atlantic followed by England, northern Spain and Ireland. Additionally, the results of a recent exercise to catalogue the herbarium records for Scotland held by the Natural History Museum have been used. Where appropriate, distribution maps have been reviewed and adjusted by relevant researchers.

For rocky shores, the detailed descriptions and photographs in Lewis (1964) can be used to indicate where biotopes occurred in the 1950s and early 1960s (see also Lewis, 1957a, 1957b; Lewis & Powell, 1960). In Orkney the work of Jones and Baxter also provides a quantitative baseline from the late 1970s onwards (Baxter *et al.*, 1985).

Appendices 6 and 7 include detailed reviews with maps showing the current recorded distribution of species and biotopes that reach their northern or southern limits in Scotland or are at the northern recorded limits of their distribution on nearby coasts.

4. KEY ENVIRONMENTAL FACTORS THAT DEFINE DISTRIBUTIONAL RANGE

4.1 Presence of suitable habitats

Species have required habitats (physical, chemical and sometimes biological) and will only be found where those habitats occur. Many habitats in Scotland, such as rocky shores, are widely distributed and so are the species that require that habitat unless some other factor such as temperature restricts their occurrence. Where a habitat is very restricted in occurrence (for instance the only habitat for the sea anemone *Amphianthus dohrnii* in Scotland is the sea fan, *Swiftia pallida,* which occur at very few locations) the distribution of a species will reflect occurrence of the habitat and may not be influenced by physical conditions such as temperature.

4.2 Temperature

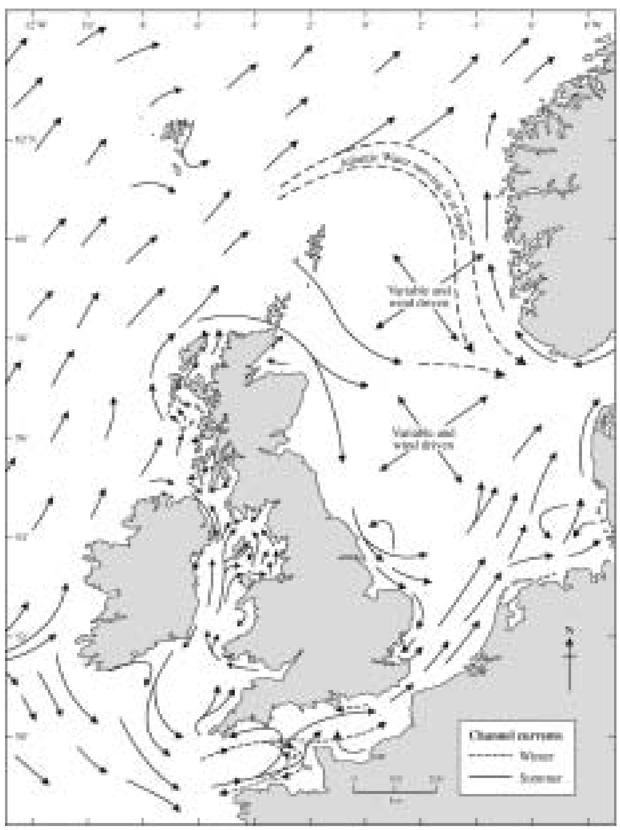
The distribution of many species follows summer or winter isotherms (Figure 1). However, the reason for temperature affecting distribution (and abundance) varies and includes:

- survival of adults (heat or cold stress);
- development of eggs or other propagules;
- 'triggering' release of propagules;
- survival of larval stages of animals (in cold waters, larvae may not develop fully to metamorphosis).
- survival of post-settlement of juveniles

For some species, local warming might be important. Warm summer temperatures in surface waters of enclosed areas such as lagoons (including obs), sea lochs or even rockpools may enable the production of propagules and perhaps survival of local populations in those isolated locations. Also, waters which remain cool because of thermal isolation of deeper waters may encourage reproduction in relict populations of species that were much more widespread in former colder times. In the intertidal, air temperatures can be important with both extremes of cold (e.g. Crisp, 1964; Todd & Lewis, 1984) and heat (e.g. Hawkins & Hartnoll, 1985) causing kills. Warmer air temperatures would also be expected to speed development in southern species but could cause stresses in colder species.

4.3 Hydrographical conditions - direction of currents

Figure 6: The direction of near-surface residual currents around the British Isles. (From Hiscock, 1998, re-drawn from Lee & Ramster, 1981).



The overall direction of currents (the horizontal movement of water masses after the tidal element has been removed) around and near to Scotland is illustrated in Figure 6. These currents are important in the distribution of water masses and to spreading the characteristics of those water masses (including temperature) and in distributing the pelagic larvae and spores of benthic species.

Currents may also bring larvae from distant sources to establish populations of a species that are not themselves able to reproduce – either because individuals are too distant from each other for male and female propagules to meet or because water temperatures are too cold or too hot for propagules to develop. In this case, occurrence of the species may be sporadic and only on outward coasts that 'catch' the currents.

Currents may also sweep the larvae of intertidal species offshore so that they do not spread further than the headland or other feature that provides the obstruction causing offshore direction. The direction of currents may be adverse to the spread of a species. Larval retention in lochs (such as the Clyde) and bays could lead to localised pockets (Barnes & Barnes, 1977).

4.4 Geographic barriers

The absence of suitable habitats for the settlement of a species over a large area may mean that larvae do not survive the time required to reach a suitable habitat for settlement. An extreme example of such geographical isolation occurs in Scotland for shallow water species between the Hebrides or Ireland and Rockall. It might also be the case that the distance between mainland Scotland or Orkney to Shetland including Fair Isle is too great for the survival of the larvae of some benthic animals. Seaweeds seem to be much less constrained by geographic barriers in their distribution and may exhibit a continuum of change with no obvious boundaries or breaks providing that suitable habitats are present.

4.5 Water 'quality'

Some species may require a particular water 'quality' in terms of nutrient status for propagules to survive or thrive and therefore colonise an area. The importance of water quality has been demonstrated for the English Channel where the numbers of postlarval fish and the larvae of other species especially decapods is high when water masses off Plymouth become of the '*Sagitta elegans* type' (Russell, 1973). The 'fertility' of such water was also demonstrated by Wilson (1951) in experimental studies rearing larvae. Wilson (1951) concluded "*This is the first observation that has been made to show that the difference in bottom faunas from one region to another may be related to the ability, or otherwise, of larval stages to develop in the overlying water mass*". It follows that the occurrence of many of the south-western species present only on the outer west coast of Scotland may have much more to do with water quality in the area than temperature. Increase in water temperatures inshore may not therefore result in wider occurrence of certain species where water quality is important to larval survival.

5. LIKELY EFFECTS OF CLIMATE CHANGE ON MARINE ECOSYSTEMS

A wide range of changes to marine environmental conditions may occur as a result of climate change. Those predicted changes include the following:

1. A rise in seawater temperature. This change, together with a rise in air temperature and sea level, is occurring already and is likely to continue.
2. A rise in sea level brought about by thermal expansion and by melting ice caps.
3. A rise in air temperature (affecting intertidal ecosystems).
4. Increased levels of ultra violet light (also due to decreasing ozone concentrations in the stratosphere) adversely affecting some shore organisms and larvae in very shallow water.

5. An increase in variation and extremes including increased ‘storminess’ and greater winter rainfall and summer drought.
6. In the longer term, a slowing of the North Atlantic ocean circulation decreasing the amount of heat transported into north-west Europe with a possibility that it might ‘shut-off’ altogether.

However, likely effects may be moderated or exacerbated by other events, For instance, increased levels of ultra violet light might be moderated if an increase in cloudiness, as predicted by up to 4% by 2080 (Hulme & Jenkins 1998), occurs.

Although many changes might occur, increased seawater temperature is by far the dominant factor effecting alterations in distribution and abundance of species and the factor most likely to occur in the next 50 to 100 years. The next section is therefore dominated by the likely effect of increased seawater temperature.

6. MECHANISMS OF CLIMATE CHANGE EFFECTS

Increased seawater temperatures, especially at the time of breeding and larval dispersal are likely to be effective in increasing the distribution and abundance of southern species in Scotland through the following mechanisms:

1. More frequent successful gonad development or more broods will lead to greater reproductive output.
2. Larval development will be accelerated and species that do not currently reach final stages for settlement because water temperature is too low, will settle.
3. Larval survival will be higher.
4. More consistent recruitment among year classes will occur leading to more balanced age distribution.

The importance of temperature and likely favourable effects of increased temperature have been particularly demonstrated in prosobranch molluscs, decapod crustaceans and barnacles. Many species require temperature to reach a certain high level before spawning can occur. Such temperature requirements are clearly important in determining whether or not larvae are produced. Other factors may be important in determining whether larvae survive and settle. For instance, Lindley (1998) demonstrated that the intermoult times of the pelagic larvae of decapods was much shorter in warmer waters. Such a shortening of the developmental time of larvae provides the scope for progression through the different larval stages within the time limits of the primary productive season and therefore improved likelihood of survival to settlement. The importance of seawater temperature to larval survival may therefore be one of the factors leading to the latitudinal gradient of brachyuran species numbers with 54 known from the English Channel and only two from Svalbard.

Increased seawater temperatures are likely to have an adverse effect on breeding in species that require a low temperature ‘trigger’ to reproduce. For instance, Hutchins (1947) suggested that the southern limits of distribution of the barnacle *Semibalanus balanoides*[1] was limited by the isotherm of the minimum monthly mean surface temperature of 7.2ºC and suggested that if the winter temperature failed to fall below that temperature, the species was unable to breed.

Increased temperature is not thought likely to have an immediately adverse effect on sessile or sedentary species that are already established. Long-lived species with a predominantly northern distribution are likely to persist as adults long after they have ceased to reproduce successfully in the locality. However, it is possible that higher levels of insolation and/or air temperatures may kill some northern intertidal species.

[1] Species names are those used in Howson & Picton (1997) where authorities can be found.

A reduction in the frequency of cold winters is also likely to be important in allowing survival of established populations, although, conversely, warmer summer temperatures may also have adverse effects. For instance, species adversely affected by the cold winter of 1962-63 (Crisp, 1964) are likely to be ones that will survive further north than at present if milder winters prevail. Species that are adversely affected by significant warming (especially in the intertidal) may become less abundant as a result of mortality in warmer or brighter conditions.

Recovery rates for species after losses due to cold climatic events may also suggest the rate at which colonisation of previously colder locations might occur. Where these observations are documented, they have been incorporated into the detailed assessments of likely rate of change in species distributions.

7. LIKELY EFFECTS OF CLIMATE CHANGE ON SPECIES

7.1 Introduction

The list of species that have good distributional records and have climatically restricted distributions in Scotland is given in Appendix 4.

Our study suggests that the following scenarios of change or stability in response to current climate change expectations are likely to occur:

1. Boreal-arctic species at the southern limits of their range in Scotland where higher temperatures will make reproduction or survival difficult will decline or disappear (those extending south may be restricted to a few northern or eastern locations).
2. Species at the northern limits of their range in Scotland where higher temperatures will make reproduction more likely or frequent or will improve prospects for larval survival will increase in abundance and extend in their distribution providing that they are not prevented by biogeographical or hydrographical barriers.
3. Some species may decline or increase in abundance because their grazers or predators increase or decline in abundance. If those species are characterising or keystone species in biotopes, the biotopes may be substantially altered.
4. Species that do not currently occur in Scotland because they are southern species requiring higher temperatures to breed will extend to Scotland only if their life history characteristics allow extension of range across significant biogeographical or hydrographical barriers.
5. Changes will be most apparent first in mobile species such as fish.
6. Amongst benthic species, response will be greatest in those with a planktonic stage in their life history.
7. Change is likely to be particularly marked in enclosed waters where increased local warming may occur.
8. Increased surface warming may isolate more frequently the deeper parts of some enclosed water bodies where a thermocline forms behind a sill, leading to deoxygenation.
9. There may be locations where sea level rise will introduce seawater into currently fresh water habitats creating new brackish water habitats.
10. Increased storminess may shift communities, particularly intertidal communities, to those characteristic of more wave exposed conditions.

Southern species that already occur in Scotland and have life cycles that include a planktonic phase are likely to extend their distributional limits northwards and increase in abundance within their present range. However, those southern species that currently extend to NE Ireland or to North Wales and/or NW England, will only extend to the coast of Scotland if currents are favourable and there are no geographical barriers.

7.2 Effects of increase in air temperatures on open shore species

Algae

Many of the intertidal algae characteristic of Scottish shores occur extensively further south (and north) of Scotland suggesting that they are unlikely to be adversely affected by increased temperatures of the scale currently envisaged. However, higher temperatures and increased insolation than at present could cause mortality in some northern species with subsequent effects on the zonation of shore species. For instance, exposed rocky shores on Fair Isle have 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). This extensive distribution of algae up the shore was attributed to a combination of continual swell and damp climatic conditions. If conditions become less damp, zonal extent might decrease. Similarly, high shore ephemeral algae (for instance, *Porphyra* spp., *Prasiola stipitata*, *Enteromorpha* spp., *Blidingia* spp.) are likely to occur for less of the year and be absent for most of the summer (Hawkins & Hartnoll, 1983). However, increased air temperatures are unlikely to have either an adverse or a positive effect on the occurrence and abundance of most intertidal algae. If increased storminess occurs, extension of zones landwards might occur or at least the adverse effects of increased dessication might be offset.

Animals

Increased air temperatures may result in mortality of some species in some years and therefore reductions in abundance or distributions. For instance, Bowman (1978) observed that 'overheating' in upper shore pools and on open rock in 1976 (a particularly hot summer) had resulted in loss of limpets, *Patella vulgata*, on the north coast and elsewhere in Scotland.

Conversely, some species might be more likely to survive if the coldest winter temperatures become less severe. For instance, the snakelocks anemone *Anemonia viridis* is susceptible to low temperatures (Crisp, 1964) and may survive and spread to new locations as adult individuals as a result of mild winters. For other species, development of gonads might be favoured by increased air temperatures so that fecundity increases.

7.3 Effects of increased air temperatures on species in enclosed waters

Some of the habitats for which Scotland is most important in a European context are the shallow landlocked lagoonal habitats including the obs in the Hebrides and fjardic sea lochs such as Loch Maddy. Several of these locations are cSACs.

There is a possibility that surface or near-surface waters in enclosed habitats with deep water may warm sufficiently to create a thermocline strong enough to isolate bottom waters, causing de-oxygenation. It is likely that only a few habitats may be affected in this way as Scottish inshore waters are mainly subject to strong tidal streams and therefore mixing of the water column. However, there are situations where occasional de-oxygenation events are known to occur (for instance at the head of Sullom Voe (Pearson & Eleftheriou, 1981), Loch Obisary (Mitchell *et al.*, 1980)) and such events might become more frequent or occur for the first time in some new locations. Such locations would be those having a sill that isolates the deeper water.

7.4 Effects of increased air temperatures on surface waters and intertidal isolated water bodies (rockpools)

It is most likely that milder winter conditions may help survival of species in rockpools. Species such as blennies and gobies and the sea anemone *Anemonia viridis* may remain in pools for a longer period of the year rather than moving to deeper water for winter. Several species extend towards their northern limits primarily in pools rather than the open shores and include the algae *Cystoseira tamariscifolia* and *Bifurcaria bifurcata* and the limpet *Patella ulyssiponensis*. Their extension northwards as a result of climate warming will therefore be initially in pools. The alga *Fucus distichus* subspecies *distichus* occurs in upper shore rockpools on very wave exposed coasts and does not extend further south than the 13ºC summer isotherm. However, experimental studies (see Appendix 7) suggest that it may be day length rather than temperature that determines reproduction and survival so that this 'obvious' candidate for decline may not.

7.5 Effects of increase in seawater temperatures

Widescale effects including increased abundance and extension of distribution of southern species alongside reduced abundance and retreat in the distribution of northern species are the most likely effects of increased seawater temperatures across the continental shelf. However, the rate at which change occurs and whether any change occurs will vary greatly from species to species. Amongst species living on or near the seabed, fish are likely to react most in concert with temperature change as they are mobile. Crustaceans will also respond fairly rapidly if it is temperature that controls adult distribution. Next, benthic species that have a long-lived planktonic larvae and which reproduce frequently will, in the case of southern species, extend their distribution rapidly. Finally, species with a short-lived larva or which reproduce asexually and do not have a mobile phase will increase in abundance where they occur at present but be slow to extend northwards. Also, such species may not make the jump across geographical barriers such as the North Channel between Northern Ireland and Scotland, the Pentland Firth to Orkney or the Fair Isle Channel to Shetland. Rate of retreat of northern species will be very dependant on the longevity of existing individuals with probably long-lived species such as the sea anemone *Bolocera tuediae* persisting for many tens of years even if reproduction has ceased. Others, such as the limpet *Tectura testudinalis*, which most likely lives for only a few years, will disappear more quickly.

7.6 Biotic interactions

Several keystone or dominant seabed species are likely to be affected by seawater warming. 'Keystone' species are ones which, through their predatory activities (for instance, grazing by sea urchins or limpets), or by mediating competition between prey species (for instance, by eating sea urchins), maintain community composition and structure. The term is also applied here to species which provide a distinctive habitat (for instance a bed of the horse mussel *Modiolus modiolus*, beds of fucoid algae, a maerl bed) and whose loss would therefore lead to the disappearance of the associated community. Other species dominate the seabed and define particular biotopes without being' keystone' and include, for instance, barnacles. In some cases, loss of a particular species may not be significant in terms of provision or maintenance of habitat and the continued presence of a particular biotope. For instance, loss of the northern sea urchin *Strongylocentrotus droebachiensis* would most likely be compensated for by increased abundance of the common sea urchin *Echinus esculentus* so that grazing would continue. Expansion of *Paracentrotus lividus* would produce a new and more efficient grazer into a habitat without such a species. Reduction in abundance of the cold water barnacle *Semibalanus balanoides* would be compensated for by increased abundance of *Chthamalus* spp. However, if the abundance of some species such as the horse mussel decined, there may be significant effects on the associated fauna and flora. In the case of loss of horse mussel beds, the biotope would most likely change to a sedimentary one.

A most important effect of climate change might be to alter the abundance and quality of meroplankton organisms that are important as food to other marine life. For example, the cold water barnacle, *Semibalanus balanoides,* releases its larvae in synchrony over a short period in the spring, late March to early May depending on latitude. In early spring the nauplii can be numerically dominant in the plankton, prior to the spring outburst of copepods.

They may constitute an important food for larvae and juvenile stages of spring spawning herring, gadoids and other fish, especially in enclosed bays and lochs. If *Semibalanus balanoides* is replaced by *Chthamalus* as the dominant barnacle, this resource is lost. *Chthamalus* breeds over a longer period in summer, with successive broods, at a time when other zooplankton species are available to the young fish and other animals that feed on plankton. Similar considerations may apply to meroplanktonic larvae of other animals, such as the zooea larvae of crabs and prawns that can be very abundant in the spring (see Lindley, 1998). Such effects of climate change are much more difficult to observe and to take into account than conspicuous events in shore or sublittoral seabed organisms but are important to take into account when predicting or accounting for change.

8. DEVELOPING A 'RULE BASED' SYSTEM FOR ASSESSING LIKELY EFFECTS FOR A PARTICULAR SPECIES

8.1 Components

The rate of geographical extension or reduction of distributional extent or change in the abundance of species at existing locations in response to increases or decreases in temperature are likely to be determined by:

1. Mobility of existing populations – can they swim, drift or walk or are they dependent on larval distribution?
2. Presence of viable populations for the production of larvae – 'relict' populations or populations that have recruited from distant sources and do not produce gametes, or populations where individuals are too widely separated for gametes to meet may not be reproductively viable and so not be a source for distributional extension.
3. Type of reproductive and dispersal mechanisms – sessile or sedentary benthic species which reproduce asexually or that have a benthic or short-lived larval/juvenile stage will extend their distributions less rapidly than those with long-lived planktonic propagules, but may persist longer in the face of adverse conditions.
4. Survival of larvae in relation to water temperature – some larvae require threshold temperatures to develop to a final settlement stage and will perish if those temperatures are not reached.
5. The presence of suitable habitats for settlement within the potential extension of range according to mobility of dispersive stages.
6. Lethal temperature limits of adults – in the case of lower temperatures, some adults may perish in the winter or not reproduce if they require warm water for maturation of gonads. In the case of higher temperatures, some species that require a low temperature trigger to reproduce may fail or some might be killed by high temperatures.
7. Presence or absence of geographical barriers to potential spread (for instance, offshore currents may sweep larvae away from suitable inshore habitats).
8. The presence of favourable currents to enable spread (residual currents in the direction of temperature increase, occasional fast currents bringing larvae from distant sources).
9. Longevity of individuals in existing populations – if climate changes 'shuts-down' reproduction and therefore local recruitment, existing populations will persist until the end of their natural life span is reached.

A variety of scenarios are likely and the key and decision tree given below can be applied to a wide range of species.

8.2 Mechanisms - effects for southern species in a temperature rise scenario

1. Free-swimming species – likely to respond immediately – their distribution is likely to 'track' changes in temperature isotherms for critical temperature ranges (i.e. whether they require warm waters in summer or cannot tolerate cold waters in winter). For example, red mullet *Mullus surmuletus*, John Dory *Zeus faber*, cuttlefish *Sepia officinalis* would all extend their distributions in Scotland due to warmer seawater temperatures.

2. Sedentary or sessile species with long-lived planktotrophic larvae – more larvae are likely to be produced leading to an increased abundance of the species locally and the possibility of extension of range. For example, the purple sea urchin *Paracentrotus lividus*.

3. For sedentary or sessile species that reproduce asexually or have short-lived larvae, abundance is likely to increase at the locations where the species already occurs. Extension of range will occur through individuals detaching from the substratum or larvae being carried (usually short distances) in the water column. Few species are likely to detach and float away, an exception being the snakelocks anemone *Anemonia viridis*. Occasional 'jetstream' currents at the time of detachment or reproduction may take individuals or short-lived larvae a considerable distance so that, providing suitable habitats are present, there will be a gradual extension of range (for example, larvae of the snakelocks anemone *Anemonia viridis* and the sea fan *Eunicella verrucosa*).

8.3 Mechanisms - effects for northern species in a temperature rise scenario

1. Species that are free swimming or walking are likely to respond immediately and retreat from the pre-existing southern limits of their range. For instance, the northern stone crab *Lithodes maia*, the viviparous blenny *Zoarces viviparus*.

2. Sedentary or sessile species are likely to remain present for as long as adults live but recruitment is unlikely to occur. For instance, the tortoiseshell limpet *Tectura testudinalis*, the sea urchin *Strongylocentrotus droebachiensis*.

Exceptions to the above two scenarios may occur where populations are isolated by barriers such as the sills of sea lochs and where deeper waters maintain conditions where reproduction and settlement continues (for instance, in case of the arctic relict bivalve mollusc *Thyasira gouldii*: Blacknell & Ansell, 1974; Southward & Southward, 1991). Species that reproduce asexually as well as sexually such as many sea anemones may continue to produce new individuals even though larvae are not being produced (may include the cold water anemone *Bolocera tuediae*).

Some species that may be expected to decline in abundance as a result of temperature rise may be restricted in their distribution for reasons other than temperature and may persist. For instance, with the exception of the St Kilda population, the brown seaweed *Fucus distichus distichus* does not occur south of the summer 13°C isotherm in Britain. A simplistic extrapolation from the present distributional range would suggest that following a 1°C and 2°C rise in summer sea temperature the 13°C isotherm would have moved north of the British Isles and *Fucus distichus distichus* would therefore become extinct in Britain. However, laboratory and autecological field studies indicate that mature *Fucus distichus distichus* plants can tolerate higher temperatures (McLaclan, 1974; Bird & McLaclan, 1976). Embryos also develop at 15°C (and higher). A critical factor is probably daylength; short daylengths stimulate the onset of receptacle formation and this will not change with global warming. Bird & McLachlan (1976) showed that the formation of receptacles was independent of temperature but maturation progressed with increasing temperature to at least 15°C. It is a possibility that a 2°C rise in sea temperature may make no difference to the populations of *Fucus distichus distichus* in northern Scotland. Stormier sea conditions (predicted as a result of global warming) and competition from other marine organisms may, however, do so. Why *Fucus distichus distichus* does not occur more widely in Britain, as could be inferred from laboratory and autecological studies (and also shown by subspecies *anceps*) remains unclear.

8.4 Mechanisms – the importance of residual currents.

Residual currents are those that carry water masses (including larvae or passively transported adults) in a particular direction and are indicated after the ebb and flow of tidal currents are removed from records. There are a number of fixed current meters established around the Scottish coast which indicate daily, seasonal and annual changes. Tracking the movement of radioactive contaminants from the Sellafield nuclear reprocessing plant in Cumbria has also provided valuable insights into the long-term movement of water masses. For instance, the movement of radiocaesium discharged from Sellafield suggest a residual flow northwards along the west coast of Scotland of about 1.7 km a day (Economides, 1989). Occasional 'jetstream' currents which might especially occur along shelf sea fronts may be important. These 'jetstreams' are partly apocryphal but Simpson *et al.* (1979) found residual current velocities of 20 cm/s parallel to the Islay front which would be approximately equivalent to movement of water with passive larvae of about 10 km in one direction in one day.

8.5 Exceptions - localised effects in isolated waters

There are several locations in Scotland where poor water exchange with sheltered water bodies may result in localised warming (if temperatures rise) in shallow or surface waters. Two significant effects are likely:

1. Shallow waters may be come more amenable to 'blooms' of species that thrive in warm water during the summer. Such species include the non-native alga *Sargassum muticum* and possibly some fish such as *Ctenolabrus rupestris.*
2. Where the isolated waters have a shallow sill or are sluiced, deeper waters may become isolated through thermal stratification during summer and consequently become deoxygenated.

8.6 The 'key' - determining the likely effects of temperature increase on a particular species

The following key and description of types assumes an increase in air and seawater temperatures and is based on the components described above.

1.	The species is pelagic (swims or drifts in the water column) …………………	2
	The species is sedentary or sessile (attached to or crawling on the seabed)	3
2.	The species is northern in distribution ………………………………………...	Type A
	The species is southern in distribution ……………………………………….	Type D*
3.	The species has a planktonic distributional phase …………………………….	4
	The species has a benthic larva, very short lived (a few hours) pelagic phase or reproduces asexually ………………………………………………...	5
4.	The species are long-lived (>5years) and likely to reproduces infrequently or not at all, at least at its geographical limits. ("infrequently" means only every few years) …………………….……………………………………….	Type F*

	The species is short-lived (<5 years) and currently reproduces frequently (usually once a year and over a prolonged period) ………………………….	6
5.	The species currently reproduces infrequently or not at all, at least at its geographical limits. ("infrequently" means only every few years) …………….	7
	The species currently reproduces frequently (usually once a year and over a prolonged period) …………………………………………………………….	8
6.	Species is northern in distribution ……………………………………………..	Type C
	Species is southern in distribution ……………………………………………….	9
7.	Species is northern in distribution ……………………………………………..	Type B
	Species is southern in distribution ………………………………………………..	Type E
8.	Species is northern in distribution ……………………………………………..	Type C
	Species is southern in distribution ………………………………………………..	Type E
9.	The species occurs in populations sufficiently dense or close so that gametes will meet.	Type G*
	The species occurs as isolated individuals and gametes are unlikely to meet OR the species occurs at isolated locations or habitats where other suitable locations or habitats are likely to be too distant for propagules to reach.	Type E

* Use the decision tree that follows (Figure 7) to determine importance of barriers to spread.

Type A (northern volatiles)

Species that are pelagic or demersal (such as plankton and fish) where the adults respond rapidly to temperature change. Significant changes will occur in relation to annual variations in temperature with an overall reduction in abundance and 'retreat' northwards over the next 50 years.

Type B (northern stables)

Species that currently have a northern distribution that will 'retreat' northwards but very slowly as individuals are long-lived and recruit irregularly. Reproductive success at current southern limits will be reduced as a result of higher temperatures. Decline in abundance at southern limits but no significant change expected in distribution in the next 50 years.

Type C (northern 'retreaters')

Species that currently have a northern distribution which will decline in abundance and 'retreat' northwards rapidly (in 'concert' with isothermal changes), are short-lived (<5years) and rely on regular recruitment from the plankton or from benthic larvae. The speed of change in abundance and distribution might fluctuate depending on the occurrence of particularly warm years. Significant reductions in abundance and distributional extent are to be expected in the next 50 years.

Type D (southern volatiles)

Species that are pelagic or demersal (such as plankton and fish) where the adults respond rapidly to temperature change. Significant changes will occur in relation to annual variations in temperature with an overall expansion in distribution northwards and increase in abundance within their present limits over the next 50 years.

Expansion of distribution northwards may be prevented or slowed by geographical barriers such as locations where currents sweep offshore or extensive areas where favoured (demersal) habitats are absent.

Apply Figure 7, the water currents and quality decision tree.

Type E (southern stables)

Species that currently have a predominantly southern distribution which will expand northwards or become more abundant within their present range but slowly. Individuals are long-lived and reproduce infrequently by benthic or short lived larvae or by asexual division. Reproductive success at current northern limits of distribution will improve as a result of higher temperatures. Abundance of individuals will increase at locations where they are already found. Northward extent will increase very little in the next 50 years and not at all where significant geographical barriers exist.

Type F (southern gradual extenders)

Species that currently have a predominantly southern distribution that will expand northwards and increase in abundance at their current locations and in a sporadic way dependent on particularly favourable years for reproduction. The species currently reproduce infrequently at least at their geographical limits but have a planktonic larva. There will be a 'lag' period between temperature increase and expansion in abundance or northern extent.

Expansion of distribution northwards may be prevented or slowed by geographical barriers such as locations where currents sweep offshore or extensive areas where favoured habitats are absent.

Apply Figure 7, the water currents and quality decision tree.

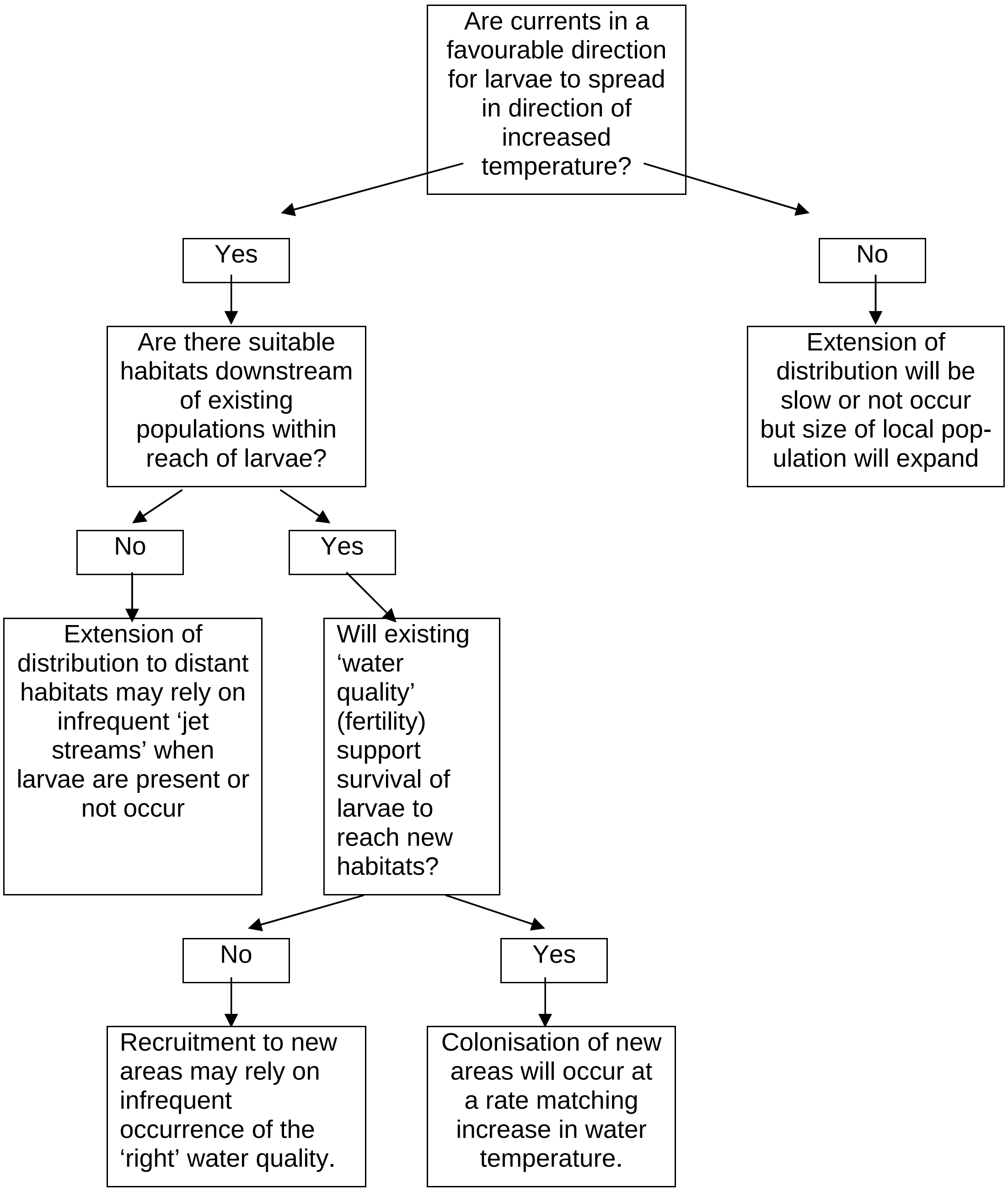
Type G (southern rapid extenders)

Species that currently have a predominantly southern distribution which will expand northwards at about the same rate as isothermal changes in sea or air temperatures providing that currents are favourable and there are no barriers to spread. Species will become more abundant within their present range.

Expansion of distribution northwards may be prevented or slowed by geographical barriers such as locations where currents sweep offshore or extensive areas where favoured habitats are absent. Water quality may also be important in determining whether or not larvae settle and survive. The decision tree below is for species that have the ability to spread (Types D, F, G).

Apply Figure 7, the water currents and quality decision tree.

Figure 7: Water currents and quality decision tree for southern species.



9. EXAMPLES OF POSSIBLE CHANGE

9.1 Likely effects on representative species

A potentially large number of species will be affected by climate change. Representative species have been selected based on the likelihood that their distribution and abundance will change, complementarity (similar species representing northern and southern distributions), and their suitability for monitoring studies. Detailed study has been undertaken for 23 species (see Table 1 for the species selected and Appendix 7 for conclusions). Temperature change has been taken as the most important factor determining changes in distribution and abundance. No attempt has been made to predict localised changes in temperature and the present isotherm lines have been used to represent 1ºC and 2ºC rises in temperature. However, winter or summer isotherms have been used depending on which it is thought might be most important in determining current distribution patterns.

9.2 Likely effects on susceptible biotopes

Biotopes likely to be changed or lost as a result of climate change are those where key characterising or structuring species may be affected by seawater warming. The biotopes identified as likely to change in distribution and extent as a result of temperature rise are listed with reasons for inclusion in Appendix 5. Those for which an assessment of current distribution and likely effects has been undertaken, including some from the list of biotopes included in statutes and directives (Appendix 3), are marked in Appendix 5 and conclusions are given in Appendix 7.

Not all biotopes that appear likely to be adversely affected by warmer conditions or higher levels of insolation will change. For instance, biotopes dominated by foliose algae or by the kelp *Alaria esculenta* are known to spread further up the shore (to conditions where desiccation is more severe) if grazers are removed. There may be some adverse effects on such lower shore biotopes including more frequent bleaching events but overall decline in distribution is not expected in Scotland. Also, species currently restricted to rockpools but which dominate open shore areas in southern Europe (*Bifurcaria bifurcata* and *Cystoseira* species especially) are not expected to expand in abundance to such an extent that they take-over open shores in Scotland. Similarly but conversely, it is not expected that temperature change will be sufficient in Scotland to reduce abundance or extent of the cold-water kelp *Alaria esculenta* which is dominant in some lower shore and shallow sublittoral biotopes on exposed coasts in Scotland, although decline in south-west England and Wales is expected. It is difficult to predict if there might be any adverse effects on the distinctive rock biotopes present in Scottish sea lochs as little is known of the biology of key component species such as the brachipod *Neocrania anomala* and the sea anemone *Protanthea simplex.* A similar lack of knowledge of biology makes it difficult to predict likely effects on the deep burrowing megafauna communities of sea lochs or the reefs of the tube worm *Serpula vermicularis*. However, as reefs of *Serpula* are also known from Killary Harbour in southern Ireland, it might be expected that they will withstand higher temperatures. No intertidal sediment biotopes are identified as likely to be subject to decline or loss or to appearance and spread in Scotland.

10. LOCATIONS WHERE CHANGE MIGHT BE PARTICULARLY ACUTE

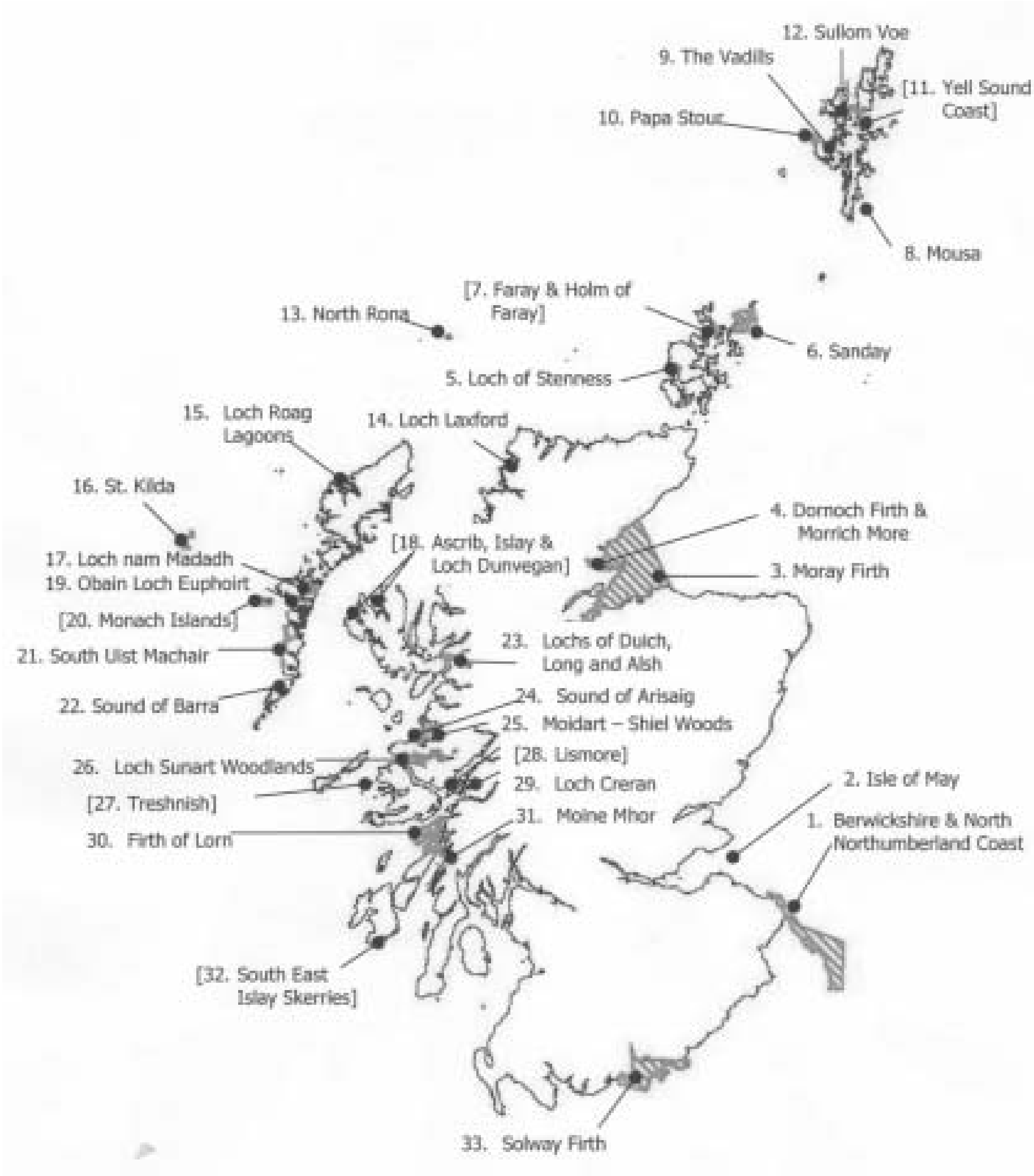
Change may be particularly acute at open coast locations or in enclosed areas with high water exchange where self-recruiting but small populations of southern species already occur and will increase in abundance to dominate habitats. Conversely, in open coastal areas or in enclosed areas with high water exchange where present cold waters prevail, reduced abundance of cold water species such as the horse mussel *Modiolus modiolus* may greatly affect the communities that develop within the beds or clumps that they form.

Change would most likely occur first in those communities that are naturally variable, with turnover moving towards southern species dominating.

Warming of surface waters of enclosed areas such as sea lochs with a sill and low water exchange or the obs in the Hebrides may have two significant effects:

- Warmer shallow waters will encourage reproduction and increase in abundance of southern species currently of low abundance.
- There will be a larger difference between warm surface waters and cold deeper waters increasing thermal isolation of deeper waters and causing deoxygenation for extended periods or more frequent and longer periods of deoxygenation where episodes already occur.

Figure 8: Location of proposed and candidate SACs in Scotland (map supplied by SNH, square brackets added to indicate sites without seabed habitats).



11. RELEVANCE TO SCOTTISH SACs

Candidate SACs are distributed all around the Scottish coast (Figure 8) and form a potentially useful, although not exclusive, network for monitoring changes in the distribution of biotopes and species and the abundance of species populations. Although many of the designations are based on non-benthic criteria (e.g. seals at Mousa, dolphins in the Moray Firth) these sites will be of use in benthic monitoring. They will also encompass most of the major biotopes.

The Solway Firth SAC will be of particular value in monitoring *Sabellaria alveolata.* The network of west coast SACs should encompass most of the species likely to change. SACs in Orkney and Shetland will be of value in monitoring species like *Strongylocentrotus doebachiensis* which may well disappear from Scotland. Some south and western species are likely to extend around the north east corner of Scotland and increase in abundance on North Sea coasts. Therefore the SACs on the east coast could be employed here – although coverage is currently poor.

12. RECOMMENDATIONS FOR FUTURE ACTION BY SNH

The years 2000 to 2005 should be a baseline against which future changes in the distribution and abundance of species and the distribution and extent of biotopes are assessed.

Some species will require specialist recording (for instance of the barnacles *Chthamalus stellatus* and *Chthamalus montagui*, species of the limpet *Patella* and trochid snails) by experienced marine biologists. Abundances of the animals should generally be expressed using a semi-quantitative logarithmic scale such as that described by Crisp & Southward (1958) or the MNCR abundance scale (Hiscock, 1996). At key stations, the critical species of barnacles, limpets and top shells should be counted in replicated quadrats using stratified random sampling with within site nesting of replicate sets of quadrats. The quadrat size is correlated with the abundance of the species: 5cm x 5cm to 50cm x 50cm for the barnacles, 50cm x 50cm to 1m x 1m for limpets and topshells. Appropriate methods are given in Hawkins & Jones (1992) and are currently being developed for monitoring in Special Areas of Conservation (SAC) (see www.english-nature.org.uk/uk-marine).

For many species, a more general descriptive approach might be adopted both on the shore and underwater, but still at specific locations. Accuracy of identification and care in the use of abundance scales is essential but the surveys should be aimed at searching for appearances and disappearances rather than declines and increases in abundance.

Although targeted and repeatable survey at particular locations is required, a more general observation scheme should be launched so that records can be logged from wherever observations are made. The scheme would be focussed on species that are easily recognised and include a high proportion of ones that may be subject to climate change effects. The scheme would be co-ordinated by a Scottish institute but also contribute to UK or Britain and Ireland projects and contribute information to the UK National Biodiversity Network. The scheme can be Web-based and such a project is already demonstrated on www.marlin.ac.uk/wwf (the WWF-UK ORCA programme). A modification of the *Seasearch* programme would achieve such recording and further development of volunteer recording under the activities of the National Biodiversity Network is planned. Some studies such as the SAC monitoring surveys are already underway but may need to be adjusted to ensure that species that are likely to change (and that are noted in this report and the Phase 1 report) are especially targeted for detailed survey.

There are locations around the Scottish coast that could be used for targeted recording exercises. Table 3 is an initial proposed list of locations with explanation of why they have been selected. As far as possible, locations have been suggested because historical data or at least knowledge exists for them. However, many reasons are of a practical (access) nature and some depend on presence of local expertise. There is an opportunity to combine climate change effects monitoring with the studies required to report on the conservation status of SACs. It is expected that the list will be substantially modified after discussion with marine biologists with a thorough knowledge of Scotland and a meeting of those biologists should be organised to determine sites and methods.

Table 3. Initial proposed list of locations around the Scottish coast that could be targeted for establishing a baseline and recording change in species abundance and presence in relation to climate change. Sites that are known to be in proposed or candidate SACs are emboldened.

Location	Inter-tidal	Sub-tidal	Notes
Southerness Point, Solway	+		*Sabellaria alveolata* colonies.
Port Patrick, Galloway	+		Barnacles and limpets.
Burrow Head, Galloway	+		Barnacles and limpets (area of inshore warming in summer)
Mull of Galloway (E. side)		+	Southern Anthoza.
Cumbrae (Connell's sites)	+		Barnacles and limpets including *Tectura testudinalis*. *Gibbula umbilicalis*.
East side of Cumbrae		+	Southern Anthoza.
Loch Fyne		+	Northern species and species characteristic of sea loch.
Tip of the Kintyre peninsula (at lighthouse?)	+		Barnacles and limpets, *Chthamalus stellatus* especially. *Gibbula umbilicalis*.
Caol Scotnish (Loch Sween)		+	*Lithothamnion glaciale* maerl beds.
Ardnoe Point, Crinan		+	Southern v. northern species in the 'Erect sponges and *Swiftia pallida*' biotope.
Easdale	+		Barnacles and limpets. *Gibbula umbilicalis*.
Open coast of Mull incl. Iona	+		Barnacles and limpets *Gibbula umbilicalis*.
Tiree		+	*Dictyopteris membranacea*
Loch nam Umah	+		*Codium adhaerens*
Ardnamurchan Peninsula	+		*Paracentrotus lividus*
Eigg	+		*Paracentrotus lividus*
Rudh Arisaig	+		Barnacles and limpets. *Gibbula umbilicalis*.
Sound of Arisaig		+	Maerl, *Phymatolithon calcaereum,* beds and component species.
Loch Duich		+	'Classic' rock and sediment sealoch biotopes.
Strome Narrows, Loch Carron		+	Southern v. northern species. *Modiolus* and maerl beds. Long-term records available.
Skye, Point of Sleat and Trumpan Head	+		Barnacles and limpets. *Gibbula umbilicalis*. *Paracentrotus lividus.*
Rudha Reid, north of Gairloch	+		Barnacles and limpets. *Gibbula umbilicalis*.
Point of Stoer/ Scourie	+		Barnacles and limpets. *Gibbula umbilicalis*.
Borve Point, Barra	+		Barnacles and limpets. *Gibbula umbilicalis*.
Barra/South Uist sandy beaches	+		*Sabellaria alveolata*.
Loch Eyenort		+	Southern Anthozoa.
Harris and Lewis, Husinich, Carloway, Butt of Lewis	+		Barnacles and limpets. *Gibbula umbilicalis*.
Balnakeil Bay	+		*Sabellaria alveolata.*

Loch Eriboll (entrance)		+	Southern Anthozoa.
Faraid Head, Durness	+		Barnacles and limpets.
Strathy Point	+		Barnacles and limpets.
Dunnet Head	+		Barnacles and limpets.
Duncansby Head	+		Barnacles and limpets.
Brough Head, Orkney	+		Barnacles and limpets. *Gibbula umbilicalis*.
Scapa Flow, Orkney		+	Southern Anthozoa. *Cucumaroa frondosa* (in sounds).
Scatness, Shetland	+		Barnacles and limpets.
Ronas Voe, Shetland		+	Deep sheltered rock – southern Anthozoa.
Skaw Taing, Sullom Voe, Shetland		+	*Modiolus* beds and associated species. (History of study.)
Bressay Sound, Lerwick, Shetland		+	*Cucumaria frondosa* and *Strongylocentrotus droebachiensis*.
Wick	+		Barnacles and limpets. *Gibbula umbilicalis*.
Brora	+		Barnacles and limpets. *Gibbula umbilicalis*.
Portknockie	+		Barnacles and limpets. *Gibbula umbilicalis*.
Kinnairds Head	+		Barnacles and limpets. *Gibbula umbilicalis*.
Peterhead	+		Barnacles and limpets. *Gibbula umbilicalis*.
Garron Point, Stonehaven	+		Barnacles and limpets. *Gibbula umbilicalis*.
Arbroath	+		Barnacles and limpets. *Gibbula umbilicalis*.
Fife Ness	+		Barnacles and limpets. *Gibbula umbilicalis*.
Isle of May		+	Northern fauna.
St Abbs / Eyemouth	+		Barnacles and limpets. *Gibbula umbilicalis*.
St Abbs / Eyemouth		+	Northern fauna

There are various baselines of biological information that can be used to identify any change in the distribution and abundance of species. They include the records of commercial species of fish maintained by Fisheries Research Services in Aberdeen, records collected during monitoring exercises linked to the National Marine Monitoring Programme and to SAC management, the results of survey and monitoring in Shetland and Orkney linked to the oil terminals there, and the results of single surveys such as the MNCR series. There is also much anecdotal and unpublished information that needs to be reviewed and curated. Much unpublished information is available which needs to be rescued and archived properly to contribute to the establishment of a baseline of current and recent distributional information. Initiatives taken after the commencement of the project described in this report will develop work on climate change effects on marine species and biotopes in Britain and Ireland. The new work will link to the climate change project MONARCH (Modelling Natural Resource Responses to Climate Change) which is appraising the impact of climate change on:

1. changes in coastal processes, in particular the impact of the relocation of sediments, changes in water temperature and sea-level rise on the availability of benthic invertebrates for local bird popluations;

2. seven Biodiversity Action Plan (BAP) priority habitats on changes in ocean temperatures and other variables, indicating possible future relocations. The habitats are chalk reefs, maerl beds, *Serpula vermicularis* reefs, *Sabellaria alveolata* reefs, *Sabellaria spinulosa* reefs, *Modiolus modiolus* beds and *Lophelia pertusa* reefs.

13. REFERENCES AND BIBLIOGRAPHY OF RELEVANT LITERATURE

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APPENDICES

Appendix 1. Information on species distributions from A.J. Southward and S.J. Hawkins

Polychaetes

Anecdotal evidence (I. Rees, pers. comm. to S.J. Hawkins; S.J. Hawkins, own observations) suggest that *Sabellaria* which was trimmed back from Llandudno/Penrhyn (Wilson, 1977) to Criccieth following the cold winter of 1962/3 has been very slow to recover in this area (Cunningham *et al.*, 1984).

Sea urchins

Mention has been made of the southern or lusitanian sea urchin *Paracentrotus lividus*. Forbes recorded this from Donegal Bay to the south-west tip of Cork. The Crisp and Southward data for 1958 show it as extending from just east of Malin Head in north Donegal to the western side of the Old Head of Kinsale. Towards each of these limits there is a dramatic drop in intertidal abundance, suggesting some strong environmental character is affecting settlement and survival rather than availability of planktonic larvae. In Brittany the species was heavily fished after the baseline survey of Fischer Piette (1933, 1937), and by the 1970s it could be found only with difficulty at the most inaccessible headlands. A similar trend began to develop in south-west Ireland with the rise of commercial fishing, but *Paracentrotus* was still abundant in Galway Bay in the 1970s. Records of this sea-urchin to the north and east of Brittany and Ireland are very few. Several finds of *Paracentrotus* are listed in the Plymouth Marine Fauna (Marine Biological Association, 1957). The first record of *Paracentrotus* from Scottish waters was by Hobson in 1950 (MacEwen & Hobson, 1954), for a specimen collected on Muck. Later, specimens were found in the Sound of Sleat. A survey of Skye by Southward and Southward in 1971 found it at the Point of Sleat (2 specimens) and at Duntulm Castle (one specimen). With global warming, and if fishing is prevented, this sea-urchin is very likely to become more common in western Scotland, particularly in the area from Tiree to Skye, where sea surface temperature may be higher than farther north. However, it was not found by detailed searching on Tiree in 1962. More recently *P. lividus* was recorded during 1999 in Eigg (J. M. Baxter and D. Donnan, pers. comm.) and Barra (S. Scott, pers. comm.). If it became very abundant this species might have ecological consequences for the fauna and flora due to intense grazing pressure, as reported in other regions where related genera can be locally abundant.

The arctic/boreal sea urchin, *Strongylocentrotus droebachiensis*, which to some extent occupies a similar but deeper water (in Shetland) habitat to *Paracentrotus*, is smaller and less obvious. It is abundant at times in Shetland (see photograph in Baxter & Usher 1994), and has been reported from the sublittoral of the North Sea coasts of Scotland. It occurs in Norway, off eastern Canada and in Alaska. This species would be expected to decline in Scotland in the face of global warming, but this would probably not affect otters that might feed on it along the coast, since *Echinus esculentus* would still be available for them.

Seastars

The common seastar, *Asterias rubens* is present on most suitable shores in Britain under stones at LW, and also sublittorally, ranging down to 100m. In west coast Scottish localities it is accompanied by, or may be replaced by, the boreal starfish *Leptasterias muelleri*, which differs in incubating it eggs rather than producing pelagic larvae. The Crisp and Southward data suggests that *Leptasterias* is best developed inside the sea lochs; there are records from Loch Melfort in Argyll, and from Loch Eport, Loch Roag and Bernera Sound in the outer islands. This species would be expected to be a sensitive indicator of global climate change, but requires careful searching and good identification skills.

Molluscs

Certain bivalve molluscs that live in sulphide-rich habitats include species that are of arctic/boreal distribution, belonging to Forbes' group of 'boreal outliers'. The genus *Thyasira* contains a number of cold water species recorded from west coast Scottish sea lochs, notably *Thyasira gouldii*, and *Thyasira ferruginea* (Forbes & Hanley, 1853). *Thyasira ferruginea* was reported from the upper Clyde Sea and Loch Fyne, areas where other cold-water species occur (for example, *Calanus finmarchicus* and *Meganyctiphanes norvegica* are abundant in the plankton of Loch Fyne and Loch Striven). But extensive dredging in Loch Fyne and off Millport in 1984 produced only the warm-water species *Thyasira flexuosa*. And specimens in the faunal collection at the Millport Marine Station, labelled "*Thyasira ferruginea*", were also the warm water species. In contrast, the occurrence in Scottish waters of *Thyasira gouldi*, was confirmed by Blacknell & Ansell (1974), who found it abundant in Loch Etive in the 1970s. By 1989 this population had so declined that only two live specimens were taken in several days bottom sampling (Southward & Southward, 1991, 1992). It is not clear if this decline was a result of climate changes or local factors such as change in land use and in run-off from the land. Unfortunately there has been no recent funding available for re-investigation of the benthos in other Scottish lochs.

The top-shell *Osilinus (=Monodonta) lineata* has been found from Roman villas on the Isle of Wight and in large quantities in middens on Portland. In recent times its eastern limit in the English Channel has been Lyme Regis (in numbers) although odd specimens have been found on Portland. Recent warming along the South coast has not seen much increase in abundance or range on a time scale of decades (S.J. Hawkins, pers. observs. 1980-2000 – Lyme Regis to the Isle of Wight). Similarly, in North Wales, *Osilinus lineata* were trimmed back from Anglesey to Criccieth following the cold winter of 1962/3, with only odd specimens being found at Rhosneigr and other locations by S.J. Hawkins and research students in the mid 1980s and early 1990s.

In the early 1980s a broad scale survey of the proportions of the limpets *Patella depressa* to *Patella vulgata* was undertaken (Hawkins, unpublished, some data are in Southward *et al*., 1995). This showed lower abundance of the southern species, *Patella depressa* at most sites from Anglesey to the Isle of Wight on the south and west coasts, and also in northern France compared to surveys by Crisp & Southward (1958), Crisp & Fischer-Piette (1959) and unpublished records of Southward & Crisp. No changes in range were detected but abundance at the extreme limits of *Patella depressa* was much reduced. Observations in Portugal also suggested that *Patella vulgata* was spreading southwards, a trend first spotted by Fischer-Piette in the 1960s. *Patella depressa* has recovered to some extent in the late 1980s to 1990s (Southward *et al.*, 1995; S.J. Hawkins pers. observs.) so this species appears to have responded rapidly to warming.

Crustacea

In addition to the barnacles commented upon in the main text, a number of crustaceans have been shown to have distribution limits in the British Isles. In particular, the small hermit crab, *Clibanarius erythropus* colonized south-west England in the 1950s, but disappeared during the cold spell after 1962 (Southward & Southward, 1988). Another hermit crab of southern character, *Catapagurus timidus*, which occurs from the Mediterranean to Brittany, was recorded from the Isles of Scilly and south-west Scotland during the 1950s (Harvey 1964; Pike & Williamson 1959). These two southern species might well flourish in Scottish waters if warming continues.

The large spider crab, *Maja squinado*, is common in south-west Britain (Marine Biological Association, 1957). It is occasionally taken in the Irish Sea (Bruce *et al.*, 1963). The stone crab, *Lithodes maia*, is a northern form of similar habitat that reaches its southern limits in the Celtic Sea (personal record) and is sometimes encountered in the Irish Sea (Bruce *et al.*, 1963). These two species might be expected to change their distribution and abundances with rising temperatures, one advancing, the other retreating north.

Pogonophoran tube-worms

The small perviate Pogonophora are mostly found in the deep sea, but a few species extend up onto the continental shelves where the water is stratified in summer, where the temperature on the bottom is below 10°C in summer, and where autumn mixing does not increase sea temperature above 13°C. An outlying population of one pogonophoran, *Siboglinum holmei,* was recorded in the North Minch in 1963, and another population off Kerry was sampled in 1957 and 1960 (Southward, 1963). This species has not been reported from the west coast sea lochs, in contrast to conditions in Norway where a comparable species extends close inshore in the fjords around Bergen. The Minch population would be at risk only if sea temperatures were to increase by several degrees.

Fish

It needs to be remembered that herring are at their southern limit in the British Isles and Brittany. This northern fish would be at risk from rising temperatures. The Clyde herring stock might be affected by warming in the same way as the Plymouth stock in the 1930s, when recruitment failed under increasing temperatures, competition with pilchard, and over-fishing.

In contrast, pilchard might extend their range northwards with rising sea temperatures. The breeding range of pilchard during the warm phase before 1962 extended from W. Ireland to the southern North Sea, including most of the English Channel. The breeding range was more restricted in the cold spell from 1963 to 1980, but extensive spawning returned to Plymouth waters after 1981.

Algae

A number of species of macroalgae of southern character penetrate into Scottish waters, notably *Cystoseira tamariscifolia* in the inner and outer Hebrides (no records for Harris and Lewis though). Another southern species, *Bifurcaria bifurcata*, is much more widespread on the western coast of Ireland than shown in the Provisional Atlas of Marine Algae (Norton 1985), extending from south-west Cork to west Donegal (54° N). It was not seen in Scotland by Crisp and Southward in 1953-62, and there are no Scottish Records in the Provisional Atlas (Norton, 1985). However, more interest attaches to those algae of northern character, already close to their southern limit in the British Isles. Powell (1957) charted the distribution of *Fucus distichus distichus* down the western coasts, and the Crisp & Southward database includes records for 1958 in Kerry and Clare, 1962 in Barra and 1953 in Orkney; there are records for St. Kilda but not for the inner Hebrides (Norton, 1985). There are no additional records of this northern fucoid for the cool period of 1962-1980 when the species might possibly have been expected to increase its range. It has never been recorded from the east coast of Scotland. *F. distichus distichus* is likely to retreat northwards under the influence of global warming, but debilitating effects of higher temperatures might be mitigated if the weather became more stormy and exposed rocks more frequently washed by waves. The red alga *Odonthalia dentata* reaches its southern limits in the Irish Sea and may retreat northwards.

Ascophyllum nodosum is a boreal species that reaches its southern limit in the British Isles and Northern France. It is a characteristic dominant of the mid-intertidal of sheltered Scottish shores, and was formerly exploited for agriculture and industry (fertilizer, iodine, alginates). It is still grazed by sheep at some localities. In the south of England there are signs that this alga is under stress and may not be recruiting. At a shore near Plymouth the well-documented decline of this species between the 1930s and the 1970s has been attributed to anthropogenic factors (Holme and co-workers in the1970s), but it is likely that climate effects may also be involved. Across the Channel, the species flourishes in Brittany and survives harvesting. However, along the north coast of Brittany the strong tidal mixing provides lower summer sea temperatures, and also increases the supply of inorganic nutrients.

Appendix 2. Benthic marine species which occur in Scotland or may spread there or be affected by expected climate change and which are listed in statutes, directives or Biodiversity Action Plans.

UK BAP = UK Biodiversity Action Plan. W&C Act = Wildlife & Countryside Act 1981. NI Order = Wildlife (NI) Order 1985.

* = species for which basic information on current distribution and biology relevant to climate change effects has been undertaken (Appendix 5). ** = species for which information on current distribution and biology relevant to climate change effects has been researched and predictions made of future likley change in distributions and abundance (Appendix 7).

Species	Common name	Statute, directive or BAP	Found in Scotland	Distribution
*Eunicella verrucosa***	pink sea-fan	UK BAP W&C Act Sched. 5	No	Records from the south west of England and Wales and the west coast of Ireland only.
Funiculina quadrangularis *	tall sea pen	Species statement in UK BAP	Yes	Numerous records for the west of Scotland.
Amphianthus dohrnii *	sea fan anemone	UK BAP	Yes	Recorded off Mull and Jura and in the Firth of Lorn. Also present off the south coast of Devon and Cornwall and at Lundy.
Sabellaria alveolata *	Honeycomb worm	UK BAP	Yes	Predominantly southern in occurrence. Recorded in the Solway Firth in Scotland as well as other locations on the west of the UK. One record from Lewis.
Sabellaria spinulosa	ross worm	UK BAP	Yes	Recorded thoughout the UK but reefs or crusts recorded only in southern Scotland.
*Modiolus modiolus**	horse mussel	UK BAP	Yes	Recorded thoughout the UK although only occurs as beds of large individuals north of west Wales. Important in forming five biotopes in Scotland.
Atrina fragilis *	a fan shell	UK BAP	Yes	Recorded off the west of Scotland (especially around Mull), Shetland, Orkney and the Moray Firth. Also present in south-west England. Rarely encountered.
Ostrea edulis *	native oyster	UK BAP	Yes	Recorded off the west coast of Scotland and Shetland.
Thyasira gouldi *	northern hatchett shell	UK BAP	Yes	Northern species recorded from upper Loch Etive, Loch Eil and Loch Sunart. The status at the latter two sites is currently unknown.

Echinus esculentus	edible sea urchin	IUCN Red Data Book; NI Order Shed.7	Yes	Recorded thoughout the UK.
Styela gelatinosa *	a sea squirt	Species statement in UK BAP	Yes	Records from Clyde sea only.
Pomatoschistus microps	common goby	Berne Conv. App. III	Yes	Recorded commonly around Scotland and off the south coast of England.
Pomatoschistus minutus	sand goby	Berne Conv. App. III	Yes	Recorded thoughout the UK.
Lithothamnion corallioides *	Maerl	Habitats Directive Annex V	Yes	Recorded off the west coast of Scotland and Shetland. Also occurs of the west coast of Ireland and SW England.
Phymatolithon calcareum	Maerl	Habitats Directive Annex V	Yes	Commonly recorded in Scotland, also occurs on the west coast of the England and Wales.
Anotrichium barbatum	a red alga	UK BAP	No	Recorded in Cardigan Bay only
Ascophyllum nodosum ecad *mackaii* *	a brown alga	UK BAP	Yes	Recorded off Lewis, Shetland and the west coast of Scotland.
Zostera marina / angustifolia	eel grass	UK BAP	Yes	Commonly recorded in Scotland, also occurs on the west coast of the UK.

Appendix 3. Benthic biotopes which are part of Biodiversity Action Plans (BAPs) and are either found in Scotland or are likely to spread there in response to expected climate change.

* = included in detailed reviews of likely effects of climate change (Appendix 7). Habitat Directive Annex 1 habitats are: S = Sandbanks which are slightly covered by seawater all the time; E = Estuaries; M&S = Mudflats and sandflats not covered by seawater at low tide; L = lagoons; B = Large shallow inlets and bays; R = Reefs; C = Caves.

Intertidal and subtidal habitats	Biotope code	Main Species	Notes	Habitats directive habitat
Sabellaria alveolata reefs	MLR.Sab.Salv *	*Sabellaria alveolata*	Recorded from south and west coasts of England and Wales and as far north as the Solway Firth. One record from Lewis.	R
Mudflats	LMU.Smu		Contains 4 distinct biotopes which occur in Scotland yet are not special or likely to be affected by climate change.	M&S L
	LMU.Mu		Contains 3 distinct biotopes that just extend into Scotland.	M&S
	LMS.MS		Contains 4 distinct biotopes which occur in Scotland yet are not special or likely to be affected by climate change.	M&S L
Sheltered muddy gravels	IMX.FaMx.VsenMtru	*Venerupis senegalensis* & *Mya truncata*	Not special to Scotland or likely to be affected by climate change.	E B
	LMX.Mare	*Mya arenaria* & polychaetes	Not special to Scotland or likely to be affected by climate change.	E B
	LMX.MytFab	*Mytilus edulis* & *Fabricia sabella*	Not special to Scotland or likely to be affected by climate change.	E B
	IMX.FaMx.An	burrowing anemones	No records.	N/a
Sabellaria spinulosa reefs	CMX.SspiMx *	*Sabellaria spinulosa* & *Polydora* spp.	Reefs (including crusts) recorded off the coasts of England and Wales, just extending north into Scotland.	R
Tidal rapids	ECR.Alc		Contains 4 distinct biotopes which occur in Scotland but are not special to Scotland or likely to be affected by climate change.	R B

Tidal rapids	ECR.BS		Contains five distinct biotopes which occur in Scotland. All except ECR.HbowEud (see below) are not special to Scotland or likely to be affected by climate change.	R B
	ECR.BS.HbowEud *	*Halichondria bowerbanki*, *Eudendrium arbusculum* & *Eucratea loricata*	Recorded from the Clyde area sea lochs only.	R B
Modiolus modiolus beds	CMX.ModMx *	*Modiolus modiolus*	Recorded off the Shetland, Orkney, west Scotland, Wales and east England.	R B
	SCR.Mod.ModCvar *	*Modiolus modiolus* & *Chlamys varia*	Recorded in Strangford Lough only.	R B
	SCR.Mod.ModHAs *	*Modiolus modiolus* & fine hydroids	Recorded off west Scotland, Shetland and Orkney only.	R B
	MCR.M.ModT *	*Modiolus modiolus* & hydroids & red algae	Recorded off west Scotland, Shetland, Orkney and NW Wales.	R B
	CMX.ModHo *	*Cerianthus lloydii* & *Modiolus modiolus*	Recorded off west Scotland and Shetland.	R B
Seagrass beds	IMS.Sgr.Zmar	*Zostera marina & Z. angustifolia*	Not special to Scotland or likely to be affected by climate change.	S L
	IMS.Sgr.Rup *	*Ruppia maritima*	Recorded off west Scotland (especially the Outer Hebrides), Shetland, Orkney and the Moray Firth.	S L
	LMS.Zos.Znol	*Zostera noltii*	Not special to Scotland or likely to be affected by climate change.	S M&S
Maerl beds	IMX.MrlMx.Lden	*Lithothamnion dentatum*	Knowledge of distribution is incomplete.	S B
	IMX.MrlMx.Lfas	*Lithothamnion fasciculatum* & *Chlamys varia*	Occurs in SW Ireland.	S B
	IMX.MrlMx.Lcor *	*Lithothamnion corallioides*	Recorded in SW Ireland and UK. Scottish records are unconfirmed due to problems with identification.	S B

Maerl beds	IGS.Mrl.Lgla *	*Lithothamnion glaciale*	Northern species with southern recorded limit at Lundy. Recorded in west Scotland and Shetland. Found in variable salinity habitats.	S B
	IGS.Mrl.Phy *	*Phymatolithon calcareum*	Recorded off NW Scotland and Orkney. The major maerl bed biotope in Scotland.	S B
	IGS.Mrl.Phy.Hec	*Phymatolithon calcareum*, hydroids & echinoderms	Recorded off west Scotland, Shetland, Orkney, Strangford Lough and from Plymouth.	S B
	IGS.Mrl.Phy.R	*Phymatolithon calcareum* & red algae	Recorded off west Scotland, Shetland, Orkney, Pembrokeshire and from Plymouth.	S B
Saline lagoons	IMU.Ang.NVC A12	*Potamogeton pectinatus*	Recorded on Barra, in Shetland and Orkney. Occurrence is according to presence of lagoon conditions rather than temperature.	L
	IMU.Ang.NVC S4	*Phragmites australis*	Recorded in the Harris area only in the UK. Occurrence is according to presence of lagoon conditions rather than temperature.	L
Mud habitats in deep water	CMU.SpMeg	Seapens & burrowing megafauna	Recorded extensively in Scottish west coast sea lochs, Western Isles and Shetland. Also occurs in the Irish Sea, North Sea and off the south coast of England.	B
	CMU.SpMeg.Fun *	Seapens & *Funiculina quadrangularis*	Recorded in Scottish west coast sea lochs.	B
	CMU.Beg *	*Beggiatoa* spp.	Recorded in Scottish west coast sea lochs.	B
	CMU.BriAchi	*Brissopsis lyrifera* & *Amphiura chiajei*	Recorded in the northern Irish Sea, Clyde, Minch and some Scottish sea lochs (e.g. Loch Etive).	B
	COS.ForTHy	Foraman-iferans & *Thyasira* sp.	Recorded in the northern North Sea, some west coast Scottish sea lochs (Lochs Eil & Nevis) and the southern Irish Sea.	B
	COS.Sty *	*Styela gelatinosa*	Recorded in Clyde sea loch only (Loch Goil).	B

Serpulid reefs	CMS.Ser *	*Serpula vermicularis*	Reefs only recorded from Loch Creran and Loch Sween on west coast of Scotland. Reefs in the latter are now reported to be dead.	B R
Sublittoral sands and gravels	IGS.FaG.HalEdw *	*Halcampa chrysanthellum* & *Edwardsia timida*	Recorded in west Scotland in Loch Creran, Loch Eynort (Skye) and Church Bay (Rathlin Island). Also occurs in Strangford Narrows.	S B
	IGS.FaG.Sell	*Spisula elliptica* & venerid bivalves	A common habitat with examples found from Shetland to the Isles of Scilly.	S B
	IGS.FaS.NcirBat	*Nephyts cirrosa* & *Bathyporeia* spp.	Commonly recorded in full salinity areas of many estuaries.	S B

Appendix 4. Species with climatically restricted distributions or abundance in or near Scotland

* = species for which basic information on current distribution and biology relevant to climate change effects has been undertaken (Appendix 5). ** = species for which information on current distribution and biology relevant to climate change effects has been researched and predictions made of future likley change in distributions and abundance (Appendix 7).

Species	Common name	Current distribution other comments	North or South
Porifera			
*Axinella dissimilis**	A branching sponge	Recorded in the British Isles as far north as Mull, Northern Ireland and Anglesey.	S
*Ciocalypta penicillus**	A sponge	Recorded in the British Isles as far north as Northern Ireland and Anglesey.	S
Hemimycale columella	A sponge	Recorded off west Scotland and Shetland in Scotland.	S
Phorbas fictitius	A sponge	Records from west Scotland, Orkney and Shetland in Scotland.	S
Haliclona angulata	A sponge	Only recorded from SW Britain in the British Isles.	S
Haliclona cinerea	A sponge	Recorded from west Scotland and Orkney in Scotland.	S
Haliclona fistulosa	A sponge	Recorded from west Scotland and Orkney in Scotland.	S
Haliclona simulans	A sponge	A southern species with a few records from west Scotland and Orkney.	S
Cnidaria			
*Thuiaria thuja**	Bottle-brush hydroid	A northern species recorded south to off Northumberland in the British Isles Records from the Firth of Forth, Orkney, Shetland and Lewis in Scotland.	N
*Gymnangium montagui**	Yellow feathers hydroid	A southern species extending as far north as Northern Ireland and Anglesey in the British Isles.	S
*Alcyonium glomeratum**	Red sea fingers	A southern species with scattered records from the west coast of Scotland.	S
*Swiftia pallida***	Northern sea-fan	Only recorded in west Scotland and St Kilda in the British Isles.	N
*Eunicella verrucosa***	A sea-fan	A southern species recorded as far north as north-west Ireland and south-west Wales in the British Isles.	S
*Funiculina quadrangularis**	Tall sea pen	Recorded on the north and west coasts of Ireland and Scotland. Also occurs in the Mediterranean. Species statement in UK BAP. Geographical distribution does not indicate likleyhood of significant climate change effects.	
*Anemonia viridis***	Snakelocks anemone	Widely recorded on the west coast of Britain and Orkney but not recorded in Shetland during extensive surveys.	S

*Bolocera tuediae**	An anemone	The only records in Britain are off the south-east coast of Scotland and north east cost of England and south-west coasts of Scotland.	N
Aulactinia (=*Bunodactis*) *verrucosa**	Gem anemone	A southern species recorded at a few locations in south-west Scotland and Shetland.	S
Aiptasia mutabilis	Trumpet anemone	A southern species recorded as far north as Anglesey in the British Isles.	S
*Phellia gausapata***	An anemone	A northern species recorded in west Scotland, Shetland and Northern Ireland in the British Isles.	N
*Amphianthus dohrnii**	Sea fan anemone	Recorded in west Scotland and a few locations in south-west Britain. UK BAP species. Geographical distribution does not indicate likleyhood of significant climate change effects unless the host in Scotland (*Swiftia pallida*) declines without replacement by a southern host (*Eunicella verrucosa*).	
*Corynactis viridis**	Jewel anemone	A southern species. Recorded on open wave exposed coasts in western Scotland, Orkney and Shetland in Scotland.	S
Annelida			
*Sabellaria alveolata**	Honeycomb worm	A southern species. The only Scottish records are from the Solway Firth and on Lewis.	S
Crustacea			
*Chthamalus montagui***	Montagu's punctate barnacle	Southern species commonly recorded off the north and west coasts of Scotland, present in Orkney and Shetland. Also rare at a few places on the east coast.	S
*Chthamalus stellatus***	Poli's stellate barnacle	A southern species recorded off west Scotland, Shetland and Orkney in Scotland.	S
Balanus perforatus	A barnacle	Only recorded in south-west Britain as far north as south Wales in the British Isles.	S
Hippolyte huntii	A shrimp	A southern species which has been recorded off west and south east Ireland and south west England in the British Isles but is rare. Recorded in Scotland also recorded at Strome Narrows.	S
*Palinurus elephas**	Crawfish	Previously widely distributed in south-west Britain in the British Isles but has declined in the past 20 years. Recorded on the west coast of Scotland, Orkney and Shetland. Also a few records from the east coast of Scotland.	S
*Lithodes maia***	Northern stone crab	A northern species recorded in west Scotland and Shetland in the British Isles.	N
Polybius henslowi	Henslow's swimming crab	Southern species recorded throughout Britain except in Shetland.	S

Ebalia tumefacta	Bryer's nut crab	A southern species recorded at a few locations in south-west Scotland in Scotland.	S
Maja squinado **	Thorn backspider crab	A southern species that only extends as far north as the Isle of Man and north-west Ireland in the British Isles.	S
Corystes cassivelaunus	Maskeed crab	A southern species recorded on south-west coast of Scotland and in Orkney in Scotland.	S
Liocarcinus arcuatus	Arch-fronted swimming crab	A southern species recorded at a few locations in the south-west in Scotland.	S
Liocarcinus corrugatus	Wrinkled swimming crab	A southern species recorded from west Scotland and Lewis in Scotland. Also common in Orkney.	S
*Goneplax rhomboides**	Angular crab	A southern species recorded from a few locations on the west coast of Scotland.	S
Pilumnus hirtellus	Bristly crab	A southern species recorded on the west coast of Scotland and in Orkney.	S
*Xantho incisus**	Montagu's crab	A southern species recorded on the south-west coast of Scotland.	S
Xantho pilipes	A crab	A southern species recorded on the west coast of Scotland and in Shetland	S
Mollusca			
Tonicella marmorea	A chiton	Northern species recorded as far south as Northumberland and North Wales.	N
Tricolia pullus	Pheasant shell	A southern species of snail recorded off the west coast of Scotland but not in Orkney or Shetland.	S
*Margarites helicinus**	Pearly top shell	A northern species recorded in both west and east Scotland, Shetland and Orkney.	N
*Gibbula umbilicalis***	Flat top shell	A southern species commonly recorded on the west coast of Britain and present in Orkney.	S
Osilinus lineatus (=*Monodonta lineata*)**	Toothed top shell	A southern species which reaches its northern limits in Northern Ireland and Anglesey in the British Isles.	S
*Tectura testudinalis***	Tortoiseshell limpet	A northern species commonly recorded throughout Scotland but reaching its southern limit in the Irish Sea in the British Isles.	N
*Patella depressa***	Black-footed limpet	A southern species which reaches its northern limits at Anglesey in the British Isles.	S
*Patella ulyssiponensis*** (= *Patella aspersa*)	A limpet	Commonly recorded on the west coast of Britain and present in Orkney. Also occurs in Shetland and on the east coast of Britain as far south as Filey in Yorkshire.	S
Bittium reticulatum	Needle whelk	Recorded off west Scotland and Orkney in Scotland.	S
Cerithiopsis tubercularis	A gastropod	Occasionally recorded off west Scotland.	S

Melaraphe neritoides	Small periwinkle	A southern species that occurs on wave exposed rocky coasts. Commonly recorded throughout Britain.	S
Onoba aculeus	A gastropod	A northern species recorded off east and west Scotland, Orkney and Shetland	N
*Calyptraea chinensis**	Chinaman's hat	Rarely recorded in south-west Scotland and west Ireland.	S
Crepidula fornicata	Slipper limpet	An introduced species recorded as far north as the Wash and south-west Wales in the British Isles.	S
Clathrus clathrus	A gastropod	Records from Mull and Moray Firth.	S
Ocenebra erinacea	Oyster drill	Recorded off east Scotland, Shetland and the Firth of Forth	S
Colus islandicus	A gastropod	A northern species with a few British records from north Scotland, Shetland and Northern Ireland.	N
Acteon tornatilis	A gastropod	Occasionally recorded all around Scottish mainland.	S
Akera bullata	A sea slug	Northern species recorded off west Scotland, Shetland, Orkney and Moray Firth.	N
Pleurobranchus membranaceus	A sea slug	Recorded off west Scotland, Orkney and Shetland.	S
Tritonia nilsodhneri	A sea slug	This species has a south-western distribution in the British Isles and is recorded as far north as NW Ireland.	S
*Atrina fragilis**	Fan mussel	Present in south west England and western Scotland in the British Isles. Recorded off the west of Scotland (especially around Mull), Shetland, Orkney and the Moray Firth. Rarely encountered.	S
Limaria hians	File shell	A northern species recorded often in large numbers in west Scotland But also recorded on the south coast of England in the British Isles.	N
*Ostrea edulis**	Native oyster	Recorded from Norway to the Mediterranean and the Black Sea. Widely distributed around the British Isles. UK BAP species. Geographical distribution does not indicate likleyhood of significant climate change effects	
Crassostrea virginica	American oyster	An introduced species not recorded in Scotland.	S
Anomia ephippium	Common saddle oyster	Commonly recorded from north and west Scotland, Shetland and Orkney. Also occurs in the Firth of Forth. Included here because it is an important componant of biotopes in Scotland.	N

*Thyasira gouldi**	Northern hatchett shell	Northern species recorded from upper Loch Etive, Loch Eil and Loch Sunart. The status at the latter two sites is currently unknown. These are the most southerly European populations of this species.	N
Cerastoderma glaucum	Lagoon cockle	Rarely recorded on both coasts of Scotland and Orkney.	S
Solen marginatus	Grooved razor shell	A southern species recorded as far north as Anglesey.	S
*Gari depressa**	Large sunset shell	A southern species, just extending north into west Scotland in the British Isles.	S
Bryozoa			
*Pentapora fascialis*** (= *Pentapora foliacea*)	Ross	A southern species abundant in southwest Britain and recorded off west Scotland including at St Kilda.	S
Echinodermata			
Leptometra celtica	A crinoid	Only recorded on the west coast of Scotland in Britain.	N
*Asterina gibbosa**	Cushion star	Recorded off west Scotland and Orkney in Scotland.	S
*Leptasterias muelleri**	A star fish	A northern species recorded south to the Isle of Man and to Durham on the coast of Britain.	N
*Paracentrotus lividus***	Purple sea urchin	A southern species which is abundant in parts of south-west Ireland but has only sporadic recorded occurrences in south west England and at a few locations on the west coast of Scotland.	S
Strongylocentrotus droebachiensis **	Green sea urchin	A northern species confined to Shetland and Orkney in coastal waters.	N
*Holothuria forskali***	Cotton spinner	A southern species that is abundant in parts of south west England. Recorded off west Ireland and a few locations off west Scotland around Rum.	S
*Cucumaria frondosa***	Northern sea cucumber	A northern species widely recorded in small numbers in Shetland, also occurs in Orkney.	N
Tunicata			
Phallusia mammillata	A sea squirt	A southern species recorded as far north as Anglesey.	S
*Styela gelatinosa**	A sea squirt	Only British population is in Loch Goil (Clyde Sea). Also occurs in Scandinavia and Iceland.	N
Pisces			
Centrolabrus exoletus	Rock cook	Most abundant in southern Britain but recorded off west Scotland and in Orkney.	S
Crenilabrus melops	Corkwing wrasse	Most abundant in southern Britain but recorded off west Scotland and Orkney.	S
Ctenolabrus rupestris	Goldsinny wrasse	Recorded off west Scotland, Shetland and Orkney but not in large numbers compared with densities in similar habitas in Norway.	S

*Labrus mixtus**	Cuckoo wrasse	Widely recorded off north and west Scotland, Orkney and Shetland but uncommon. Also occurs in the Firth of Forth.	S
Lumpenus lumpretaeformis	Snake blenny	Northern species recorded off west Scotland, Shetland, Orkney only in the British Isles.	N
*Thorogobius ephippiatus**	Leopard-spotted goby	Recorded off west Scotland, Orkney and in the Firth of Forth.	
Algae			
Scinaia furcellata	A red alga	Present from the Mediterranean and Morocco to southern Norway. Southern species recorded as far north as Anglesey and south-west Ireland. In the British Isles. Also a single Scottish record from Barra.	S
Scinaia trigona (= S. turgida)	A red alga	Present from the Mediterranean and Portugal to the British Isles. Recorded in west Scotland and Shetland	S
Asparagopsis armata (*Falkenbergia* phase)	A red alga	The tetrasporophyte (*Falkenbergia*) phase of *Asparagopsis armata*) occurs as far north as Shetland but is not recorded from the east of Scotland. Not recorded from Northern Ireland. (The gametophyte phase is recorded from a few locations in south-west England and from southern Ireland in the British Isles).	S
*Bonnemaisonia hamifera**	A red alga	The tetrasporophyte phase (*Trailliella)* is widely distributed from Mauritania to northern Norway but the gametophyte (*Bonnemaisonia*) phase is only found between Spain and south-west England.	S
Naccaria wiggii	A red alga	Present from the Mediteranean and Spain to southern Britain as far north as the Isle of Man. There is a single Scottish record from north-west Scotland that requires checking.	S
*Jania rubens**	A red alga	Southern species occuring as far north as Norway. In British Isles recorded northwards to west Inverness and Aberdeen. Very rare in Northern Ireland.	S
Lithothamnion corallioides	Maerl	Present from the Canary Isles to Norway. Recorded off west Scotland and Shetland but records need checking and many are dubious. A southern species.	S
*Lithothamnion glaciale**	Maerl	Present from northern British Isles to Arctic Russia. A northern species commonly recorded in west Scotland, Shetland, Orkney and the Firth of Forth. Common in Northern Ireland. Recorded reliably south to Lundy and to Flamborough on the east coast of England.	N

*Mesophyllum lichenoides**	A calcified red alga	Present from Mauritania north to the British Isles. Recorded from west Scotland and Orkney (Shetland records require confirmation).	S
*Phymatolithon calcareum**	Maerl	Recorded off NW Scotland and Orkney. Sporadic occurences further south in Britain.The major maerl bed biotope in Scotland.	
Calliblepharis ciliata	A red alga	Present from Mauritania and the Mediterranean to the British Isles. Recorded off west Scotland and in Orkney.	N
Chondracanthus (=*Gigartina*) *acicularis*	A red alga	Present from Cameroon to the British Isles. Southern species recorded as far north as Anglesey (record needs checking) and Galway Bay	S
*Callophyllis cristata**	A red alga	Northern species recorded on west coast of Scotland, Shetland and Orkney. Also occurs on east coast and in Northumberland. This is its southern limit and does not occur in Northern Ireland.	N
Kallymenia reniformis	A red alga	Present from Morocco to the British Isles including Shetland. Recorded off west Scotland, Orkney and Shetland	S
*Stenogramme interrupta**	A red alga	Southern species recorded from Morocco to Cornwall & Devon. In Northern Ireland, rare in littoral, not uncommon in sublittoral. Absent from Scotland.	S
Rhodymenia delicatula	A red alga	Present from Morocco to the British Isles. Recorded off west Scotland, Orkney and Shetland	S
*Rhodymenia holmesii**	A red alga	Present from Morocco to the British Isles. Recorded north to Anglesey and with some records for Jura and Islay. Very rare in northern Ireland.	S
Rhodymenia pseudopalmata	A red alga	Present from Morocco and the Azores to the British Isles. Recorded off the west coast of Scotland and Orkney and in north-east England. Not recorded from Shetland.	S
Halurus equisetifolius	A red alga	Present from the Mediterranean and southern Spain to Norway and the Faroes. Recorded in SW Scotland and Orkney.	S
*Sphondylothamnion multifidum**	A red alga	Present from the Canary Island to British Isles. Distribution in Scotland restricted to a few locations on the west coast.	S
Drachiella heterocarpa (=*Myriogramme heterocarpum*)	A red alga	Present from northern Spain to the British Isles. Southern species with a few records from the Outer Hebrides and outer Solway Firth in Scotland.	S
Drachiella spectabilis	A red alga	Present in northern France and the British Isles. The only Scottish records are from Islay and St Kilda.	S

*Odonthalia dentata***	A red alga	Present from the British Isles to Spitzbergen. Recorded throughout Scotland and as far south as the Isle of Man on the west coast of Britain and Flamborough on the east coast.	N
Stilophora tenella (= S. rhizoides)	A brown alga	Present from France to Scotland. Recorded from west Scotland, Orkney and Shetland	S
*Sphacelaria arctica**	A brown alga	Northern species only recorded in Shetland in the UK. Also occurs in Denmark, Baltic, Norway & Greenland.	N
*Sphacelaria mirabilis**	a brown alga	Northern species recorded in north Wales, Cheshire, around Scotland to north-east England at Berwick-upon-Tweed.	N
Sphacelaria plumosa	a brown alga	Northern species recorded reliably in west Wales, Cheshire, around Scotland to north-east England at Flamborough Head. Rare in Northern Ireland.	N
Halopteris filicina	a brown alga	Present from the Azores and Portugal to Scotland. Recorded from western Scotland. (Shetland record requires confirmation)	S
*Dictyopteris membranacea***	a brown alga	Present from the Azores and Portugal to the British Isles. A southern species present in large amounts only in the extreme south-west of Britain with a few records from west Scotland.	S
*Taonia atomaria**	a brown alga	Present from the Azores and Portugal/southern Spain to south-west Britain to the Isle of Man and Ireland.	S
*Carpomitra costata**	a brown alga	Southern species recorded in Channel Islands and southern UK as far north as the Isle of Man and Donnegal. Rare in Ireland and only a few records from the Outer Hebrides.	S
Chorda tomentosa	a brown alga	Northern species recorded from west Scotland, Firth of Forth and Northern Ireland.	N
Laminaria ochroleuca	a kelp	Southern species currently recorded as far north as Lundy.	S
*Bifurcaria bifurcata**	a brown alga	Southern species recorded from southern Spain to England and Wales. Records from NW Ireland require checking.	S
Cystoseira baccata	a brown alga	Present from southern Spain and Portugal to south-west Britain and western Ireland.	S
Cystoseira foeniculaceus	a brown alga	A southern species only recorded in the south-west of England.	S
Cystoseira tamariscifolia	a brown alga	Recorded as far north as the mid outer hebrides, south-west Uist. Also recorded in Arisaig, south of Mallaig.	S

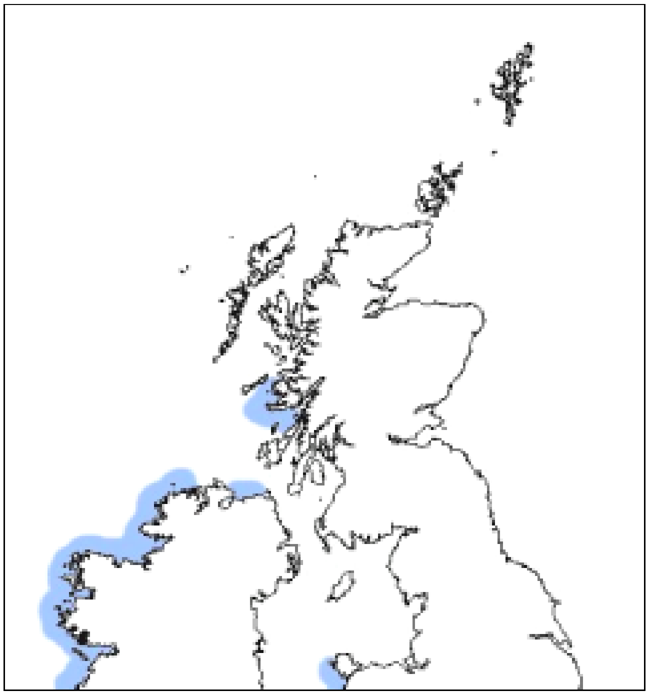
Ascophyllum nodosum ecad *mackaii**	Knotted wrack	Only recorded from Scotland in the UK and in a few locations in Ireland. Temperature may be important in distribution.	N
*Fucus distichus distichus***	A brown alga	Northern species recorded from Scotland to the Arctic. Not recorded in Northern Ireland.	N
*Fucus evansecens**	A brown alga	Present from Shetland and the Danish Baltic to the arctic. The only British records are from Shetland	N
*Codium adhaerens**	A green alga	Present Portugal to the British Isles. Scottish records limited to Argyll and Mull.	S
Codium tomentosum	A green alga	Present from the Mediterranean and Azores to northern Scotland. Also recorded in the Netherlands. Recorded in west Scotland and Orkney	S

Appendix 5. Basic information for species with a limited geographical range in or near Scotland whose distribution might change due to global warming.

The species names used in the following information sheets are those used in *The Species Directory of the Marine Fauna and Flora of the British Isles and Surrounding Seas* (Howson & Picton, 1997) where authorities for species names can be found. *Pentapora fascialis* (Pallas) is considered (Hayward & Ryland 1999) to include *Pentapora foliacea*, the name used in the Species Directory.

References given in the text of this appendix are included in the list of references following the body of the report.

1. *Axinella dissimilis* (=*Axinella polypoides*)



Common name:

Distribution:
Recorded as far north as Mull, Northern Ireland and Anglesey

Map shows likely current distribution using the following information sources:

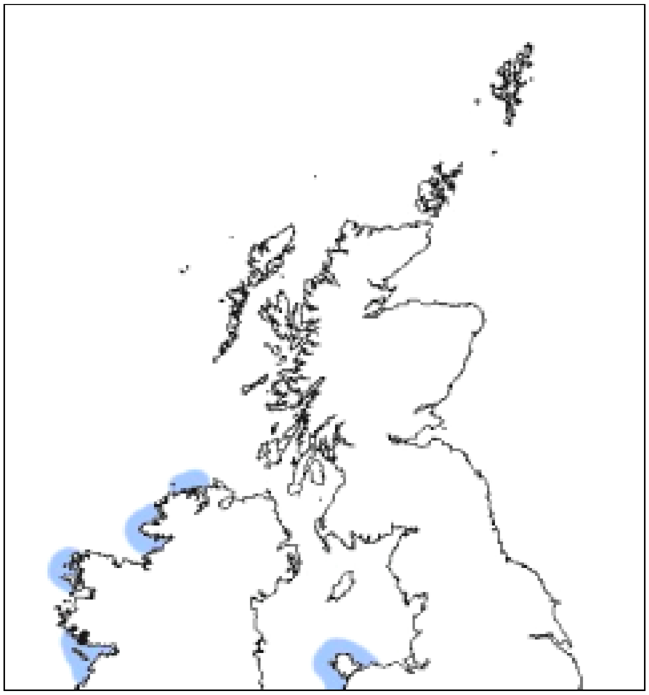
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epilithic, sublittoral (Hayward & Ryland, 1995)

Notes: This is a conspicuous species which could provide an easily identified species suitable for monitoring for changes in distribution.

Legislative protection: None

2. *Ciocalypta penicillus*



Common name:

Distribution:
Recorded as far north as Northern Ireland and Anglesey

Map shows likely current distribution using the following information sources:

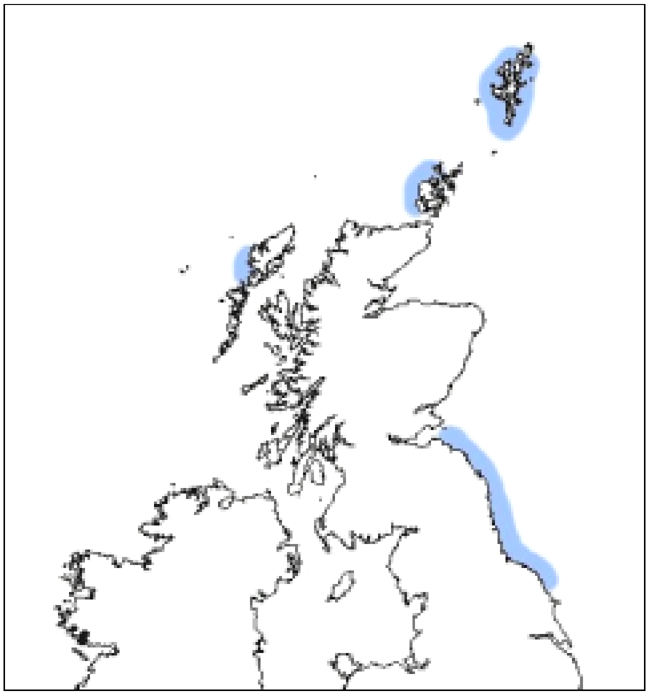
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On horizontal rock surface, sometimes partially covered by sand or silt (Hayward & Ryland, 1995)

Notes: This is a conspicuous species which could provide an easily identified species suitable for monitoring for changes in distribution.

Legislative protection: None

3. *Thuiaria thuja*



Common name:

Bottle-brush hydroid

Distribution:
A northern species recorded south to off Northumberland in the British Isles Records from the Firth of Forth, Orkney, Shetland and Lewis in Scotland.

Map shows likely current distribution using the following information sources:

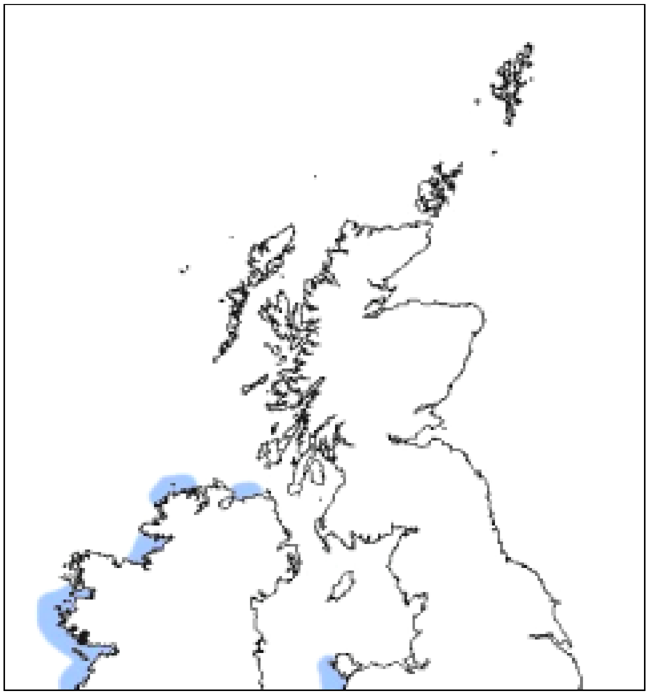
Cornelius, 1995; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On shells and similar substrata, 2 to 800m (Hayward & Ryland, 1995)

Notes: This is a conspicuous species which could provide an easily identified species suitable for monitoring for changes in distribution. The apparent lack of this species on the NE coast of Scotland is most likely due to a lack of survey information. One hundred years ago this species was commonly recorded further south in the English Channel (Cornelius, 1995).

Legislative protection: None

4. *Gymnangium montagui*



Common name:

Yellow feathers hydroid

Distribution:
Southern species extending as far north as Northern Ireland and Anglesey

Map shows likely current distribution using the following information sources:

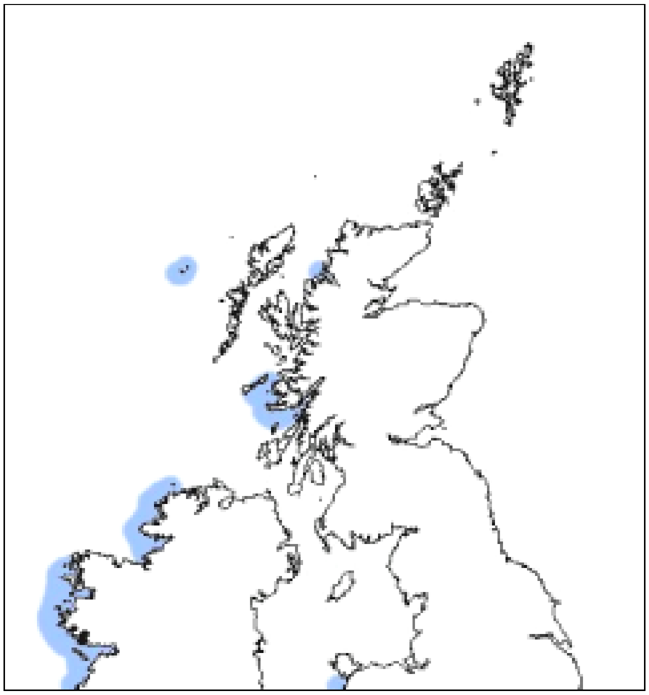
Cornelius, 1995; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On algae, shells and rock (Hayward & Ryland, 1995). Usually in deep coastal water.

Notes: This is a conspicuous species which could provide an easily identified species suitable for monitoring for changes in distribution. Reproductive season in August off Roscoff (Cornelius, 1995).

Legislative protection: None

5. *Alcyonium glomeratum*



Common name:

Red sea fingers

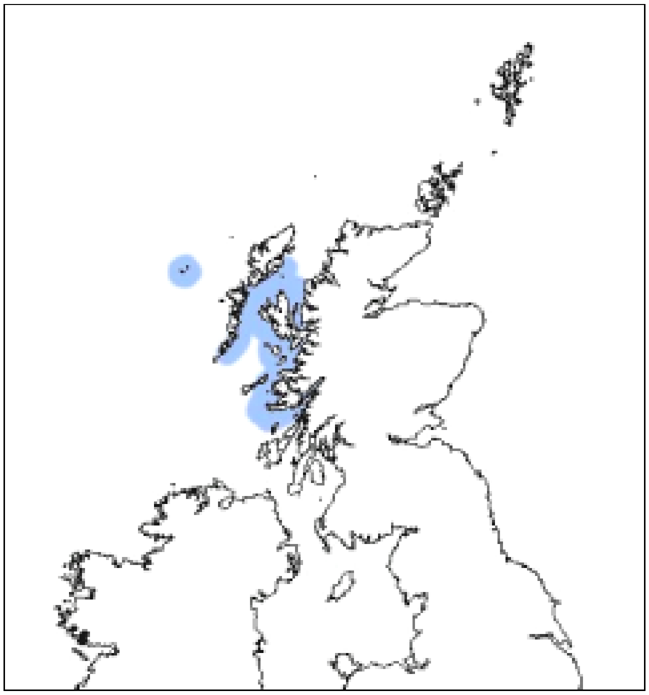
Distribution:
A southern species with scattered records from the west coast of Scotland.

Map shows likely current distribution using the following information sources:

Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	In gullies or caves sheltered from wave action; below 10-50m (Manuel, 1981; Hayward & Ryland, 1995)
Notes:	Distribution is mainly restricted to wave sheltered locations except in the Isles of Scilly where it is widespread on sheltered and exposed coasts.
Legislative protection:	None

6. *Swiftia pallida*



Common name:

Northern sea-fan

Distribution:
Only recorded in west Scotland and St Kilda in the British Isles. Also occurs in deep water in the Bay of Biscay and Meditteranean.

Map shows likely current distribution using the following information sources:

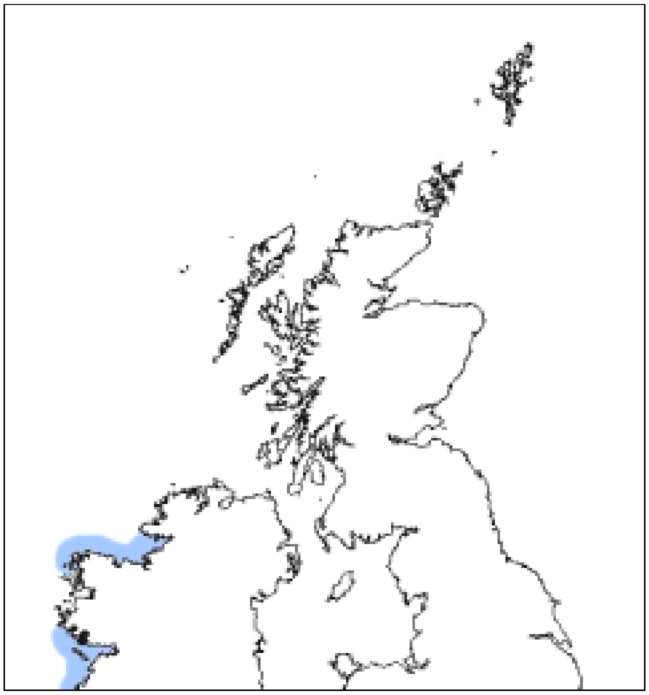
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On rocks and boulders between 18 and 60m (Manuel, 1981)

Notes: Typically northern or cold water (deep water) species which is usually present in small numbers except at a few locations. It is a host for the nationally rare sea anemone, *Amphianthus dohrnii.* A conspicuous, easily identified species, but it may be confused with *Eunicella verrucosa.*

Legislative protection: None

7. *Eunicella verrucosa*



Common name:

Pink sea-fan

Distribution:
Southern species recorded as far north as NW Ireland and SW Wales. Recorded east in the English Channel to Portland. Also common in SW Europe, Mediteranean and NW Africa.

Map shows likely current distribution using the following information sources:

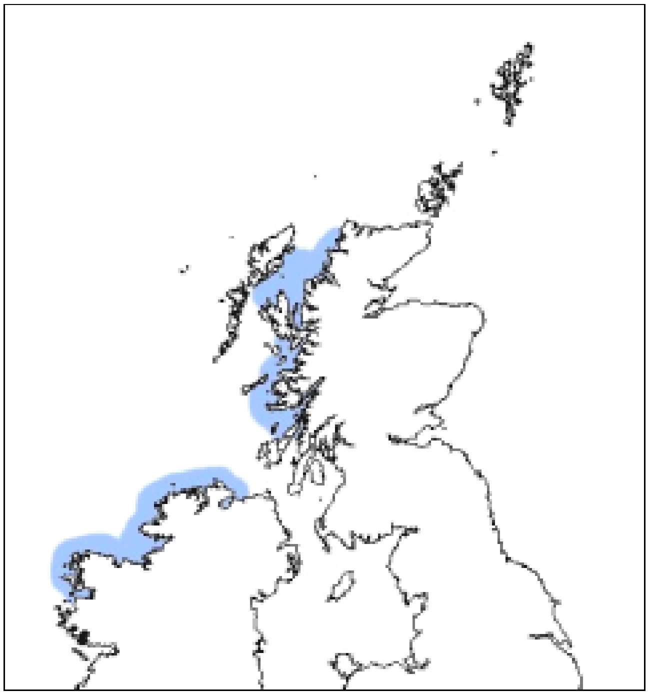
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Attached to rocks deeper than 10m (Hayward & Ryland, 1995).

Notes: A large, easily recognisable species suitable for the purposes of monitoring change. Recorded as far east as Margate in historical records (Manuel, 1981). Care is required to distinguish this species from *Swiftia pallida.*

Legislative protection: UK Species Action Plan
Wildlife and Countryside Act (1981): Schedule 5

8. *Funiculina quadrangularis*



Common name:

Tall sea pen

Distribution:
Recorded on the north and west coasts of Ireland and Scotland. Also occurs in the Mediterranean.

Map shows likely current distribution using the following information sources:

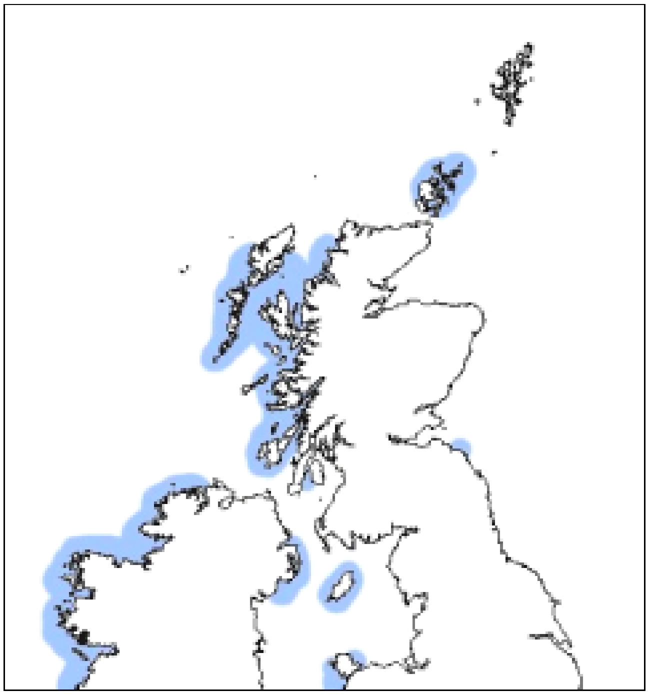
MERMAID
(www.jncc.gov.uk/mermaid)

Preferred habitat: In mud on sheltered shores especially in sea lochs; sublittoral to 15m (Hayward, Nelson-Smith & Shields, 1996). These habitat requirements are very specific resulting in its restricted distribution.

Notes: This species is only found in inshore waters in Scotland where it is a dominant feature of deep undisturbed and extremely sheltered sediments. Although not necessarily restricted to Scotland because of cold water, consideration of possible input of warmer waters is required.

Legislative protection: UK Biodiversity Action Plan: Species statement

9. *Anemonia viridis*



Common name:

Snakelocks anemone

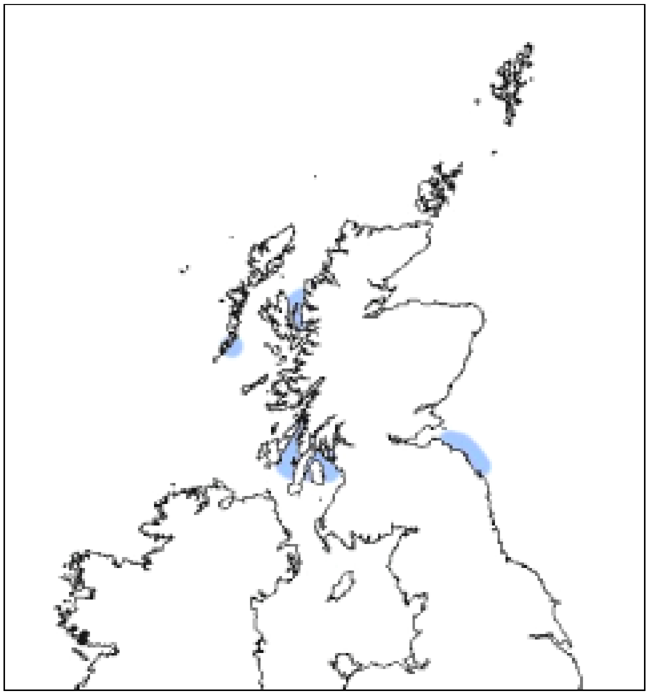
Distribution:
Widely recorded on the west coast of Britain and Orkney but not recorded in Shetland during extensive surveys.

Map shows likely current distribution using the following information sources:

Crisp & Southward, unpub data; Lewis, 1964; Hawkins & Jones, 1992; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	Eulittoral and sublittoral fringe pools on sheltered to moderately exposed shores; prefers areas open to light (Hawkins & Jones, 1992; Hayward & Ryland, 1995)
Notes:	Unable to tolerate prolonged conditions of extreme cold (Manuel, 1981). May be present on the NE coast of Scotland but records are unavailable. Absence from Shetland indicated by wide survey work. A conspicuous species suitable for monitoring.
Legislative protection:	None

10. *Bolocera tuediae*



Common name:

Deeplet anemone

Distribution:
The only records in Britain are off the south-east coast of Scotland and north east cost of England and south west coasts of Scotland.

Map shows likely current distribution using the following information sources:

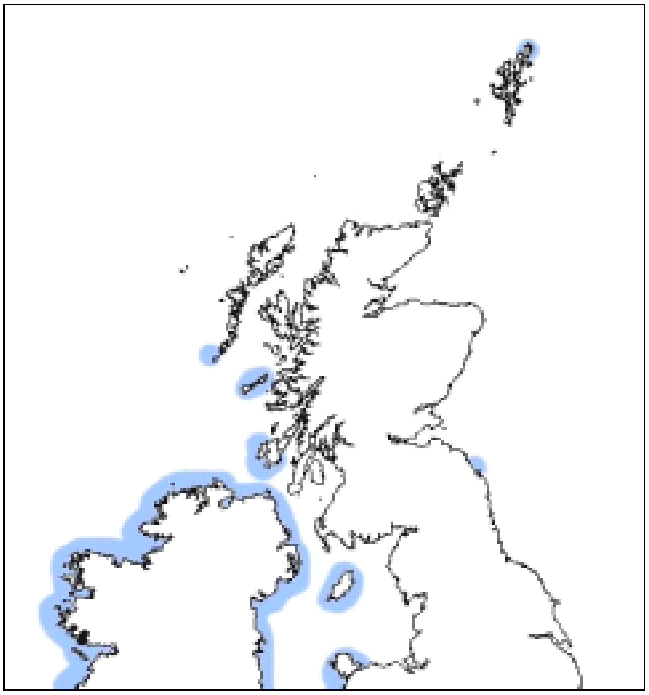
MERMAID
(www.jncc.gov.uk/mermaid)

Preferred habitat: Sublittoral below 20m (Hayward & Ryland, 1995). Offshore species occuring on rocks, stones and shells (Manuel, 1981).

Notes: A northern species, although surprisingly not recorded from Orkney/Shetland. May be long lived and with care can be readily identified and suitable for monitoring the effects of climate change.

Legislative protection: None

11. *Aulactinia verrucosa (=Bunodactis verrucosa)*



Common name:

Gem anemone

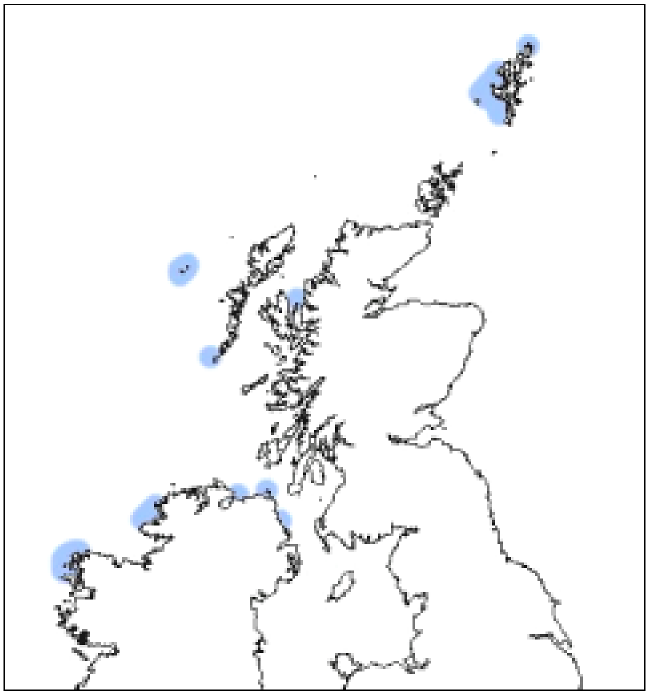
Distribution:
Southern species recorded at at few locations in SW Scotland and Shetland

Map shows likely current distribution using the following information sources:

Bruce *et al.*, 1963; Manuel, 1981; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	Intertidal in crevices and pools (especially with Corallina) or attached to rock beneath a layer of sand or gravel on sheltered to exposed shores; rarely found below low water on sheltered to exposed shores (Hayward & Ryland, 1995).
Notes:	A southern species, the record from Shetland requires checking. The habitat in which it is found is rather specialised and careful searching is required for this species.
Legislative protection:	None

12. *Phellia gausapata*



Common name:

Distribution:
Northern species recorded in west Scotland and Shetland and Northern Ireland.

Map shows likely current distribution using the following information sources:

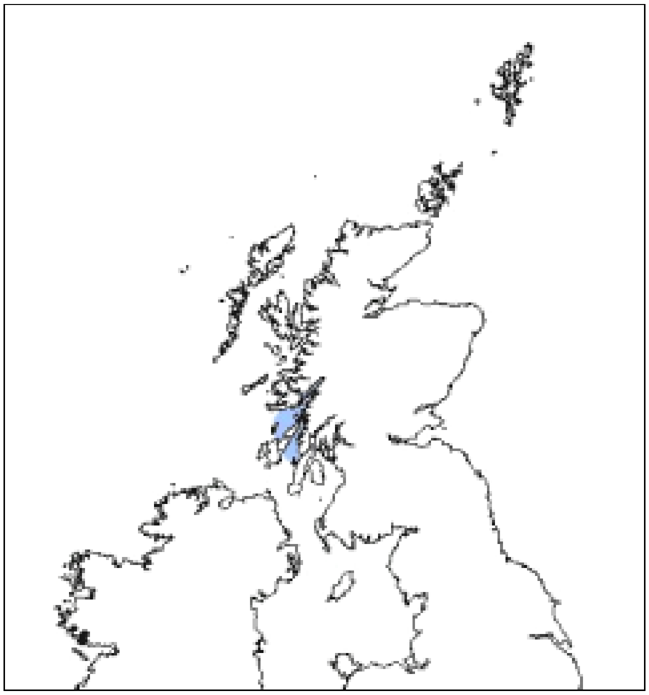
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Vertical bedrock usually at exposed locations.

Notes: A somewhat inconspicuous sea anemone which requires careful observation skills but as a northern species it should be included in any future monitoring.

Legislative protection: None

13. *Amphianthus dohrnii*



Common name:

Sea fan anemone

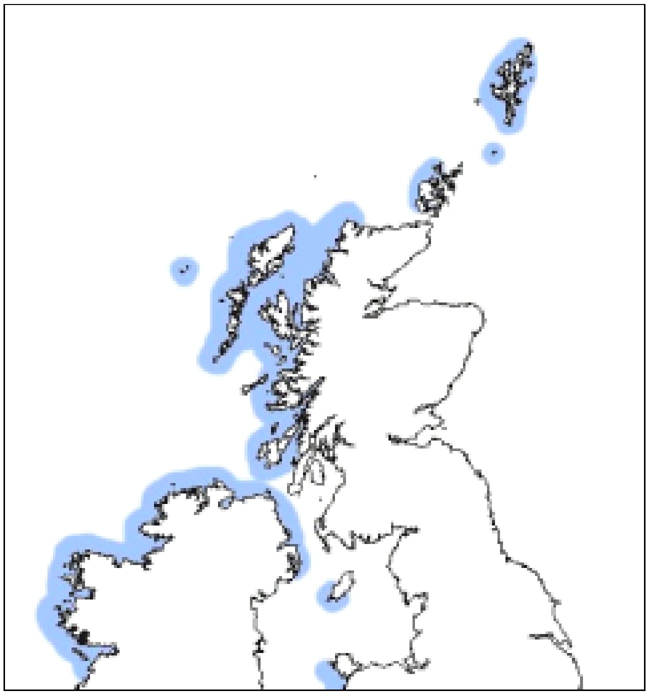
Distribution:
Recorded in west Scotland and a few locations in SW Britain.

Map shows likely current distribution using the following information sources:

Anon, 1999; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	Sea fans (*Eunicella verrucosa* and *Swiftia pallida*) and sometimes tubular hydroids, especially *Tubularia indivisa*.
Notes:	The distribution of this species follows that of the sea fan *Swiftia pallida* in Scotland. However, it is found at only a few southern sites where *Swiftia* occurs. Since the anemone is found in south-west England, it may be a southern species and more research is needed to establish if its restricted distribution in Scotland is the result of seawater temperatures.
Legislative protection:	UK Biodiversity Action Plan: Species statement

14. *Corynactis viridis*



Common name:

Jewel anemone

Distribution:
A southern species. Recorded on open wave exposed coasts in western Scotland, Orkney and Shetland in Scotland.

Map shows likely current distribution using the following information sources:

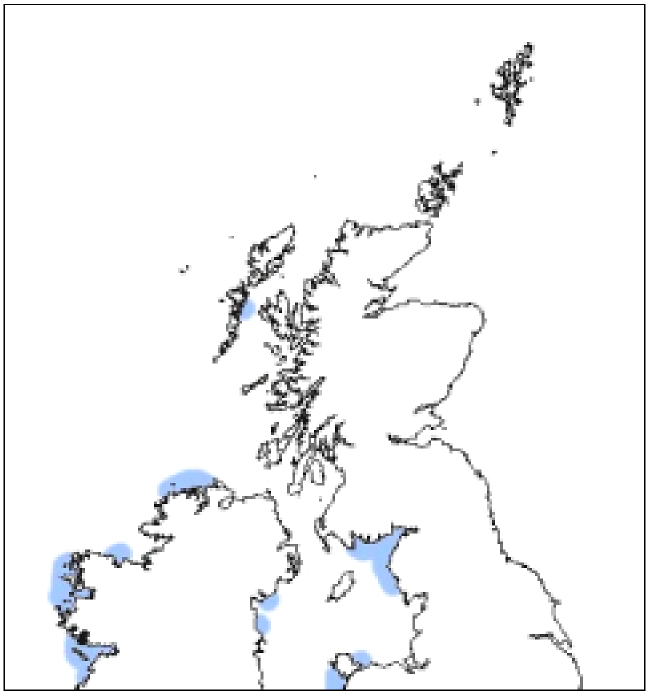
Bruce *et al.*, 1963; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Common in depths below 5m beneath overhangs and in caves; also found at low water in shaded places (Hayward & Ryland, 1995). Often forms dense aggregations on vertical rock faces (Manuel, 1981).

Notes: Occurrences in Scotland are generally of smaller patches or sparser colonies than occur farther south in the British Isles.

Legislative protection: None

15. *Sabellaria alveolata*



Common name:

Honeycomb worm

Distribution:
Only Scottish records are from the Solway Firth and off Lewis. MERMAID record from Outer Hebrides requires checking.

Map shows likely current distribution using the following information sources:

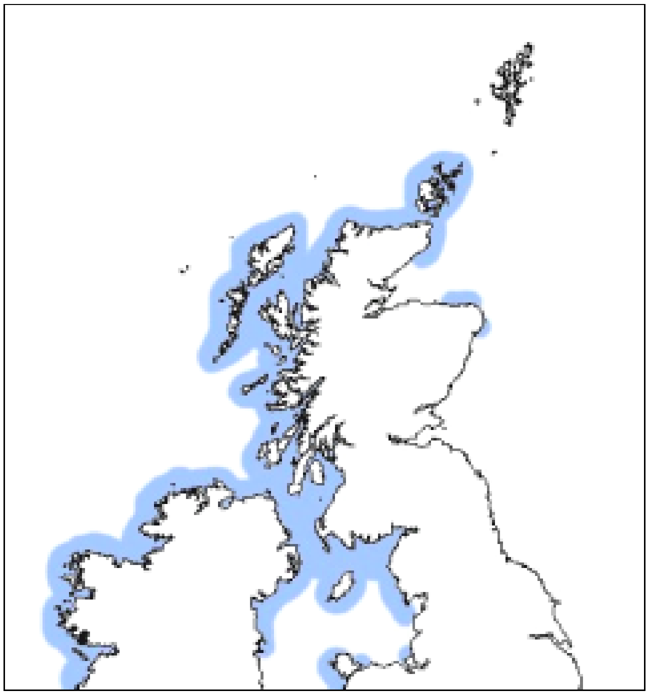
Crisp & Southward, unpubl. data; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Moderately exposed to exposed shores or in strong currents; lower eulittoral and sublittoral fringe; Needs high water movement to supply coarse sand (Hawkins & Jones, 1992)

Notes: Larval settlement patchy and spasmodic; reefs usually between 5 and 7 years old (Hawkins & Jones, 1992). Suitable habitats for this species may be rare in SW Scotland.

Legislative protection: UK Biodiversity Action Plan: Species statement

16. *Chthamalus montagui*



Common name:

Montagu's punctate barnacle

Distribution:
Southern; common on west coasts of Scotland; present in Orkney and Shetland and rare at a few places on the east coast.

Map shows likely current distribution using the following information sources:

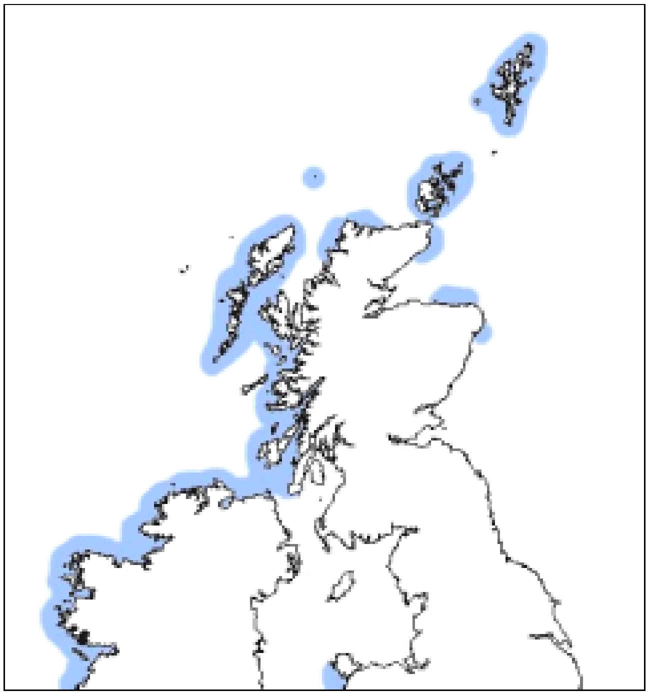
Unpublished surveys of Southward & Crisp (1953-1962); Crisp, Southward & Southward, 1981; Burrows, Hawkins & Southward, 1992; Hawkins & Jones, 1992; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: High to mid eulittoral on exposed to moderately sheltered shores (Hawkins & Jones, 1992)

Notes: Hermaphrodite; normally cross fertilizing but can still self impregnate if necessary; planktonic larvae for ~4 weeks (Burrows, 1988; Hawkins & Jones, 1992); breeding period, period of larval settlement and density of recruits are all reduced near northern limits of distribution; brood from May-August; cyprids settle July-September (Wales) (Kendall & Bedford, 1987), July-October (Devon) (Pannacciulli, 1995); will only breed above 15°C, optimum at 24-25°C (Patel & Crisp, 1960); may not breed every year in Scotland. The abundance of *C. montagui* and *C. stellatus* has been shown to be sensitive to short term change in seawater and air temperatures. This may provide a sensitive early indication of change.

Legislative protection: None

17. *Chthamalus stellatus*



Common name:

Poli's stellate barnacle

Distribution:
Southern species recorded off west Scotland, Shetland and Orkney.

Map shows likely current distribution using the following information sources:

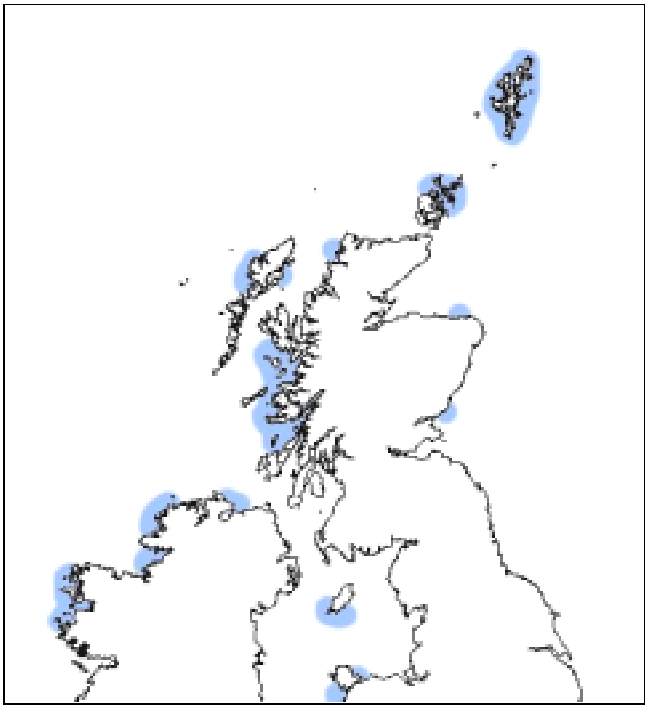
Crisp, Southward & Southward, 1981; Hawkins & Jones, 1992; Burrows, Hawkins & Southward, 1992; O'Riordan, Myers & Cross, 1995; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Mid to low eulittoral on exposed shores (Hawkins & Jones, 1992). Favours more exposed sites than *C. montagui* (Crisp, Southward & Southward, 1981).

Notes: Hermaphrodite; planktonic larvae for 4-6 weeks (Hawkins & Jones, 1992). The abundance of *C. montagui* and *C. stellatus* has been shown to be sensitive to short term change in seawater and air temperatures. This may provide a sensitive early indication of change.

Legislative protection: None

18. *Palinurus elephas*



Common name:

Crawfish

Distribution:
Previously widely distributed in south west Britain in the British Isles but has declined in the past 20 years. Recorded on the west coast of Scotland, Orkney and Shetland. Also a few records from the east coast of Scotland.

Map shows likely current distribution using the following information sources:

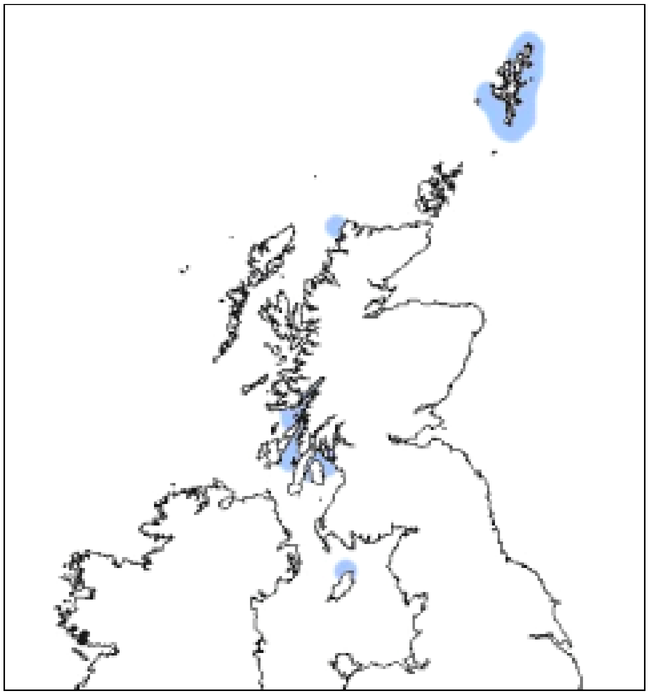
Bruce *et al.*, 1963; Ansell & Robb, 1977; Hunter, Shackley & Bennett, 1996; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: From 5 to 70m (Ansell & Robb, 1977) on rocky habitats.

Notes: This species occurs sporadically and has declined in abundance in SW England during the past 30 years. Larval supply may be affected by water quality conditions (K. Hiscock, unpubl. data).

Legislative protection: None

19. *Lithodes maia*



Common name:

Northern stone crab

Distribution:
Northern species recorded in west Scotland and Shetland

Map shows likely current distribution using the following information sources:

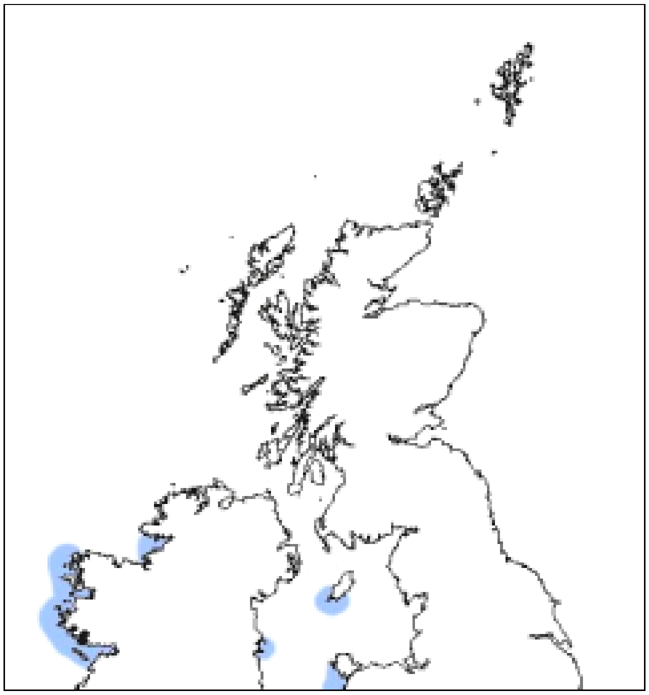
Bruce *et al.*, 1963; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Offshore from 10 to 100m (Hayward & Ryland, 1995)

Notes: A northern species although occurring in inshore (possibly colder) areas further south in Scotland. A conspicuous, easily recognizable species (although sometimes confused with *Maja squinado*) suitable for monitoring any impact of climate change. Rare in Celtic Sea (AJS, unpubl. data).

Legislative protection: None

20. *Maja squinado*



Common name:

Thorn back spider crab

Distribution:
Only extends as far north as the Isle of Man and NW Ireland

Map shows likely current distribution using the following information sources:

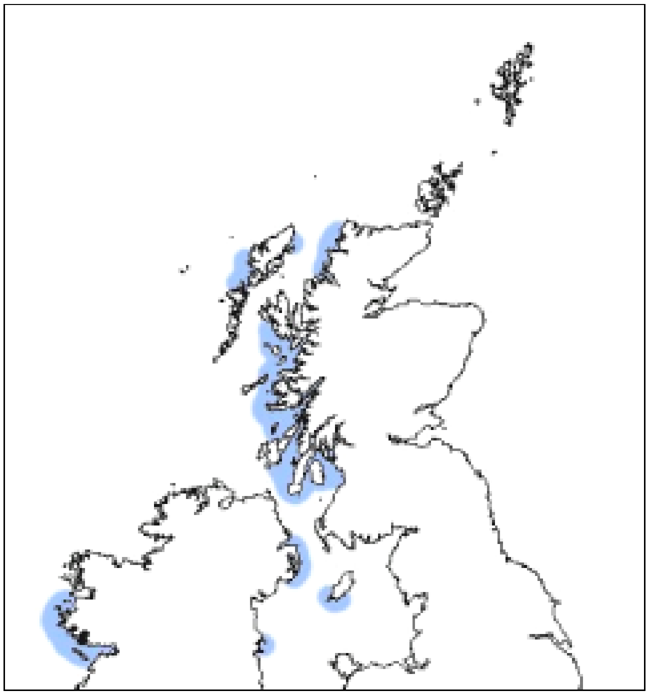
Bruce *et al.*, 1963; Clark, 1986; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Low water to 73m (Ingle, 1980)

Notes: Larvae October & November (Isle of Man) (Ingle, 1980). Usually recorded in small numbers at the northern most limit of its distribution. A conspicuous easily recognised species but may be sometimes confused with *Lithodes maia*. Suitable for monitoring.

Legislative protection: None

21. *Goneplax rhomboides*



Common name:

Angular crab

Distribution:
A southern species recorded from a few locations on the west coast of Scotland.

Map shows likely current distribution using the following information sources:

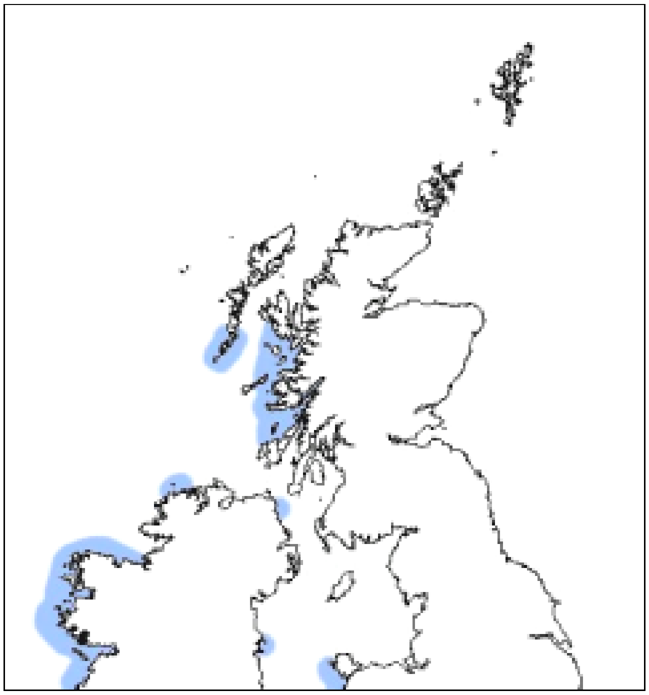
Bruce *et al.*, 1963; Clark, 1986; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Lower shore to 100m burrowing in mud and sandy mud (also found between 146-1478m) (Ingle, 1980).

Notes: Zoeae September & October (Irish Sea) (Ingle, 1980).

Legislative protection: None

22. *Xantho incisus*



Common name:

Montagu's crab

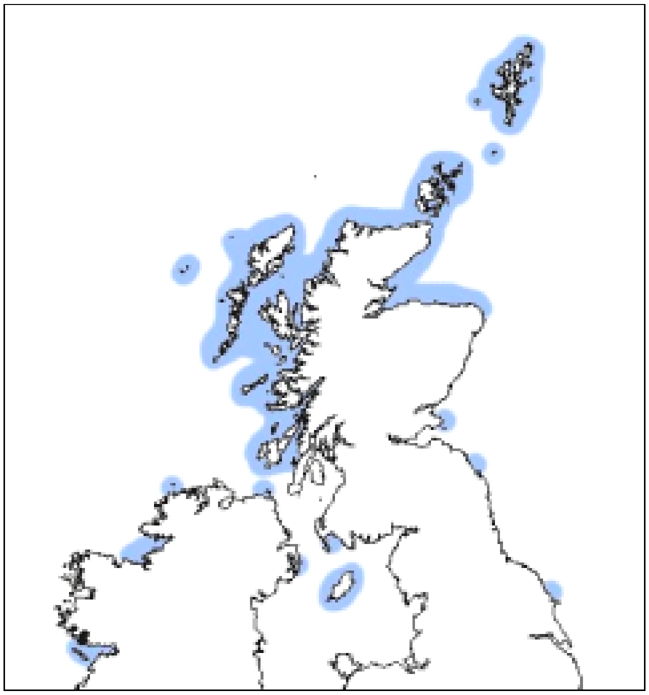
Distribution:
Recorded on SW coast of Scotland

Map shows likely current distribution using the following information sources:

Clark, 1986; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	Lower shore to 37m (Ingle, 1980)
Notes:	Ovigerous May-July, larvae May-July & September-October (Galway Bay) (Ingle, 1980)
Legislative protection:	None

23. *Margarites helicinus*



Common name:

Pearly top shell

Distribution:
Northern species recorded in both west and east Scotland, Shetland and Orkney

Map shows likely current distribution using the following information sources:

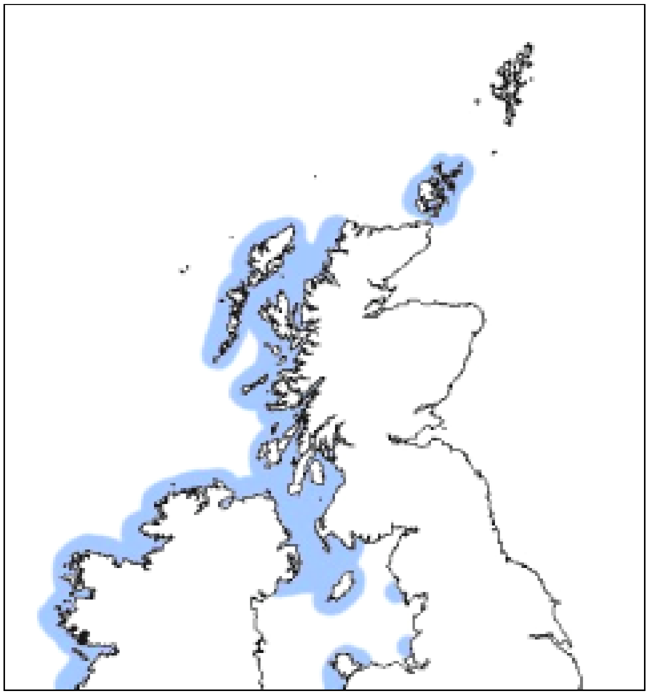
Bruce *et al.*, 1963; Seaward, 1982; 1990; 1993; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Low shore and sublittoral, under stones, in pools and on algae (Hayward & Ryland, 1995)

Notes: An easily identified northern species of intertidal gastropod suitable for monitoring.

Legislative protection: None

24. *Gibbula umbilicalis*



Common name:

Flat top shell

Distribution:
A southern species commonly recorded on the west coast of Britain and present in Orkney. Also occurs on the east coast of Scotland but not in Shetland.

Map shows likely current distribution using the following information sources:

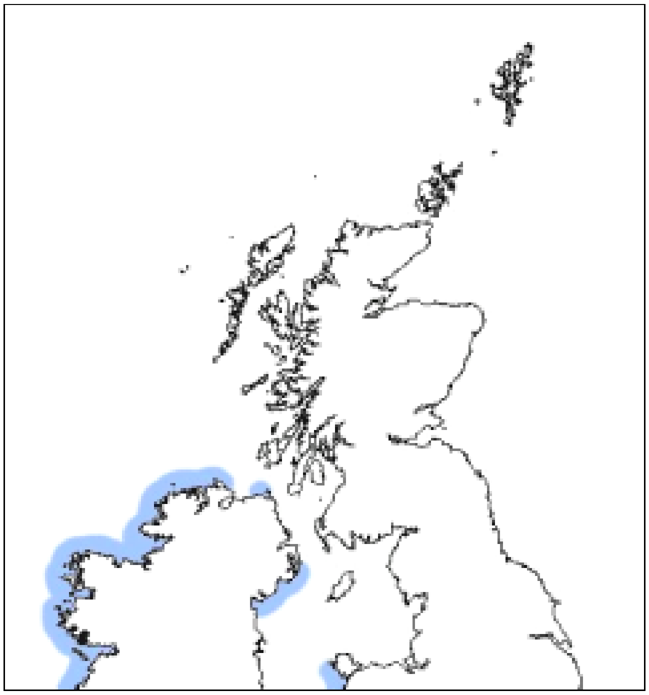
Bruce *et al.*, 1963; Lewis, 1964; Seaward, 1982,, 1990,, 1993; Hawkins & Jones, 1992; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Mid to lower eulittoral on sheltered to moderately exposed shores (Hawkins & Jones, 1992)

Notes: Gonad development begins in April/May; synchronized initial major spawning in August followed by further small releases of gametes; reproductive season not always successful at northern limits of distribution; mature at 2 years old (Garwood & Kendall 1985); larvae settle within a few days; life span about 10 years (Hayward & Ryland 1995; Hayward, Nelson-Smith & Shields,1996). Widely distributed in Scotland but not present in Shetland. Care needs to be taken in separating this species from *Gibbula cineraria*, but abundances whould be assessed in relation to any effect of climate change.

Legislative protection: None

25. *Monodonta lineata*



Common name:

Toothed topshell

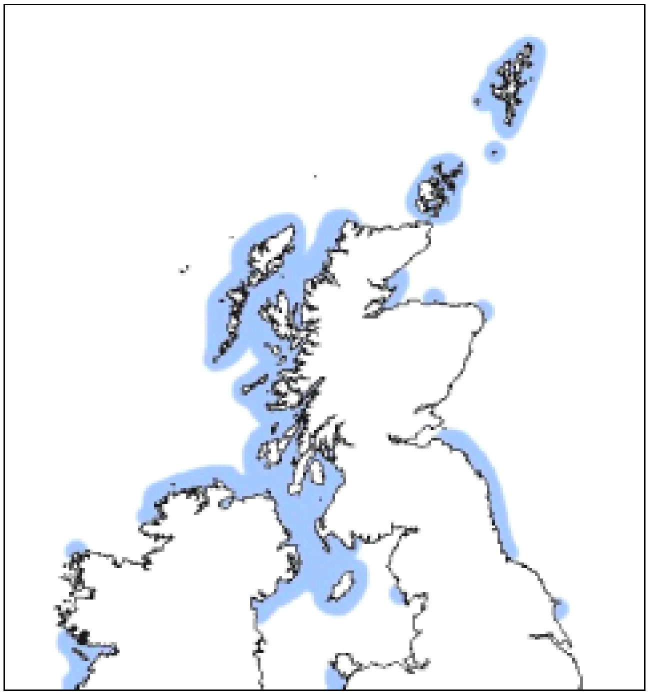
Distribution:
Southern species which reaches its northern limits in Northern Ireland and Anglesey

Map shows likely current distribution using the following information sources:

Lewis, 1964; Seaward, 1982; 1990; 1993; Hawkins & Jones, 1992; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	Mid to upper eulittoral on moderately sheltered to exposed shores (Hawkins & Jones 1992); avoids excessive exposure and shingle or sand (Hayward & Ryland 1995)
Notes:	Gonad development begins in April/May; synchronized initial major spawning in July followed by further small releases of gametes; reproductive season not always successful at northern limits of distribution; mature at 2 years old (Garwood & Kendall 1985). An easily recognized intertidal species that needs specific searching for. May occur in very small numbers where recruitment is from distant populations. However, to spread further north, populations would need to be significantly large enough to be self-recruiting.
Legislative protection:	None

26. *Tectura testudinalis (=Tectura tessulata)*



Common name:

Tortoiseshell limpet

Distribution:
A northern species commonly recorded throughout Scotland but reaching its southern limit in the Irish Sea in the British Isles.

Map shows likely current distribution using the following information sources:

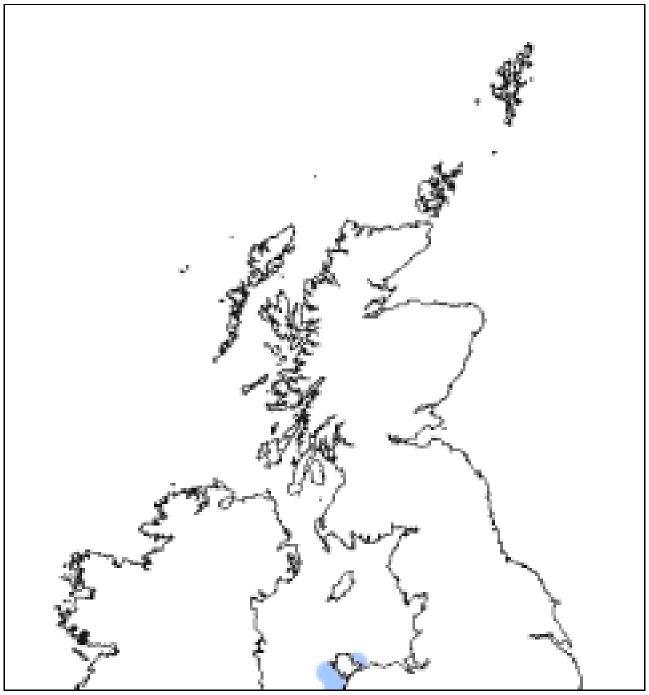
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On boulders and small stones (especially with *Lithothamnion*); low water to 50m (Hayward & Ryland, 1995)

Notes: A readily identifiable intertidal limpet although sometimes confused with *Acmaea virginea* (a species that has a more southern distribution).

Legislative protection: None

27. *Patella depressa*



Common name:

Black-footed limpet

Distribution:
Southern species which reaches its northern limits at Anglesey

Map shows likely current distribution using the following information sources:

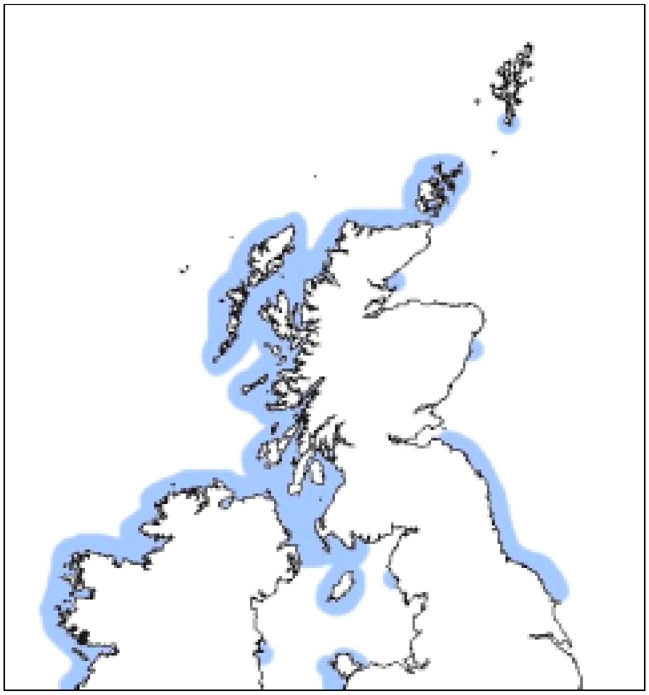
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Moderately exposed to exposed shores; eulittoral, commonest around MTL (Hawkins & Jones, 1992)

Notes: Protandrous hermaphrodite; gametes released into the sea to form planktonic larvae; settle in pools after 4 days (Hawkins & Jones, 1992)

Legislative protection: None

28. *Patella ulyssiponensis (=Patella aspera)*



Common name:

Distribution:
Commonly recorded on the west coast of Britain and Orkney. Also occurs on east coast of Scotland and Shetland

Map shows likely current distribution using the following information sources:

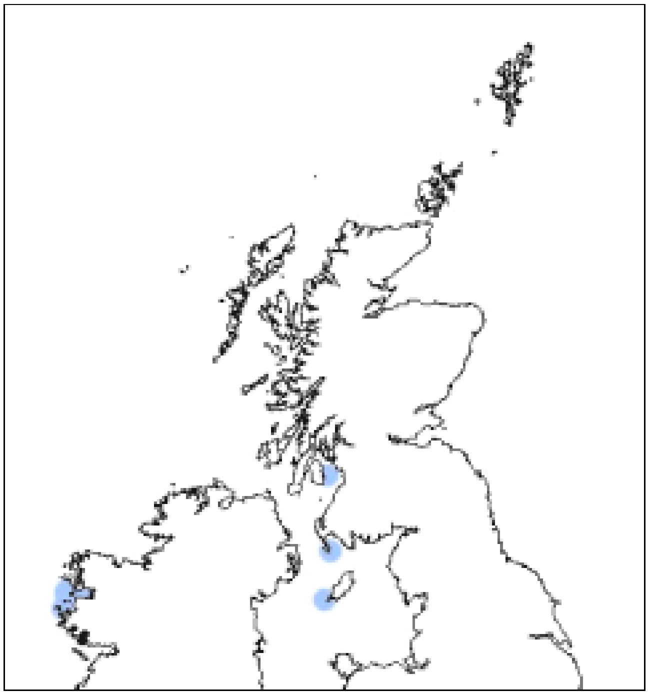
Bruce *et al.*, 1963; Seaward, 1982; 1990; 1993; Hawkins & Jones, 1992; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Exposed coasts below MLWN or in pools on midshore (Hawkins & Jones, 1992)

Notes: Protandrous hermaphrodite; gametes released into the sea to form planktonic larvae; settle in pools after 4 days (Hawkins & Jones, 1992)

Legislative protection: None

29. *Calyptraea chinensis*



Common name:

Chinaman's hat

Distribution:
Rarely recorded in SW Scotland and west Ireland.

Map shows likely current distribution using the following information sources:

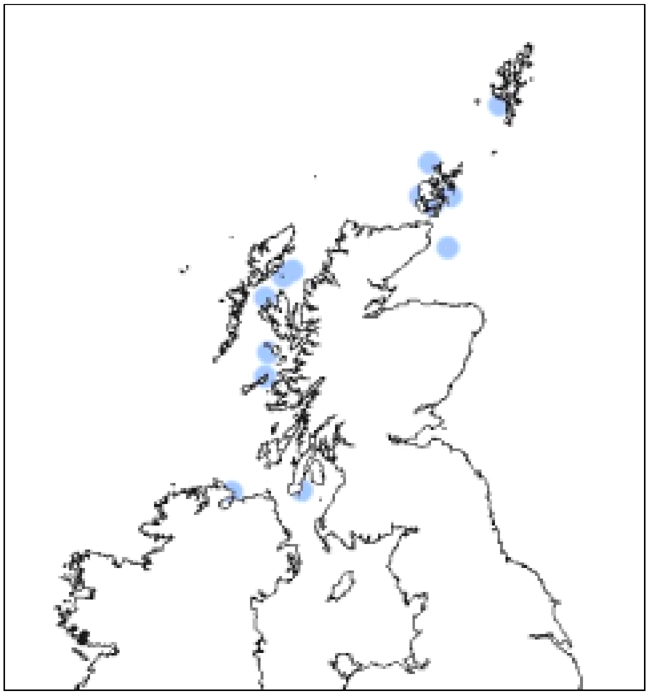
Bruce *et al.*, 1963; Seaward, 1982; 1990; 1993; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Low water to 20m, on and under stones, often on sheltered shores with soft substrat (Hayward & Ryland, 1995)

Notes: A warm water species.

Legislative protection: None

30. *Atrina fragilis (=Pinna fragilis)*



Common name:

Fan mussel

Distribution:
Present in south west England and western Scotland in the British Isles. Recorded off the west of Scotland (especially around Mull), Shetland, Orkney and the Moray Firth. Rarely encountered.

Map shows likely current distribution using the following information sources:

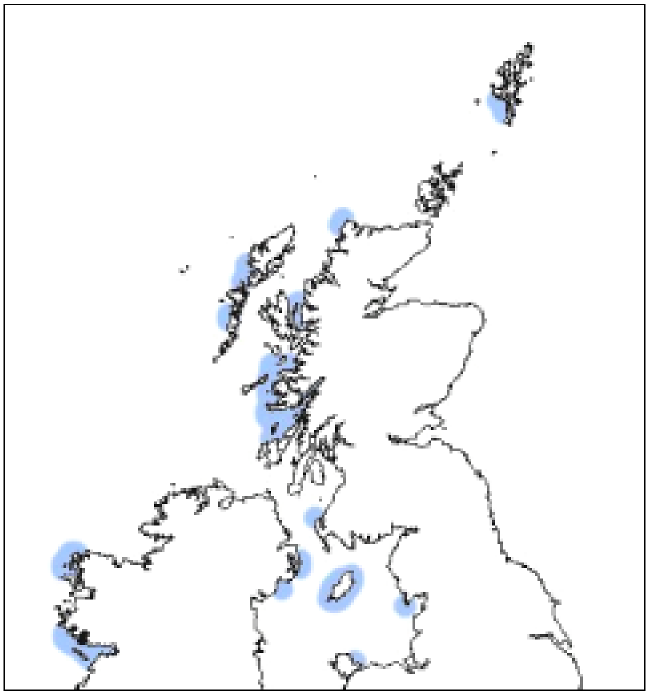
S. Smith, pers. comm.; Woodward, 1985; Seaward, 1982; 1990; 1993

Preferred habitat: Part buried in mud, sandy mud or gravel, attached to stones or pieces of shell; offshore (Tebble, 1966; Hayward, Nelson-Smith & Shields, 1996)

Notes: This species seems to be naturally rare in occurrence but populations are adversely effected by mobile fishing gears. Individuals may be long lived. More needs to be understood about the reproductive biology and recruitment of this species.

Legislative protection: UK Species Action Plan
Wildlife and Countryside Act (1981): Schedule 5

31. *Ostrea edulis*



Common name:

Native oyster

Distribution:
Recorded from Norway to the Mediterranean and the Black Sea. Widely distributed around the British Isles.

Map shows likely current distribution using the following information sources:

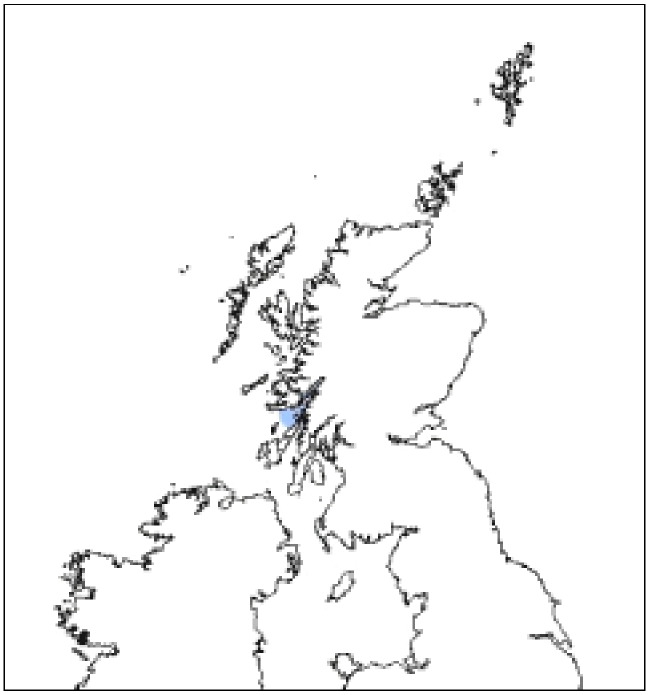
Bruce *et al.*, 1963; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On course bottoms from ELWS to 80m (Hayward & Ryland, 1995). Associated with highly productive estuarine and shallow coastal water habitats (Anon, 1999).

Notes: Breeding season is from May to August (Hayward, Nelson-Smith & Shields, 1996). Populations have become reduced or extinct partly due to fishing. This species has declined very significantly, at least in England and Wales, in the past 100 years or so. The causes are uncertain and whether climate change might affect distribution is also uncertain. However, as a valued species, careful consideration of the likely impact of change is needed.

Legislative protection: UK Species Action Plan

32. *Thyasira gouldi*



Common name:

Northern hatchet shell

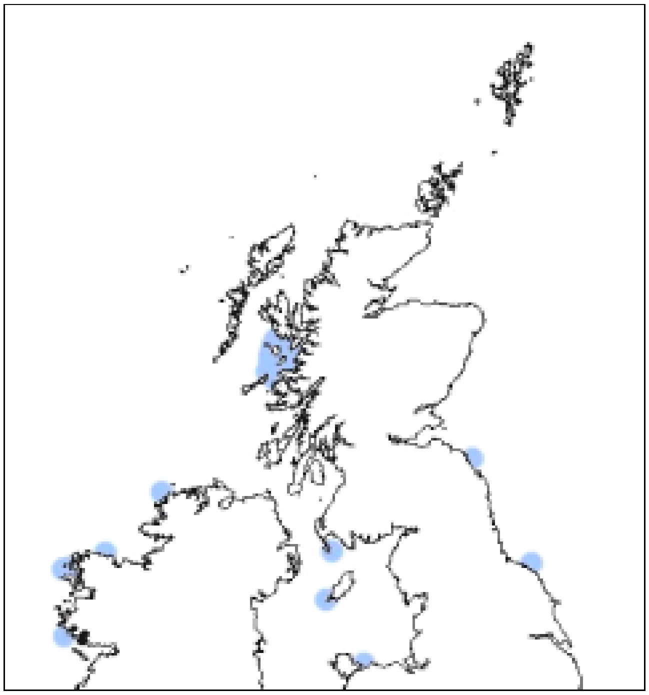
Distribution:
Northern species recorded from upper Loch Etive, Loch Eil and Loch Sunart. The status at the latter two sites is currently unknown. These are the most southerly European populations of this species.

Map shows likely current distribution using the following information sources:

Anon, 1999

Preferred habitat:	In anoxic soft mud, silt clay or clay mud sediments. Found at a depth between a few and several 100 m (Anon, 1999).
Notes:	Occurs in patches. May not be able to tolerate rapid increases in water temperature. A northern species which prefers low water temperatures but has acclimatised to warmer bottom temps (7-13°C) in upper Loch Etive (Anon, 1999). This species is a 'classic' relict species, surviving in the cold deep waters of a few sea lochs. It is believed to be left over from previous wider distributions during colder times.
Legislative protection:	UK Species Action Plan Wildlife and Countryside Act (1981): Schedule 5

33. *Gari depressa*



Common name:

Large sunset shell

Distribution:
Southern species, just extending north into west Scotland

Map shows likely current distribution using the following information sources:

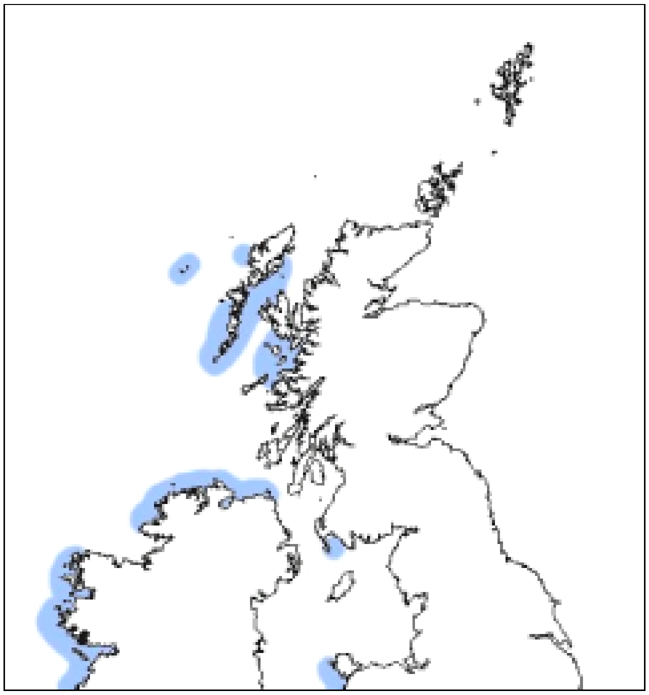
Bruce *et al.*, 1963; Seaward, 1982; 1990; 1993; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Low shore to 50m in coarse sand or gravel (Tebble, 1966; Hayward & Ryland, 1995)

Notes:

Legislative protection: None

34. *Pentapora fascialis (=Pentapora foliacea)*



Common name:

Ross

Distribution:
A southern species abundant in southwest Britain and recorded off west Scotland including at St Kilda.

Map shows likely current distribution using the following information sources:

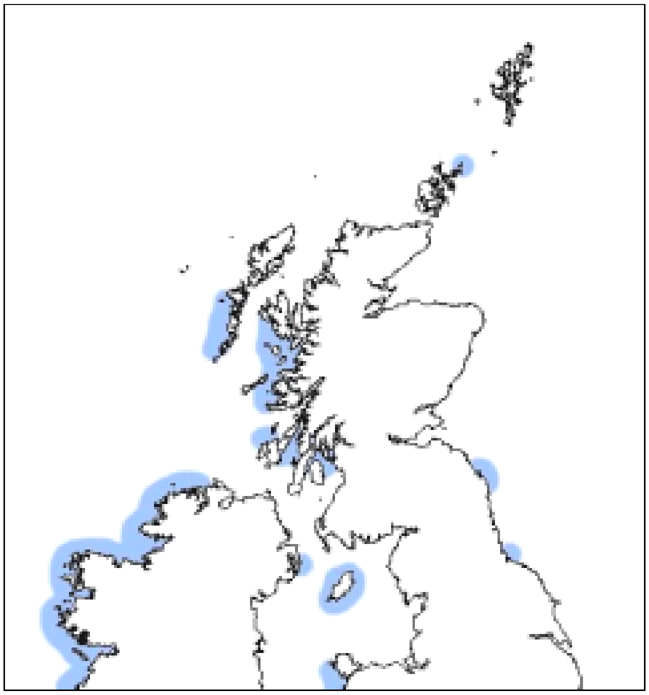
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Sublittoral, either below edge of kelp forest or on *Laminaria* holdfasts; most abundant between 25-34m; on rocky, current swept bottoms, on bedrock or attached to stones (based on Hayward & Ryland, 1979).

Notes: A conspicuous, easily recognized species that is much more abundant and widely distributed in the south-west. Occurs on a wide range of tide exposed and wave exposed habitats.

Legislative protection: None

35. *Asterina gibbosa*



Common name:

Cushion star

Distribution:
Recorded off west Scotland and Orkney

Map shows likely current distribution using the following information sources:

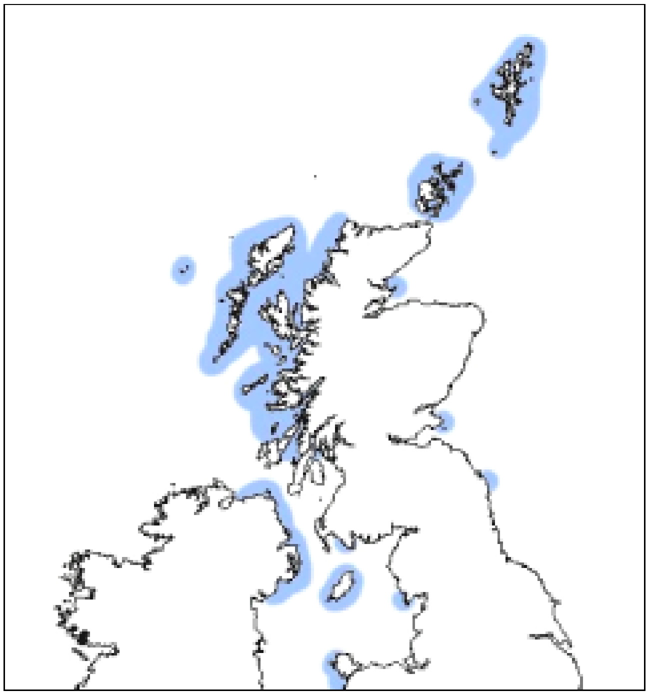
Bruce *et al.*, 1963; Lewis, 1964; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Rock pools to 125m subtidal; lives on or below stones, also found among algae, sponges and Zostera (Mortensen, 1927)

Notes: Breeding season, May-June; eggs attached to stones; no pelagic larval stage (Mortensen, 1927). This small cushion star needs careful searching for but occurs intertidally and should provide a good indicator of change in distribution. Care is required to separate this species from *Asterina phylactica.*

Legislative protection: None

36. *Leptasterias muelleri*



Common name:

Distribution:
A northern species recorded widely around the British Isles except on the south coast.

Map shows likely current distribution using the following information sources:

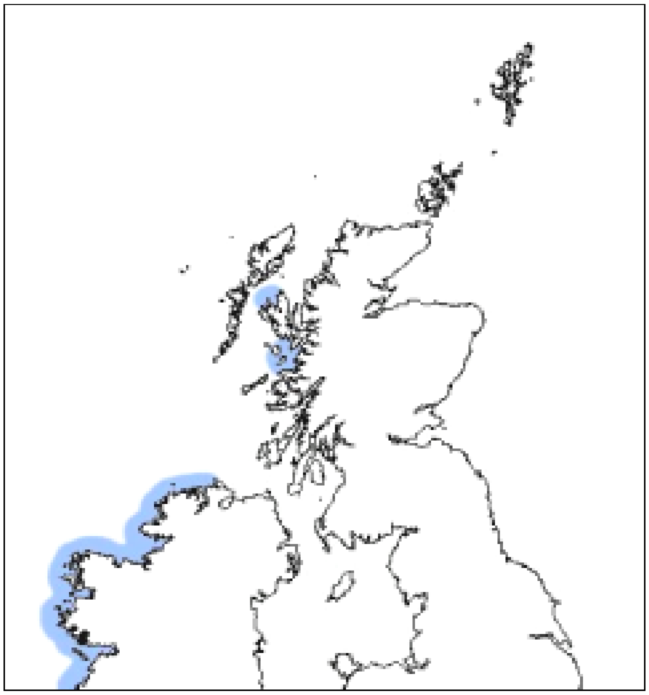
Bruce *et al.*, 1963; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Under stones

Notes: Breeding season in early spring (March to April) (Mortensen, 1927).

Legislative protection: None

37. *Paracentrotus lividus*



Common name:

Purple sea urchin

Distribution:
A southern species which is abundant in parts of south-west Ireland but has only sporadic recorded occurrences in south west England and at a few locations on the west coast of Scotland.

Map shows likely current distribution using the following information sources:

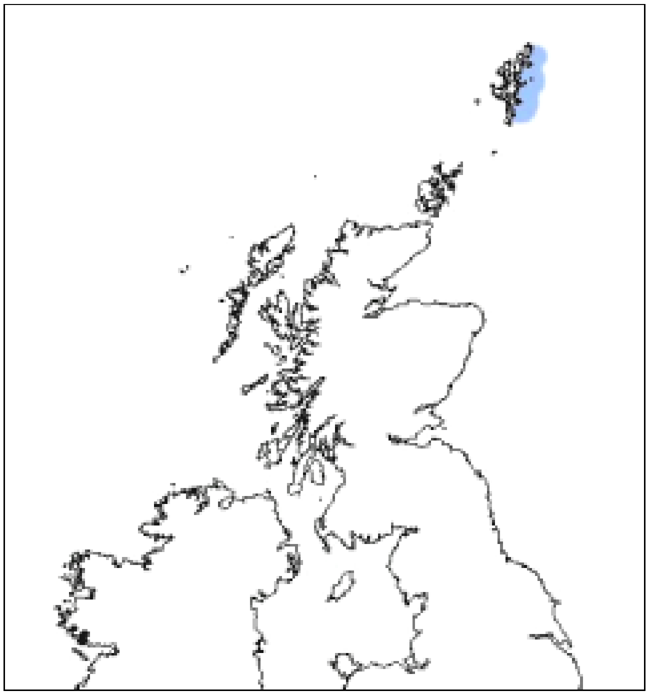
Crisp & Southward, unpubl. data; Lewis, 1964; Hawkins & Jones, 1992; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Low shore pools and sublittoral on moderately exposed shores (Hawkins & Jones, 1992)

Notes: Gonad growth autumn to winter (maximum at low tempertures 10°C), maturing spring to early summer, followed by spawning; initial spawning triggered by either 15 hour day length (Brittany) or temperature of 13-15°C (Ireland); double spawnings have been found but single more likely in Ireland (Byrne, 1990; Spirlet *et al.*, 1998); spawning ends when water temperature reaches 17°C. Declined in Ireland due to fishery.

Legislative protection: None

38. *Strongylocentrotus droebachiensis*



Common name:

Green sea urchin

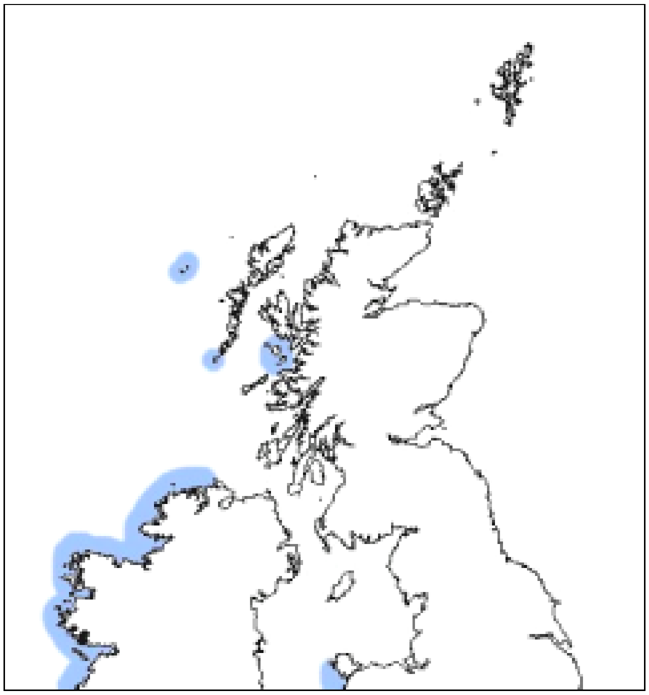
Distribution:
A northern species confined to the east coast of the British Isles. Probably occurs on all North Sea coasts of Britain.

Map shows likely current distribution using the following information sources:

Mortensen, 1927; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	Infralittoral fringe down to 1200m (Hayward & Ryland, 1995). May bore holes (Mortensen, 1927).
Notes:	Breeding season in early spring (Mortensen, 1927).
Legislative protection:	None

39. *Holothuria forskali*



Common name:

Cotton spinner

Distribution:
A southern species that is abundant in parts of south west England. Recorded off west Ireland and a few locations off west Scotland around Rum.

Map shows likely current distribution using the following information sources:

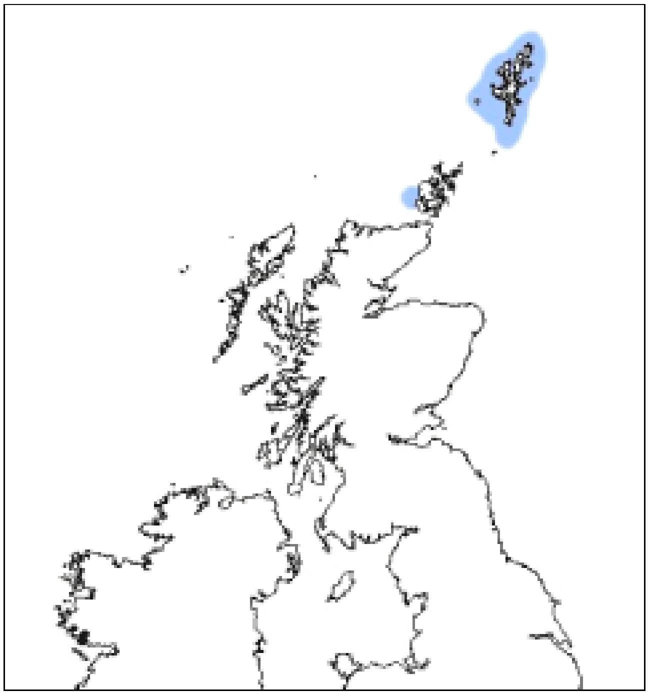
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Shallow water (Mortensen, 1927)

Notes: Breeding season in summer months (Mortensen, 1927). A widely distributed species in SW Britain, easily recognised and suitable for monitoring studies. Could be confused with *Cucumaria frondosa*, so care needed in identification.

Legislative protection: None

40. *Cucumaria frondosa*



Common name:

Northern sea cucumber

Distribution:
A northern species widely recorded in Shetland, also occurs in Orkney

Map shows likely current distribution using the following information sources:

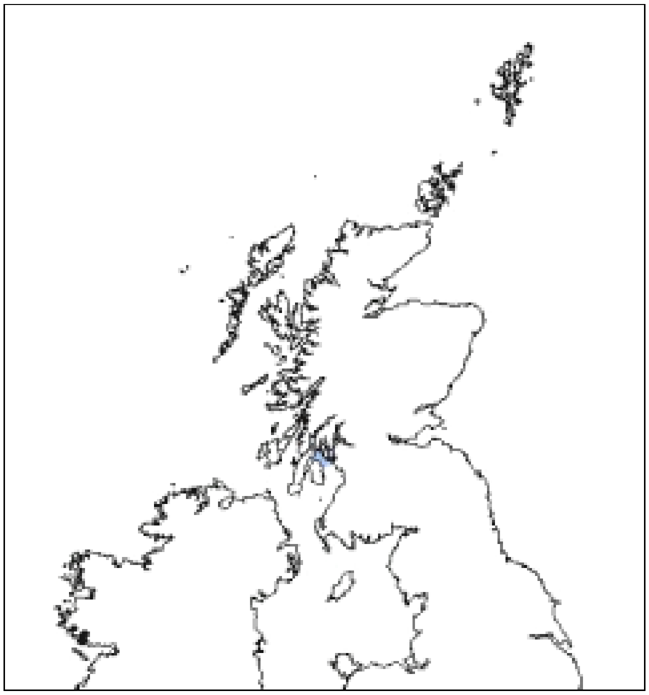
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Low shore to 200m sublittoral; especially amoung Laminarians (Mortensen, 1927)

Notes: Breeding season, February-March (later further north) (Mortensen, 1927). This far northern species is readily identified although sometimes confused with *Holothuria forskali*. Numbers are usually very small at any one location.

Legislative protection: None

41. *Styela gelatinosa*



Common name:

Distribution:
Only British population is in Loch Goil (Clyde Sea). Also occurs in Scandinavia and Iceland.

Map shows likely current distribution using the following information sources:

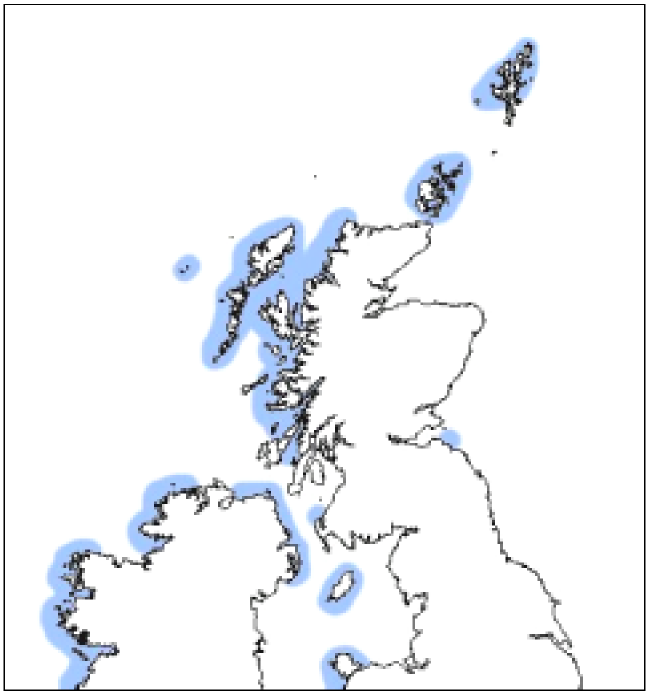
MERMAID
(www.jncc.gov.uk/mermaid)

Preferred habitat: Soft mud, in very sheltered conditions (Anon, 1999).

Notes: The natural heritage importance of this species (it is only known in the British Isles from one location in Scotland) means that consideration should be given to the likely effects of climate change. Cold water species.

Legislative protection: UK Biodiversity Action Plan: Species statement

42. *Labrus mixtus (=Labrus bimaculatus)*



Common name:

Cuckoo wrasse

Distribution:
Commonly recorded off north and west Scotland, Orkney and Shetland. Also occurs in the Firth of Forth

Map shows likely current distribution using the following information sources:

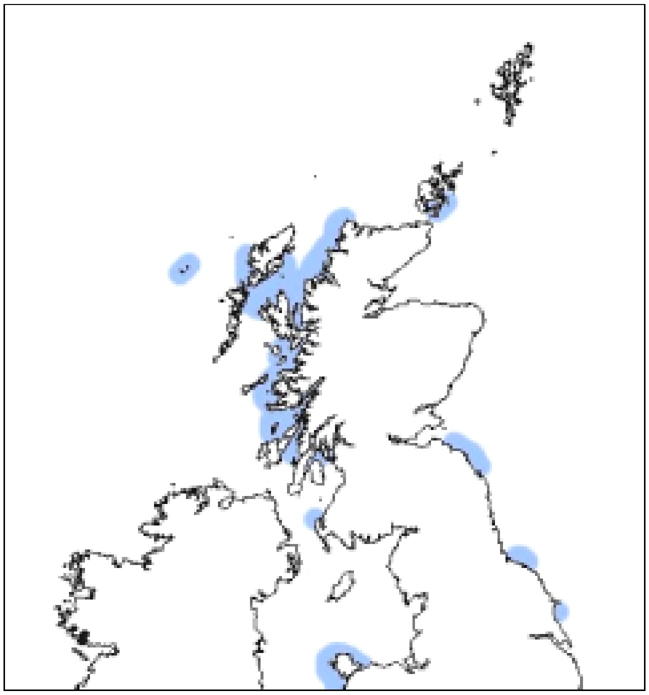
Bruce *et al.*, 1963; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Littoral 2-200m, mainly 40-80m (Whitehead *et al.*, 1986)

Notes: Reproductive season, May-July (North Sea and Channel) (Whitehead *et al.*, 1986). Although widely distributed, records are sporadic and numbers are small. An easily recognised species suitable for monitoring changes, particularly in abundance.

Legislative protection: None

43. *Thorogobius ephippiatus*



Common name:

Leopard-spotted goby

Distribution:
Recorded off west Scotland, Orkney and in the Firth of Forth

Map shows likely current distribution using the following information sources:

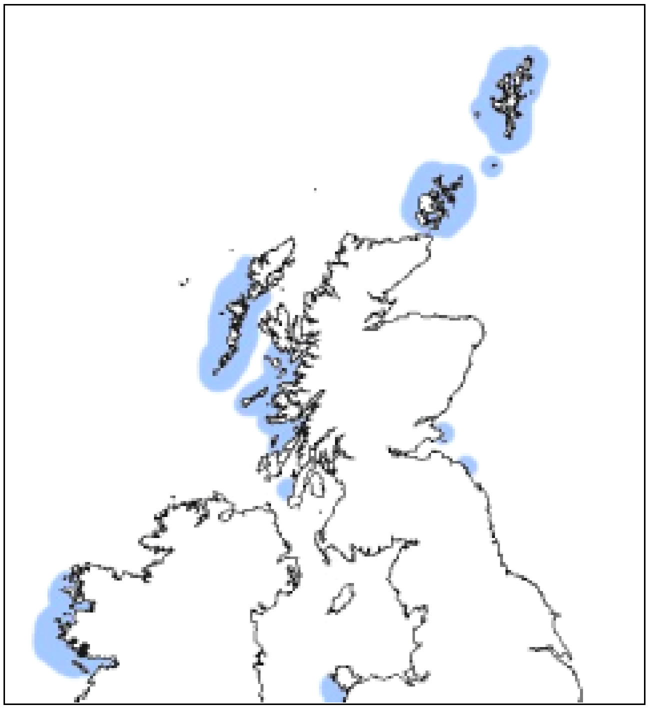
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Inshore in or near crevices of steep rock faces, to 40m (usually 6-12m); rarely in deep intertidal pools (Whitehead *et al.*, 1986)

Notes: Reproductive season, May-July (Plymouth); mature at 3 to 4 years (Whitehead *et al.*, 1986). Although widely distributed in Scotland this species is apparently absent from Shetland. Therefore it should be included in any studies of changes in distribution.

Legislative protection: None

44. *Bonnemaisonia hamifera*



Common name:

A red alga

Distribution:
The tetrasporophyte phase (*Trailliella)* is widely distributed from Mauritania to northern Norway but the gametophyte (*Bonnemaisonia*) phase is only found between Spain and south-west England. In Scotland, tetrasporophyte phase extends to Shetland, gametagial phase extends to Argyll.

Map shows likely current distribution using the following information sources:

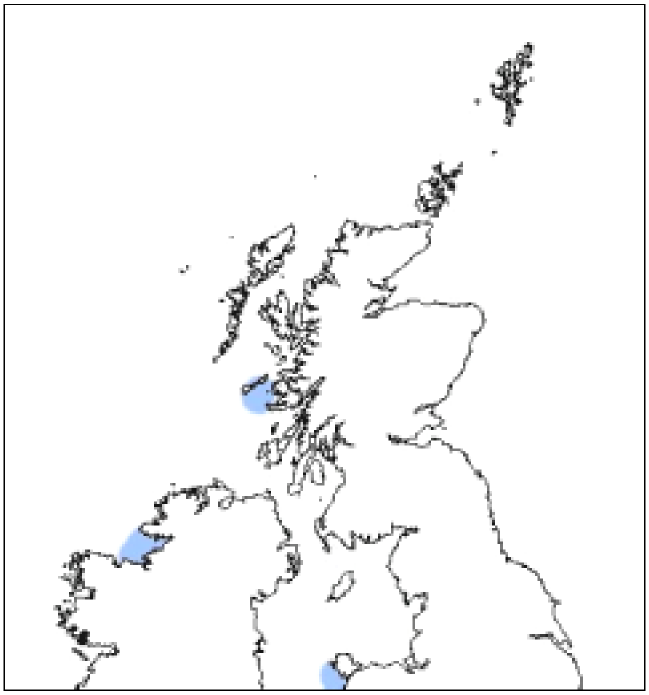
Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Gametangial phase sublittoral attached to other algae, occasionally lower littoral in deep pools; tetrasporangial phase epiphytic or (epilithic) lower littoral to 8m sublittoral (Dixon & Irvine, 1977)

Notes: Tetrasporangial found further north than gametangial phase; gametangial phase found throughout the year, best growth spring and early summer; tetrasporangial phase occurs as dense clumps in summer and isolated filaments in winter; spermatangial plants infrequent in Britain; can spread vegetatively (Dixon & Irvine, 1977). Northern limit of gametophyte corresponds to the 13°C October isotherm. Tetrasporophyte reaches its limit further north at the 10°C summer isotherm. The northern lethal boundary is not reached since both forms can survive water temperatures below 0°C (Luning, 1990). Species introduced from Japan (~1890). Abundance: tetrasporophyte is common whereas gametophyte is only common in the south and west.

Legislative protection: None

45. *Jania rubens*



Common name:

Distribution:
Southern species occuring as far north as Norway. In British Isles recorded northwards to west Inverness and Aberdeen. Very rare in Northern Ireland.

Map shows likely current distribution using the following information sources:

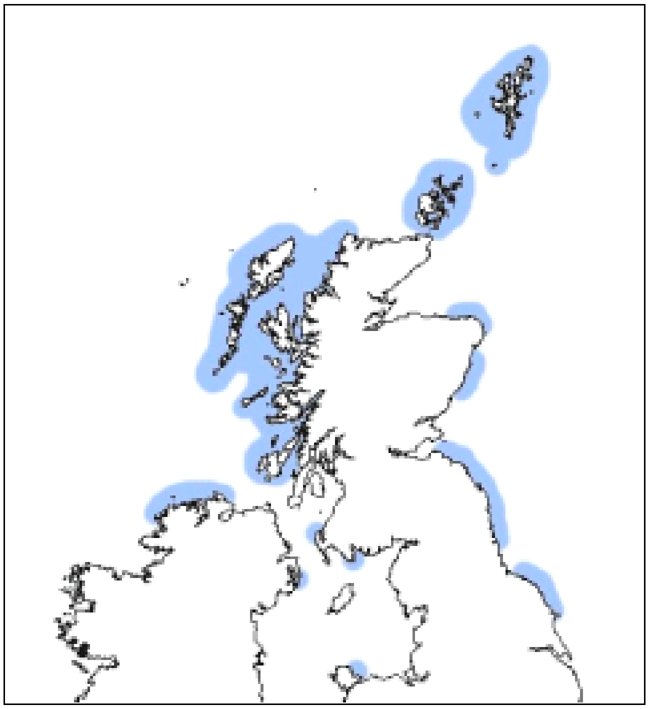
Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epiphytic on *Cladostephus, Cysteroseira* and *Halopithys* in British Isles; sublittoral to 8m; extreme shelter to exposed pools (Irvine & Chamberlain, 1994)

Notes: Monoecious; annual; fronds arise in Autumn, fertile by April; can regenerate from lateral branches (esp in warm water); growth from 10-30 °C, spores fail at 10 °C, spores attach at 17-20 °C, fertile between 11-17 °C; gametangial and tetrasporangial plants equally common (Irvine & Chamberlain, 1994). Abundance: common on west coast only. Recently died back in southern North Sea (Scott & Tittley, 1998). An easily recognised species although it is sometimes confused with *Corallina officinalis.* Suitable for intertidal surveys of distributional changes.

Legislative protection: None

46. *Lithothamnion glaciale*



Common name:

Maerl

Distribution:
Present from northern British Isles to Arctic Russia. A northern species commonly recorded in west Scotland, Shetland, Orkney and the Firth of Forth. Common in Northern Ireland. Recorded reliably south to Lundy and to Flamborough on the east coast of England.

Map shows likely current distribution using the following information sources:

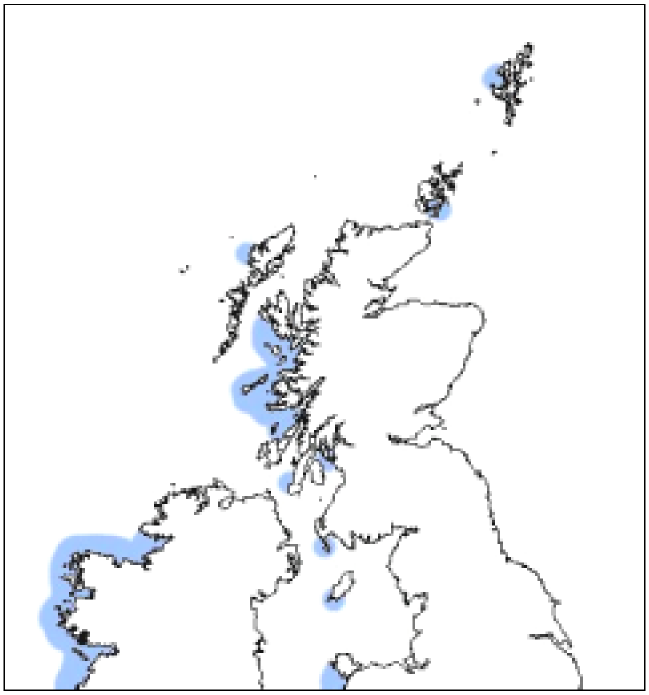
Irvine & Chamberlain, 1994, Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epilithic on bedrock and pebbles; lower littoral in pools and sublittoral to 34m; sheltered habitats with some water movement (Irvine & Chamberlain, 1994). Found in variable salinity.

Notes: Gametangial plants dioecious; common; branches can detatch and contribute to maerl; fast growing; bisporangial conceptacles present throughout year; capable of rapid growth at 13.5°C (Irvine & Chamberlain, 1994). Abundance: common.

Legislative protection: None

47. *Mesophyllum lichenoides*



Common name:

Distribution:
Southern species extending from the Canaries and Mediterranean to the British Isles. Recorded off west Scotland as far north as Orkney. (Shetland records require confirmation).

Map shows likely current distribution using the following information sources:

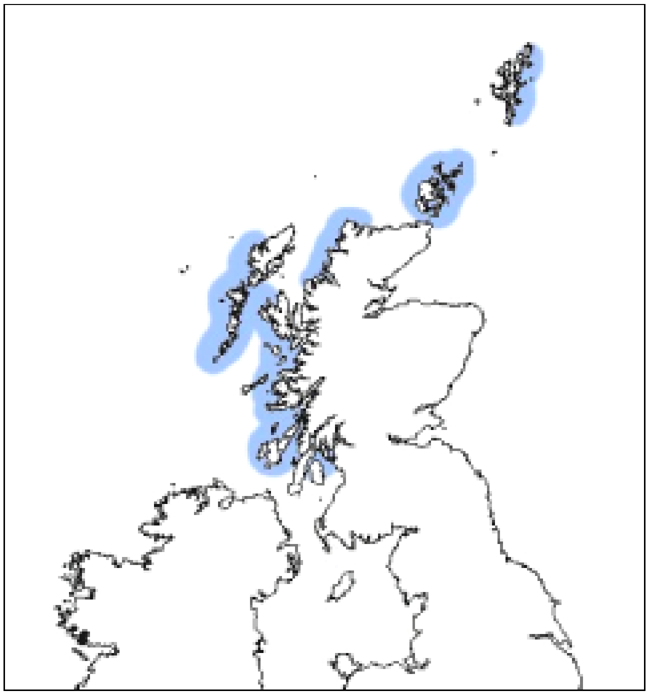
Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epiphytic on *Corallina*; lower littoral to 8m sublittoral; fairly to very exposed shores (Irvine & Chamberlain, 1994)

Notes: Gametangial concepticles dioecious; perennial; gametangial conceptacles from February-April, tetrasporangial for April to December (Irvine & Chamberlain, 1994). Abundance: locally common. Good recognisable species to monitor for spread to east coast.

Legislative protection: None

48. *Phymatolithon calcareum*



Common name:

Maerl

Distribution:
Widely distributed on south and west coasts of Britain from Dorset to Shetland.

Map shows likely current distribution using the following information sources:

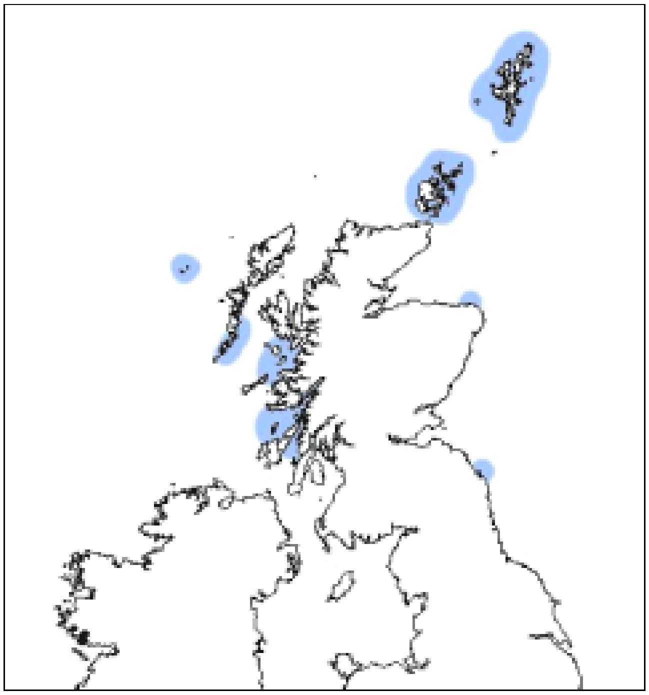
MERMAID (www.jncc.gov.uk/mermaid), MarLIN (www.marlin.ac.uk)

Preferred habitat: On a mixture of substrates between 1 and 30m on sheltered to exposed shores. Usually found with *Lithothamnion glaciale* in Scotland.

Notes: Supports a wide range of species some of which occur mainly or only in maerl biotopes. Distribution in the NE Atlantic seems to be determined by seawater temperature as well as presence of suitable habitats and change is likely in rising temperatures. This species may also be dredged commercially. No crustose forms in Britain so propagation must be virtually entirely vegetative (MarLIN, www.marlin.ac.uk). Often confused with *Lithothamnion coralloides.* This species forms the major maerl bed biotope in Scotland.

Legislative protection: Part of Habitats Directive Annex V:
UK Biodiversity Action Plan: Species statement

49. *Callophyllis cristata*



Common name:

Distribution:
Northern species recorded on west coast of Scotland, Shetland and Orkney. Also occurs on east coast and in Northumberland. This is its southern limit and does not occur in Northern Ireland.

Map shows likely current distribution using the following information sources:

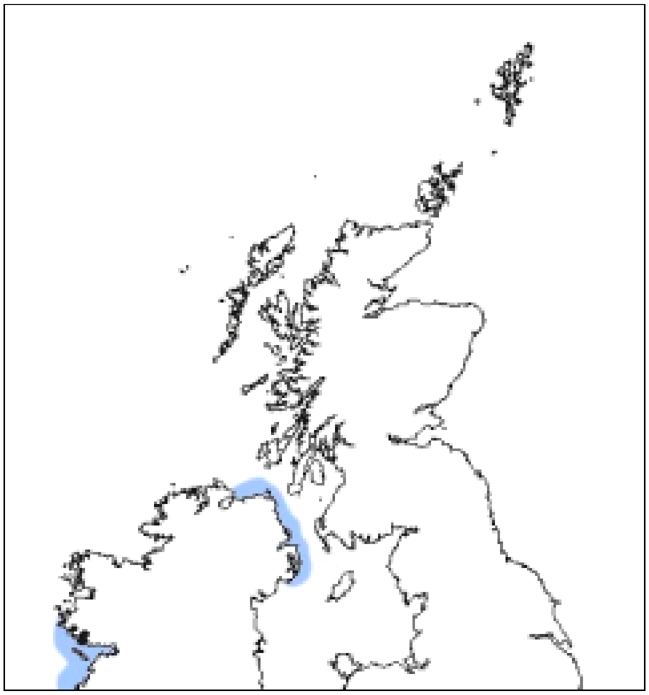
I. Tittley (unpubl. data), Norton, 1985; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epiphytic on Laminaria; upper sublittoral to at least 30m; sheltered and moderately exposed; full salinity (Irvine, 1983)

Notes: Gametangial plants dioecious; perenial; (southern reports dubious?); cystocarps recorded from June-October, tetrasporangia from June-July (GB) (Irvine, 1983). Abundance: common.

Legislative protection: None

50. *Stenogramme interrupta*



Common name:

Distribution:
Southern species recorded from Morocco the Cornwall & Devon. In Northern Ireland, rare in littoral, not uncommon in sublittoral. Absent from Scotland.

Map shows likely current distribution using the following information sources:

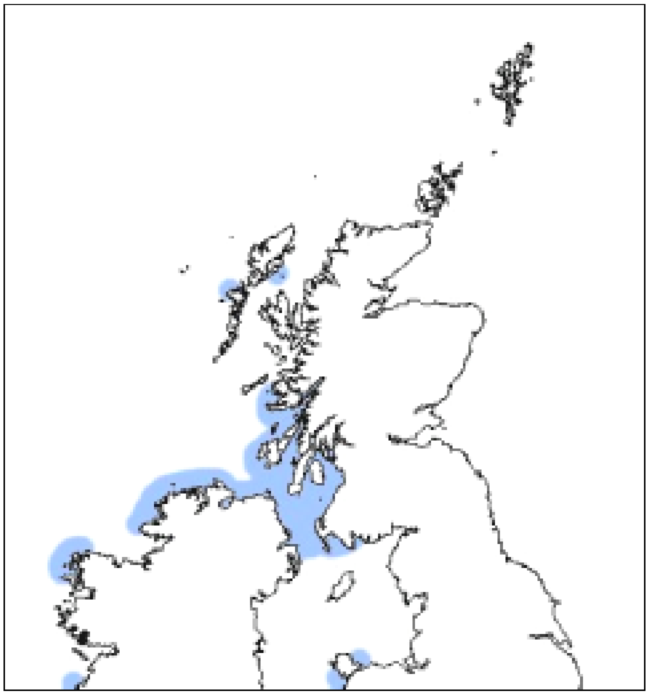
Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epilithic; sublittoral to 13m; sheltered areas on small stones, shell, gravel and mud (Dixon & Irvine, 1977). Usually in areas exposed to moderate tidal streams.

Notes: Gametangial plants dioecious; perrenial, plants sterile in first year, fertile in summer of second; tetrasporangia and cystocarps occur throughout year, most abundant July-Sept (Dixon & Irvine, 1977). This species is found in a fairly specific habitat (tide swept cobbles) and is readily recognised by its broken mid ribs. Suitable for any studies of distributional changes.

Legislative protection: None

51. *Rhodymenia holmesii*



Common name:

Distribution:
Present from Morocco to the British Isles. Recorded north to Anglesey and with some records for Jura and Islay. Very rare in northern Ireland.

Map shows likely current distribution using the following information sources:

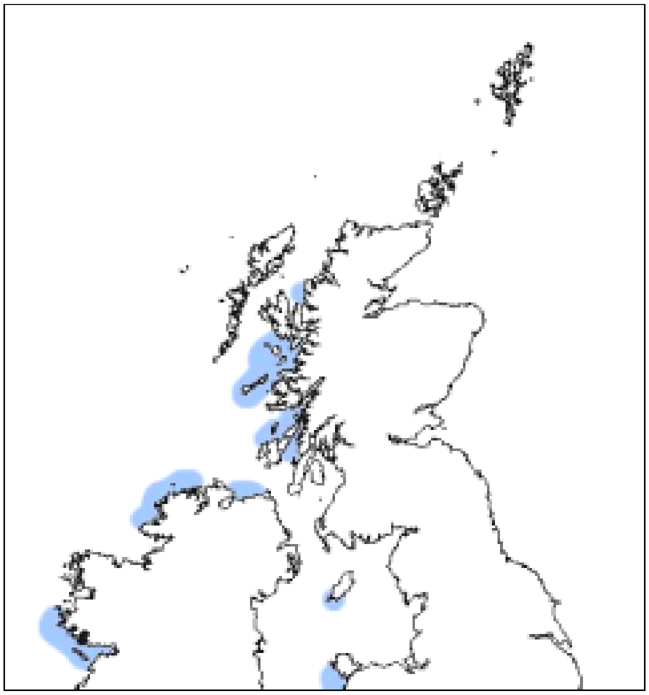
I. Tittley (unpubl. data), Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epilithic (in soft rock); tolerate sand cover and some exposure; lower littoral and sublittoral to at least 25m (Irvine, 1983)

Notes: Gametangial plants dioecious; young fronds appear February-March; spermatangia recorded for November, cystocarps and tetrasporangia for April, June-September (Irvine, 1983). Abundance: rare/sporadic in Scotland.

Legislative protection: None

52. *Sphondylothamnion multifidum*



Common name:

Distribution:
Southern species recorded from the Canaries & Meditteranean to the British Isles. Scottish records from Inverness, Ross & Cromarty. Very rare in Northern Ireland.

Map shows likely current distribution using the following information sources:

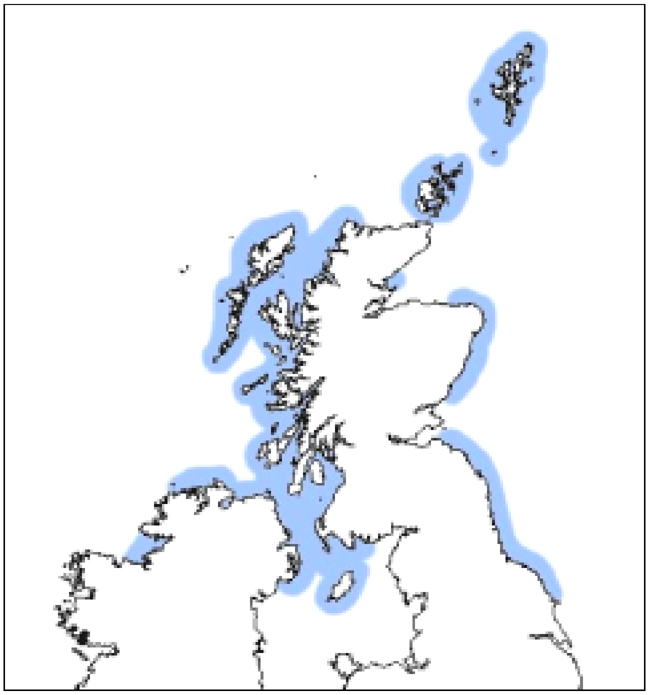
Norton, 1985, Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On bedrock from shady low shore pools to 30m subtidal, also on mobile substrates (mearl/pebbles), tolerant of sand scour, very sheltered to very exposed (Maggs & Hommersand, 1993)

Notes: Annual, gametangial plants found on S coast of England; may be confused; erect fronds annual; spermatangia recorded in July, procarps and cystocarps in July and September, tetrasporangia in June-September (Maggs & Hommersand, 1993). Abundance: common on west coast only. Becoming more common in Scotland.

Legislative protection: None

53. *Odonthalia dentata*



Common name:

Distribution:
Northern species recorded throughout Scotland and as far south as the Isle of Man and Northern Ireland (County Mayo & Down). Also recorded on the east coast as far south as Flamborough. Occurs from Spitzbergen to British Isles.

Map shows likely current distribution using the following information sources:

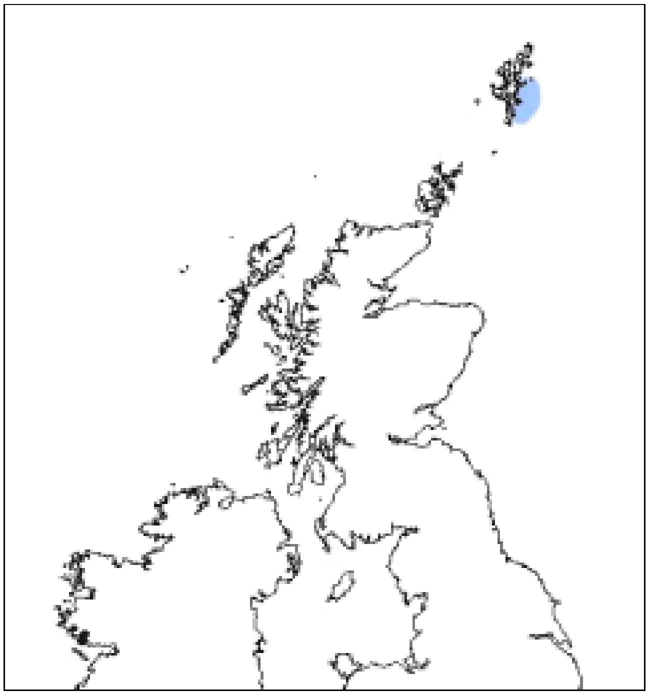
Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: On bedrock, boulders, cobbles (also epiphyte on Laminaria); pools, ELW to 20m; moderately to extermely exposed nad sheltered sites with strong tide; most abundant in shallow kelp forests (Maggs & Hommersand, 1993)

Notes: Plants dioecious; perennial (up to 9yrs); easiliy identified; details of growth and repro form IoM; new growth begins in February, stops by July at maximum weight, fronds lost throughout summer and autumn; spermatangia in November-February, cystocarps in December-June, and tetrasporangia in November- June (IoM); in Scotland cystocarps and tetrasporangia occur until August (Maggs & Hommersand, 1993). Adundance: common in north. A readily recognisable and often abundant red alga whose southern limit near to the SW coast of Scotland makes it a good indicator species suitable for any monitoring study.

Legislative protection: None

54. *Sphacelaria arctica*



Common name:

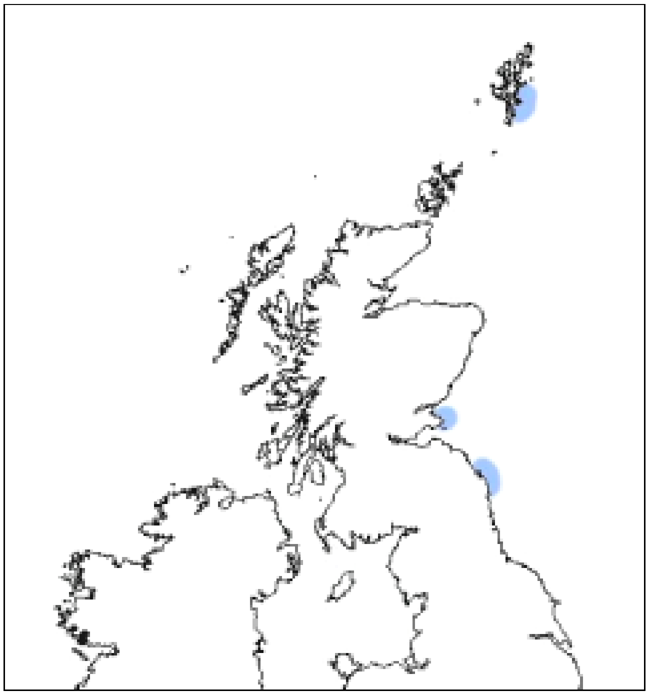
Distribution:
Northern species only recorded in Shetland in the UK. Also occurs in Denmark, Baltic, Norway & Greenland.

Map shows likely current distribution using the following information sources:

I. Tittley (unpubl. data)

Preferred habitat:	Sand scoured rocks, littoral pools and sublittoral. Can tolerate low salinity.
Notes:	Grows well at 4-12°C. Rare species which is sensitive to disturbance. Abundance very rare. Requires further surveying and research as this species is a good example that could potentially be lost from the Scottish flora.
Legislative protection:	None

55. *Sphacelaria mirabilis*



Common name:

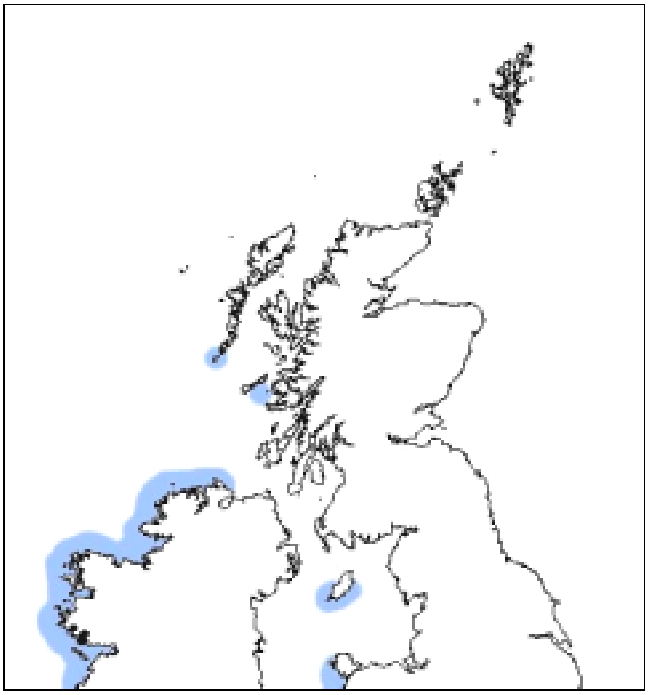
Distribution:
Nothern species recorded on north east coast of UK in Shetland, Fife and Northumberland. Also occurs in Norway, SW Sweden and the Gulf of Maine.

Map shows likely current distribution using the following information sources:

Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:	Intertidal rocks and pools; forms feathery crusts
Notes:	Germinates better at 12°C than at 4°C. Temperature and daylength may limit distribution. Abundance: rare.
Legislative protection:	None

56. *Dictyopteris membranacea*



Common name:

Distribution:
Present from the Azores and Portugal to the British Isles. A southern species present in large amounts only in the extreme south-west of Britain with a few records from west Scotland.

Map shows likely current distribution using the following information sources:

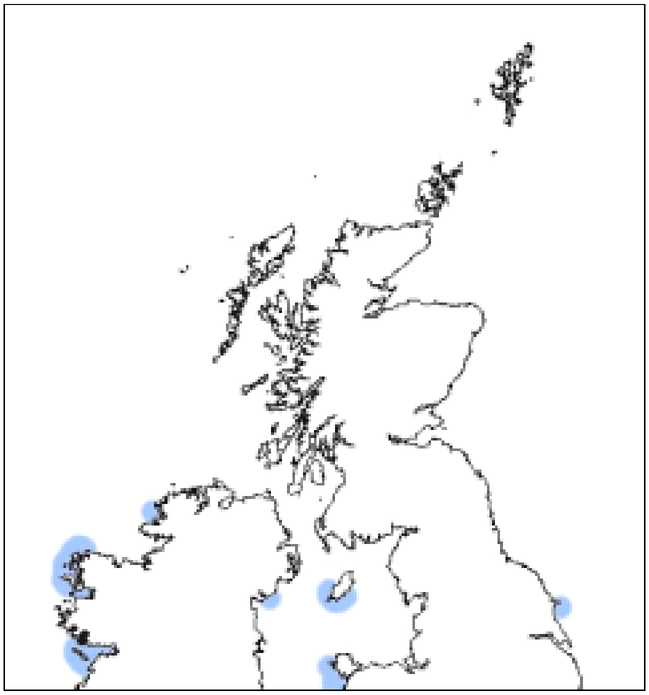
Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat:

Notes: Annual; there is a positive relationship between growth and temperature (Friedlander and Ben-Amotz, 1990). Abundance: rare. Often dominant in subtidal habitats in SW Britain but generally rarely encountered in Scotland. An easily recognised species suitable for any studies of distributional changes.

Legislative protection: None

57. *Taonia atomaria*



Common name:

Distribution:
Southern species recorded from the Azores to Ireland, England and the Isle of Man. Very rare in Northern Ireland and absent in Scotland.

Map shows likely current distribution using the following information sources:

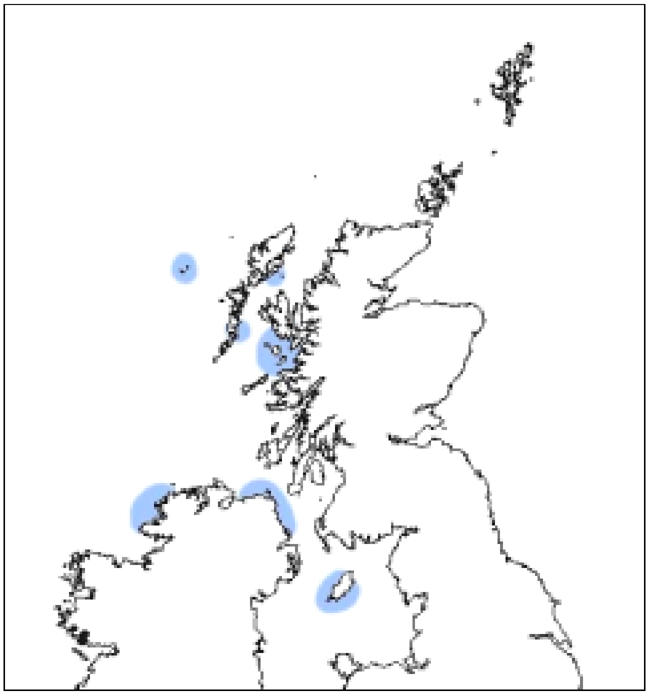
I. Tittley (unpubl. data), Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Found in areas of sand scour

Notes: Temperature and daylength may limit current distribution. Easily recognisable species.

Legislative protection: None

58. *Carpomitra costata*



Common name:

Distribution:
Southern species recorded in Channel Islands and southern UK as far north as the Isle of Man and Donnegal. Rare in Ireland and only a few records from the Outer Hebrides.

Map shows likely current distribution using the following information sources:

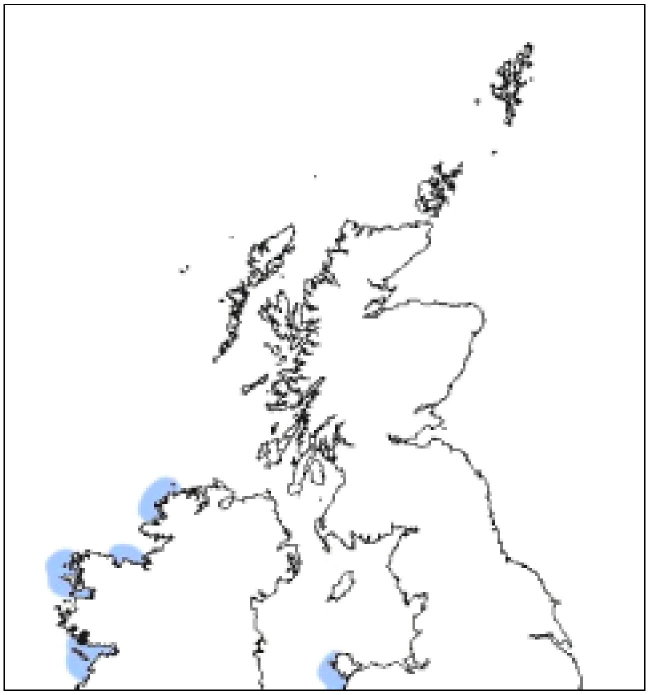
I. Tittley (unpubl. data), K. Hiscock (unpubl. data), Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Epilithic on bedrock and boulders; sublittoral to 37m; tolerant of sand cover (Fletcher, 1987)

Notes: Probably summer annual, recorded June to September (Fletcher, 1987). Good recognisable species to monitor.

Legislative protection: None

59. *Bifurcaria bifurcata*



Common name:

Distribution:
Southern species recorded from southern Spain to England and Wales. Records from NW Ireland require checking.

Map shows likely current distribution using the following information sources:

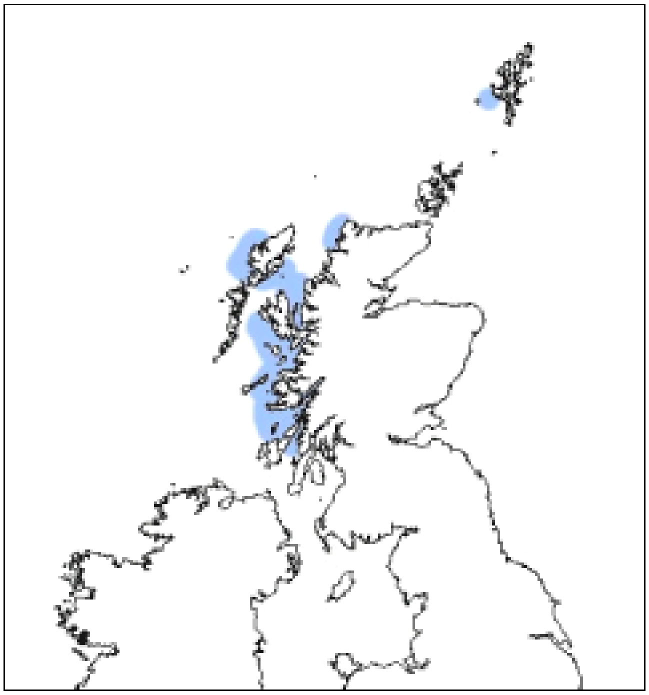
Crisp & Southward, unpubl. data; I. Tittley (unpubl. data), Norton, 1985; Picton & Costello, 1998; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Pool dwelling at northern limits of distribution; found on open rock at low shore in Spain (Todd & Lewis, 1984)

Notes: Intolerant of low air temperatures (Todd & Lewis, 1984). Absent from Scotland. A rock pool species (in Britain) which is conspicous and easily identified and would therefore provide a suitable species for monitoring changes in distribution. Also forms low water zone in south-west England and west Ireland.

Legislative protection: None

60. *Ascophyllum nodosum mackaii*



Common name:

A brown alga

Distribution:
Only recorded from Scotland in the UK and in a few locations in Ireland.

Map shows likely current distribution using the following information sources:

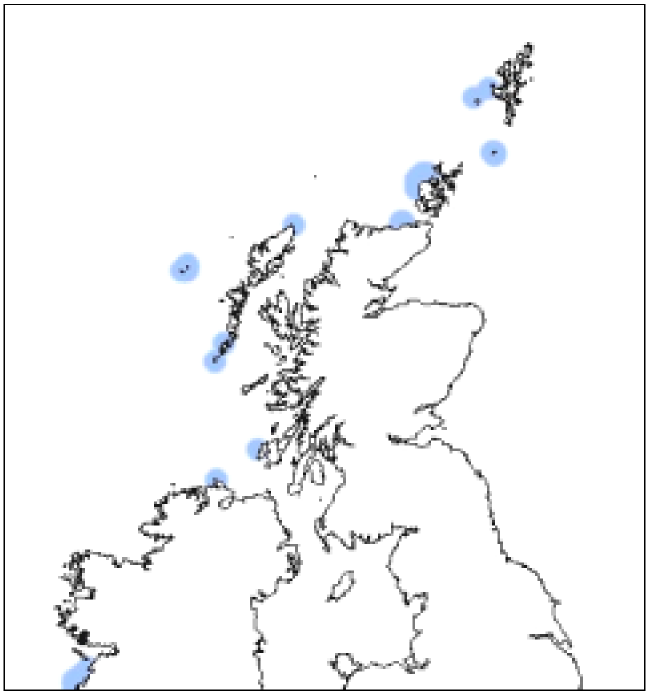
MERMAID
(www.jncc.gov.uk/mermaid)

Preferred habitat: In variable or low salinity

Notes: Scotland is the main European stronghold of this ecad of the much more widely distributed *Ascophylum nodosum*, although significant populations occur in Ireland. Habitat seems most important in determining the development of this growth form but consideration should be given to the effects of climate change. Occurs as unattached balls.

Legislative protection: UK Biodiversity Action Plan: Species statement

61. *Fucus distichus distichus*



Common name:

Distribution:
Northern species recorded from Scotland to the Arctic. Not recorded in Northern Ireland.

Map shows likely current distribution using the following information sources:

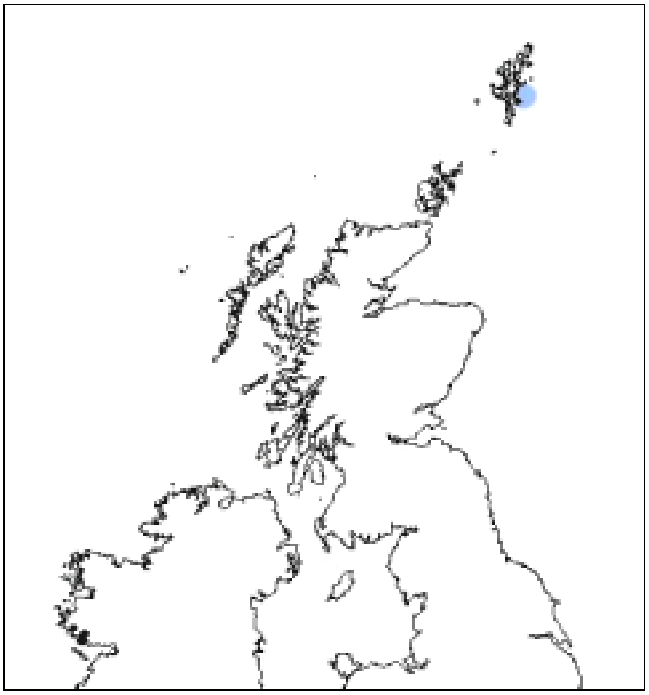
Powell, 1957; MERMAID (www.jncc.gov.uk/mermaid)

Preferred habitat: Tide pools on very exposed sites (Sideman & Mathieson, 1983; Pearson & Brawley, 1996).

Notes: Maximum growth winter and spring (Canada); repro Nov-May;mature at 2yrs; life span 2-3yrs; competes with Chondrus crispus; monoecious (capable of self fertilization); avoids gamete release at high tide (when water turbulent); zygotes remain unattached for at least one tidal cycle (at the low temps recorded during repro season); daytime gamete release (light required?) (Sideman & Mathieson, 1983; Pearson & Brawley, 1996). Its occurrence on exposed sites means that locations where it is found are isolated and may be difficult to access. Nevertheless, a northern species, dedicated surveys should be undertaken to establish a baseline of its current distribution. Abundance: rare. Populations sporadic and restricted which may indicate it is sensitive to disturbance.

Legislative protection: None

62. *Fucus evanescens*



Common name:

Distribution:
Northern species recorded from Denmark, Norway, Faroes, Iceland and Shetland (only British record).

Map shows likely current distribution using the following information sources:

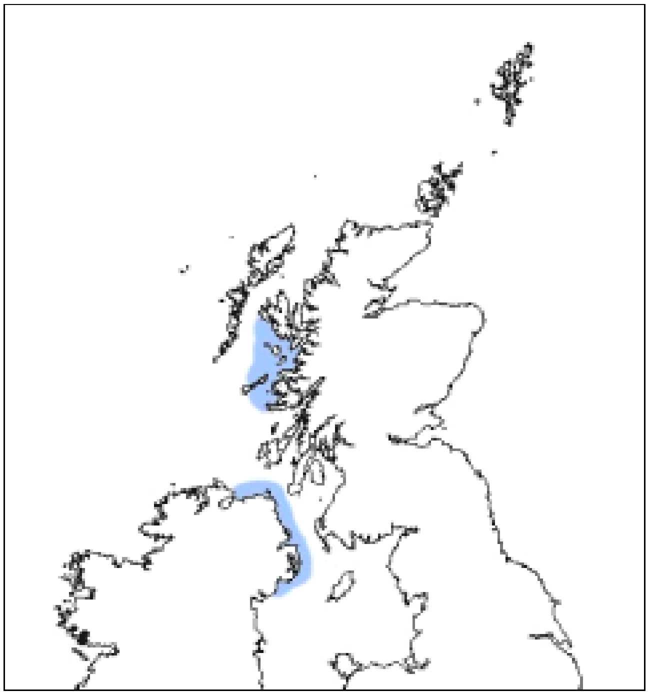
I. Tittley (unpubl. data), K. Hiscock (unpubl. data)

Preferred habitat: Mid-eulittoral to upper sublittoral at moderate to very sheltered sites (Sideman & Mathieson, 1983)

Notes: Maximum growth early summer (NW Atlantic); biomodal reproductive period (spring/Autumn); mature at 2yrs; loss of tissue after reproduction; life span 2-3yrs; competes with *Chondrus crispus* (Sideman & Mathieson, 1983). Abundance: rare. This species has been widely searched for in Scotland and the one record from Shetland (in Lerwick Harbour) is considered to be a true record of its distribution. Development of Lerwick Harbour may have adversely effected the occurrence of this species which requires searching far and recording as a baseline.

Legislative protection: None

63. *Codium adhaerens*



Common name:

Distribution:
Southern species recorded from Portugal/Mediterranean to British Isles. Scottish records from Inverness, Argyll and Mull. Rare in Northern Ireland.

Map shows likely current distribution using the following information sources:

I. Tittley (unpubl. data), MERMAID (www.jncc.gov.uk/mermaid)

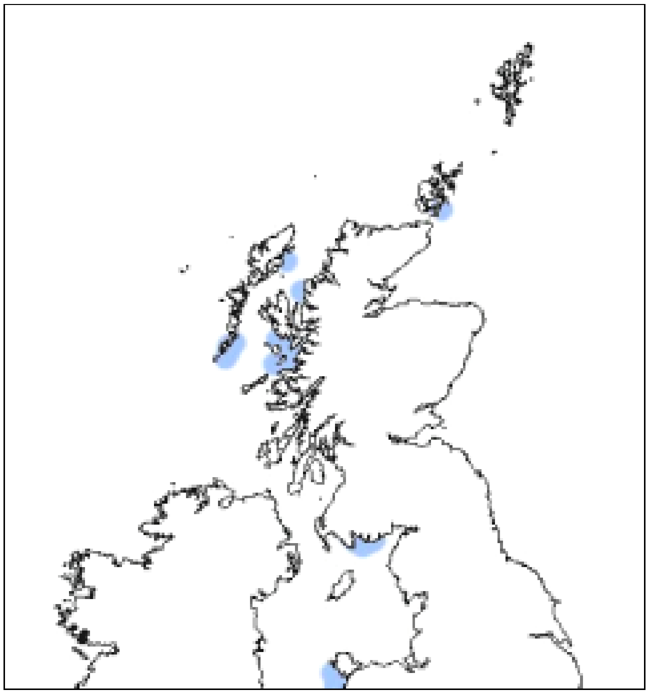
Preferred habitat:	Lower littoral & sublittoral fringe; sheltered and exposed; low light and strong flow of water (Burrows, 1991)
Notes:	Reproduces by biflagellate gametes; dioecious or occasionally monoecious; probably more common than distribution; plants present all year; fertile through summer; rarely fruit in some localities (Burrows, 1991). Abundance: rare on west coast only. Becoming more widespread in Scotland.
Legislative protection:	None

Appendix 6. Detailed information sheets for biotopes that are part of Biodiversity Action Plans or that may change in distribution as a result of climate change.

Most of the information for the biotope sheets has been adapted from Connor *et al.* (1997a,b) and MERMAID, www.jncc.gov.uk/mermaid. Species names follow Howson & Picton (1997).

In the Natural Heritage Importance section, * = biotopes that may be consistently found within the Habitats Directive Annex I type, ** = biotopes that are particularly characteristic of the Habitats Directive Annex I type (i.e. restricted or almost restricted to that type).

1. *Chthamalus* spp. on exposed upper eulittoral rock



Biotope Code: ELR.MB.Bpat.Cht

Distribution:
Recorded on the west coast of Britain as far north as Orkney.

Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

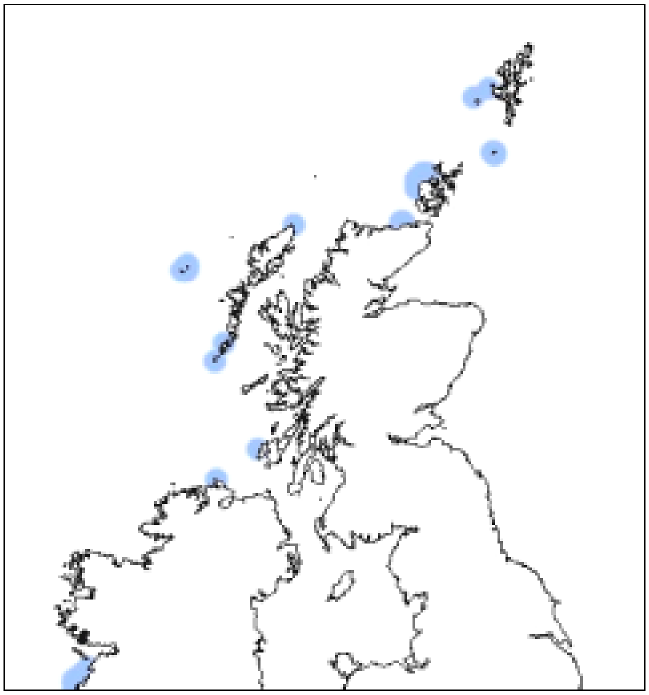
Description:

Exposed to moderately exposed upper and mid eulittoral bedrock and boulders are characterised by dense barnacles, *Chthamalus* spp. and the limpet *Patella vulgata*. On the west coast *Chthamalus* spp. dominate the upper to mid eulittoral, often forming a distinct white band above a darker *Semibalanus balanoides* zone (BPat.Sem). This is because *Chthamalus montagui* is better adapted to resist desiccation and, therefore, extends further up the shore. There is much regional variation in the distribution and zonation of *Chthamalus* spp. In more northern latitudes, such as north-west Scotland, the abundance of *Chthamalus* is greater on more wave exposed shores. In the south-west *Chthamalus* spp. can be the dominant barnacle throughout the eulittoral zone. Patches of *Lichina pygmaea* may be prominent within the *Chthamalus* zone, especially in the south. Cracks and crevices in the rock provide a refuge for small mussels *Mytilus edulis*, winkles *Littorina saxatilis* and the dogwhelk *Nucella lapillus*. Damp crevices are also frequently occupied by red algae, particularly *Osmundea pinnatifida* and encrusting coralline algae. With decreasing wave exposure *Fucus vesiculosus* is able to survive and this alga gradually replaces the barnacles and *Patella* biotope (see FvesB). *Chthamalus* spp. are uncommonly abundant in the upper eulittoral zone in very sheltered sealochs in Argyll, West Scotland.

Physical environment:	On bedrock and large boulders on very exposed to moderately exposed shores.
Main species:	*Chthamalus montagui, Chthamalus stellatus, Patella vulgata, Melarhaphe neritoides, Littorina neglecta* & *Mytilus edulis.*
Likely change in relation to warming and notes:	Overall appearance and functioning will be similar but component species of barnacles and limpets might change from predominantly northern (*Semibalanus balanoides*, *Patella vulgata*) to predominantly southern (*Patella ulyssiponensis*, *Chthamalus* spp.) species. Monitoring these species may provide an indication of more widespread change.

Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs * Large shallow inlets and bays * Estuaries *

2. *Fucus distichus* and *Fucus spiralis* f. *nana* on extremely exposed upper shore rock



Biotope Code: ELR.FR.Fdis

Distribution:
Recorded on east Orkney. This biotope is also thought to occur in Shetland and St. Kilda

Map shows likely current distribution using the following information sources:

Powell, 1957; MERMAID (www.jncc.gov.uk/mermaid)

Description:
Extremely exposed gently or steeply sloping upper shore bedrock may support a mixture of *Fucus distichus* and *Fucus spiralis* f. *nana*, the latter often at the top of the zone. This biotope is rare and restricted to the far north and west coasts. This mixed band is generally found between the *Verrucaria maura* and *Porphyra* zone (Ver.Por) above, and the *Mytilus edulis* and barnacle zone below (MytB). Although it may occur above a red algal zone (Mas), as recorded on Barra or above a *Porphyra* and sparse barnacle zone (Ver.Por) as on St Kilda.

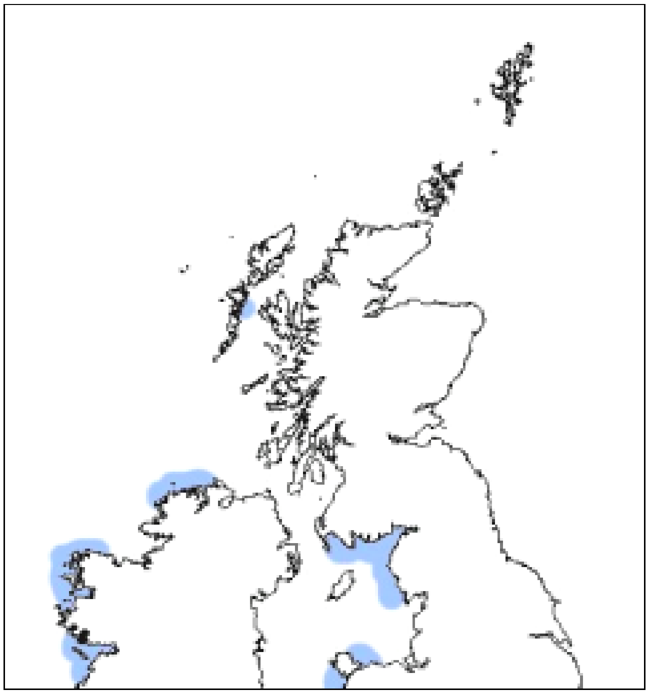
Physical environment: Occurs on bedrock on extremely exposed shores.

Main species: *Melarhaphe neritoides, Littorina neglecta, Hildenbrandia rubra, Fucus distichus, Fucus spiralis, Verrucaria maura* & *Verrucaria mucosa.*

Likely change in relation to warming and notes: The northern species that characterise and give the biotope its name may decline in abundance and disappear from many shores so that the biotope will decline in abundance and extent in Scotland. Dedicated searches have been undertaken for *Fucus distichus* but many locations are isolated and difficult to access.

Natural heritage importance Part of Habitats Directive. Annex I Habitat:
Reefs *

3. *Sabellaria alveolata* reefs on sand-abraded eulittoral rock



Biotope Code: MLR.Sab.Salv

Distribution:
South and west coasts of England and Wales and as far north as the Solway Firth. There is also one record on MERMAID from SE Uist.

Map shows likely current distribution using the following information sources:

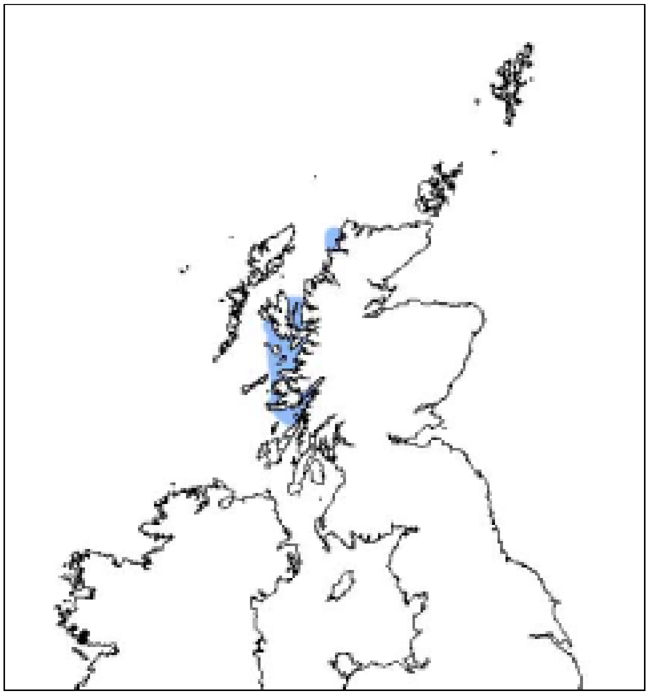
MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Many wave-exposed boulder scar grounds in the eastern basin of the Irish Sea (and as far south as Cornwall), are characterised by reefs of *Sabellaria alveolata* which build tubes from the mobile sand surrounding the boulders and cobbles. The tubes formed by *Sabellaria alveolata* form large reef-like hummocks, which serve to further stabilise the boulders. Other species in this biotope include the barnacles *Semibalanus balanoides*, *Balanus crenatus* and *Elminius modestus* and the molluscs *Patella vulgata*, *Littorina littorea*, *Nucella lapillus* and *Mytilus edulis*. Low abundances of algae tend to occur in areas of eroded reef. The main algal species include *Porphyra* spp., *Mastocarpus stellatus*, *Ceramium* spp., *Fucus vesiculosus*, *Fucus serratus*, *Enteromorpha* spp. and *Ulva* spp. On exposed surf beaches in the south-west *Sabellaria* forms a crust on the rocks, rather than the classic honeycomb reef, and may be accompanied by the barnacle *Balanus perforatus* (typically common to abundant). On wave-exposed shores in Ireland, the brown alga *Himanthalia elongata* can also occur.

Physical environment:	Found on cobbles, boulders, pebbles and sand on exposed to moderately exposed open coasts.
Main species:	*Sabellaria alveolata, Semibalanus balanoides*, *Balanus perforatus*, *Elminius modestus*, *Littorina littorea*, *Nucella lapillus* & *Palmaria palmata*.
Likely change in relation to warming and notes:	More extensive occurrence in suitable habitats in western Scotland is expected. The one record in south-east Uist should be checked
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs * Large shallow inlets and bays * Estuaries * UK Habitat Action Plan: *Sabellaria alveolata* reefs

4. *Ascophyllum nodosum* ecad. *mackii* beds on extremely sheltered mid eulittoral mixed substrata.



Biotope Code: SLR.FX.AscX.mac

Distribution:
Widely distributed in isolated locations in sea lochs on the west coast of Scotland. Possibly present in Shetland (Brindister Voe).

Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Beds of the free-living *Ascophyllum nodosum* ecad *mackaii*. Cobbles and other hard substrata are often characterised by the normal form of *Ascophyllum nodosum* and other fucoids such as *Fucus serratus* and *Fucus vesiculosus*. The loose mats of *A. nodosum* ecad *mackaii* provide a cryptic and humid habitat for mobile species such as gammarids, the shore crab *Carcinus maenas*, littorinid molluscs (especially *Littorina littorea*) and eels *Anguilla anguilla*. *Semibalanus balanoides* and *Mytilus edulis* are commonly attached to pebbles and cobbles on the sediment, while the infauna may contain *Arenicola marina*, *Lanice conchilega* and other polychaetes.

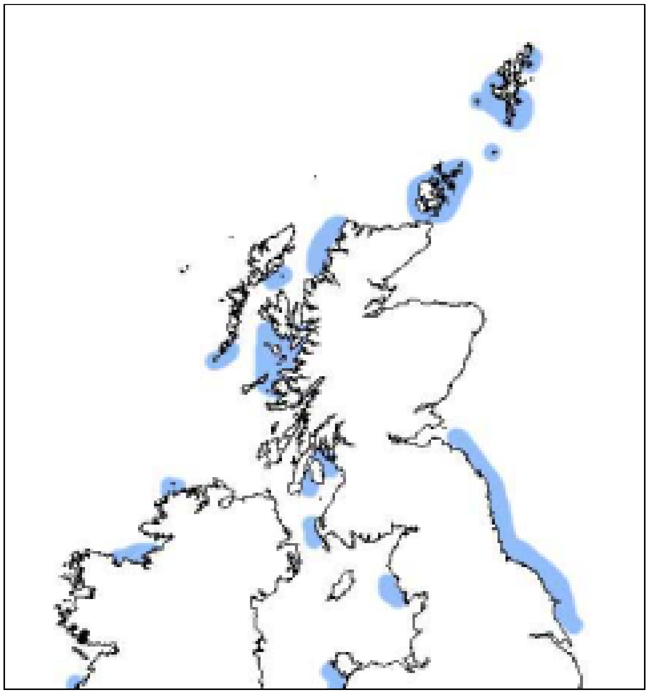
Physical environment: Extremely sheltered mid shore mixed substrata, usually subject to variable salinity due to freshwater runoff.

Main species: *Littorina saxatilis*, *Littorina littorea*, *Anguilla anguilla*, *Ascophyllum nodosum mackii.*

Likely change in relation to warming and notes: This biotope is particularly important as the ecad. *mackii* is especially developed on the shores of Scottish sea lochs. However, the biotope is recorded from southern and south-west Ireland where temperatures are higher than in Scotland at present. It seems likely that physical habitat and low salinity conditions are most important in determining presence of this biotope so that it is expected to continue to be present in Scotland.

Legislative protection: Part of Habitats Directive Annex I Habitats:
Large shallow inlets and bays **
UK Habitat Action Plan: *Ascophyllum nodosum mackii* beds

5. *Corallina officinalis* and *coralline crusts* in shallow eulittoral rockpools.



Biotope Code: LR.Rkp.Cor

Distribution:
Present at open coast wave-exposed locations all around the coast of Scotland.

Map shows likely current distribution using the following information sources:

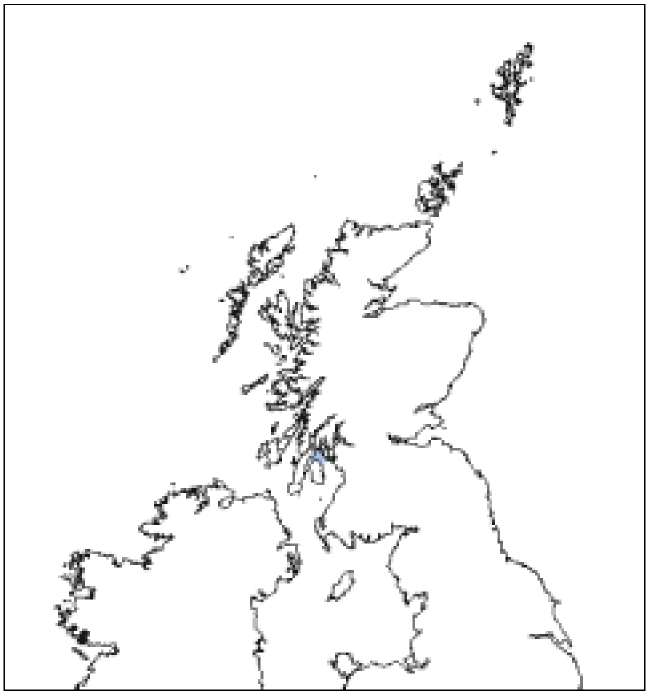
MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Shallow rockpools throughout the eulittoral zone may be characterised by a covering of encrusting coralline algae on which *Corallina officinalis* often forms a dense turf. These 'coralline' pools have a striking appearance as they are dominated predominantly by red algae. Filamentous and foliose red algae found in these pools include *Dumontia contorta*, *Mastocarpus stellatus* and *Ceramium rubrum*. The green algae *Cladophora rupestris* and *Enteromorpha* spp. can also occur. The pools may hold large numbers of grazing molluscs, particularly *Littorina littorea* (which often occurs in exceptionally high densities in upper shore pools), *Patella vulgata* and *Gibbula cineraria*. Gastropods may graze these pools to such an extent that they are devoid of any foliose red algae, and are reduced to encrusting coralline algae and large numbers of gastropods. Within the pools, pits and crevices are often occupied by the anemone *Actinia equina* and small *Mytilus edulis*. In Ireland, the sea urchin *Paracentrotus lividus* can dominate these shallow coralline pools (see Cor.Par). In south-west Britain, the brown alga *Bifurcaria bifurcata* (Cor.Bif) or *Cystoseira* spp. (Cor.Cys) can be regionally dominant.

Physical environment:	Moderate to high wave exposure and suitable rock structure to form pools.
Main species:	Encrusting Corallinacea, *Corallina officinalis.*
Likely change in relation to warming and notes:	The character of the various sub-biotopes is greatly dependent on the occurrence of southern species. There is therefore likely to be a shift towards sub-biotopes that include species such as the alga *Cystoseira tamariscifolia* and an increase in the number of areas where the sea urchin *Paracentrotus lividus* occurs. It may also be that increased warming of pools together with continued spread via water currents will lead to the presence of the non-native wireweed *Sargassum muticum*.
Legislative protection:	Part of Habitats Directive Annex I Habitats: Reefs *

6. *Halichondria bowerbanki, Eudendrium arbusculum* and *Eucratea loricata* on reduced salinity tide-swept circalittoral mixed substrata



Biotope Code: ECR.BS.HbowEud

Distribution:
Recorded from the Clyde area sea lochs only.

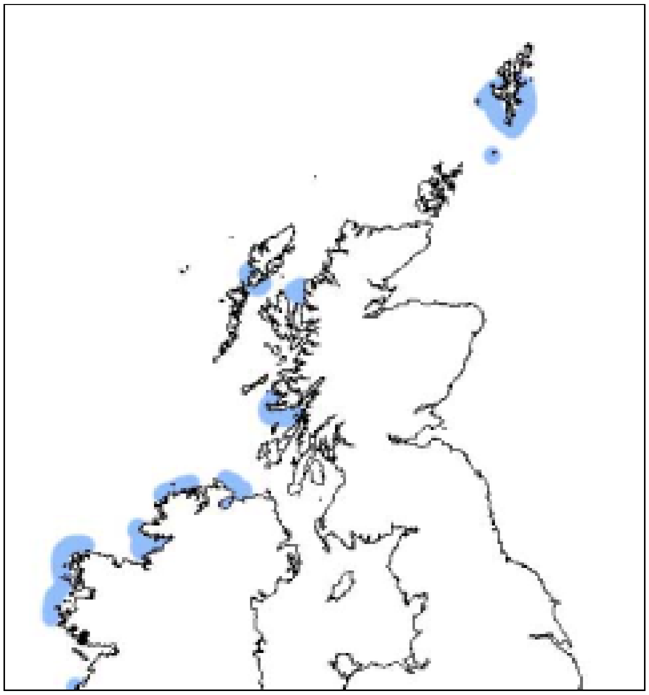
Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

Description:
Circalittoral mixed substrata (bedrock, boulders, cobbles and pebbles) in reduced salinity conditions and strong tidal streams. *Halichondria bowerbanki*, *Mycale lobata*, *Eudendrium arbusculum* and *Alcyonidium diaphanum* are particularly characteristic of these conditions. This biotope is only known from Loch Etive, a very impoverished low salinity version is present in the upper basin of Loch Etive.

Physical environment:	Occurs on bedrock, boulders, cobbles and pebbles on very sheltered shores.
Main species:	*Halichondria bowerbanki, Eudendrium arbusculum, Balanus crenatus & Ascidiella scabra.*
Likely change in relation to warming and notes:	Although restricted in occurrence to Scotland, it is not expected that warming will affect this biotope as component species are widely distributed in appropriate habitats.
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs ** Large shallow inlets and bays ** UK Habitat Action Plan: Tidal rapids

7. Coralline crusts, *Parasmittina trispinosa*, *Caryophyllia smithii*, *Haliclona viscosa*, polyclinids and sparse *Corynactis viridis* on very exposed circalittoral rock.



Biotope Code: ECR.Efa.CCParCar

Distribution:
Present in exposed or very wave-exposed habitats at scatted locations along the west coast and in Shetland.

Map shows likely current distribution using the following information sources:

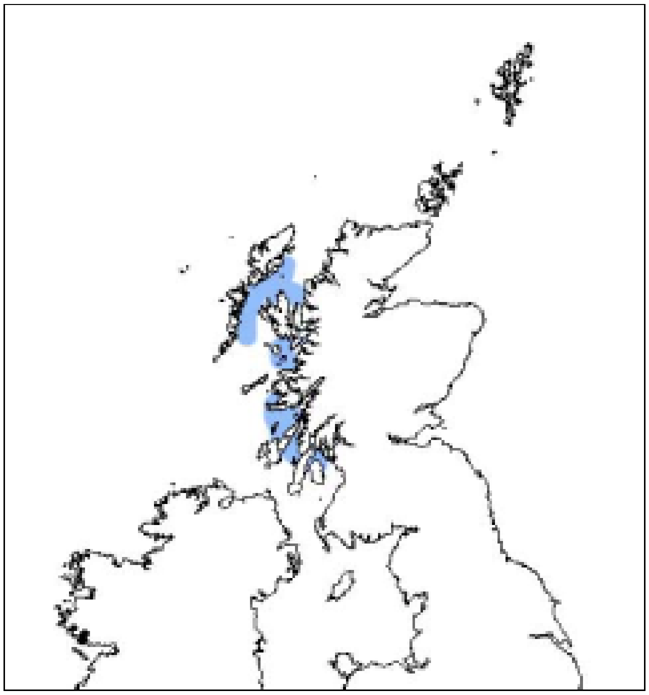
MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Sparse *Corynactis viridis*, encrusting bryozoans and coralline algae on clean, often deep circalittoral rock. The fauna is often sparse and has the appearance of being grazed but may also be effected by violent wave action working into deep water during winter storms. Other species include large specimens of the sponge *Haliclona viscosa*, the bryozoan *Parasmittina*, the sea cucumber *Holothuria forskali*, the cup coral *Caryophyllia* and sparse hydroids such as *Schizotricha frutescens* and *Nemertesia antennina*. This biotope also contains polyclinid ascidians. There appears to be a northern (Shetland/Orkney) variant of this biotope which is virtually devoid of sponges, whilst *Caryophyllia* is less common than in the south and west and grazing by *Echinus* seems to have a marked effect.

Physical environment:	Occurs on bedrock and large stable boulders and cobbles at exposed and very wave-exposed locations.
Main species:	*Alcyonium digitatum, Caryophyllia smithii, Corynactis viridis, Parasmittina trispinosa, Porella compressa,* encrusting Corallinacea.
Likely change in relation to warming and notes:	This is one of several circalittoral open coast biotopes that occasionally include southern species. The abundance and occurrence of species such as the jewel anemone *Corynactis viridis*, the sea cucumber *Holothuria forskali*, the ross *Pentapora fascialis* (=*Pentapora foliacea*) and, in less exposed situations, red sea fingers *Alcyonium glomertum* and zoanthid anemone *Parazoanthus axinellae* is likely to increase as a result of increased temperatures.
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs **

8. Erect sponges and *Swiftia pallida* on slightly tide-swept moderately exposed circalittoral rock



Biotope Code: MCR.Xfa. ErSSwi

Distribution:
Present in appropriate wave-sheltered habitats along the west coast and along the east coast of the Outer Hebrides.

Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

Description:

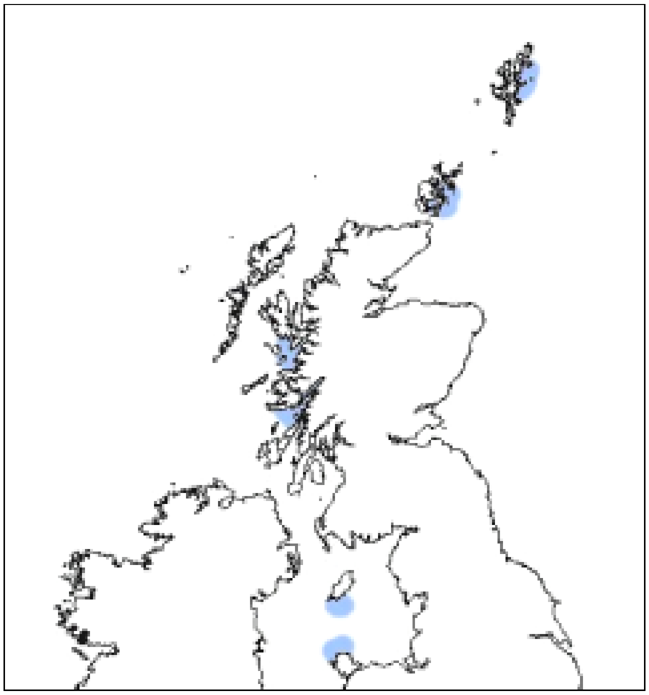
Circalittoral rock subject to slight tidal currents, with the seafan *Swiftia pallida* and various erect branching and cup sponges, including *Axinella infundibuliformis*, *Stelligera* spp. and *Raspailia* spp. The rocky surfaces usually have a sparse turf of hydroids including *Aglaophenia tubulifera* and *Schizotricha frutescens*, bryozoans *Bugula* spp., *Caryophyllia smithii*, *Porella compressa* and occasionally *Alcyonium glomeratum* and *Diazona violacea*. The feather stars *Antedon bifida* and *Antedon petasus* (the latter more numerous in deeper water than the former) and large solitary ascidians *Ascidia mentula* and *Polycarpa pomaria* (see AmenCio) are also characteristic of the less exposed sites with this biotope. Rock surfaces often with *Neocrania anomala* - found both in Irish and Scottish examples of this biotope. Short verticals and overhangs occasionally with *Parazoanthus anguicomus*. *Mycale lingua* recorded in deep water at some of the sites in Scottish sealochs. There are a few records from Kenmare River in SW Ireland which have *Swiftia* and *Eunicella* at the same sites. These records have been included in ErSEun although there were several other biotopes in Kenmare River which share close links with those from Scottish sealochs.

Physical environment: Occurs on bedrock, stable boulders and cobbles on exposed to moderately exposed shores.

Main species: *Alcyonium glomeratum, Swiftia pallida, Caryophyllia smithii, Parasmittina trispinosa, Porella compressa, Antedon bifida*, *Antedon petasus*, encrusting Corallinacea.

Likely change in relation to warming and notes:	Probable loss of the sea fan *Swiftia pallida*, and addition in inshore areas of southern species such as the zoanthid anemone *Parazoanthus axinellae*, ross *Pentapora foliacea* and the yellow branching sponge *Axinella dissimilis* together with the possible addition the Scottish fauna of the southern sea fan *Eunicella verrucosa* would most likely change this biotope to the 'southern form': MCR.Xfa.erSEun (erect sponges, *Eunicella verrucosa* and *Pentapora foliacea* on slightly tide-swept moderately exposed circalittoral rock).
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs ** Large shallow inlets and bays *

9. *Modiolus modiolus* beds with hydroids and red seaweeds on tide-swept circalittoral mixed substrata



Biotope Code: MCR.M.ModT

Distribution:
Recorded off west Scotland, Shetland, Orkney and NW Wales.

Map shows likely current distribution using the following information sources:

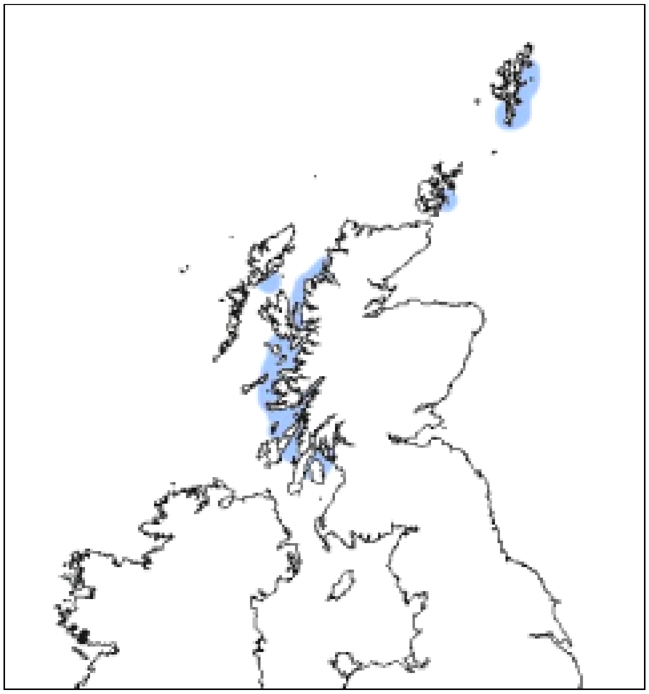
A.J. Southward, unpubl. data; MERMAID (www.jncc.gov.uk/mermaid)

Description:

Modiolus beds on mixed substrata (cobbles, pebbles and coarse muddy sediments) in moderately strong currents, typically on the open coast but also in tide-swept channels of marine inlets. Often with sponges such as *Hemimycale columella*, hydroids such as *Sertularia argentea*, *Hydrallmania falcata* and *Abietinaria abietina*, *Alcyonium digitatum*, barnacles, *Alcyonium digitatum*, bryozoans such as *Alcyonidium mytili* and ascidians *Dendrodoa grossularia*. This biotope is typified by examples off the north-west Lleyn Peninsula in N Wales and off Co. Down, Northern Ireland.

Physical environment:	Occurs on cobbles, pebbles and *Modiolus* shells on moderately exposed to sheltered shores.
Main species:	*Modiolus modiolus, Sertularia argentea, Alcyonium digitatum, Pomatoceros triqueter, Balanus crenatus, Hyas araneus, Electra pilosa,* Corallinaceae & *Phycodrys rubens*
Likely change in relation to warming and notes:	This biotope is the one most typically found in Scotland. It includes a rich variety of species associated with clumps of horse mussels. However, *Modiolus* biotopes do occur further south than Scotland suggesting that a significant rise in temperature would be required to adversely affect the presence of *Modiolus* as a key structuring species. Overall, there may be some decline in locations of marginal suitability for this biotope.
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs ** Large shallow inlets and bays ** UK Habitat Action Plan: *Modiolus modiolus* beds

10. Sheltered *Modiolus* (horse-mussel) beds



Biotope Code: SCR.Mod

Distribution:

Map shows likely current distribution using the following information sources:

MERMAID (www.jncc.gov.uk/mermaid)

Description:

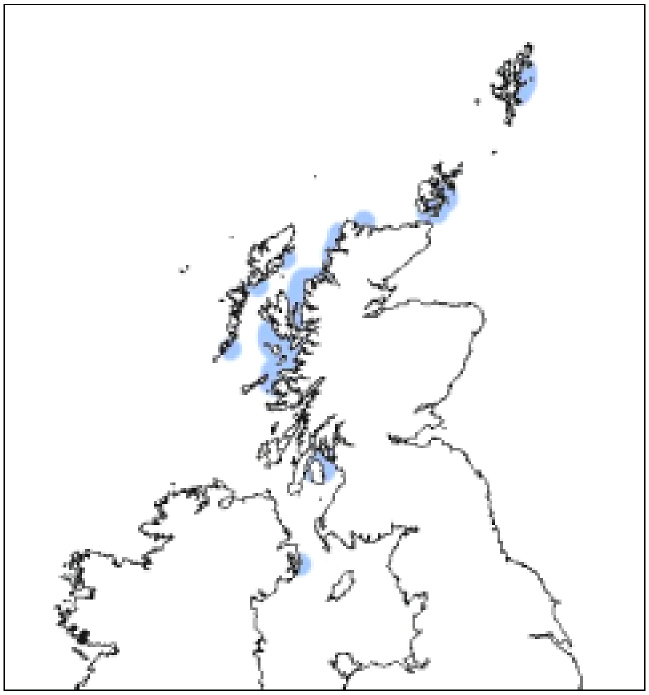
Circalittoral mixed substrata, not influenced by significant tidal currents, with clumps or more extensive beds of *Modiolus modiolus*. ModHAs typically occurs in sealochs and the Shetland voes. Large solitary ascidians (*Ascidiella aspersa*, *Corella parallelogramma*, *Ciona intestinalis*) and fine hydroids (*Bougainvillia ramosa*, *Kirchenpaueria pinnata*) present attached to the mussel shells. Decapods such as spider crabs and *Munida rugosa* typically present. *Aequipecten opercularis* often present. The much richer version of this biotope ModCvar has far more sponges and hydroids growing on and amongst the *Modiolus* and large numbers of *Chlamys varia*. Brittlestars *Ophiothrix fragilis* and *Ophiocomina nigra*, as well as *Ophiopholis aculeata* are often common, sometimes forming a dense bed as described in Oph. The biotope ModHo, characterised by *Modiolus* and holothurians occurs in similar physiographic features, although seems to be in softer sediment in some cases.

Physical environment: Mixed substrata on sheltered to very sheltered shores.

Main species: ModHAs: *Modiolus modiolus, Aequipecten opercularis,* Corallinaceae*, Munida rugosa, Pomatoceros triqueter* & Terebellidae.
ModCvar: *Cerianthus lloydii, Urticina felina, Pomatoceros triqueter, Balanus balanus, Pagurus bernhardus, Gibbula cineraria, Pleurobranchus membranaceus, Modiolus modiolus, Chlamys varia, Aequipecten opercularis, Asterias rubens, Ophiothrix fragilis, Psammechinus miliaris, Echinus esculentus, Ciona intestinalis, Corella parallelogramma* & *Ascidiella aspersa.*

Likely change in relation to warming and notes:	This biotope is the one most typically found in Scotland. It includes a rich variety of species associated with clumps of horse mussels. However, *Modiolus* biotopes do occur further south than Scotland suggesting that a significant rise in temperature would be required to adversely affect the presence of *Modiolus* as a key structuring species. Overall, there may be some decline in locations of marginal suitability for this biotope and of the several species associated with the biotope that appear to be more abundant in Scotland including *Balanus balanus*, *Chlamys varia*, *Aequipected opercularis* and *Psammechinus miliaris.*
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs ** Large shallow inlets and bays ** UK Habitat Action Plan: *Modiolus modiolus* beds

11. *Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand



Biotope Code: IGS.Mrl.Phy

Distribution:
Recorded off NW Scotland, Orkney and Shetland.

Map shows likely current distribution using the following information sources:

MERMAID (www.jncc.gov.uk/mermaid)

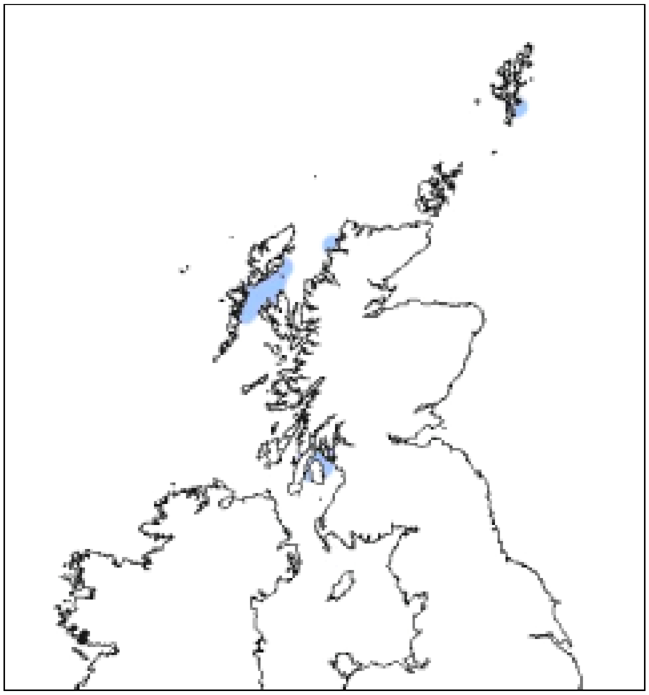
Description:

Maerl beds characterised by *Phymatolithon calcareum* in gravels and sands. Associated epiphytes include red algae such as *Cryptopleura ramosa*, *Brongniartella byssoides* and *Plocamium cartilagineum* with *Desmarestia* spp. and *Dictyota dichotoma* also very often present. Algal species may be anchored to the maerl or to dead bivalve shells amongst the maerl. Polychaetes, such as *Chaetopterus variopedatus*, and the gastropods *Gibbula magus* and *Gibbula cineraria* may be present. *Liocarcinus depurator* and *Liocarcinus corrugatus* are often present, although they may be under-recorded; it would seem likely that robust infaunal bivalves such as *Circomphalus casina*, *Mya truncata* and *Dosinia exoleta* are more widespread than available data currently suggests. At some sites where IGS.Phy occurs, there may be significant patches of maerl gravel containing the rare burrowing anemone *Halcampoides elongatus*; this may be a separate biotope, but insufficient data exists at present. Northern maerl beds in the UK do not appear to contain *L. corallioides* but in south-west England and Ireland *L. corallioides* may occur to some extent in IGS.Mrl.Phy as well as IMX.Lcor, where it dominates. In IGS.Mrl.Phy.Hec hydroids present are typically erect colonies such as *Nemertesia* spp. and often occur on the maerl or attached to dead shells within the maerl. Echinoderms such as *Antedon bifida*, *Ophiothrix fragilis*, *Ophiocomina nigra*, *Ophiura albida* and *Neopentadactyla mixta* are occasional or frequent in Phy.HEc but do not often occur in Phy.R.

Physical environment:	Maerl gravel and course sand on moderately exposed shores.
Main species:	*Phymatolithon calcareum, Lithothamnion corallioides, Neopentadactyla mixta, Cerianthus lloydii* & *Plocamium cartilagineum.*
Likely change in relation to warming and notes:	This is the type of maerl bed found in full salinity conditions in Scotland**.**

Legislative protection:	Part of Habitats Directive. Annex I Habitats: Sandbanks which are slightly covered by sea water all the time ** Large shallow inlets and bays * Lagoons * Habitats Directive Annex V UK Habitat Action Plan: Maerl beds

12. *Lithothamnion glaciale* maerl beds in tide-swept variable salinity infralittoral gravel



Biotope Code: IGS.Mrl.Lgla

Distribution:
Northern biotope with southern limit at Lundy. Recorded in west Scotland and Shetland.

Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

Description:

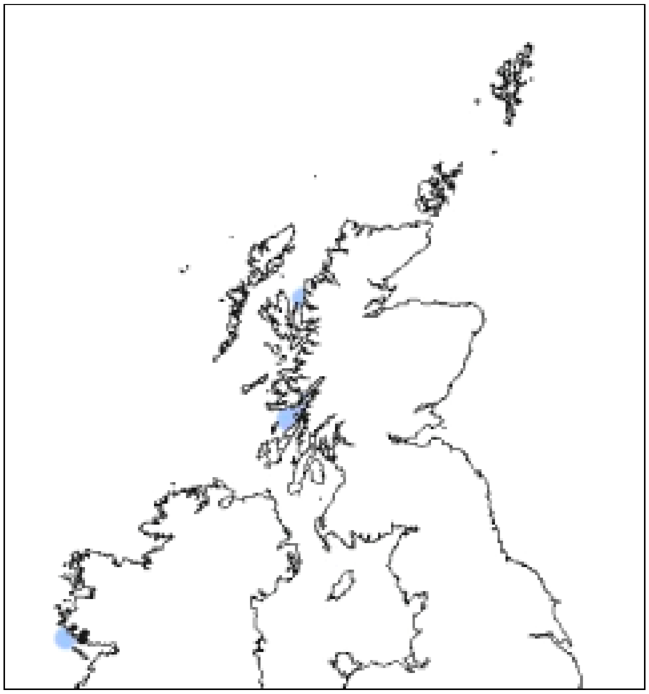
Upper infralittoral tide-swept channels of coarse sediment subject to variable or reduced salinity which support distinctive beds of *Lithothamnion glaciale* maerl 'rhodoliths'. *Phymatolithon calcareum* may also be present as a more minor maerl component. This biotope can often be found at the upper end of Scottish sealochs where the variable salinity of the habitat may not be immediately obvious. Associated fauna and flora may include species found in other types of maerl beds (and elsewhere), e.g. *Chaetopterus variopedatus*, *Lanice conchilega*, *Mya truncata*, *Plocamium cartilagineum* and *Phycodrys rubens*. Lgla, however, also has a fauna that reflects the slightly reduced salinity conditions, e.g. *Psammechinus miliaris* is often present in high numbers along with other grazers such as chitons and *Tectura* spp. *Hyas araneus*, *Ophiothrix fragilis* and *Henricia oculata* are also fairly typically present at sites. In Scottish lagoons (obs) this biotope may show considerable variation but the community falls within the broad description defined here.

Physical environment: Maerl; shell gravel; stones and coarse sediment on sheltered to extremely sheltered shores.

Main species: *Lithothamnion glaciale, Laminaria saccharina, Phymatolithon calcareum, Psammechinus miliaris, Ophiothrix fragilis, Mya truncata, Tectura virginea* & *Cerianthus lloydii.*

Likely change in relation to warming and notes:	*Lithothamnion glaciale* is widespread and often abundant in the Arctic region and reaches its southern limit of distribution in Britain (Yorkshire, Lundy) and Ireland (Galway, Down). The distinctive beds of maerl ‘rhodoliths’ that occur in Scotland are the most likely maerl beds to be adversely affected by sea water temperature warming. However it seems likely that warming would need to be substantial (2ºC or more) for significant change to occur in the maerl. Some componants of the biotope such as *Tectura testudinalis* may be lost and the maerl bed might beome dominated by *Phymatolihon calcareum*, already a component of the biotope.
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Sandbanks which are slightly covered by sea water all the time * Large shallow inlets and bays ** Lagoons * UK Habitat Action Plan: Maerl beds

13. *Lithothamnion corallioides* maerl beds on infralittoral muddy gravel



Biotope Code: IMX.MrlMx.Lcor

Distribution:
Recorded in SW Ireland and UK. Scottish records are unconfirmed due to problems with identification.

Map shows likely current distribution using the following information sources:

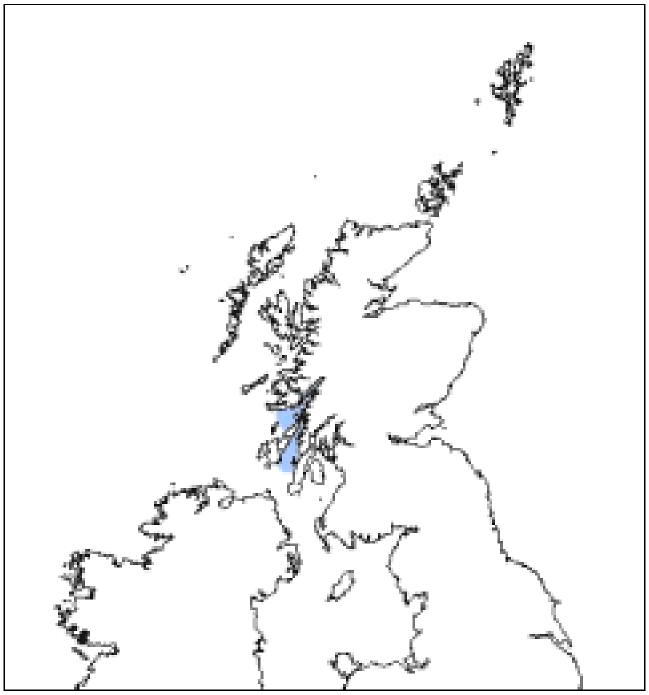
MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Live maerl beds in sheltered, silty conditions which are dominated by *Lithothamnion corallioides* with a variety of foliose and filamentous seaweeds. Live maerl is at least common but there may be noticeable amounts of dead maerl gravel and pebbles. Other species of maerl, such as *Phymatolithon calcareum* and *Phymatolithon purpureum*, may also occur as a less abundant component. Species of seaweed such as *Dictyota dichotoma*, *Halarachnion ligulatum*, *Gracilaria verrucosa* and *Ulva* spp. are often present, although are not restricted to this biotope, whereas *Dudresnaya verticillata* and *Cutleria multifida* tend not to occur on other types of maerl beds. The anemones *Anthopleura ballii*, *Anemonia viridis* and *Cereus pedunculatus* and the fan worm *Myxicola infundibulum* are typically found in Lcor whereas *Echinus esculentus* tends to occur more in other types of maerl. Lcor has a south-western distribution in Britain and Ireland. Sheltered, stable, fully saline maerl beds in the north of Great Britain (where *L. corallioides* has not been confirmed to occur) may need to be described as an analogous biotope to Lcor (see Phy).

Physical environment:	Muddy maerl gravel on sheltered to very sheltered shores.
Main species:	*Lithothamnion corallioides, Phymatolithon calcareum, Dictyota dichotoma, Dudresnaya verticillata* & *Tectura virginea.*
Likely change in relation to warming and notes:	Many of the species in this biotope are southern in distribution.
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Sandbanks which are slightly covered by sea water all the time ** Large shallow inlets and bays ** Habitats Directive Annex V UK Habitat Action Plan: Maerl beds

14. *Halcampa chrysanthellum* and *Edwardsia timida* on sublittoral clean stone gravel



Biotope Code: IGS.FaG.HalEdw

Distribution:
Recorded in west Scotland in Loch Creran, Loch Eynort (Skye) and Church Bay (Rathlin Island). Also occurs in Strangford Narrows.

Map shows likely current distribution using the following information sources:

MERMAID (www.jncc.co.uk/mermaid)

Description:

Periodically (seasonally?) disturbed sublittoral stone gravel with small pebbles characterised by the presence of the anemones *Halcampa chrysanthellum* and *Edwardsia timida*. This biotope may also be contain opportunistic red seaweeds such as *Palmaria palmata*, Associated species are often typical of a hydroid/bryozoan turf but with infauna such as *Sabella pavonina* and *Megalomma vesiculosum*. It should be noted that this habitat may show considerable variation in community composition.

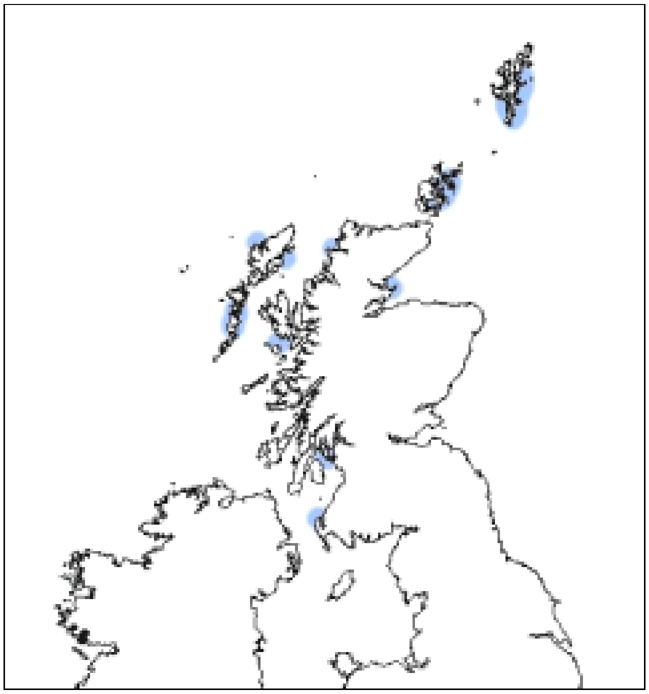
Physical environment: On clean stone gravel with pebbles on moderately exposed to sheltered shores

Main species: *Edwardsia timida* & *Halcampa chrysanthellum.*

Likely change in relation to warming and notes:

Legislative protection: Part of Habitats Directive. Annex I Habitat:
Large shallow inlets and bays *
UK Habitat Action Plan: Sublittoral sands and gravels

15. *Ruppia maritima* in reduced salinity infralittoral muddy sand



Biotope Code: IMS.Sgr.Rup

Distribution:
Recorded off west Scotland (especially the Outer Hebrides), Shetland, Orkney and the Moray Firth.

Map shows likely current distribution using the following information sources:

MERMAID (www.jncc.gov.uk/mermaid)

Description:

In sheltered brackish muddy sand and mud, beds of *Ruppia maritima* and more rarely *Ruppia spiralis* may occur. These beds may be populated by fish such as *Gasterosteus aculeatus* and *Spinachia spinachia* which are less common on filamentous algal-dominated sediments. Seaweeds such as *Chaetomorpha* spp., *Enteromorpha* spp., and *Chorda filum* are also often present. In some cases the stoneworts *Chara aspera* and *Lamprothamnium papulosum* occur. Although only recorded from Scotland in the searches undertaken for this study, it is likely the biotope occurs in the Fleet in Dorset, England.

Physical environment: Occurs on muddy fine sand to mud on extremely sheltered shores.

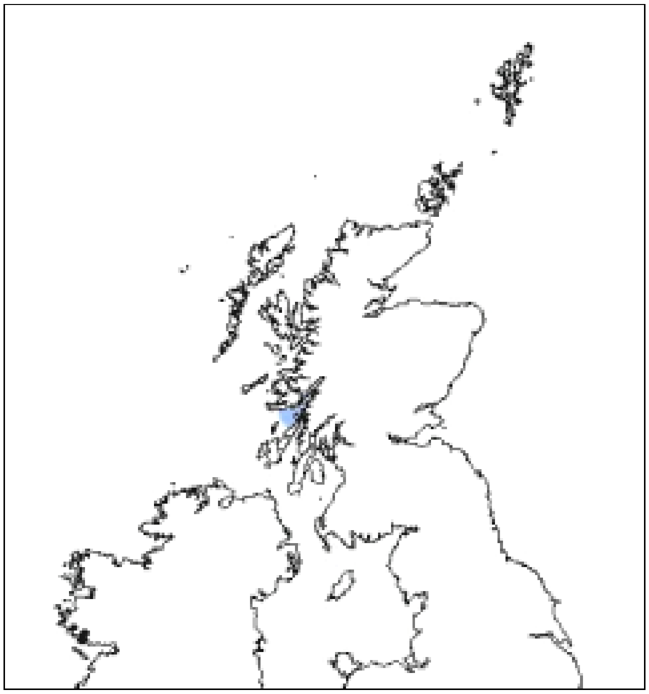
Main species: *Ruppia maritima, Ruppia spiralis, Lamprothamnium papulosum, Filamentous green algae, Mysidae*

Likely change in relation to warming and notes: *Lamprothamnium papulosum* is a red list species.

Legislative protection: Part of Habitats Directive. Annex I Habitats:
- Sandbanks which are slightly covered by sea water all the time **
- Estuaries *
- Lagoons **

UK Habitat Action Plan: Seagrass beds

16. *Serpula vermicularis* reefs on very sheltered circalittoral muddy sand



Biotope Code: CMS.Ser

Distribution:
Reefs only recorded from Loch Creran and Loch Sween on west coast of Scotland. Reefs in the latter are now reported to be dead.

Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Large clumps (mini 'reefs') of the calcareous tubes of *Serpula vermicularis*, typically attached to stones on muddy sediment in very sheltered conditions in sealochs. A rich associated biota attached to the calcareous tube may include *Esperiopsis fucorum*, thin encrusting sponges, the ascidians *Ascidiella aspersa*, *Pyura microcosmus* and *Diplosoma listerianum* and fine hydroids such as *Halopteris catharina*. In shallow water dense *Phycodrys rubens* may grow on the 'reefs'. Reefs from Loch Creran have been recently studied. The only other known site in UK for these reefs is Loch Sween, where they are reported to have deteriorated. Otherwise only known from Salt Lake, Cliffden and Killary Harbour, Co. Galway.

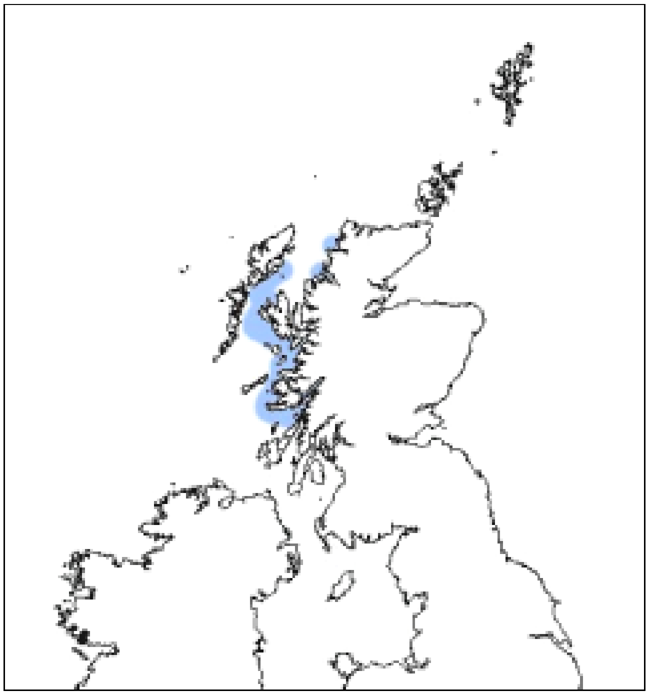
Physical environment: Occurs on calcareous tubes, pebbles and shells on sediment on very sheltered to extremely sheltered shores.

Main species: *Kirchenpaueria pinnata, Eupolymnia nebulosa, Myxicola infundibulum, Pomatoceros triqueter, Serpula vermicularis, Pandalus montagui, Psammechinus miliaris, Diplosoma listerianum, Corella parallelogramma, Ascidiellaspersa, Dendrodoa grossularia, Pyura microcosmus,* Corallinaceae & *Phycodrys rubens.*

Likely change in relation to warming and notes: A rich habitat which is included because of its importance.

Legislative protection: Part of Habitats Directive. Annex I Habitats:
Reefs **
Large shallow inlets and bays **
UK Habitat Action Plan: Serpulid reefs

17. Seapens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral soft mud



Biotope Code: CMU.SpMeg.Fun

Distribution:
Recorded in Scottish west coast sea lochs.

Map shows likely current distribution using the following information sources:

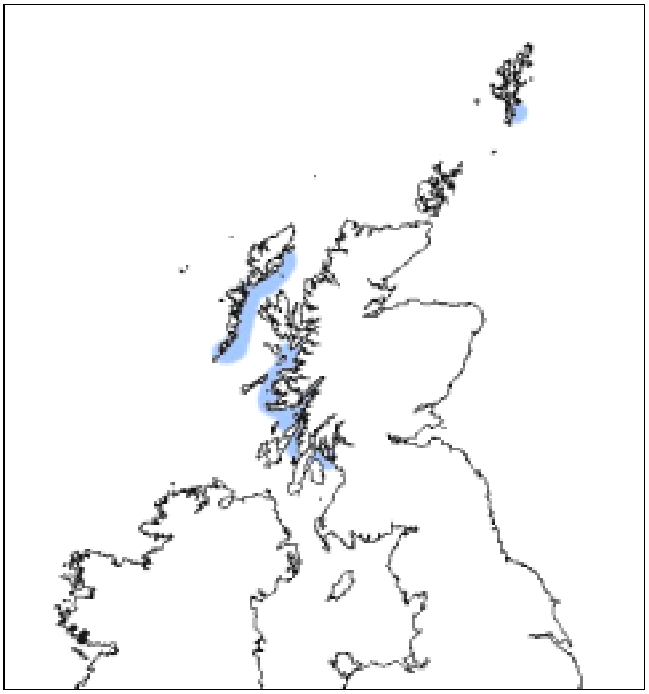
MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Deep muds, especially in sealochs, which support populations of seapens such as *Virgularia mirabilis* and *Pennatula phosphorea*, but sometimes also with forests of the nationally scarce *Funiculina quadrangularis*. The sediment is usually extensively burrowed by crustaceans, the most common of which is *Nephrops norvegicus*, but *Callianassa subterranea* may also be present (the latter is likely to be under-recorded by grab sampling because it is deep burrowing). *Lesueurigobius friesii* is present at many sites. *Amphiura* spp. are usually present in high densities

Physical environment:	On mud on sheltered to very sheltered shores.
Main species:	*Funiculina quadrangularis, Pennatula phosphorea, Nephrops norvegicus, Turritella communis* & *Amphiura filiformis.*
Likely change in relation to warming and notes:	This is a Scottish biotope where Scotland holds the major European resource and requires assessment of any impact of climate change.
Legislative protection:	Part of Habitats Directive. Annex I Habitat: Large shallow inlets and bays * UK Habitat Action Plan: Mud habitats in deep waters

18. *Beggiatoa* spp. on anoxic sublittoral mud



Biotope Code: CMU.Beg

Distribution:
Recorded in Scottish west coast sea lochs.

Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Sublittoral soft anoxic mud, often in areas with poor water exchange with the open sea, can have a conspicuous bacterial mat covering of *Beggiatoa* spp. The anoxia may be a result of natural conditions of poor water exchange in some sealochs (and many Scandinavian fjords) or artificially under fish farm cages from nutrient enrichment. The fauna is normally impoverished at such sites, with few elements of the infaunal communities present in other muddy biotopes. Scavenging species such as *Asterias rubens* and *Carcinus maenas* are typically present where the habitat is not too anoxic but in extreme conditions of anoxia little survives other than the *Beggiatoa*. The polychaete *Ophiodromus flexuosus* occurs in high densities at the interface between oxygenated and deoxygenated sediments (in Norwegian fjords).

Physical environment: On mud on very sheltered to extremely sheltered shores.

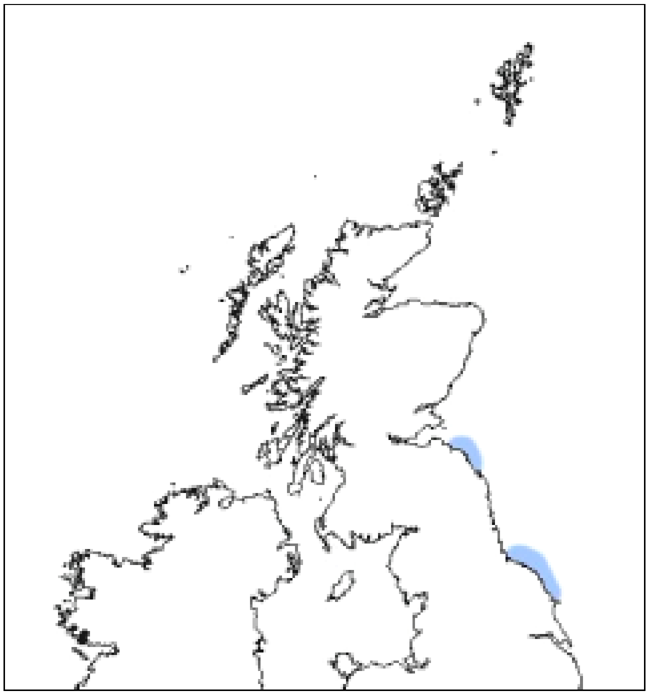
Main species: *Beggiatoa* spp.

Likely change in relation to warming and notes: This biotope is included as anoxia can occur as a result of thermal stratification (which may increase as a result of warming).

Legislative protection: Part of Habitats Directive. Annex I Habitats:
- Large shallow inlets and bays *
- Lagoons *

UK Habitat Action Plan: Mud habitats in deep water

19. *Sabellaria spinulosa* and *Polydora spp.* on stable circalittoral mixed sediment



Biotope Code: CMX.SspiMx

Distribution:
Reefs recorded off the east coast of England, just extending north into Scotland.

Map shows likely current distribution using the following information sources:

MERMAID
(www.jncc.gov.uk/mermaid)

Description:

The tube-building polychaete *Sabellaria spinulosa* at high abundances on mixed sediment, with *Polydora* spp. tubes attached. Infauna comprise typical sublittoral polychaete species, together with the bivalves *Abra alba* and *Nucula nitidosa*. Epifauna comprise calcareous tubeworms, pycnogonids, hermit crabs and amphipods.

Physical environment: Occurs on mixed sediments on moderately exposed shores.

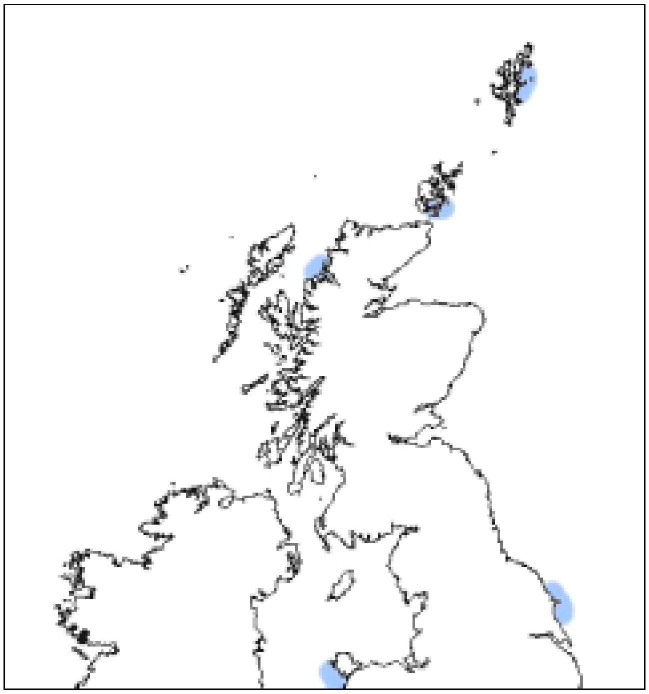
Main species: *Tubulanus*, Nematoda, *Polynoidae*, *Pholoe*, *Phyllodocidae*, *Eteone*, *Glycera*, *Glycinde nordmanni*, *Syllis*, *Exogone naidina*, *Exogone verugera*, *Nephtys*, *Lumbrineris gracilis*, *Prionospio*, *Spiophanes bombyx*, *Cirratulidae*, *Mediomastus fragilis*, *Scalibregma inflatum*, *Sabellaria spinulosa*, *Ampharetidae*, *Abra alba*, *Sphenia binghami*, *Ophiura* spp.

Likely change in relation to warming and notes:

Legislative protection: Part of Habitats Directive. Annex I Habitats:
- Reefs **
- Large shallow inlets and bays *
- Estuaries *

UK Habitat Action Plan: *Sabellaria spinulosa* reefs

20. *Modiolus modiolus* beds on circalittoral mixed sediment



Biotope Code: CMX.ModMx

Distribution:
Recorded off the Shetland, Orkney, west Scotland, Wales and east England.

Map shows likely current distribution using the following information sources:

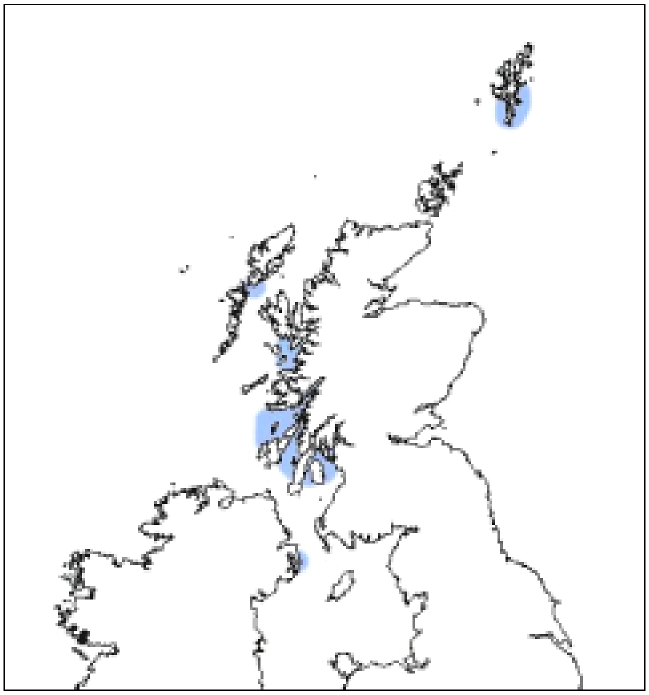
MERMAID
(www.jncc.gov.uk/mermaid)

Description:

Muddy gravels and coarse sands in deeper water of continental seas may contain venerid bivalves with beds of *Modiolus modiolus*. The clumping of the byssus threads of the *M. modiolus* creates a stable habitat that attracts a very rich infaunal community. Brittlestars such as *Ophiothrix fragilis* may also occur with this community. This biotope is very similar to the 'boreal off-shore gravel association' and the 'deep Venus community' described by previous workers (Ford 1923; Jones 1951). Similar *Modiolus* beds on open coast stable boulders, cobbles and sediment are described under MCR.ModT.

Physical environment:	Occurs on muddy gravel and sand, with shells and stones on moderately exposed to sheltered shores.
Main species:	*Modiolus modiolus, Buccinum undatum* & *Ophiothrix fragilis*
Likely change in relation to warming and notes:	
Legislative protection:	Part of Habitats Directive. Annex I Habitats: Reefs ** Large shallow inlets and bays * Estuaries * UK Habitat Action Plan: *Modiolus modiolus* beds

21. Sparse *Modiolus modiolus*, dense *Cerianthus lloydii* and burrowing holothurians on sheltered circalittoral stones and mixed sediment



Biotope Code: CMX.ModHo

Distribution:
Recorded off west Scotland and Shetland.

Map shows likely current distribution using the following information sources:

A.J. Southward, unpubl. data; MERMAID (www.jncc.gov.uk/mermaid)

Description:

Pebbles and cobbles on muddy shell gravel in sealochs with dense *Cerianthus lloydii* and sparse *Modiolus modiolus*. Large burrowing holothurians (many only extend their tentacles above the sediment surface seasonally) include *Psolus phantapus*, *Paracucumaria hyndmani*, *Thyonidium commune*, *Thyone fusus* and *Leptopentacta elongata*. This biotope is well developed in the Clyde sealochs, although many examples are rather species-poor. Some examples in south-west Scotland sealochs have greater quantities of boulders and cobbles and therefore have a richer associated biota (compared with other sheltered *Modiolus* bed biotopes such as ModHAs). Examples in Shetland are somewhat different in having the cucumber *Cucumaria frondosa* amongst sparse *Modiolus* beds and a slightly different balance in abundance of other species; for example the brittlestar *Ophiopholis aculeata* is more abundant in these far northern examples in the voes and narrows (see Oph.Oacu).

Physical environment: Occurs on pebbles, boulders and cobbles on muddy gravel on sheltered to very sheltered shores.

Main species: *Modiolus modiolus, Cerianthus lloydii, Pagurus bernhardus, Ophiura albida* & *Psolus phantapus.*

Likely change in relation to warming and notes:

Legislative protection: Part of Habitats Directive. Annex I Habitat:
Large shallow inlets and bays **
UK Habitat Action Plan: *Modiolus modiolus* beds

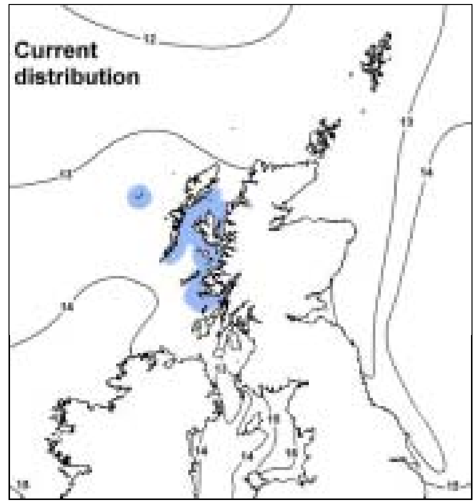
Appendix 7. Predictions of climate change (temperature rise) for selected representative species.

The species names used in the following information sheets are those used in *The Species Directory of the Marine Fauna and Flora of the British Isles and Surrounding Seas* (Howson & Picton, 1997) where authorities for species names can be found. *Pentapora fascialis* (Pallas) is considered (Hayward & Ryland 1999) to include *Pentapora foliacea*, the name used in the Species Directory.

1. *Swiftia pallida* 157
2. *Eunicella verrucosa* 159
3. *Anemonia viridis* 161
4. *Phellia gausapata* 163
5. *Chthamalus montagui* 165
6. *Chthamalus stellatus* 167
7. *Lithodes maia* 169
8. *Maja squinado* 171
9. *Gibbula umbilicalis* 173
10. *Osilinus lineatus* (=*Monodonta lineata*) 175
11. *Patella depressa* 178
12. *Tectura testudinalis* 180
13. *Pentapora fascialis* (=*Pentapora foliacea*) 182
14. *Paracentrotus lividus* 184
15. *Strongylocentrotus droebachiensis* 186
16. *Holothuria forskali* 188
17. *Cucumaria frondosa* 190
18. *Lithothamnion glaciale* 192
19. *Odonthalia dentata* 194
20. *Dictyopteris membranacea* 196
21. *Codium adhaerens* 198
22. *Bifurcaria bifurcata* 200
23. *Fucus distichus distichus* 202

1. ***Swiftia pallida***

Image: *Swiftia pallida* at Ardnoe Point.
Image width c. 25 cm.
Unknown / JNCC



Common name: Northern sea-fan

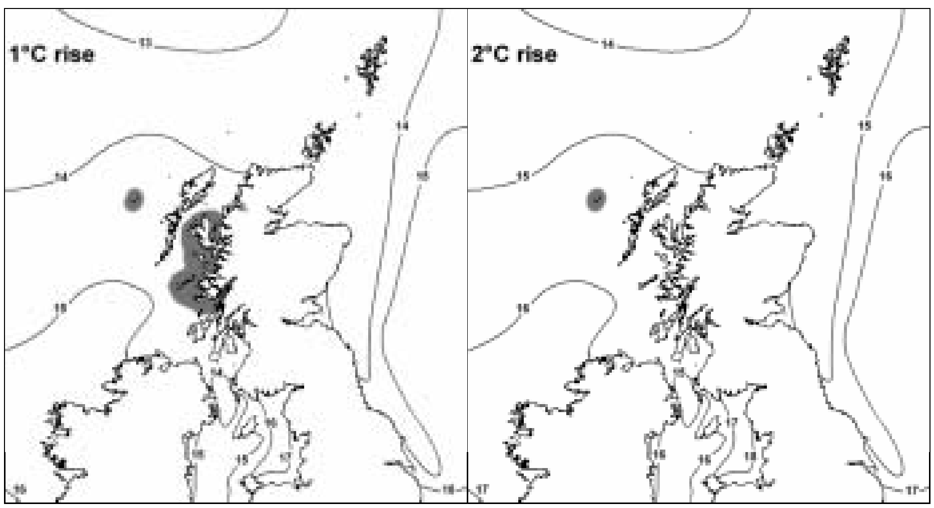
Current distribution: Only recorded in west Scotland and St Kilda in Great Britain.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:

Likely future distribution



Summary: *Swiftia pallida* will become less abundant and, with a 2ºC rise in summer seawater temperatures, will no longer occur on the mainland coast although there will be a lag period of 20+ years after temperatures reach 2ºC higher.

Climate change type: Type B, Northern stables

Expected change in distribution: Remain in areas where it is currently Frequent (Firth of Lorne to Skye on the mainland and St Kilda) (1ºC) or cease to be present in Scotland except for St Kilda (2ºC).

Explanation: *Swiftia pallida* is a cold water / deep water species with probably lecithotrophic short-lived larvae recruiting locally. Reproductive ‘triggers’ may be cold or warm temperatures and, if winter low temperature is important, decline in relation to rising temperatures may be slower than now predicted on the basis of summer temperatures. The fact that it occurs in quite high densities in some locations suggests that it is currently not at the limits of it's geographical range as affected by temperatures. Furthermore, the presence of a population of *Swiftia* only, apparently, in the Kenmare River in Ireland (Picton & Costello 1998) suggests that the species typically has a very localised distribution but is self-sustaining even in a part of the British Isles where summer (although possibly not winter) temperatures are typically warmer than in Scotland. The species is probably quite long lived (over 10 years) and existing colonies will persist even if temperature rise makes reproductive viability lower. Therefore, where quite high densities occur, the species would be expected to persist, although in declining density, for more than 20 years after a critically high temperature is reached.

Expected rate of change in distribution: Retreat in distribution is likely to be slow (unlikely to be revealed for 20 years + after a change in temperature).
Explanation: Sea fans usually grow slowly and once established are unlikely to be adversely affected by higher temperatures and so persist but not be replaced by new stock.

Expected change in abundance or population structure at locations where the species already occurs: Significant decrease in abundance expected.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: The apparent absence of *Swiftia* from Shetland suggests that geographical barriers have prevented colonization and therefore a self-sustaining population. Those geographical barriers will continue to prevent colonization in Shetland even in a situation of retreat.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: Biotope MCR.ErSSwi (Erect sponges and *Swiftia pallida* on slightly tide-swept moderately exposed circalittoral rock) remains the same but characterizing species change and the biotope might become closer to MCR.ErSEun (Erect sponges *Eunicella verrucosa* and *Pentapora foliacea* on slightly tide-swept moderately exposed circalittoral rock).

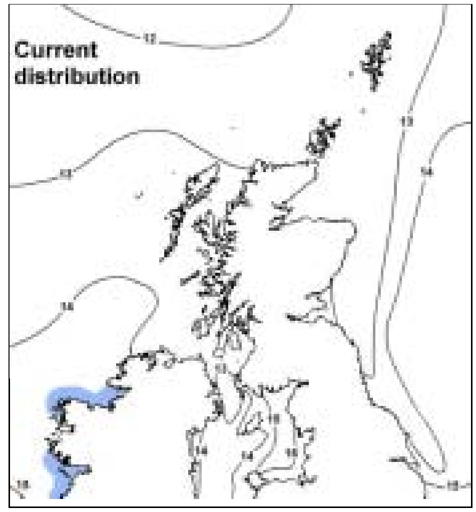
Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species. Care will need to be taken in separating *Eunicella verrucosa* (which is white and sparsely branching in Irish examples) from *Swiftia pallida*.

References:

Picton, B.E. & Costello, M.J. (1998). *The BioMar biotope viewer: a guide to marine habitats, fauna and flora in Britain and Ireland*. Dublin: Environmental Sciences Unit, Trinity College. (CD-ROM)

2. *Eunicella verrucosa*

Image: Colonies of pink and of white forms of *Eunicella verrucosa* at Lundy. Image width c. 50 cm. Keith Hiscock.



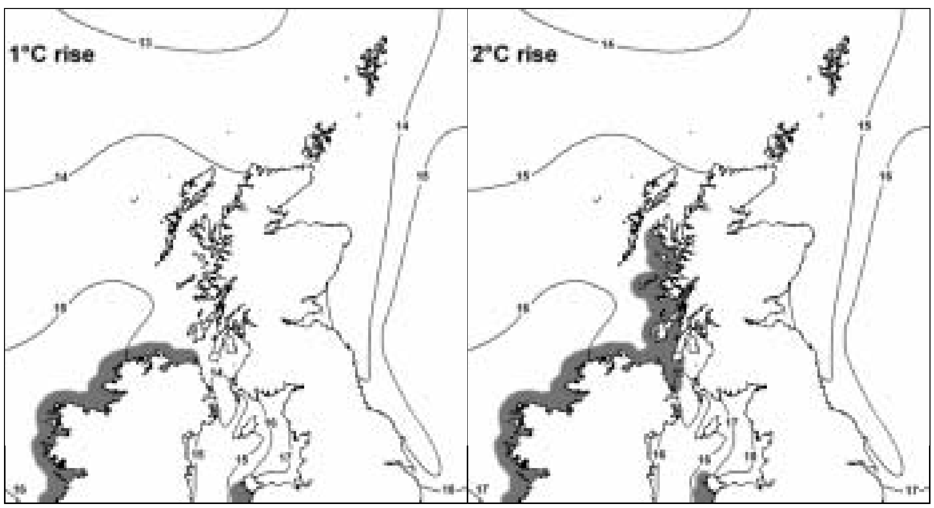
Common name: Pink sea fan

Current distribution: A southern species recorded as far north as NW Ireland and SW Wales.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:
Likely future distribution



Summary: *Eunicella verrucosa* will become more abundant where it currently exists and should spread slowly along the Northern Irish coast. **If** the species extends across the significant geographical barrier of the North Channel, it will spread only slowly and would not be expected to start to colonise areas indicated in Scotland for 30 years+ after a 2ºC rise in summer seawater temperatures.

Climate change type: Type E, Southern stables.

Expected change in distribution: Occurrence in Scotland not expected (1ºC) or extension to the mainland of western Scotland (2ºC).

Explanation: *Eunicella verrucosa* is a boreal-lusitanean species most likely with a short-lived lecithotrophic larva. However, it does colonise new surfaces such as wrecks remote from rocky areas and so has the ability to spread. The maximum northerly extent of distribution appears to correspond approximately to the 14ºC summer isotherm. Its distribution is therefore likely to extend northwards in the Irish Sea from its current recorded northern limit in north Pembrokeshire eventually reaching the Lleyn Peninsula and west Anglesey. However, the extensive sedimentary areas of the east basin of the Irish Sea may prove too much of a barrier even if many larvae are being produced. Recruitment from Northern Ireland is more likely than through the Irish Sea although large numbers of larvae will need to be produced and favourable currents occur so that the crossing is made successfully.

Expected rate of change in distribution: Expansion in distribution is likely to be very slow (unlikely to be revealed for 30 years + after a change in temperature).
Explanation: It is most likely that the larvae of *Eunicella verrucosa* are short lived and will be produced infrequently and in small numbers at the edge of range. Colonies are slow growing (c. 1 cm in branch length *per annum*) and it is unknown at what size they become reproductively viable but expected to be a few years after settlement. It might require several years in which large numbers of larvae are produced and a favourable current occurs for the establishment of a viable population in Scotland to build-up.

Expected change in abundance or population structure at locations where the species already occurs: Not present currently in Scotland.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: It might require several years in which large numbers of larvae are produced and a favourable current occurs for the establishment of a viable population in Scotland to build-up. Geographical barriers will continue to prevent colonisation in Shetland even in a situation of expansion.

Species that might be displaced by increased abundance of this species: None.

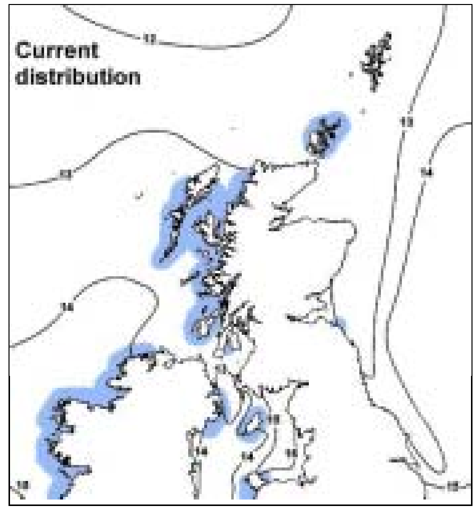
Effects on biotopes: Biotope MCR.ErSSwi (Erect sponges and *Swiftia pallida* on slightly tide-swept moderately exposed circalittoral rock) may 'evolve' into MCR.ErSEun (Erect sponges *Eunicella verrucosa* and *Pentapora foliacea* on slightly tide-swept moderately exposed circalittoral rock).

Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species. Care will need to be taken in separating *Eunicella verrucosa* (which is white and sparsely branching in Irish examples) from *Swiftia pallida*.

References:

3. *Anemonia viridis*

Image: The green form of *Anemonia viridis*. Rum Bay, Plymouth. Image width c. 10 cm. Keith Hiscock



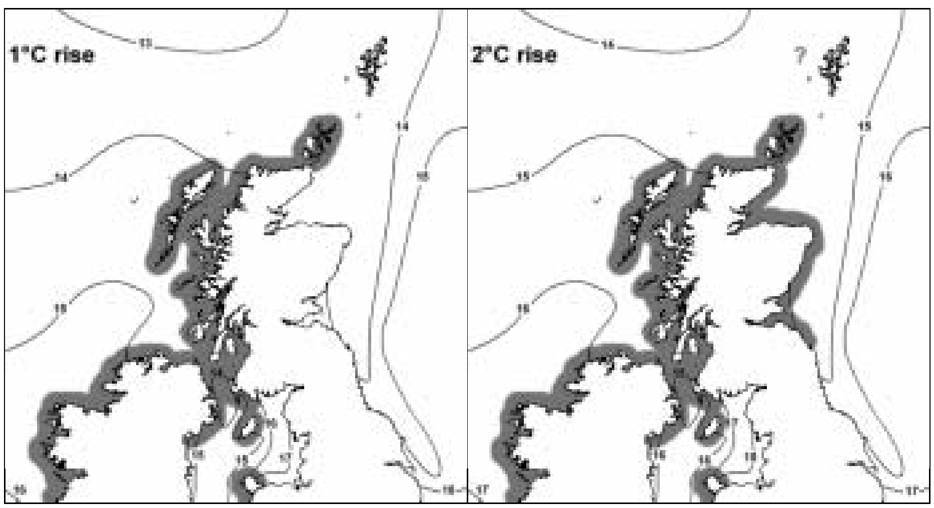
Common name: Snakelocks anemone

Current distribution: A southern species recorded as far north as Orkney. Absent from Shetland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:
Likely future distribution



Summary: Gradual extension and increase in abundance around the coast of mainland Scotland, the Hebrides and in Orkney but unlikely to extend to Shetland.

Climate change type: Type F, Southern gradual extenders.

Expected change in distribution: Spread north and east to about Duncansby Head (1ºC) or Berwick (2ºC).
Explanation: Distribution appears to be determined by temperature. Increase in air and seawater temperatures, including milder conditions in winter, will enable/allow spread

Expected rate of change in distribution: Sporadic but moderately rapid. Could extend 10 to 50 km in one year but only under favourable conditions. Overall extension likely to be slow with changes/new locations observed only several years after change in temperature.
Explanation: Planulae larvae are lecithotropic but most likely remain in the plankton for several days (J.Turner, pers. comm.) and could therefore increase extent by probably more

than 10 but less than 50 km in one year following successful breeding. Adults may also release from the seabed and allow themselves to be carried by currents but probably not a great distance. Populations that were apparently destroyed during the 1962-63 cold winter had “only recently become re-established” (Manual, 1981) indicating that recruitment from unaffected areas occurred quite slowly.

Expected change in abundance or population structure at locations where the species already occurs: Increase (through longitudinal fission and sexual reproduction but also because of reduction in the mortality that most likely occurs in cold winters at the limit of distribution).

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Local warming of rockpools in which the species is found may increase prospects for production of gametes and accelerate expansion of extent. Larvae may be swept offshore at locations such as Cape Wrath and may not ‘turn the corner’ to colonise the north and east coasts. The distance between Orkney and Shetland including Fair Isle might be too great for the fairly short-lived lecithotropic larvae to make the jump.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: *Anemonia viridis* is found in coralline rockpools (LR.Cor) although is only specifically noted as characterising in LR.Rkp.Cor.Par which has the sea urchin *Paracentrotus lividus* and is only identified from southwest Ireland. Nevertheless, *Anemonia* is likely to be an addition to coralline rockpool biotopes and to damp lower shore situations without adverse effects on other species there. Similarly, *Anemonia* is frequently found attached to seagrass *Zostera marina* (IMS.Zmar) where it is an addition to the diversity of this biotope.

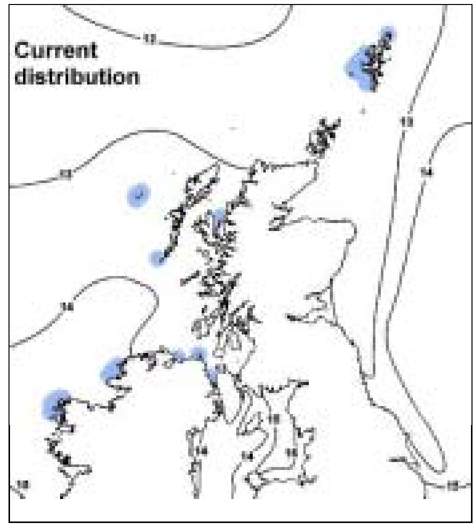
Suggested monitoring: Recording scheme by volunteers guided to locations. Part of a programme searching for a small range of easily identified species.

References:

Manual, R.L. (1981). *British Anthozoa.* London: Academic Press.

4. *Phellia gausapata*

Image: *Phellia gausapata* at Rockall. Image width c. 8 cm. David Connor / JNCC

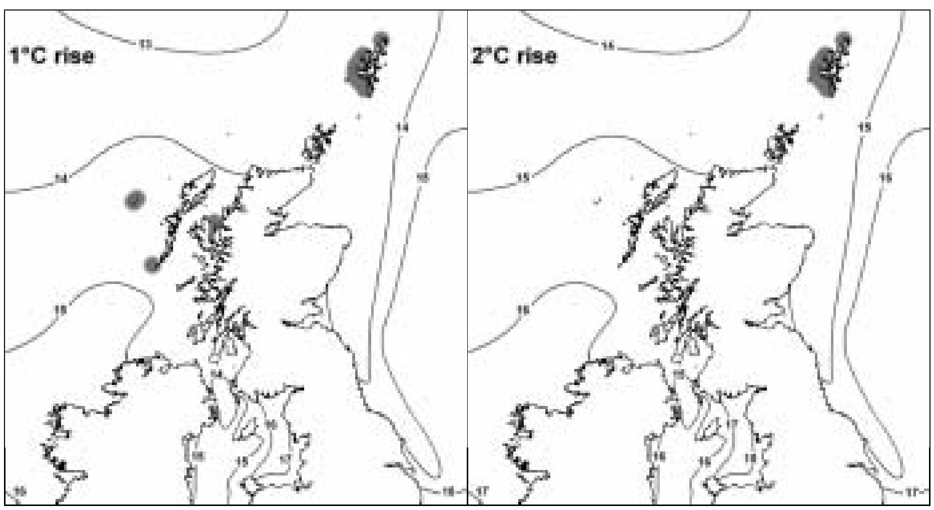


Common name:

Current distribution: A northern species recorded in west Scotland, Shetland and Northern Ireland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:
Likely future distribution

Summary: *Phellia gausapata* is likely to become less abundant and, with a 2ºC rise in summer seawater temperatures, will no longer occur on the mainland coast although there will be a lag period of many decades after temperatures reach 2ºC higher.

Climate change type: Type B, Northern stables

Expected change in distribution: Decline and eventual retreat. At 1ºC increase, may be lost from less wave exposed locations and, at 2ºC from mainland Scotland and Orkney but not for several decades after new temperatures are reached.
Explanation: *Phellia gausapata* is a cold water species that reproduces asexually by basal laceration (Manual, 1981). No information has been found on the triggers for asexual or likely sexual reproduction or for any lethal temperature limits. Once established, the anemones are likely to be more tolerant of change in maximum or minimum temperatures than are important for reproduction. Because of the predominantly asexual reproduction and the usually long-

lived nature of sea anemones, any adverse effects of increased temperature are therefore likely to be revealed only slowly. Where quite high densities occur, the species would be expected to persist, although in gradually declining density, for more than several decades after a critically high temperature adversely affecting reproduction is reached. It may also be that the southern jewel anemone *Corynactis viridis*, which lives in similar habitats, may out-compete for space with *Phellia gausapata* as temperature conditions favour more southern species.

Expected rate of change in distribution: Retreat in distribution is likely to be slow (unlikely to be revealed for 20 years + after a change in temperature).
Explanation: *Phellia gausapata* is most likely, as in other anemones, long-lived. Established populations may persist for some time and continue to reproduce asexually.

Expected change in abundance or population structure at locations where the species already occurs: Decline.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: None.

Species that might be displaced by increased abundance of this species: Not relevant.

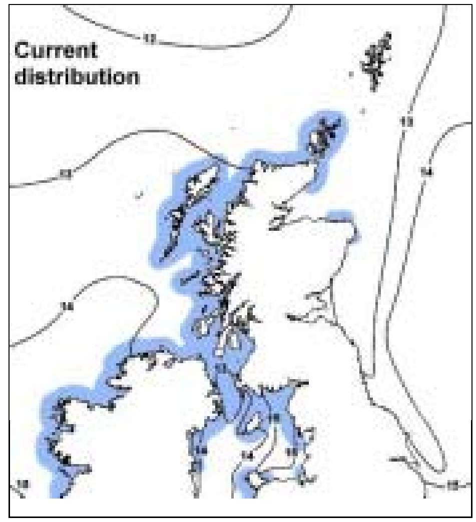
Effects on biotopes: *Phellia gausapata* is a characterising species in EIR.KfaR.AlaAnSC (*Alaria esculenta* forest with dense anemones and sponge crusts on extremely exposed infralittoral bedrock) which is recorded only at Rockall. Otherwise, it occurs especially in wave exposed biotopes on vertical or steeply sloping rock including those in EIR.SG (Robust faunal cushions and crusts). Other anemones, especially the widely distributed *Sagartia elegans*, may increase in abundance if *Phellia* declined and the jewel anemone *Corynactis viridis*, a southern species, take over space vacated by *Phellia.*

Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species.

References:
Manual, R.L. (1981). *British Anthozoa.* London: Academic Press.

5. *Chthamalus montagui*

Image: *Cthamalus montagui*. Image width c. 12 mm. Alan Southward.

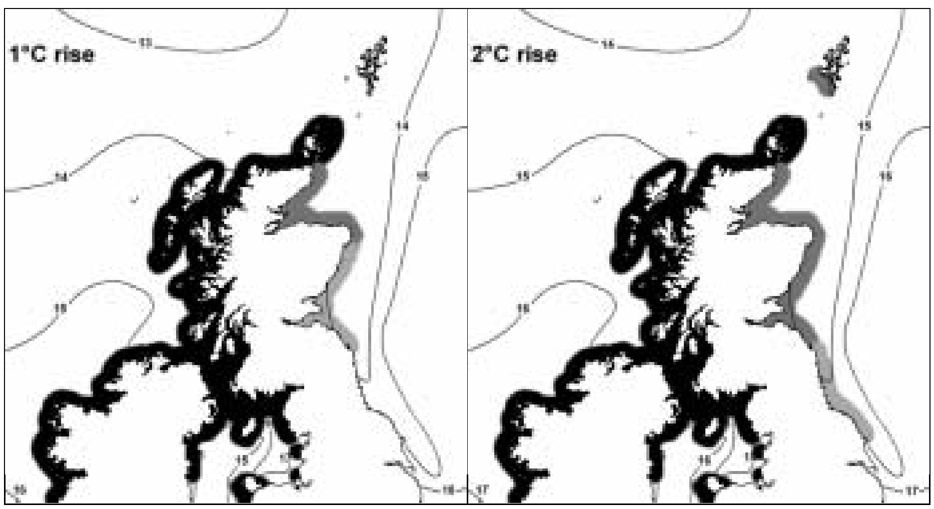


Common name: Montagu's punctate barnacle

Current distribution: A southern species recorded as far north as Orkney. Rare on the east coast of Scotland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:

- Annual recruitment
- Occasional recruitment
- Not breeding

Summary: Abundance and occurrence will increase within the current geographical range of the species. Distributional range will extend down the east coast. Expansion of range will closely follow increase in summer temperatures.

Climate change type: F to G, Southern extender**.**

Expected change in distribution: Increased occurrence and abundance along the northern and western coasts; extension of range down the eastern coast. Replacement of *Semibalanus balanoides* as the dominant barnacle in the upper mid eulittoral.
Explanation: Higher summer temperatures, both air and seawater, will result in more regular and prolonged release of planktonic larvae at existing locations. There may also be additional broods. The larvae remain in the plankton for several weeks so the potential to extend is high. However, development to a settling stage may not occur if the larvae are swept into too cold waters so extension is not measured by distance travelled.

Expected rate of change in distribution: Expansion of range will closely follow increase in summer temperatures.
Explanation: *Chthamalus montagui* larvae develop in response to temperature and are capable of distribution beyond limits on development imposed by cold temperatures so that temperature rather than dispersal ability will determine rate of extension.

Expected change in abundance or population structure at locations where the species already occurs: Expansion of dominance in the upper and mid eulittoral subzones will occur closely following increase in summer temperatures.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Spread to Shetland is strongly dependant on the direction of residual currents (which generally sweep eastwards past the north of Orkney). There may not be sufficient longevity of the planktonic stage to reach Shetland although Fair Isle may act as a 'staging post'.

Species that might be displaced by increased abundance of this species: *Semibalanus balanoides* is likely to be displaced in the upper and mid eulittoral at locations where the abundance of *Chthamalus montagui* increases.

Effects on biotopes: ELR.Bpat (Barnacles and *Patella* spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock) is characterised by *Semibalanus balanoides* in the north at present but *Chthamalus* spp. in the south-west. *Chthamalus montagui* will become more abundant and displace *Semibalanus balanoides* but the biotope will remain the same. Because *Chthamalus montagui* is better able to resist dessication than *Semibalanus balanoides*, the barnacle zone will extend further up the shore.

Suggested monitoring: Recording annually at selected stations by specialist marine biologists or trained volunteers.

References:
Crisp, D.J., Southward, A.J., & Southward, E.C. (1981). On the distribution of the intertidal barnacles, *Chthamalus stellatus*, *Chthamalus montagui* and *Euraphia depressa*. *Journal of the Marine Biological Association of the United Kingdom,* **61**, 359-380.

6. *Chthamalus stellatus*

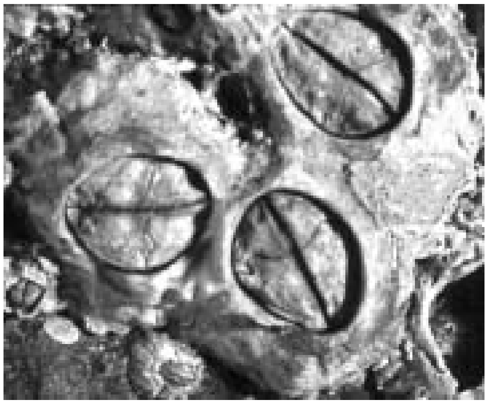
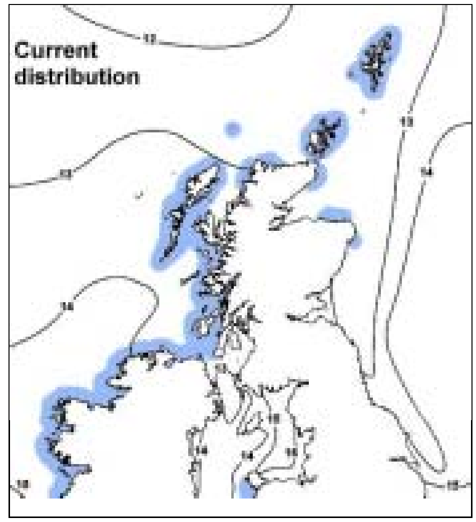


Image: *Cthamalus stellatus*. Image width c. 10 mm. Alan Southward.

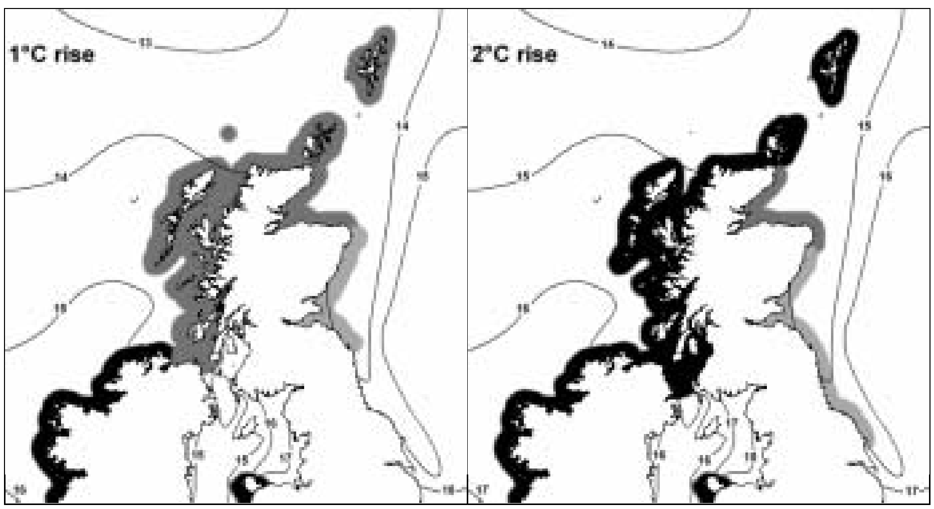


Common name: Poli's stellate barnacle

Current distribution: A southern species recorded as far north as Shetland, but rare on the east coast of Scotland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:
- Annual recruitment
- Occasional recruitment
- Not breeding

Summary: Abundance and occurrence will increase within the current geographical range of the species. Distributional range will extend down the east coast. Expansion of range will closely follow increase in summer temperatures.

Climate change type: F to G, Southern extender.

Expected change in distribution: Increased occurrence and abundance along the northern and western coasts; extension of range down the eastern coast. Replacement of *Semibalanus balanoides* as the dominant barnacle in the lower midlittoral especially on wave exposed shores.

Explanation: Higher summer temperatures, both air and seawater, will result in more regular and prolonged release of planktonic larvae at existing locations. There will also be additional broods (Burrows *et al*. 1992). The larvae remain in the plankton for several weeks so the potential to extend is high. However, development to a settling stage may not occur if the larvae are swept into too cold waters so extension is not measured by distance travelled.

Expected rate of change in distribution: Expansion of range will closely follow increase in summer temperatures.
Explanation: [AJS to check and change] *Chthamalus stellatus* larvae develop in response to temperature and are capable of distribution beyond limits on development imposed by cold temperatures so that temperature rather than dispersal ability will determine rate of extension. *Chthamalus stellatus* has greater dispersive powers than *Chthamalus montagui* (Burrows 1988; Pannacuilli *et al.* 1996) and range extension of breeding populations could occur faster than for *Chthamalus montagui*.

Expected change in abundance or population structure at locations where the species already occurs: Expansion of dominance in the mid eulittoral subzone will occur closely following increase in summer temperatures. The higher abundance will be most evident in wave-exposed sites.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Larval distribution may be over dispersed on eastern coasts and settlement inhibited by scarcity of exposed rocky shores.

Species that might be displaced by increased abundance of this species: *Semibalanus balanoides* is likely to be displaced in the lower half of the mid eulittoral at locations where the abundance of *Chthamalus stellatus* increases.

Effects on biotopes: ELR.Bpat (Barnacles and *Patella* spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock) is characterised by *Semibalanus balanoides* in the north at present but *Chthamalus* spp. in the south-west. *Chthamalus stellatus* will become more abundant and displace *Semibalanus balanoides* especially on exposed coasts but the biotope will remain the same.

Suggested monitoring: Recording annually at selected stations by specialist marine biologists. Photographic sampling and examination of images by professsional marine biologists.

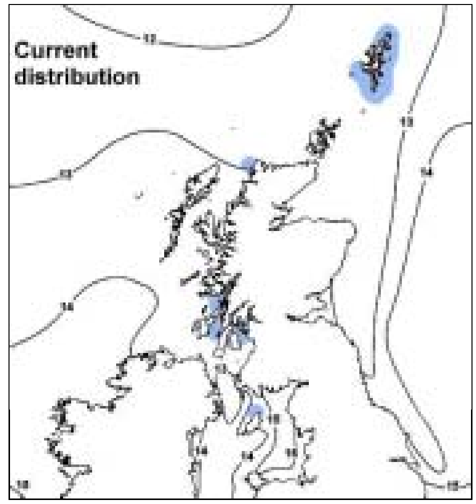
References:

Crisp, D.J., Southward, A.J., & Southward, E.C. (1981). On the distribution of the intertidal barnacles, *Chthamalus stellatus*, *Chthamalus montagui* and *Euraphia depressa*. *Journal of the Marine Biological Association of the United Kingdom,* **61**, 359-380.

Southward, A.J. (1976). On the taxonomic status and distribution of *Chthamalus stellatus* in the north-east Atlantic region. *Journal of the Marine Biological Association of the United Kingdom,* **56**, 1007-1028.

7. *Lithodes maia*

Image: *Lithodes maia.* Image width c. 40 cm. Sue Scott / JNCC

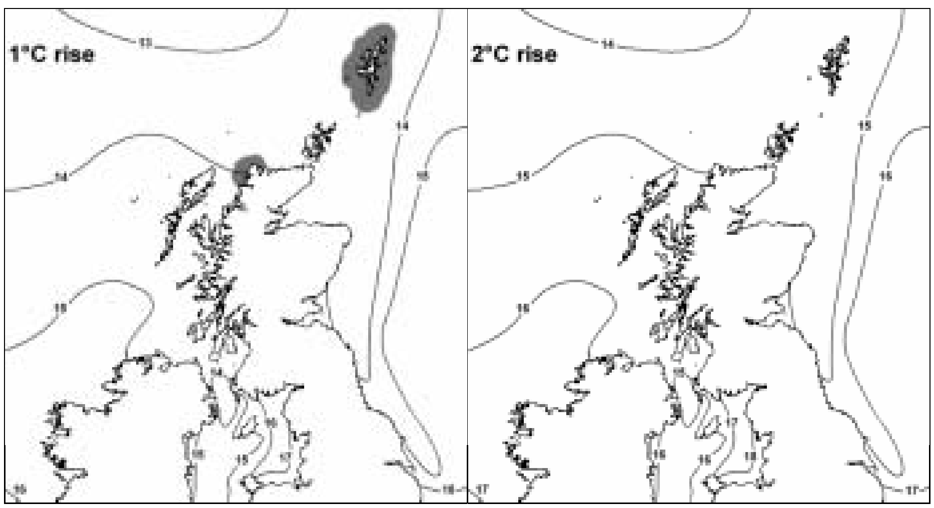


Common name: Northern stone crab

Current distribution: A northern species recorded in west Scotland and Shetland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:

Likely future distribution

Summary: Decline in abundance and loss after a few years from areas of temperature increase.

Climate change type: Type C, Northern retreaters

Expected change in distribution: Retreat northwards to about Cape Wrath (1ºC) or cease to be present in Scottish inshore waters (2ºC).

Explanation: *Lithodes maia* occurs in inshore areas most likely as an outlier of deeper water populations. The current recorded distribution seems to be restricted to areas where summer surface temperatures inshore do not rise above 14ºC including one record as far south as between the Isle of Man and the Mull of Galloway (Bruce, Colman & Jones, 1963). The surface water temperature appears of importance to larval development with development poor at 12ºC compared to 9ºC (Anger, 1996). Larvae spend about three months in surface waters (www.qc.dfo.ca/iml/en/ress/cr-epin – cited on 12 April 2000). Larval survival is therefore likely to be affected by warming sea surface temperatures.

Expected rate of change in distribution: Retreat in distribution slow. Possibly with a ten to 20 year lag after temperature reaches defined levels.
Explanation: Adults are likely to survive and remain in the same areas but will eventually die and not be replaced.

Expected change in abundance or population structure at locations where the species already occurs: Significant decrease in abundance expected.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: It is not known if the species has a lethal temperature for adults that is within the range of temperatures predicted.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: None detectable.

Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species. Care will need to be taken in ensuring that *Maja squinado* is not mistaken for *Lithodes maia* (photographic evidence of significant finds required).

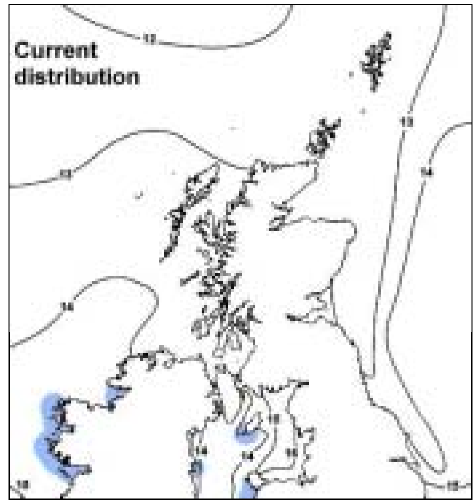
References:

Bruce, J.R., Colman, J.S. & Jones, N.S. (1963). *Marine Fauna of the Isle of Man*. Liverpool University Press.

Anger, K. (1996). Physiological and biochemical changes during lecithotrophic larval development and early juvenile growth in the northern stone crab, *Lithodes maja* (Decapoda: Anomura). *Marine Biology 126,* 283-296.

8. *Maja squinado*

Image: *Maja squinado* with carapace covered in barnacles. North Devon. Image width c. 30 cm. Keith Hiscock

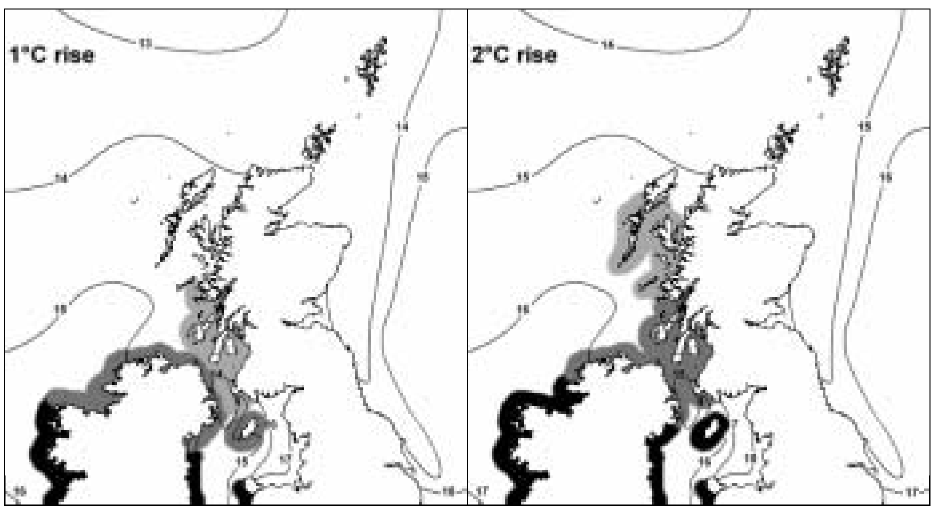


Common name: Thorn back spider crab

Current distribution: A southern species recorded as far north as the Isle of Man and NW Ireland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:
- Annual recruitment
- Occasional recruitment
- Not breeding

Summary: *Maja squinado* is likely to spread to Scottish waters and increase in abundance and distribution although only on the west coast with increase in summer temperatures
.

Climate change type: Southern rapid extenders.

Expected change in distribution: Spread northwards on the west coast to about Mull (1ºC) or Skye and to the outer Hebrides (2ºC).

Explanation: *Maja squinado* has a planktonic larva that most likely lives for several weeks thus providing the 'opportunity' to make the journey from Northern Ireland to Scotland. However, larvae are present in the plankton only during September and October in the northern Irish Sea (Williamson, 1956) compared to July to September in the Plymouth area (Lebour, 1926) suggesting that prospects for production of larvae are best in warmer waters. Larval survival and progression through all stages to settlement is most likely within the period of the primary productive season if temperatures are sufficiently high (Lindley, 1998).

Expected rate of change in distribution: Small numbers should start to appear in south-west Scotland a few years after summer temperatures have regularly reached higher levels. However, recruitment will be from distant breeding stocks with only a slight (1ºC) rise in temperature. Once temperatures reach 2ºC higher than at present, more frequent recruitment can be expected from distant breeding stocks and Scottish stocks may begin to breed at which point numbers are likely to increase and spread rapidly and in accordance with rising seawater temperatures.
Explanation: Spread to Scotland will be dependant on suitable currents carrying larvae to Scotland. Suitable conditions may occur only every few years but the crabs live for several years and so do not require regular recruitment to establish a population. Suitable habitats for settlement are widespread in Scotland. However, breeding from Scottish stocks is only likely after temperatures reach a suitable level, probably at the 2ºC increase.

Expected change in abundance or population structure at locations where the species already occurs: Not relevant to Scotland.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Spread to Scotland is dependant of water currents carrying larvae to suitable habitats.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: *Maja squinado* does not characterise any particular biotopes and is widely distributed usually in small numbers in shallow rock and sediment biotopes. Occurrence in Scotland will not alter occurrence of any biotopes.

Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species. Care will need to be taken in ensuring that *Lithodes maia* is not mistaken for *Maja squinado*.

References:

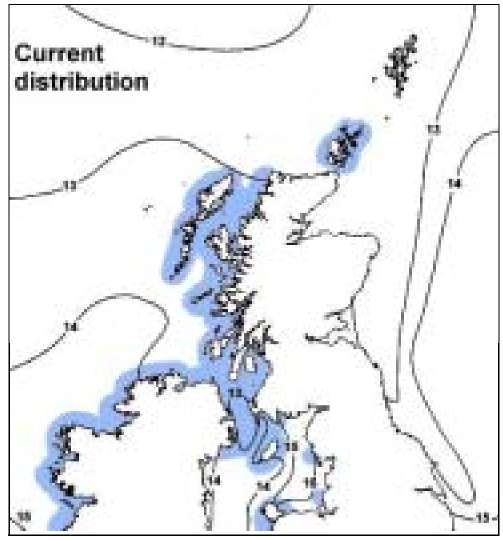
Lebour, M.V. (1926). Studies of the Plymouth Brachyura. I. The rearing of crabs in captivity with a description of the larval stages of *Inachus dorsettensis*, *Macropodia longirostris* and *Maia squinado*. *Journal of the Marine Biological Association of the United Kingdom*, **14**, 795-821.

Lindley, J.A. (1998). Diversity, biomass and production of decapod crustacean larvae in a changing environment. *Invertebrate Reproduction and Development,* **33**, 209-219.

Williamson, D.I. (1956). The plankton of the Irish Sea. *Bulletin of Marine Ecology*, **3**, 87-114.

9. *Gibbula umbilicalis*

Image: *Gibbula umbilicalis* top and underside view showing smooth round aperture. Whitsand Bay, South Cornwall. Image width c. 4 cm. Keith Hiscock.

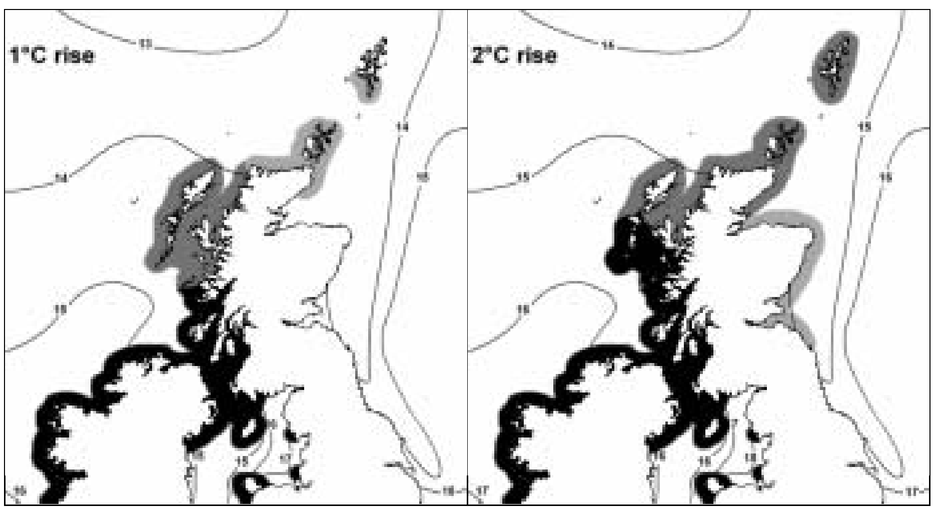


Common name: Flat top shell

Current distribution: A southern species recorded as far north as Orkney. Rarely recorded on the east coast of Scotland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:
- Annual recruitment
- Occasional recruitment
- Not breeding

Summary: *Gibbula umbilicalis* will extend its distribution to the north and east coasts of Scotland and will increase in its abundance in suitable habitats where it already occurs. It is unlikely to spread to Shetland because of the distance between Orkney and Shetland and the improbability that Fair Isle would be a 'staging post'.

Climate change type: Type G, Southern rapid extenders.

Expected change in distribution: Abundance and occurrence will increase within the current geographical range of the species. Distributional range will extend down the east coast. However, the species might not spread to Shetland.
Explanation: There are suitable habitats present along the eats coast of Scotland and so spread is expected. However, prosobranch veligers may not extend far offshore (Fretter & Shale 1973 found very low numbers only 6 km offshore of Plymouth compared with inshore).

Colonisation of Shetland would only occur if suitably strong currents in the right direction occurred at the right time to colonise. Fair Isle is not considered as a ‘staging post’ as suitable (sufficiently sheltered) habitats are too few to support populations that would produce large numbers of larvae.

Expected rate of change in distribution: Expansion of range will closely follow increase in summer temperatures.
Explanation: There are extensive suitable habitats on in eastern Scotland. Larvae are long lived and so will recruit inshore and the population will build.

Expected change in abundance or population structure at locations where the species already occurs: Abundance will increase and the structure of the population will become more even between year classes.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Geographical barriers – areas of open sea may restrict extension of range.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: *Gibbula umbilicalis* is a characterising species of the MLR.BF (Barnacles and fucoids on moderately exposed shores) biotopes and of MLR.R.Osm (*Osmundea* (*Laurencia*) *pinnatifida* and *Gelidium pusillum* on moderately exposed mid eulittoral rock). However, it is widely distributed (but not characterising) in other biotopes together with other prosobranchs. Whilst it might compete for food resources with other grazing molluscs, it is not expected that any biotopes would be changed in type by its occurrence.

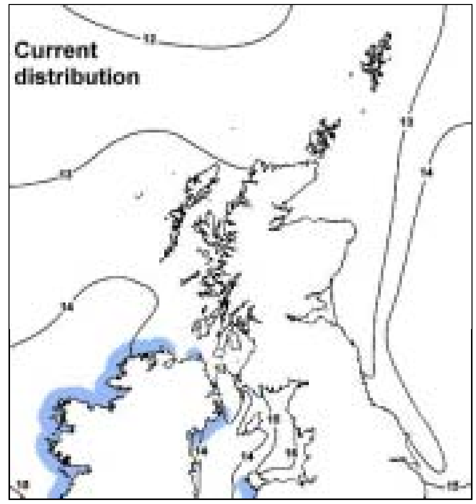
Suggested monitoring: Recording scheme by specialist marine biologists or trained volunteers guided to locations. Sites on the north and east coast of Scotland should be especially targeted for presence. Abundance should be monitored in Orkney. Part of a programme of searching for a small range of easily identified species by volunteers. However, samples will be required to confirm identification.

References:

Fretter, V. & Shale, D. (1973). Seasonal changes in population density and vertical distribution of prosobranch veligers in offshore plankton at Plymouth. *Journal of the Marine Biological Association of the United Kingdom*, **53**, 471-492.

10. *Osilinus lineatus* (=*Monodonta lineata*)

Image: *Osilinus lineatus* top view and underside showing 'tooth'. South Devon. Image width c. 2 cm (left); 1.2cm (right). Keith Hiscock

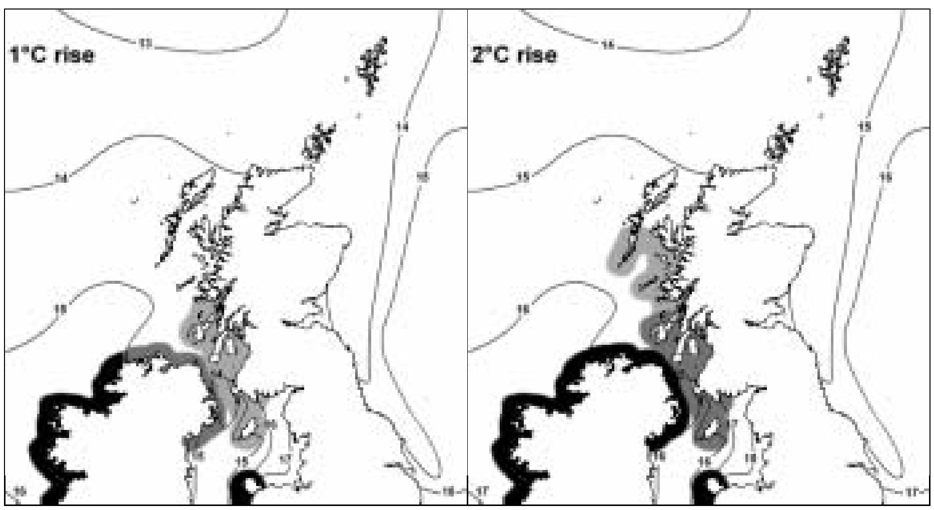


Common name: Toothed topshell

Current distribution: A southern species recorded as far north as Anglesey and Northern Ireland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:
- Annual recruitment
- Occasional recruitment
- Not breeding

Summary: Larvae may not reach south-west Scotland and may not extend to offshore islands. There may be occurences in south-west Scotland following a rise in air and sea temperatures of 1ºC. Those occurences are likely to be none-breeding and sparse. Increased production of larvae from sources outside of Scotland and the capability of Scottish populations to breed after temperatures have risen by about 2ºC, should enable the species to expand its distribution and abundance sporadically according to incidence of favourable conditions for breeding and distribution, eventually extending to much of the west coast and possibly The Hebrides.

Climate change type: Type F, Southern gradual extenders.

Expected change in distribution: May not reach Scotland or offshore islands in Scotland. If it reaches Scotland, spread northwards on the west coast to about Mull (1ºC) or Skye (2ºC).
Explanation: Prosobranch veligers may not extend far offshore (Fretter & Shale 1973 found

very low numbers only 6 km offshore of Plymouth compared with inshore). Hawkins & Hiscock (1983) found few *Osilinus* on Lundy, 11 km from the nearest mainland, and suggested poor larval dispersal and that Lundy-produced larvae would be swept away and not colonise the island. It may take a significant period of suitably strong currents in the right direction at the right time to colonise the Scottish coast. The suggested change in distribution assumes that air and seawater temperature is important for breeding and the survival of larvae. However, Kendall, Williamson & Garwood (1987) dispute that particularly warm conditions are required for *Monodonta lineata* to develop its gonads or to spawn. Near the northern limits of distribution in west Wales, they found that cold winters may adversely affect survival of settled individuals. It seems likely that a variety of factors including distance from existing populations (geographical barriers), seawater temperature and air temperature are important in determining current absence from Scotland. Also, populations might need to build and the species does not appear to be very long-lived (two and a half years in Brittany according to Daguzan 1991). Once established in Scotland, there are widespread suitable habitats and the species should extend in accordance with change in temperature represented by summer seawater.

Expected rate of change in distribution: Fairly rapid once a breeding population is established on the south-west Scottish coast.
Explanation: Once established and breeding is successful, there are extensive suitable habitats on the south-west and west coast of Scotland. Larvae will recruit inshore and the population will build.

Expected change in abundance or population structure at locations where the species already occurs: Increase (following colonisation). Irregular size structure, missing year classes and a bias towards older animals is predicted by Lewis *et al*. (1982) in edge-of-range populations.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Geographical boundaries to larval distribution (see above).

Species that might be displaced by increased abundance of this species: Additional grazing of fucoid algae and therefore reduction in abundance may occur.

Effects on biotopes: No mention has been found of *Osilinus* in the biotopes classification although it can be the dominant species on some sheltered very bare upper shore rocks especially where shallow pools occur. It may be that additional grazing by *Osilinus* will reduce abundance of fucoids in SLR.F.Fspi (*Fucus spiralis* on moderately exposed to very sheltered upper eulittoral rock) and in SLR.F.Fves (*Fucus vesiculosus* on sheltered mid eulittoral rock).

Suggested monitoring: Recording scheme by specialist marine biologists or trained volunteers guided to locations. Sites on the Mull of Kintyre and Islay may be particularly targetted. Part of a programme of searching for a small range of easily identified species by volunteers. However, samples will be required to confirm identification.

References:

Daguzan, J. (1991). Research on growth and ecology of *Monodonta lineata* (daCosta) (Gastropoda, Prosobranchia, Trochidae) living on the Atlantic coast of Brittany. *Cahiers de Biologie Marine*, **32**, 3-22.

Fretter, V. & Shale, D. (1973). Seasonal changes in population density and vertical distribution of prosobranch veligers in offshore plankton at Plymouth. *Journal of the Marine Biological Association of the United Kingdom*, **53**, 471-492.

Hawkins, S.J. & Hiscock, K. (1983). Anomalies in the abundance of common eulittoral gastropods with planktonic larvae on Lundy Island, Bristol Channel. *Journal of Molluscan Studies,* **49**, 86-88.

Kendall, M.A., Williamson, P. & Garwood, P.R. (1987). Annual variation in recruitment and population structure of *Monodonta lineata* and *Gibbula umbilicalis* populations at Aberaeron, mid-Wales. *Estuarine & Coastal Marine Science*, **24**, 499-511.

Lewis, J., Bowman, R.S., Kendall, M.A. & Williamson, P. (1982). Some geographical components in population dynamics: possibilities and realities in some littoral species. *Netherlands Journal of Sea Research*, **16**, 18-28.

Turk, S.M., & Seaward, D.R. (1997). The marine fauna of the Isles of Scilly - Mollusca. *Journal of Natural History,* **31**, 555-633.

11. *Patella depressa*

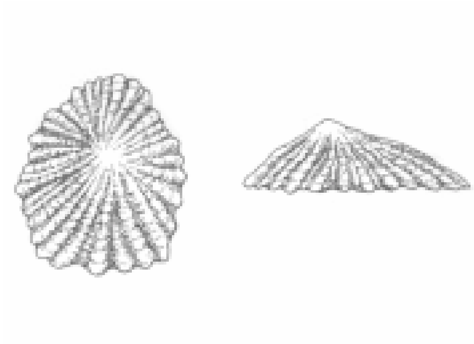
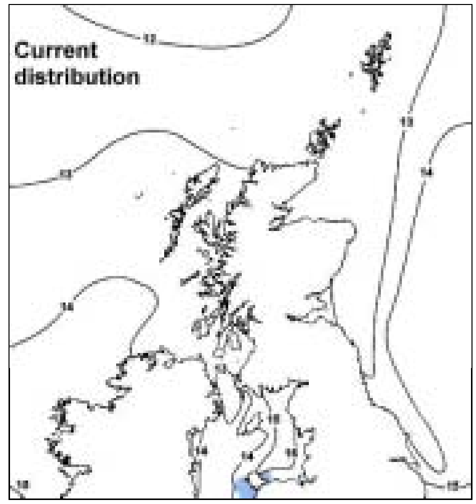


Image: *Patella depressa* line drawing. Shell length c. 2 cm. From: Hawkins & Jones (1992)



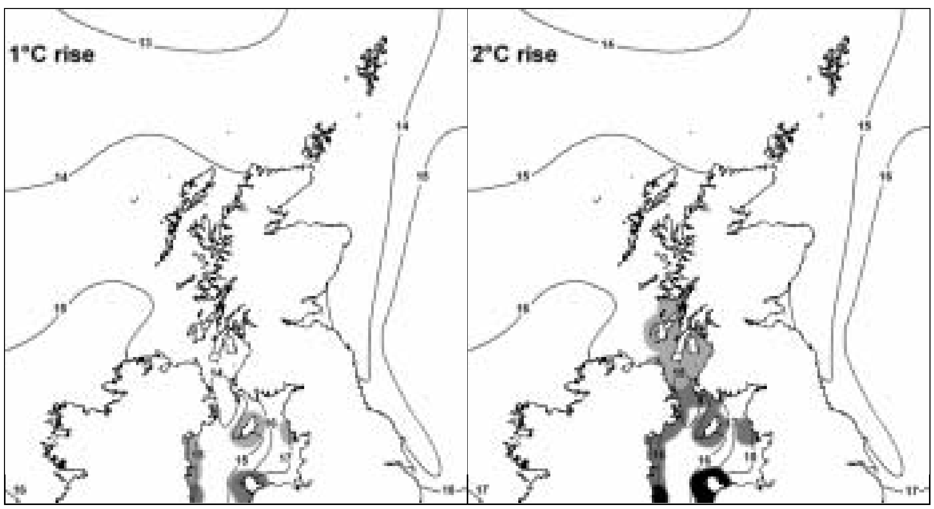
Common name: Black-footed limpet

Current distribution: A southern species which reaches its northern limits on Anglesey.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:
- Annual recruitment
- Occasional recruitment
- Not breeding



Summary: May not extend to Scotland even following significant warming. Spread is likely to be slow and unlikely to be beyond south-west Scotland if it occurs.

Climate change type: Type F, Southern gradual extenders.
Expected change in distribution: May not spread to Scotland. Would probably not reach Scotland following a 1ºC rise but may spread as far as Islay and Jura and into the Firth of Lorn on a 2ºC rise.
Explanation: *Patella depressa* failed to establish in Ireland after the last ice age whilst spreading along the English and Welsh coasts as far as Anglesey in the north and the Isle of Wight in the east. Neither has it colonised the Isle of Man although transplant experiments have shown that it can survive and reach maturity there (S.J. Hawkins, unpublished). Powers of dispersal may therefore prevent spread to Scotland across significant geographical barriers. If the sea barriers are crossed, it should thrive on the Irish coast and the Isle of Man and eventually in Scotland.

Expected change in abundance or population structure at locations where the species already occurs: Occasionally recruiting or non-recruiting populations will recruit annually. Irregular size structure, missing year classes and a bias towards older animals is predicted by Lewis *et al*. (1982) in edge-of-range populations. (Such changes would occur outside of Scotland, on Anglesey and the Lleyn Peninsula.)

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: *Patella depressa* does not seem to disperse as well as *Patella vulgata* and *Patella ulyssiponensis*. For instance, it is not common on Lundy (Hawkins & Hiscock 1983), nor in the Isles of Scilly (Crisp & Southward 1958). It has failed to reach Ireland. Should it do so, Ireland would be the most likely path to Scotland although an alternative route exists via the Isle of Man or Cumbria where suitable habitats are further apart.

Species that might be displaced by increased abundance of this species: The balance between numbers of *Patella depressa* and *Patella vulgata* changes with climate change (Southward *et al*. 1995). Increases in *Patella depressa* would result in decreases in *Patella vulgata.*

Effects on biotopes: Fucoid-barnacle biotopes may become less dominated by fucoids. In areas where *Patella depressa* increases, there is less likelihood of '*Fucus* escapes' and the dynamic patchiness typical of the middle of moderately exposed shores. This will be because *Patella depressa* does not aggregate under clumps of *Fucus* in the same way as *Patella vulgata* (Roberts, Hawkins & Thompson, unpublished observations). Grazing pressure should also be more stable with the two species recruiting at different times of the year.

Suggested monitoring: Stratified random sampling of the proportion of *Patella depressa* to *Patella vulgata* on seaward-facing, well-drained midshore rock on moderately exposed shores at key locations. Timed searches at edge of range locations recording abundance using appropriate scales. Key locations are Northern Ireland, Isle of Man, Cumbria, Galloway, Islay.

References:

Crisp, D.J. & Southward, A.J. (1958). The distribution of intertidal organisms along the coasts of the English Channel. *Journal of the Marine Biological Association of the United Kingdom*, **37**, 157-208.

Hawkins, S.J. & Hiscock, K. (1983). Anomalies in the abundance of common eulittoral gastropods with planktonic larvae on Lundy Island, Bristol Channel. *Journal of Molluscan Studies,* **49**, 86-88.

Hawkins, S.J. & Jones, H.D. (1992). *Marine Field course guide. 1, Rocky shores*. London, IMMEL Publishing.

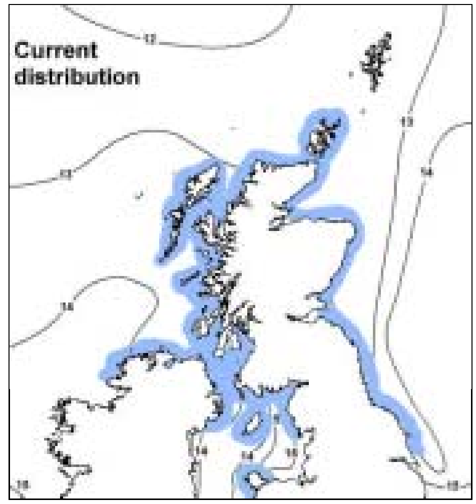
Lewis, J., Bowman, R.S., Kendall, M.A. & Williamson, P. (1982). Some geographical components in population dynamics: possibilities and realities in some littoral species. *Netherlands Journal of Sea Research*, **16**, 18-28.

Southward, A.J., Hawkins, S.J. & Burrows, M.T. (1995). 70 years observations of change in distribution and abundance of zooplankton and intertidal organisms in the western English-Channel in relation to rise in sea temperature. *Journal of Thermal Biology*, **20**, 127-155.

Southward, A.J. & Crisp, D.J. (1954). The distribution of certain intertidal animals around the Irish coast. *Proceedings of the Royal Irish Academy*, **57(B),** 1-29.

12. *Tectura testudinalis*

Image: *Tectura testudinalis* on lower shore rocks at Millport. Image width c. 3 cm. Keith Hiscock.

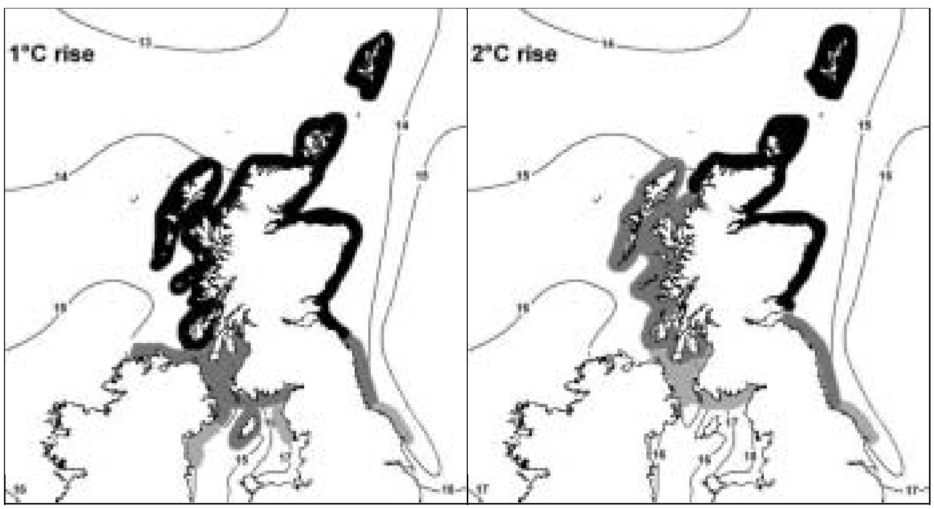


Common name: Tortoiseshell limpet

Current distribution:

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:
- Annual breeding
- Occasional breeding
- Not breeding

Summary: *Tectura testudinalis* (=*Tectura tessulata*) is a circumpolar species currently reaching its southern limit in the north of England and Ireland but expected to retreat northwards in parallel with increases in temperature.

Climate change type: Type C, Northern retreaters.

Expected change in distribution: Decline or disappearance from Northern Ireland, the Isle of Man, Cumbria and only occasionally recruiting populations being found in southern Scotland. (In recent years, *Tectura testudinalis* has become much rarer in Northern Ireland (J. Nunn, pers.comm.) and in the Isle of Man (S. Hawkins, own observations).

Expected rate of change in distribution: Evidence from the Isle of Man a nd Northern Ireland suggests that retreat could be rapid – in line with changes in temperature.

Expected change in abundance or population structure at locations where the species

already occurs: Infrequent recruitment will lead to less dense populations dominated by fewer older individuals. Such a change has already occurred in Northern Ireland at least.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Since residual current flows are against the direction that recruitment would occur from larvae of distant populations, the truncation of distribution may occur rapidly. Although little is known about the distributional abilities of larvae of *Tectura testudinalis*, they are likely to be limited as in other archaeogastropods.

Species that might be displaced by increased abundance of this species: Not relevant. (Decreased abundance might allow more algal growth on the lower shore although it is most likely that other limpets will increase abundance. *Tectura virginea* may increase in abundance but occurs in slightly different habitats – deeper especially on stones and shells).

Effects on biotopes: *Tectura testudinalis* is not named as a characterising species in any infralittoral biotopes. Acmaeid limpets have been shown to be strongly associated with crustose corallines (on north American coasts, they are associated especially with *Clathromorphum circumscriptum*: Sterech, 1992). Reduction in grazing from *Tectura testudinalis* may lead to crustose corallines being overgrown. However, since garzing is undertaken by several limpet and chiton species it is more likely that there will be not change in the presence of biotopes at locations.

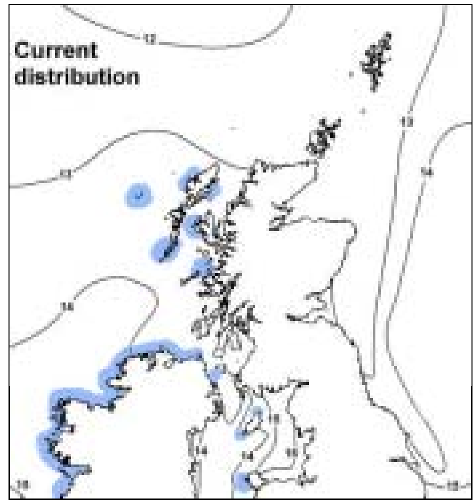
Suggested monitoring: Timed searches by specialist marine biologists or trained volunteers / quadrat counts at suitable locations. Part of a programme of searching for a small range of easily identified species by volunteers. However, samples will be required to confirm identification.

References:

Stenech, R.S. (1992). Plant-herbivore co-evolution: the fossil record. In *Plant-animal interactions in the marine benthos* (eds. D.M. John, S.J. Hawkins & J.H. Price). Oxford University Press, Oxford. (Systematics Association Special Volume No. 46).

13. *Pentapora fascialis* (=*Pentapora foliacea*[*])

Image: A small colony of *Pentapora fascialis*. Lundy. Image width c. 20 cm. Keith Hiscock.



Common name: Ross

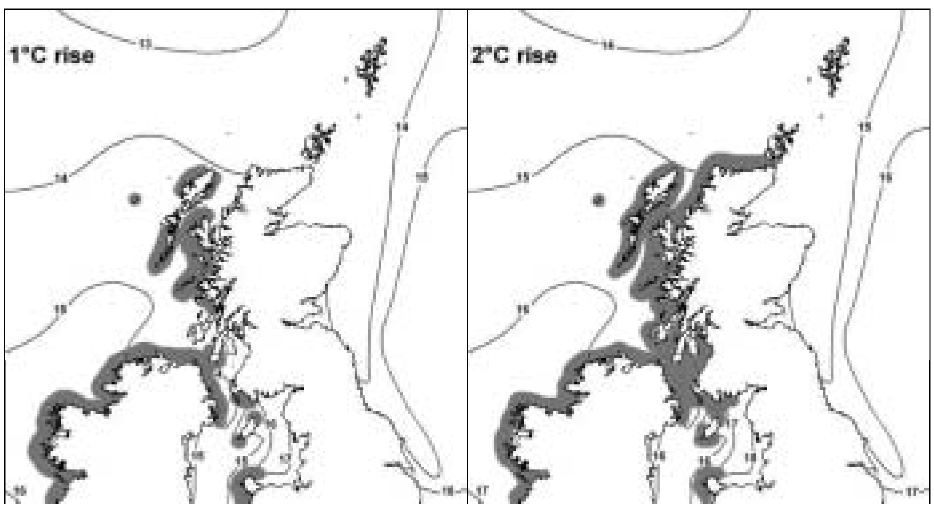
Current distribution: Widely distributed in south-west Britain and western Ireland with sporadic records from the west coast of Scotland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:

Likely future distribution



Summary: Likely to increase in abundance and extent at current locations to become more widely distributed in those locations and, following a 2ºC rise in temperature, may become generally distributed on the west coast of Scotland.

Climate change type: Type E, southern stables.

Expected change in distribution: Likely to become more widespread in the areas where it currently occurs following a 1ºC rise in seawater temperature and present in suitable habitats all along the west coast of Scotland following a 2ºC rise in temperature.

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[*] A recent classification (Hayward and Ryland, 1999) includes *Pentapora foliacea* within *Pentapora fascialis* in the family Bitectiporidae.

Explanation: Reproduction is most likely temperature dependant and so larvae will be produced more frequently and/or in larger numbers. However, the larvae are lecithotropic and so are unlikely to spend a long time in the plankton to spread to distant locations.

Expected rate of change in distribution: Change will occur slowly and it is likely to be several decades at least even following a significant (2ºC) rise in temperature before the species might be considered widely distributed on the west coast of Scotland.
Explanation: The larvae are lecithotropic and so are unlikely to spend a long time in the plankton to spread to distant locations. However, it does colonise new surfaces such as wrecks remote from rocky areas and so has the ability to spread.

Expected change in abundance or population structure at locations where the species already occurs: Increase.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: *Pentapora fascialis* appears, in its present distribution, to favour open coast areas in Scotland. It is likely that there will be some incursion to tidal sounds but not into enclosed sea lochs where habitats are unsuitable for a passive suspension feeder because of lack of water movement.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: *Pentapora fascialis* is a characteristic species in several circalittoral biotopes although is named only in the title of MCR.ErSEun (Erect sponges, *Eunicella verrucosa* and *Pentapora foliacea* on slightly tide-swept moderately exposed circalittoral rock). This is the biotope which it is suggested might develop in Scotland following significant seawater temperature rise.

Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species.

References:

Hayward, P.J. & Ryland, J.S., (1999). *Cheilostomatous Bryozoa. Part II Hippothooidea - Celleporoidea.* Synopses of the British Fauna (New Series), (ed. D.M. Kermack & R.S.K. Barnes), The Linnean Society of London. London: Academic Press. [Synopses of the British Fauna, no. 14. 2nd edition.]

14. *Paracentrotus lividus*

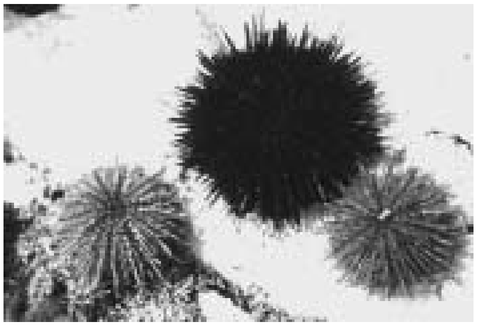
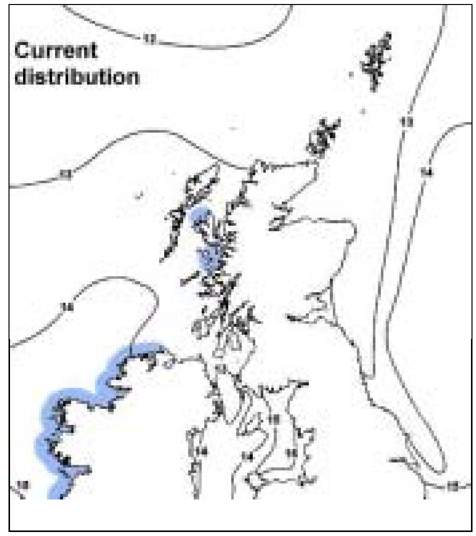


Image: *Paracentrotus lividus* (centre) sharing a tidepool in Duntulm Bay, northern Skye with two *Psammechinus miliaris*. September 1971. Image width c. 12 cm. Alan Southward.

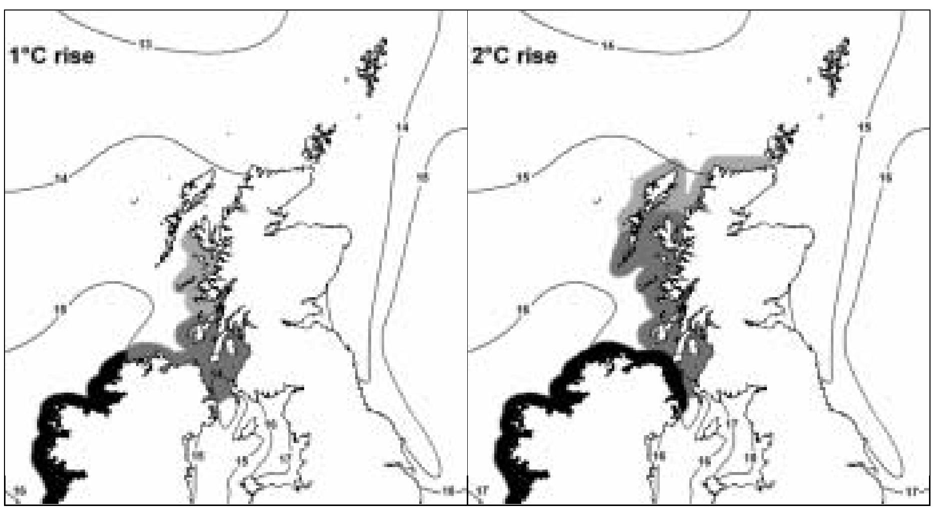


Common name: Purple sea urchin

Current distribution: A southern species recorded as far north as Skye. Rarely recorded in west Scotland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:
- Annual recruitment
- Occasional recruitment
- Not breeding

Climate change type: Type F, Southern gradual extender.

Expected change in distribution: Occurring more widely in areas where it is currently found but is very localised. Extension of range to(wards) the north coast of Scotland.
Explanation: Production of larvae occurs in spring and early summer in both the Mediterranean (Lopez *et al.* 1998) and Brittany (Spirlet, Grosjean & Jangoux 1998). The latter authors report that the rate of gametogenesis and the end of the spawning period is influenced by temperature whilst the first spawning event appears to be triggered by daylength. Therefore, a rise in temperature should favour reproduction further north than at present.

Expected rate of change in distribution: Sporadic but moderately rapid. Overall extension likely to be slow with changes/new locations observed only several years after change in temperature.

Explanation: Very large numbers of long-lived larvae are produced of which a significant number (12.7% in the study by Lopez *et al.* 1998) may survive to settlement. However, it may take a combination of a year when larval production is good and currents are favourable in speed and direction for larvae to be taken to western Scotland from Ireland. Suitable new habitats may not be available on most of the west coast of Scotland. *Paracentrotus* occurs in greatest numbers on limestone rock although may also be attracted by thick coralline crusts.

Expected change in abundance or population structure at locations where the species already occurs: Likely to be more frequent at suitable sites from Islay, through the inner islands, to Skye.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: *Paracentrotus lividus* has complex habitat requirements including clean rocky shore pools with wave action or clean sub-littoral shell gravel with less wave action. The species occurs in the intertidal in rockpools on calcareous (soft) substrata and may be particularly extensive where there are large numbers of such pools. However, encrusting coralline algae provide such substrata and rock type does not necessarily need to be limestone or chalk.

Species that might be displaced by increased abundance of this species: *Paracentrotus lividus* grazes on algae and may create rockpools dominated by robust encrusting calcareous algae with erect foliose species no longer present or present in abundance.

Effects on biotopes: The biotope LR.Rkp.Cor (*Corallina officinalis* and coralline crusts in shallow eulittoral rockpools) will become LR.Rkp.Cor.Par (Coralline crusts and *Paracentrotus lividus* in shallow eulittoral rockpools) where *Paracentrotus* colonises. However, other species are characteristic of LR.Rkp.Cor.Par including species of *Codium* and *Cladophora* especially and a ‘switch’ from the biotope to sub-biotope may not be complete. Where *Paracentrotus* colonises shallow sublittoral areas in enclosed water bodies, the likely change in biotope is unclear but a one similar to that present in very shallow water in Lough Hyne in south-west Ireland (Kitching, 1987) (and probably close to LR.Rkp.Cor.Par) may develop in some Scottish sealochs.

Suggested monitoring: Recording scheme by specialist marine biologists or trained volunteers guided to locations. Sites on Skye may be particularly targetted. Part of a programme of searching for a small range of easily identified species by volunteers. However, samples will be required to confirm identification.

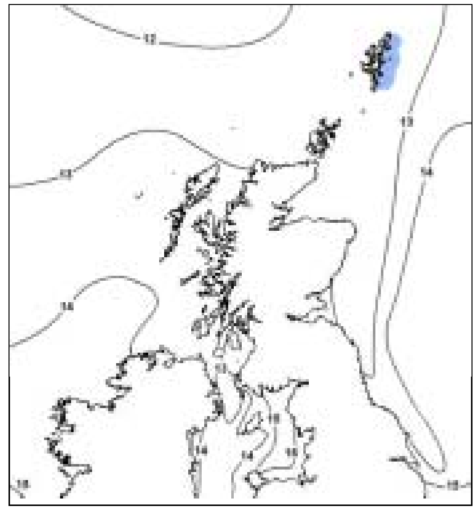
References:

Kitching, J.A. (1987). Ecological studies at Lough Hyne. *Advances in Ecological Research*, **17,** 115-186.

Lopez, S., Turon, X., Montero, E., Palacin, C., Duarte, C.M. & Tarjuelo, I. (1998). Larval abundance, recruitmenta and early mortality in *Paracentrotus lividus* (Echinoidea). Interannual variability and plankton-benthos coupling. *Marine Ecology Progress Series*, **172**, 239-251.

15. *Strongylocentrotus droebachiensis*

Image: *Strongylocentrotus droebachiensis*. Shetland*.* Image width c. 40 cm. Sue Scott / JNCC



Common name: Green sea urchin

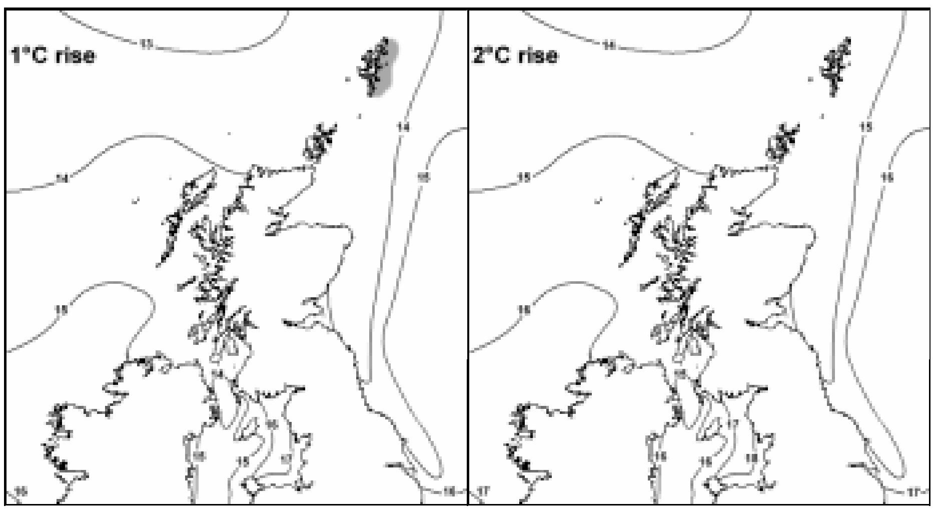
Current distribution: A northern species recorded in Shetland and confined to the east coast of Britain.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:

Likely future distribution



Summary: *Strongylocentrotus droebachiensis* will most likely persist in Shetland if seawater temperatures rise by 1ºC but recruitment and survival may cease leading to loss from Scotland following a 2ºC rise in temperature.

Climate change type: Type B, Northern stables.

Expected change in distribution: No significant change expected (1ºC) but may cease to be present in Scotland (2ºC).

Explanation: *Strongylocentrotus droebachiensis* has a long lived (~2.5 months) planktotrophic larva (Thorson, 1946). This species is unlikely to reproduce in Shetland as embryos (which are produced in early spring) have an upper temperature limit of 8ºC (Strathmann, 1987). The current records of this species on the east coast of Shetland are probably not from a self-recruiting population and may rely on larval input from elsewhere (e.g. Norway). It may be that populations in the relevant part of Norway may cease to produce larvae or significant numbers of larvae because of seawater warming there.

Expected rate of change in distribution: Retreat in distribution relatively slow.
Explanation: This species is relatively long lived (at least 10 years) (Meidel & Scheibling, 1998a) and a lethal upper temperature limit for adults will not be reached within current predictions.

Expected change in abundance or population structure at locations where the species already occurs: Population structure will change to occasional or older age classes due to infrequent recruitment.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: This species requires a low temperature (below 8ºC) to reproduce successfully, which is unlikely to be present during the period that spawning normally occurs and which may be triggered by the phytoplankton bloom (Meidel & Scheibling, 1998b).

Species that might be affected by decreased abundance of this species: It is not expected that any species will be affected as the grazing activities of *Strongylocentrotus* are likely to be no different in effect to those of *Echinus esculentus* which occurs in the same habitats in Scotland.

Effects on biotopes: The only biotope in which *Strongylocentrotus* is specifically mentioned as sometimes present is MCR.Bri.Oph.Oacu (*Ophiopholis aculeata* beds on slightly tide-swept circalittoral rock or mixed substrata). It probaly also occurs in MCR.GzFa.FaAlC (Faunal and algal crusts, *Echinus esculentus*, sparse *Alcyonium digitatum* and grazing-tolerant fauna on moderately exposed circalittoral rock). However, loss from these biotopes will be compensated for by the continued grazing activities of *Echinus esculentus*,

Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme of searching for a small range of easily identified species.

References:

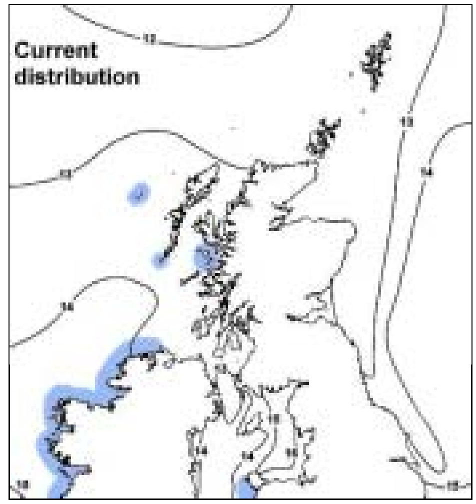
Meidel, S. K. and Scheibling, R. E. (1998a). Size and age structure of the sea urchin, *Strongylocentrotus droebachiensis*, in different habitats. In *Echinoderms San Francisco* (eds: Mooi, R. & Telford, M.), pp 737-742, AA Balkema, Rotterdam.

Meidel, S. K. and Scheibling, R. E. (1998b). Annual reproductive cycle of the green sea urchin, *Strongylocentrotus droebachiensis*, in differing habitats in Nova Scotia, Canada. *Marine Biology*, **131**, 461-478.

Strathmann, M. F. (1987). *Reproduction and development of marine invertebrates of the northern Pacific coasts.* University of Washington Press.

16. *Holothuria forskali*

Image: *Holothuria forskali.* Lundy. Picture width c.30 cm. Keith Hiscock.

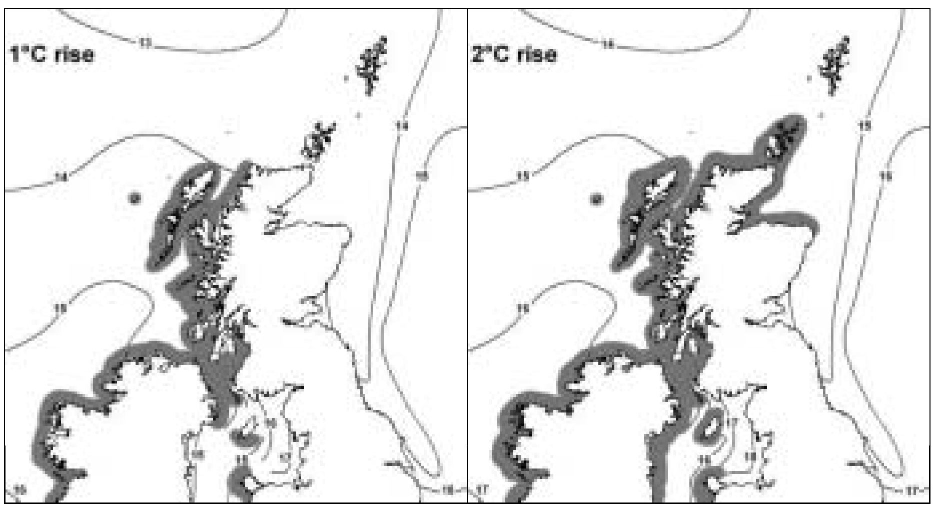


Common name: Cotton spinner

Current distribution: A southern species recorded in a few locations off west Scotland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:

Likely future distribution

Summary: Likely to increase in abundance and extent at current locations to become more widely distributed in those locations and, following a 2ºC rise in temperature, may become generally distributed on the west coast of Scotland.

Climate change type: Type F, southern gradual extenders.

Expected change in distribution: Likely to become more widespread in the areas where it currently occurs following a 1ºC rise in seawater temperature and present in suitable habitats all along the west coast of Scotland following a 2ºC rise in temperature.
Explanation: Reproduction is temperature dependant (Tuwo & Conand, 1992) and so larvae will be produced more frequently and/or in larger numbers. The larvae are planktotropic and so are likely to spread to distant locations. However, geographical barriers may slow distribution.

Expected rate of change in distribution: Change will occur more-or-less in concert with temperature rise.
Explanation: The larvae are planktotropic and so are likely to spread to distant locations providing geographical barriers do not interfere.

Expected change in abundance or population structure at locations where the species already occurs: Increase.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: *Holothuria forskali* appears, in its present distribution, to favour open coast areas in Scotland. It is likely that there will be some incursion to enclosed areas where suitable substrata exist but not into sea lochs; *Holothuria* does not generally occur in extreme shelter.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: *Holothria forskali* is a characteristic species in ECR.Efa.CCParCar (Coralline crusts, *Parasmittina trispinosa*, *Caryophyllia smithii*, *Haliclona viscosa*, polyclinids and sparse *Corynactis viridis* on very exposed circalittoral rock) and MCR.ErSEun (Erect sponges, *Eunicella verrucosa* and *Pentapora foliacea* on slightly tide-swept moderately exposed circalittoral rock). The latter biotope might develop in Scotland following significant seawater temperature rise.

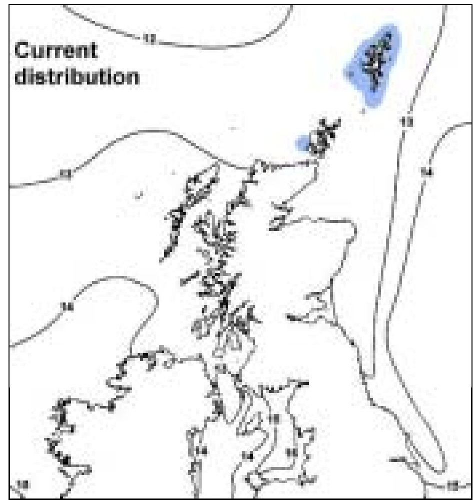
Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species.

References:

Tuwo, A. & Conand, C. (1992). Reproductive biology of the holothurian *Holothuria forskali* (Echinodermata). *Journal of the Marine Biological Association of the United Kingdom*, **72**, 745-758.

17. *Cucumaria frondosa*

Image: *Cucumaria frondosa*. Faroe Islands. Image width c. 20 cm. Bernard Picton.



Common name: Northern sea cucumber

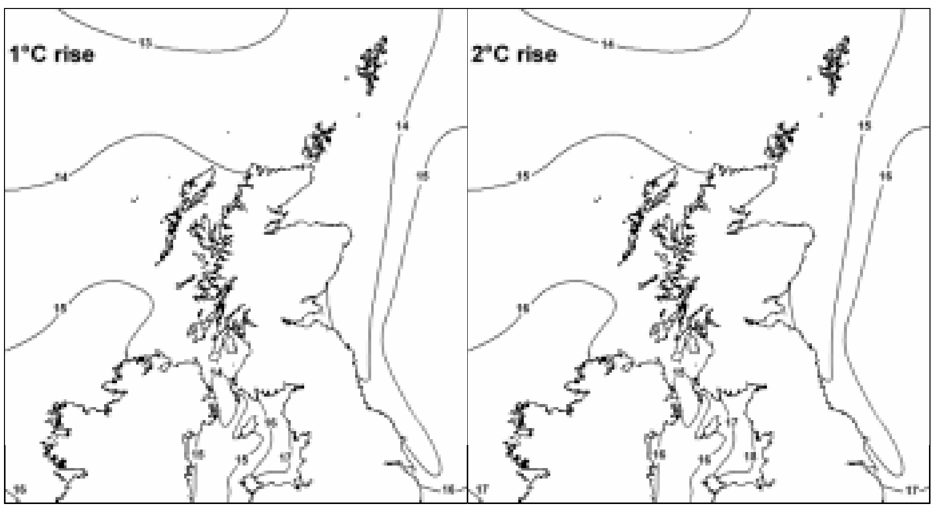
Current distribution: A northern species widely recorded in Shetland and also occurs in Orkney.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:

Likely future distribution



Summary: Cease to be present in Scottish waters following a 1ºC rise in seawater temperature.

Climate change type: Type C, Northern retreater

Expected change in distribution: Cease to be present in Scottish inshore waters (1ºC).
Explanation: The current recorded distribution seems to be restricted to areas where summer surface temperatures inshore do not rise above 13ºC. It is possible that lethal temperature for adults is important as optimal embryonic development was found to occur at 12 ºC (Hamel & Mercier, 1996): a temperature that occurs within the range of seawater temperatures that occur during the year. The species is anyway very sparse in occurrence in Scottish locations and it is questionable whether populations are viable.

Expected rate of change in distribution:
Retreat in distribution slow. Possibly with a ten to 20 year lag after temperature reaches defined levels. (Adults are likely to survive and remain in the same areas but will eventually

die and not be replaced.)

Expected change in abundance or population structure at locations where the species already occurs: Significant but gradual decline in abundance expected.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise:

Species that might be affected by decreased abundance of this species: None.

Effects on biotopes: None detectable.

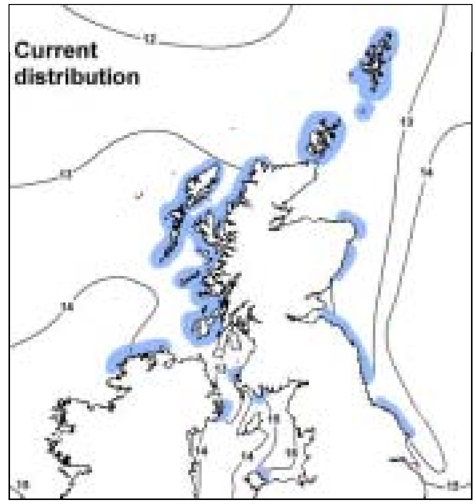
Suggested monitoring:
Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species.

References:
Hamel, J.-F., & Mercier, A. (1996). Early development, growth and spatial distribution of the sea cucumber *Cucumaria frondosa* (Echinodermata: Holothuroidea). *Canadian Journal of Fisheries & Aquaculture Sciences,* **53**, 253-271.

18. *Lithothamnion glaciale*

Image:

No image available



Common name: Maerl

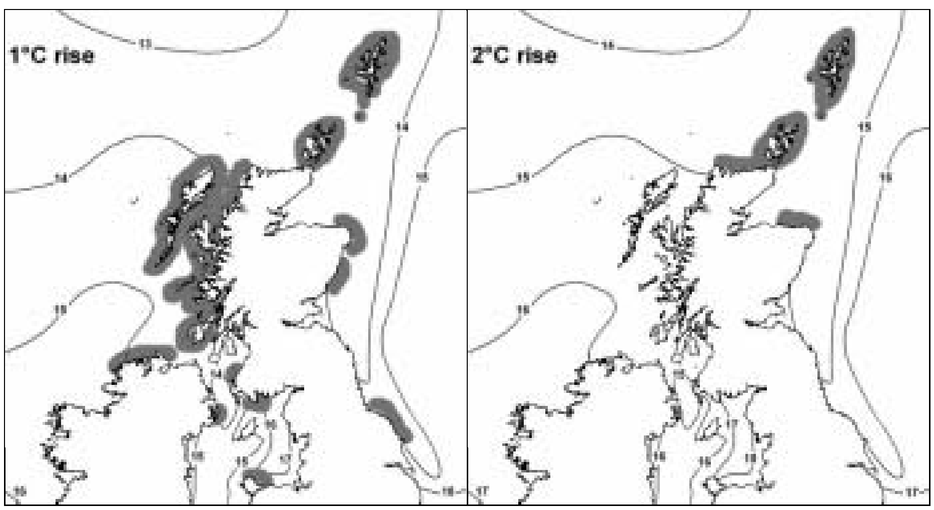
Current distribution: Widespread and often abundant in the Arctic region and reaches its southern limit of distribution in Britain (Yorkshire, Lundy) and Ireland (Galway, Down).

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:

Likely future distribution



Summary: Existing populations will persist for a considerable time (decades or centuries) but decline slowly and be replaced by other maerl species with a more southerly distribution.

Climate change type: Type B, Northern stables

Expected change in distribution: Gradual decline over decades and eventual retreat northwards.

Explanation: There is no information on temperature thresholds for the formation of reproductive structures so that impacts of seawater warming on recruitment are uncertain. Growth rate is optimum at 10-13°C, and growth rates decrease above that temperature (Adey, 1970). Temperatures within that range are likely to continue to occur but the constraint in growth at higher temperatures agrees with the northern, cold-water distribution *of L. glaciale*, the southern distributional limit of which in Britain and Ireland coincides with the 14.5°C summer isotherm. A simplistic extrapolation from the present distributional range limit to match a 1°C rise in summer sea temperatures would probably affect only the marginal populations *of L. glaciale* in Ireland, southern England, the Isle of Man and Yorkshire. Although the distributional range may remain unaffected in Scotland perhaps its abundance at littoral and shallow sublittoral levels may change. A further increase by 1°C would imply a continued reduction in southern extent but continued occurrence in northern and north-eastern Scotland, Orkney and Shetland. Decline in abundance and loss may be more marked in shallow waters than at depth.

Expected rate of change in distribution: It is uncertain as to how long existing populations will remain viable, succumb to raised temperatures, or whether there will be a differential decline according to depth.

Expected change in abundance or population structure at locations where the species already occurs: Maerl beds in Britain and Ireland are principally formed of three species of crustose coralline algae (*Lithothamnion corallioides*, *Lithothamnion glaciale*, and *Phymatolithon calcareum*). *P. calcareum* has a widespread distribution in Britain and Ireland (Norway to Spain and the Mediterranean) while *L. corallioides* is a southern species that possibly reaches its northern distributional limit in Scotland and Northern Ireland. At present *L. glaciale* replaces *L. coralloides* as a companion to *P. calcareum* in northern Britain. This may be reversed with a 2°C rise in sea temperature thus changing the species composition of the actively growing coralline components of the maerl beds.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Depth, grazing.

Species that might be displaced by increased abundance of this species: None.

Effects on biotopes: Probably many sublittoral rock biotopes with encrusting Corallinaceae as characterising species will change constituent encrusting Corallinacea species (loss of *Lithothamnion glaciale*) but associated species and the biotopes will remain the same.

IGS.Mrl.Lgla (*Lithothamnion glaciale* maerl beds in tide-swept variable salinity infralittoral gravel) are similar in componant species to maerl beds dominated by *Phymatolithon calcareum* and are likely, but not for many years, to change to those biotopes.

IGS.Mrl.Phy *Phymatolithon calcareum* (maerl beds in infralittoral clean gravel or coarse sand) biotopes may have *Lithothamnion glaciale* as a minor component but would persist even if *Lithothamnion glaciale* was lost.

Suggested monitoring: Measure cover of populations of encrusting *Lithothamnion glaciale* at all shore levels (along transect lines) at selected sites around the Scottish coast.

Record abundance of live *Lithothamnion glaciale* in selected maerl beds especially Caol Scotnish Narrows, Loch Sween.

References:

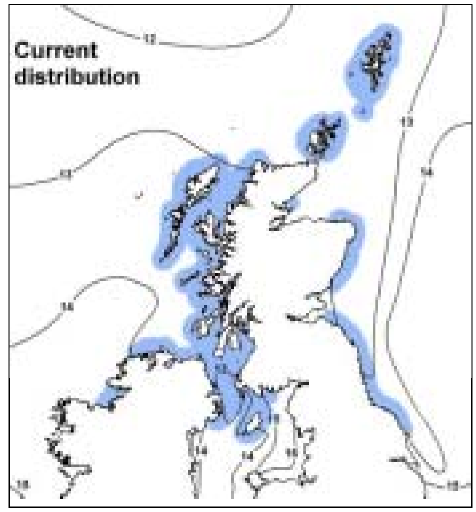
Adey W.H. (1970). The effects of light and temperature on growth rates in boreal-arctic subarctic crustose corallines. *Journal of Phycology,* **6**, 269-276.

Adey W.H. & Adey P.J. (1973). Studies on the biosystematics and ecology of epilithic crustose Corallinaceae of the British Isles. *British Phycological Journal*, **8**, 343-408.

Irvine L.M. & Chamberlain Y.M. (1994). *Seaweeds of the British Isles Vol1. Rhodophyta Part 2B Corallinales, Hildenbrandiales.* The Natural History Museum, London.

19. *Odonthalia dentata*

Image: *Odonthalia dentata* in a rockpool at Inchkeith. Image width c. 20 cm. David Irvine/NHM.



Common name:

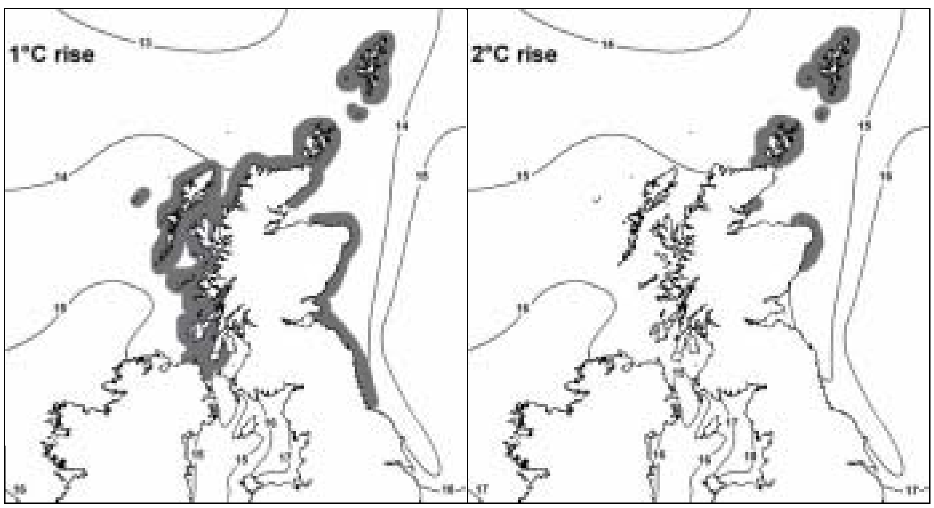
Current distribution: A circum-arctic species with a southern limit of distribution at the Isle of Man, Flamborough Head, and western Ireland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.

Key:

Likely future distribution



Summary: Change in distribution and abundance will probably only occur in Scotland following a 2°C rise in seawater temperature when the species may disappear from southern Scotland.

Climate change type: Type B, Northern retreaters

Expected change in distribution: A simplistic extrapolation from the present southern distribution limit of *O. dentata* that follows the 14.5°C summer isotherm suggests that with a 1°C rise in sea temperature the species would remain in areas where it is currently frequent (all of the Scottish coast) but perhaps retreat north from the west coast of Ireland to Ulster, from the Isle of Man to Galloway and from Yorkshire to Durham. A 2°C rise in sea temperature and a shift north of the 14.5°C isotherm suggests a retreat from the west coast of Scotland to the north of Scotland, and from Durham to Aberdeen. *O. dentata* will probably remain in Orkney and Shetland.

Explanation: Increase in sea temperature will probably exceed the reproductive maximum lethal limits (such limits have not been experimentally determined) and reduce reproductive success at the Isle of Man and elsewhere at its southern limit of distribution. Kain (1982) observed that its seasonality in reproduction can be related to geographical distribution. *O. dentata* reproduces on the Isle of Man when sea temperature is below the annual mean of 10.7°C, typical of a species with a northern distribution. Kain also noted a possible change in reproductive timing with latitude. In Scotland, Denmark and Newfoundland reproductive seasonality is similar to the Isle of Man. In Shetland and north Norway tetraspores were reported in August in contrast to February/March on the Isle of Man – thus a shift to summer sporing at higher latitude.

It is also possible that populations may survive in refugia in deeper colder waters – although Kain (1984) observed lower growth rates and plant sizes, and also fluctuation of plant densities in deeper waters.

Expected rate of change in distribution: Retreat is likely to be moderately rapid. Individual plants may survive to 4 or even 9 years but lack of recruitment will mean noticable decline at its southern limits. Initially the rate of retreat in distribution is likely to be slow as suggested by the map showing the 1°C rise in sea temperature. The 2°C rise will be more significant with any relict populations south of the suggested limit not self sustaining.

Expected change in abundance or population structure at locations where the species already occurs: There may be a significant decrease in abundance except in the north and northeast of Scotland, Orkney and Shetland. Decrease may be expected in summer biomass at the new southern limits of distribution (cf Kain, 1984).

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: None

Species that might be displaced by increased abundance of this species: None

Effects on biotopes: *Odonthalia* is mentioned as a characterising species only in biotope EIR.KfaR.LhypFa (*Laminaria hyperborea* forest with a faunal cushion (sponges and polyclinids) and foliose algae on very exposed infralittoral rock. It may be lost from the biotope in much of Scotland.

Suggested monitoring: Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species. If experienced biologists undertake survey, count individuals per square metre, measure size of plants, note reproductive phenology.

References:

Kain J.M. (1982). The reproductive phenology of nine species of Rhodophyta in the subtidal region of the Isle of Man. *British Phycological Journal*, **17**, 321-331.

Kain J.M. (1984). Seasonal growth of two subtidal species of Rhodophyta off the Isle of Man. *Journal of Experimental Marine Biology and Ecology*, **82**, 207-220.

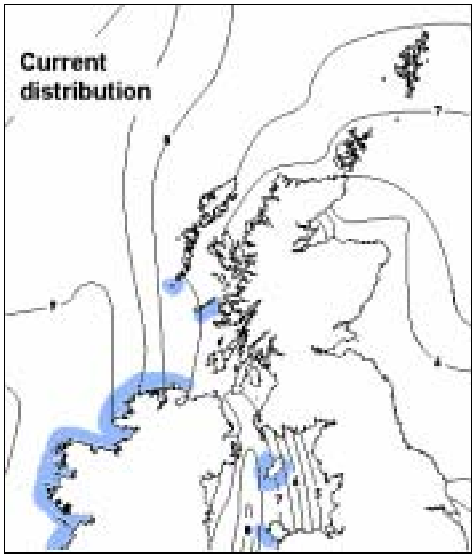
Lüning K. (1990). *Seaweeds their environment, biogeography and ecophysiology*. Wiley & Sons, New York.

Maggs C.A. & Hommersand M.H. (1993). *Seaweeds of the British Isles Vol. 1 Rhodophyta Part 3A Ceramiales.* The Natural History Museum, London.

20. *Dictyopteris membranacea*

Image:

No image available

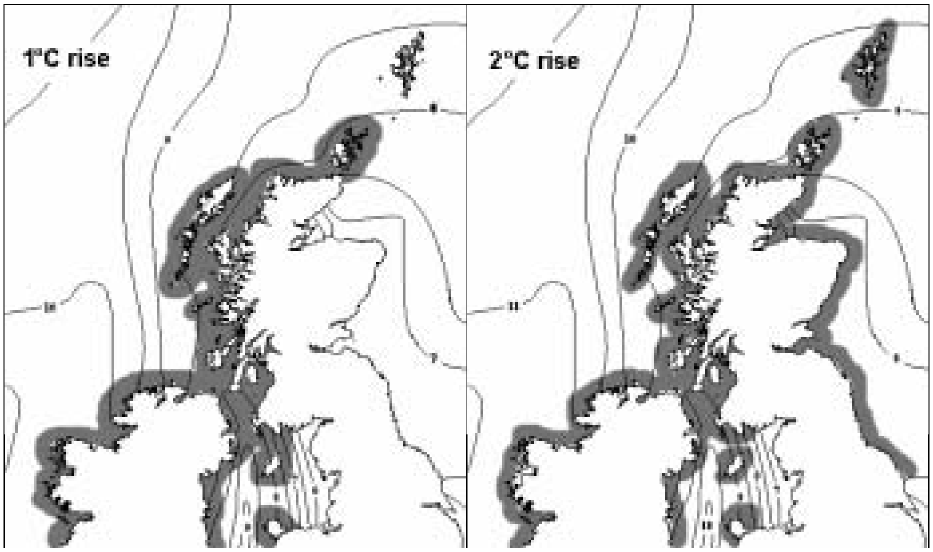


Common name:

Current distribution: A Mediterranean-Lusitanian species that occurs in the east Atlantic between the Canary Islands and Mauritania in the south and western Scotland in the north. Its northern limit of distribution is the island of Tiree where it grows at sublittoral levels (21m).

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in winter seawater temperatures.



Key:

Likely future distribution

Summary: Likely to spread northwards and increase in abundance where it currently occurs. Spread is likely to be related to winter temperatures.

Climate change type: Type G, Southern rapid extenders.

Expected change in distribution: Range extension north to Duncansby Head, Orkney and

possibly Shetland following a 1ºC rise in temperature and all around the coast of Scotland following a 2ºC rise.
Explanation: A simplistic extrapolation from the present distributional range limit coincident with the 13.5ºC summer isotherm, to follow a 1ºC rise with the 13.5ºC isotherm displaced to the north would suggest that *Dictyopteris membranacea* may spread around the entire coast of Scotland to the Orkney Islands. A 2ºC rise might allow the species to spread to Shetland. However, the distributional range limit follows the winter 7.5ºC isotherm which is probably most critical to the occurrence of this southern (warm water) species in northern waters. A simplistic extrapolation from this boundary to follow a northward displaced 7.5ºC isotherm as a result of a 1ºC rise in sea temperature, would suggest a range extension of *D. membrancea* to Duncansby Head (not as far as implied by a shift of the summer isotherm), Orkney and possibly also Shetland. A further rise of 1ºC could hypothetically allow the species to spread to the east coast of Scotland. This conclusion must remain speculative until data on the environmental tolerance of the species is available.

Expected rate of change in distribution: Uncertain but, to speculate, a 2ºC rise in sea temperature could allow for the full development of the of the Delesseriaceae-*Dictyota-Dictyopteris* assemblage in south west Scotland.

Expected change in abundance or population structure at locations where the species already occurs: Likely to become more abundant especially in south-west Scotland.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Uncertain

Species that might be displaced by increased abundance of this species: Uncertain.

Effects on biotopes:
Biotope EIR.SG.FoR.Dic (Foliose red seaweeds with dense *Dictyota dichotoma* and/or *Dictyopteris membranacea* on exposed lower infralittoral rock) may become more widespread in Scotland, particularly a facies with *Dictyopteris membranacea* as a characterising species.

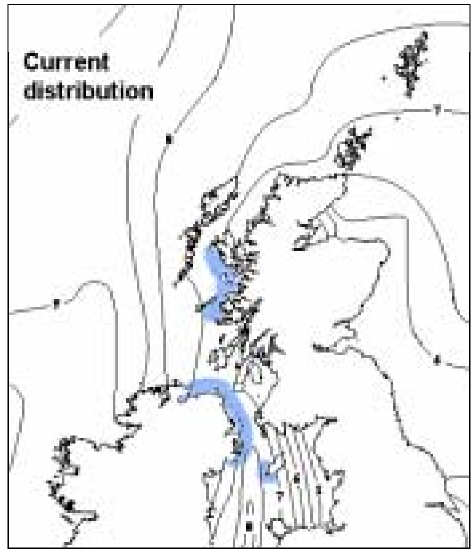
Suggested monitoring:
Recording scheme by volunteer divers guided to locations. Part of a programme searching for a small range of easily identified species. Sites on Tiree should especially be targetted.

References:
Maggs C.A. (1986). *Scottish marine macroalgae: a distributional checklist, biogeographical analysis and literature abstract*. A report to the Nature Conservancy Council. Queen's University, Belfast.

21. *Codium adhaerens*

Image:

No image available

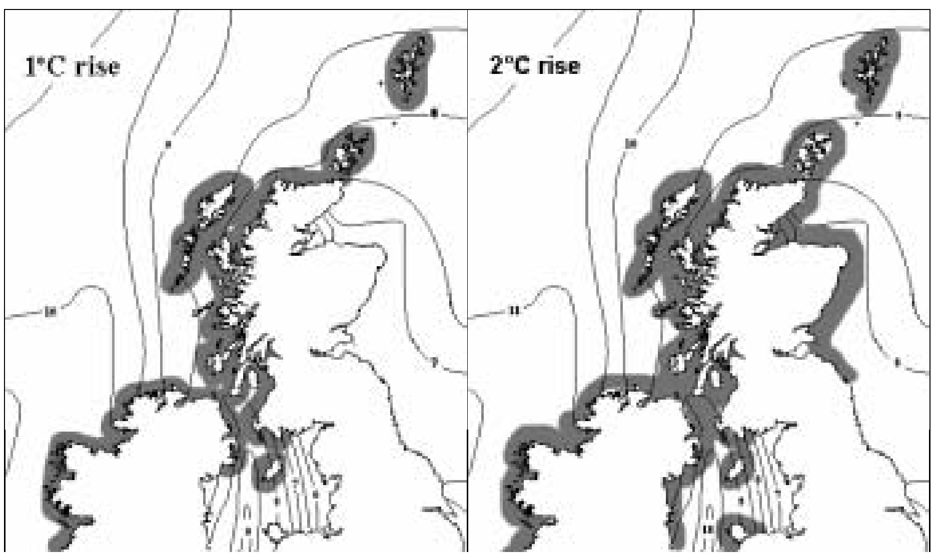


Common name:

Current distribution: Occurs commonly in the south west of England, sporadically around Ireland, on the Isle of Man and at two locations on the south-west coast of Scotland (Loch Melfort in Argyll, Loch nan Uamnh in west Inverness).

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in winter seawater temperatures.



Key:

Likely future distribution

Summary: Occurrence is likley to increase within its present distributional range and range extension will occur linked to changes in winter temperatures.

Climate change type:

Expected change in distribution: A simplistic extrapolation of the current distributional range limit to coincide with a shift to the north of the 13.5ºC summer isotherm after a 1ºC rise in sea temperature, would suggest a possible spread of *C. adhaerens* throughout Scotland to Orkney and possibly also Shetland. A 2ºC rise in summer sea temperatures would seemingly make no further difference. Repeating the exercise using the limiting winter 7ºC isotherm suggests that following a 1ºC rise in winter sea temperature *C. adhaerens* may spread to the north of Scotland at Duncansby Head, Orkney and Shetland. A further 1ºC rise in winter sea temperature implies a spread to the east coast of Scotland (and north-east England). These conclusions remain speculative pending studies on the environmental tolerance of *C. adhaerens* throughout its life-cycle.

Expected rate of change in distribution: Uncertain, little is known of the biology of *C. adhaerens* in relation to dispersal.

Expected change in abundance or population structure at locations where the species already occurs: Mats of *C. adhaerens* may increase in size and spread vegetatively.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Uncertain.

Species that might be displaced by increased abundance of this species: May outcompete other lower littoral species of moderately wave-exposed habitats.

Effects on biotopes: Not featured in any British and Irish biotopes. Tittley & Neto (2000) proposed that the prostrate *Codium adhaerens* on shores in the Azores should characterise a distinct biotope.

Suggested monitoring:
Populations in Scotland: measure vegetative growth; check for development of reproductive structures.

References:

Burrows, E. M. (1991). *Seaweeds of the British Isles Vol. 2 Chlorophyta*. Natural History Museum, London.

Knight M. & Parke M. (1931). Manx Algae. *LMBC Memoirs*, 30, 1-147.

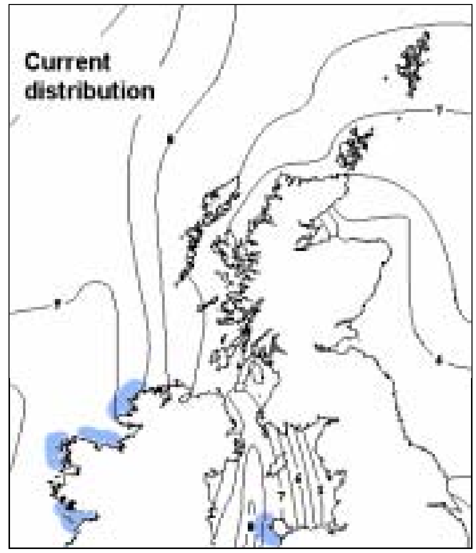
Parke M. (1936). Algological records for the Manx region. *Report of the Marine Biological Station, Port Erin, Isle of Man* for 1935: 29-32.

Powell H.T. (1966). The occurrence of *Codium adhaerens* (Cabr.) C. Ag. in Scotland, and a note *on Codium amphibium* Moore ex Harv. In *Some Contemporary Studies in Marine Science* (ed. H. Barnes), pp 591-595. Allen & Unwin, London.

Tittley, I. & Neto A.I. (2001). A provisional classification of algal-characterised rocky shore biotopes in the Azores. *Hydrobiologia* (in press).

22. *Bifurcaria bifurcata*

Image: Mass of *Bifurcaria bifurcata* in a rockpool. Image width c. 80 cm. Cape Cornwall. Keith Hiscock.

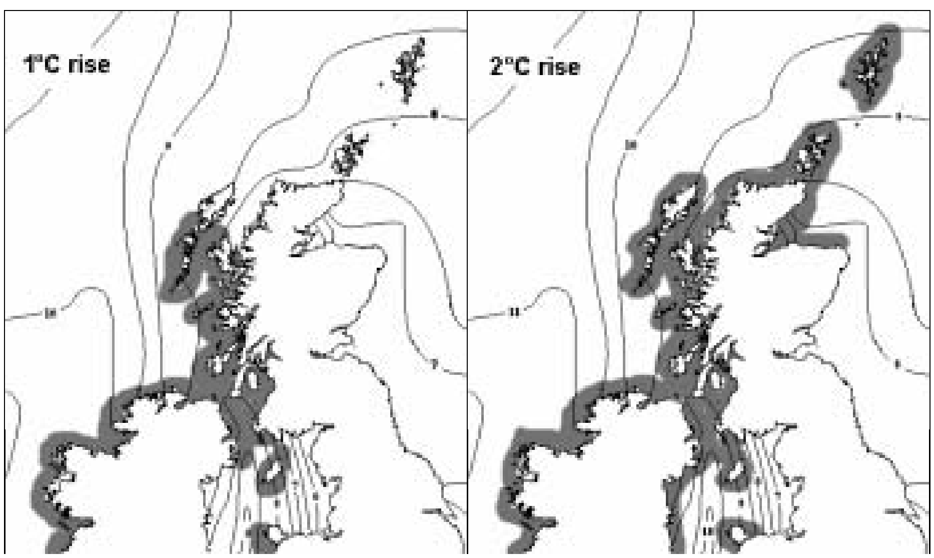


Common name:

Current distribution: Eastern Atlantic Ocean between Morocco in the south and Northern Ireland in the north. Its present northern limit of range distribution lies on the same latitude as southern Scotland and the nearest population to Scotland lies approximately 120km to the west.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:

Likely future distribution

Summary: *Bifurcaria bifurcata* is most likely restricted in distribution by winter temperatures but also seems slow to colonise rockpools so might not extend to Scotland for many years after seawater temperatures apparently become amenable.

Climate change type: Type F, gradual southern extenders

Expected change in distribution: Following a winter increase of 1ºC *Bifurcaria* could potentially spread to the south west coast of Scotland to Skye and possibly the Outer Hebrides. With a further 1ºC in winter sea temperature the distributional range of *Bifurcaria* could spread to the north of Scotland, Orkney and Shetland (but probably not the east coast).
Explanation: A simplistic extrapolation of *Bifurcaria* distribution to match its current range limit defined by the 14ºC summer isotherm would, with a 1ºC rise, extend its range distribution to include the western seaboard of Scotland almost to Cape Wrath. An additional 1ºC rise in sea temperature shifts the 14ºC isotherm further north and suggests that the species could spread throughout Scotland (including the east coast) to Orkney and Shetland. However, *Bifurcaria* is a warm water species the distribution of which coincides with and is probably limited by the 8º-9ºC winter isotherm. De Valéra (1962) recorded fertile plants in February, and Rees (1933) recorded them in April and July. In general receptacles are abundant in the darker, colder months of the year. The expected change in distribution is therefore identified on the basis of winter isotherms. These conclusions remain speculative until work on the environmental responses and tolerances of the various life history stages of *Bifurcaria bifurcata* have been undertaken.

Expected rate of change in distribution: Possibly slow; de Valéra (1962) noted that *Bifurcaria bifurcata* may be a slow starter needing the protection of other species which it may eventually outcompete. Drift fertile plants remain viable and may facilitate spread of *Bifurcaria* to an appropriate habitat where zygotes can germinate. However, germlings are only rarely noted in nature.

Expected change in abundance or population structure at locations where the species already occurs: May become more abundant at range margins.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Winter sea temperature; competition with other species for space in pools and open rock faces. Daylength may be important.

Species that might be displaced by increased abundance of this species: Uncertain.

Effects on biotopes: LR.Rkp.CorBif (*Bifurcaria bifurcata* in shallow eulittoral rock pools) may become present in Scotland.

Suggested monitoring: Recording scheme by volunteers guided to locations. Part of a programme searching for a small range of easily identified species.

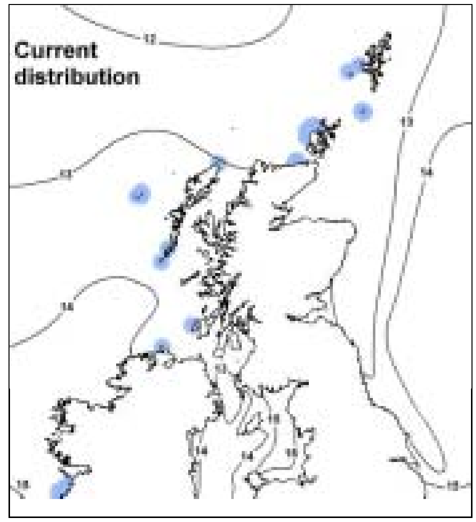
References:

De Valéra (1962). Some aspects of the problem of the distribution of *Bifurcaria bifurcata* (Velley) Ross on the shores of Ireland, north of the Shannon Estuary. *Proceedings of the Royal Irish Academy*, **62**, 77-99.

Lüning K. (1990). *Seaweeds: their environment, biogeography and ecophysiology*. Wiley & Sons, New York.

23. *Fucus distichus distichus*

Image: *Fucus distichus distichus*. Cape St Francis, Newfoundland. Image width c. 20 cm. Ian Tittley.

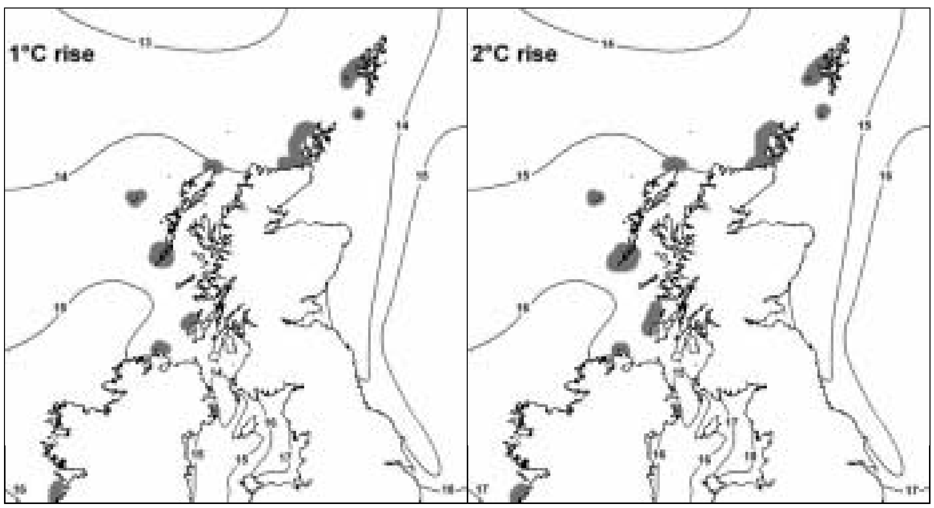


Common name:

Current distribution: A northern species recorded as far south as Islay and Ireland.

Prediction of future changes in distribution:

Likely distribution assuming a 1°C (left) or 2°C (right) rise in summer seawater temperatures.



Key:

Likely future distribution

Summary: Populations are likely to persist at the locations where they currently occur as distribution is most likely determined by daylength rather than temperature.

Climate change type: (Closest to Type B, Northern stables)

Expected change in distribution: None.
Explanation: With the exception of the St Kilda population, *Fucus distichus distichus* in Britain does not occur south of the summer 13°C isotherm. A simplistic extrapolation from the present distributional range would suggest that following a 1°C and 2°C rise in summer sea temperature, the 13°C isotherm would have moved north of the British Isles and *distichus* would therefore become extinct in Britain. However, laboratory and autecological field studies indicate that mature *distichus* plants can tolerate higher temperatures (see above). Embryos also develop at 15°C (and higher). A critical factor is probably day length; short day lengths stimulate the onset of receptacle formation and this will not change with global warming. Bird & McLachlan (1976) showed that the formation of receptacles was independent of temperature

but maturation progressed with increasing temperature to at least 15°C. It is a possibility that a 2°C rise in sea temperature may make no difference to the populations of *distichus* in northern Scotland. Stormier sea conditions (predicted as a result of global warming) and competition from other marine organisms may do so. Why *distichus* does not occur more widely in Britain, as could be inferred from laboratory and autecological studies (and also shown by subspecies *anceps*) remains unclear.

Expected rate of change in distribution: Uncertain, may be no change.

Expected change in abundance or population structure at locations where the species already occurs: Uncertain, may be no change. If losses occur and viable population persist elsewhere, recolonising is likely to be reasonably rapid. In Canada a pool was recolonised only a year after denudation. However, establishment of a new population is a lengthy process. Growth of sporelings is slow and no receptacles are formed in the first year.

Factors that may effect or restrict distribution changes in relation to seawater temperature rise: Changes in daylength and frequency of storms are likely to affect distribution.

Species that might be displaced by increased abundance of this species: Not applicable.

Effects on biotopes: *Fucus distichus distichus* is not mentioned as a characterising species in any biotopes and it is most likely that change will not occur.

Suggested monitoring: Populations to be surveyed at selected sites following field methods of Edelstein & McLachlan (1975).

References:

Bird, N.L. & McLachalan, J. (1976). Control of formation of receptacles in *Fucus distichus* L. ssp. *Distichus* (Phaeophyceae: Fucales). *Phycologia*, **15**, 79-84.

Edelstein, T. & McLachlan, J. (1975). Autecology of *Fucus distichus* ssp *distichus* (Phaeophyceae: Fucales) in Nova Scotia, Canada. *Marine Biology*, **30**, 305-324.

McLachlan, J. (1974). Effects of temperature and light on growth and development of embryos *of Fucus edentatus* and *Fucus distichus* ssp *distichus*. *Canadian Journal of Botany*, **52**, 943-951.

McLachlan, J., Chen L.C. & Edelstein T. (1971). The culture of four species of *Fucus* under laboratory conditions. *Canadian Journal of Botany, 49*, 1463-1469.

Pearson, G.A. & Brawley, S.H. (1996). Reproductive ecology of *Fucus distichus* (Phaeophyceae): an intertidal alga with successful fertilisation. *Marine Ecology Progress Series*, **143**, 211-223.

Powell, H.T. (1957). Studies in the genus *Fucus* L. I. *Fucus distichus* L. emend Powell. *Journal of the Marine Biological Association of the United Kingdom*, **36**, 407-432.

Rice, E.L. & Chapman, A.R.O. (1985). A numerical taxonomic study of *Fucus distichus* (Phaeophyta). *Journal of the Marine Biological Association of the United Kingdom*, **65**, 433-459.