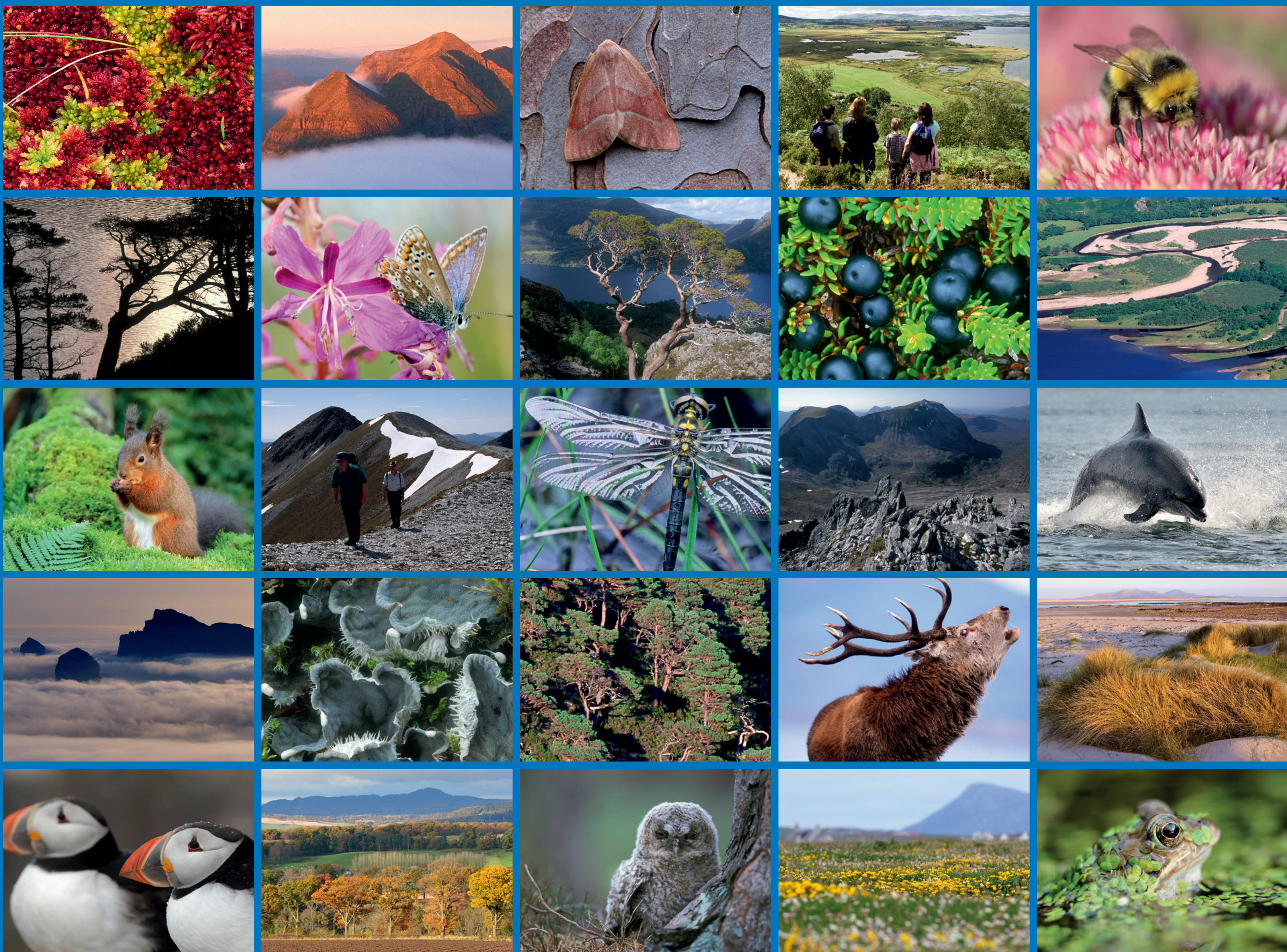
Scottish Natural Heritage
Commissioned Report No. 939

Marine Biodiversity and Climate Change (MarClim): Scotland 2014/15



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Marine Biodiversity and Climate Change (MarClim): Scotland 2014/15

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COMMISSIONED REPORT

Summary

Marine Biodiversity and Climate Change (MarClim): Scotland 2014/15

Commissioned Report No. 939
Project No: 015161
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Keywords

Rocky shores; climate change; species ranges; community temperature index.

Background

A two-year programme of ecological surveys around the rocky coast of Scotland has been completed by the Scottish Association for Marine Science and the Marine Biological Association in Plymouth. The programme revisited and extended the spatial coverage of a set of surveys done between 2002 and 2010, with reference to earlier studies from the 1950s to 1980s. The main aim was to interpret changes in geographical distributions and abundance of species in the context of recent climate (principally temperature) change, on both short- and long-term timescales. A secondary aim was to assess proposed rocky shore indicators of Good Environmental Status for the Marine Strategy Framework Directive (MSFD).

Main findings

- Rocky shores along the entire coastline of Scotland were surveyed in the summers of 2014 and 2015. Eighty-four rocky shore sites from three areas were surveyed on low spring tides during the summer of 2014: south-west Scotland from the inner Clyde to Ardnamurchan in July, the Outer Hebrides in August, and the north-west, north and north-east coasts in September. Seventy rocky shore sites were surveyed in 2015: Applecross and the north-east coast in May, Solway and the south-east in June, Shetland in July, and Orkney in July-August.
- Despite the marked general trend in increasing SST since 1980, sea surface temperature did not show an increasing trend between the two survey periods (i.e. 2002-2010 and 2014-2015).
- No northward range extensions of species reaching their poleward geographical range limits were evident.
- Changes in species abundance were observed between 2002-2010 and 2014-2015. Blue mussels declined while macroalgae increased across Scotland's coasts.
- The Community Temperature Index measured spatial and temporal changes in the balance of warm and cold water species, with a slight shift toward the latter between 2002-2010 and 2014-2015. This index is proposed as a novel indicator.
- The non-native seaweed *Sargassum muticum* (wireweed) has spread in western Scotland, with new populations appearing at sites in the inner Hebrides (Colonsay and south Mull). The northern limit of *Sargassum muticum* is not currently limited by

temperature; the species extends further into colder regions in its native range, down to an annual average 7°C. Further expansion should be expected.

- The effects of other factors such as ocean acidification and storm events are also discussed.
- Recommendations for further work and the establishment of a 10 year survey programme are presented.

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Acknowledgements

We would like to thank the funders of the UK and Ireland MarClim project (Marine Biodiversity and Climate Change: Assessing and predicting the influence of climatic change using intertidal rocky shore biota) which originally ran from 2001 to 2006, and continuing to the present day, for making this decadal comparison possible.

1. INTRODUCTION

The project sought to carry out a repeat survey of the original sites surveyed in 2001-2005 and extend the coverage to areas not sampled during the initial survey.

1.1 Project outline

The original MarClim project ran from 2001 to 2005 and was made up of a consortium of researchers at universities and research laboratories in the UK and Ireland (MBA, Plymouth Marine Laboratory, Scottish Association for Marine Science, University of Plymouth and University College Cork), led by Steve Hawkins at the Marine Biological Association UK Laboratory in Plymouth (Mieszkowska *et al.*, 2005). The project aimed to re-examine and extend existing datasets on time series and biogeographical distributions of climate-sensitive species around the UK and Ireland, and evaluate any changes observed in the light of ongoing climate change in the region.

As well as providing valuable new data on the distribution and abundance of intertidal species, the project was able to demonstrate significant shifts in the distributions of species such as the purple topshell *Osilinus* (now *Phorcus*) *lineatus* and the warm-water barnacle *Balanus* (now *Perforatus*) *perforatus* into areas previously too cold for these warm-water species. One key element of the first MarClim project was to increase understanding of how climate change influences on species interactions may produce changes at the community level and impact on ecosystem functioning.

More recently, the methods developed and refined through the MarClim project have been proposed as providing the basis of 'Good Environmental Status' indicators for intertidal rock communities under the Marine Strategy Framework Directive. Indicators of species richness (biodiversity) and community composition have been suggested that combine data from a large number of conspicuous rocky shore species recorded in biogeographic-surveys that record categorical abundance measurements (SACFOR). These indicators are designed to be sensitive to different pressures related to climate change (temperature) and water quality (turbidity and phytoplankton), as well as other potential pressures.

1.2 Policy relevance

The implications of climate change for the marine fauna and flora of Scotland are considerable but effects are currently under-recorded and under-reported. The Marine Climate Change Impacts Partnership (MCCIP) Report Cards are a key source of information for Ministers and their advisers and the wider public on what changes have already occurred and what the rate of future change might be to the distribution and abundance of key climate change indicator species. The results from this MarClim survey will ensure that the most up-to-date information is available to inform the next report card. The survey work will also allow evaluation of proposed MSFD targets and indicators for rocky shores. This is essential if the programme of monitoring is to be put in place in time to enable the UK to report on progress towards Good Environmental Status of these habitats.

1.3 Project aim

The survey work used the standard MarClim protocols as adapted and extended by the SAMS team and using the same personnel as the earlier surveys between 2002 and 2010 for a large proportion of site visits. New surveyors were also trained and their performance cross-validated with more experienced surveyors. The methods are outlined in Burrows *et al.* (2008) and are presented in detail on the MarClim website[1] and in Burrows *et al.* (2014). The methods aimed to produce standardised estimates (including zeros) of the abundance

[1] http://www.marclim.co.uk/pdf/Sampling_protocols.pdf

of a pre-defined list of species as categories for a larger set of species (>50) and as numerical estimates for a smaller subset of taxa including barnacles, limpets and topshells. The primary goal was to collect data that can detect change relative to the earlier surveys and form a solid reference for any future comparisons.

1.4 Outcomes

The project had three principal aims:
(i) Resurveys of sites visited by SAMS during the original MarClim project (2001-5) and thereafter up to 2010, and new surveys in areas not previously covered but considered important for the detection of climate change effects.
(ii) An evaluation of changes between 2002-2010 and 2014-2015 in distribution and abundance of species and ecological communities on intertidal rock, including quantitative analysis. Changes detected were considered in relation to longer-term climate change and shorter-term climatic fluctuations.
(iii) A field test of the application of the methodology to assess the rocky shore targets and indicators of Good Environmental Status as per the MSFD.

1.5 Programme of work

The work programme comprised the following:
1. The survey work employed the standard MarClim protocols
2. Surveys were organised into three 1-week to 10-day trips at the times of low spring tides in July, August and September of 2014 and four trips in the same months in 2015.
3. In 2014 the three regions visited were Ardnamurchan, Lorn and Kintyre; Outer Hebrides; and North coast, Caithness and North-east coast of Scotland. In 2015 the four regions visited were Inner Hebrides, Clyde Sea and Solway; Shetland; Orkney; and South-east coast of Scotland.

2. SURVEYS

2.1 MarClim surveys since 2002

The original MarClim programme began in 2001 and has continued annually to date in various forms around the UK every year since then. Rocky shores around Scotland were surveyed every year between 2002 and 2010, with the major efforts and widest geographical coverage in 2002 (100 sites), 2003 (92 sites) and 2004 (66 sites). A smaller set of 20-22 sites were surveyed regularly, supplemented by visits to previously unsurveyed areas in following years: 2005 (20 core sites), 2006 (20 core plus 19 NW Scotland sites), 2008 (20 core sites plus 14 in NW and NE England), 2009 (31 sites in Arran, Mull, Islay, Colonsay, Coll and Tiree) and 2010 (20 core sites). No further MarClim surveys were completed in Scotland until the start of this project in 2014. Of the 407 surveys between 2002 and 2010, the majority (275) were completed by SAMS personnel with the remainder by visiting teams from the Marine Biological Association in Plymouth.

2.2 MarClim surveys in 2014 and 2015

A series of surveys were planned and completed in the summers of 2014 and 2015, covering 84 and 70 rocky shore sites in each year respectively (Figure 1, full details in Annex A Table 1) during three week-long campaigns in July, August and September 2014 and a further four campaigns in May, June, July and August 2015. A visit to Orkney in late July 2014 (28/7 - 31/7/2014) allowed a preliminary assessment of sites previously visited in 2004, subsequently fully surveyed in August 2015 (Figure 1). Locations of surveys are shown on Figure 1. Sites visited in 2014 were: south-west Scotland from the inner Clyde Sea to Ardnamurchan in July 2014 (11-18/7/2014), the Outer Hebrides in August 2014 (9-

15/8/2014), and the north and north-east coasts in September 2014 (7-13/9/2014). In 2015, sites were visited in Applecross and the north-east coast in May 2015 (14-22/5/2015), Solway and the south-east in June 2015 (13-20/6/2015), Shetland in July 2015 (1-8/7/2015) and Orkney in July-August 2015 (30/7/2015 – 6/8/2015). Methods and personnel were the same in both 2014 and 2015, and SNH staff were encouraged to join surveys wherever possible.

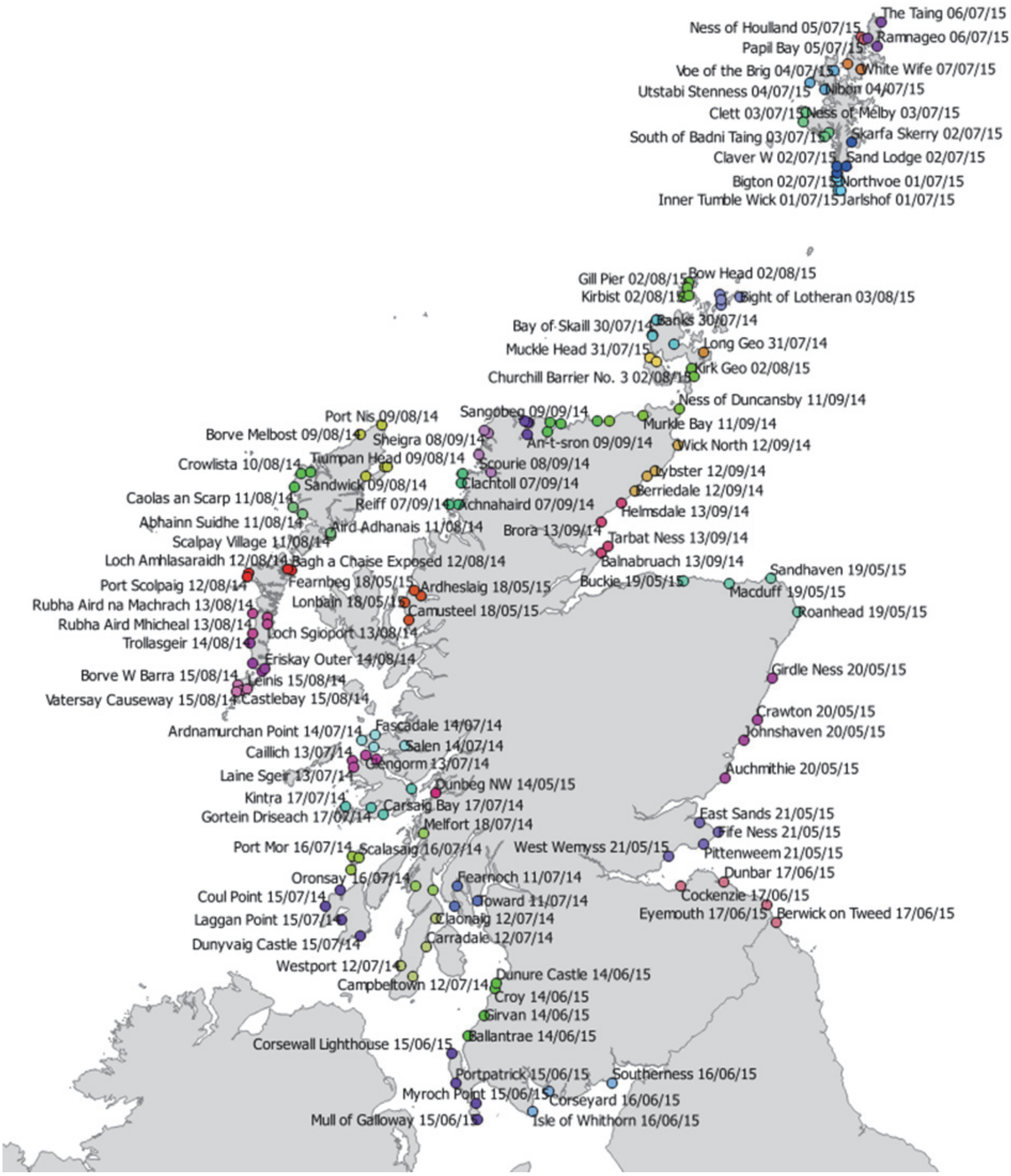


Figure 1: Sites surveyed in the summers of 2014 and 2015. Sites with same-coloured symbols were visited on the same day. (Contains OS data © Crown copyright and database right (2015))

2.3 Survey personnel and methods

The survey team consisted of Mike Burrows (MB), Robin Harvey (RH) and Gail Twigg (GT) from SAMS, joined for the September 2014 surveys by Nova Mieszkowska (NM) from the MarClim project at the Marine Biological Association in Plymouth. The team was also joined by SNH staff: Tracey Begg for two days in South Uist in August 2014, Jane Dodd for a day in Argyll in July 2014, and in Orkney by John Baxter in July of 2014 and 2015, with Professor Steve Hawkins from the University of Southampton also accompanying the survey teams in Orkney in 2015.

A minimum of two and usually three surveyors participated in each survey. Two surveyors (usually GT and RH) made categorical abundance estimates (SACFOR – see Annex C Table 4) of conspicuous species using a pre-defined checklist of species that included climate-sensitive species (see example recording sheet Annex D Table 5) and recording the abundance of other noteworthy species that may have been unexpectedly abundant, such as invasive or rare species, using SACFOR abundance scales.

Duplicate estimates of species abundance were made independently by the two surveyors for 99 species at 50 sites in 2014. This allowed a direct cross-validation of the SACFOR estimation technique, presented in Section 3.2.

One surveyor (usually MB) collected digital images of whole and partial shore views (see e.g. Figure 2), and photographed two different sized areas of substratum at three shore levels. Eight replicate approximately 40cm^2 areas (8 x 5cm, 0.04m^2) and five 50 x 50cm quadrats (0.25m^2) were randomly located at low, mid and high shore levels. Shore levels were defined by reference to the vertical distribution of barnacles (mainly *Chthamalus montagui, Chthamalus stellatus* and *Semibalanus balanoides*): high shore being 0.5m below the upper limit of barnacles if the uppermost genus were *Chthamalus* or 0.2m below the upper limit if *Semibalanus*; low shore 0.5m above the lower limit of barnacles; and mid shore half way between the high and low levels at approximately mid tide level. Two further levels were used for quantitative assessment of attached species under macroalgae: 'lower' being 0.5m below mid and 'upper' being 0.5m above mid shore.

The two sizes of area sampled were designed to record different taxa. The smaller area (Figure 3) was aimed at producing good images of barnacles, important climate-sensitive species but often difficult to identify in the field. Small coins were used as scale objects: the long axis of the elliptical image of a tilted disc always measures the same as the diameter of scale objects. The larger 0.25m^2 quadrat was designed to allow counts of mobile species and estimates of percentage cover of algae and encrusting species with supporting photographic evidence (Figure 4). Currently, the images are being used as independent confirmation of species records, and to aid identification for those species, such as barnacles, that are not easily recognised in the field. Quantitative estimates of species abundance will be derived from these images as time and resources permit and where contrasts with previous sets of images (2002-2008) from the same sites would aid detection of change.

Figure 2: Glengorm, North Mull 14:55 13/7/2014, general view of the mid to low intertidal zone.

Figure 3: Close up images of barnacles: (left) Columba's Cave, Loch Caolisport 18/7/2014, all Chthamalus montagui*; (right) Borve Point, Barra MHWN 15/8/2014, all* Chthamalus stellatus*.*

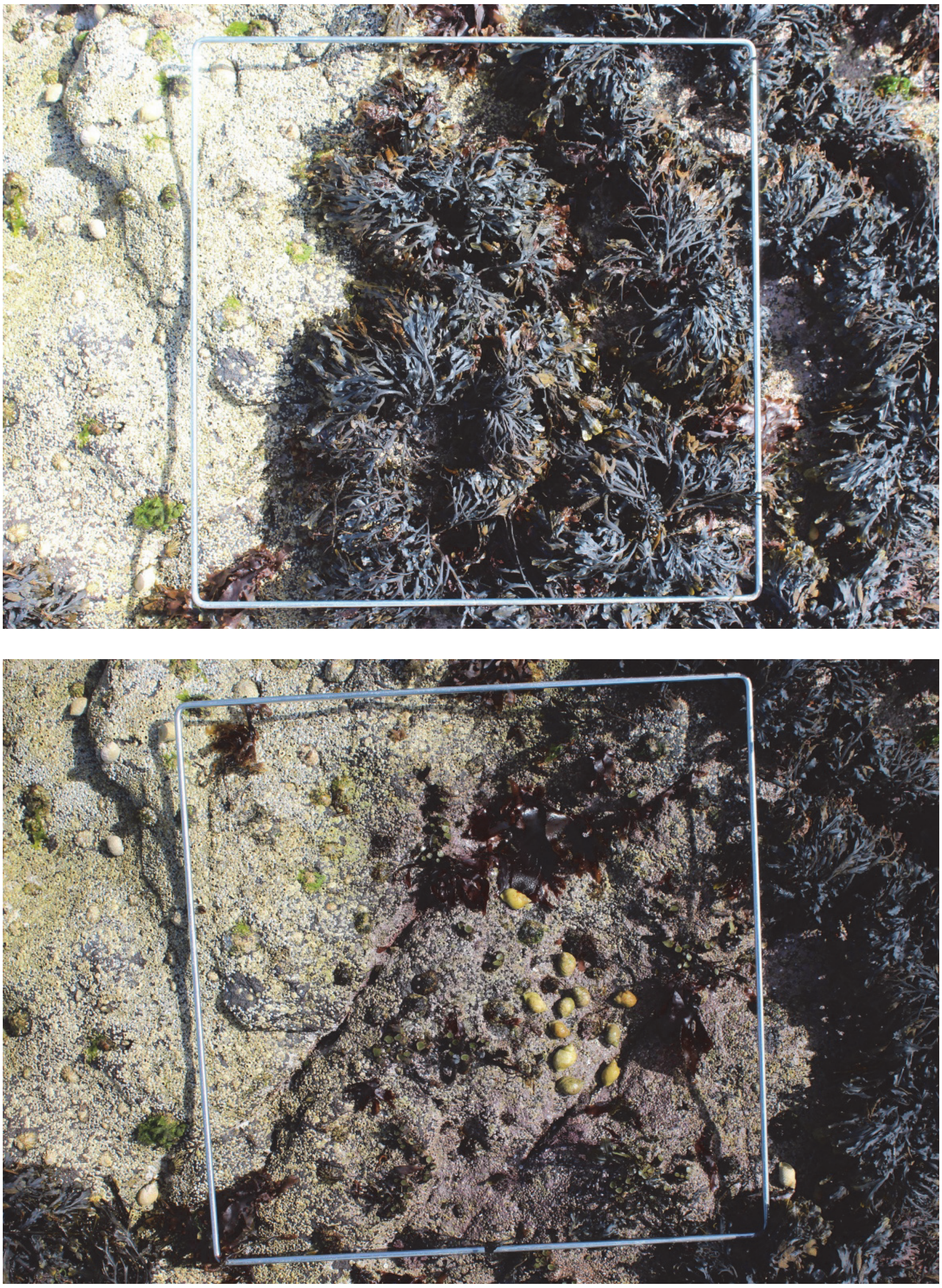


Figure 4: Glengorm, North Mull 14:55 13/7/2014, Lower1 (MTL -0.5m): an example of a 0.25m^2 quadrat (a) before, and (b) after removal of macroalgal canopy to allow estimates of percentage cover and population density of cryptic species. Dogwhelks, Nucella lapillus*, limpets,* Patella vulgata*, and the red seaweed* Palmaria palmata *can all be clearly seen and counted in the lower image, but not before the removal of Fucus vesiculosus plants.*

2.4 Data compilation and analysis methods

Site survey data were collated from on-site GPS location records, field notes and photographic data into a single data table (Annex A). *In situ* records of SACFOR abundance data were archived as scanned PDFs of data sheets (see for example Annex C), and have been entered into a single data table for cross-matching with site data (Annex E). An image catalogue has also been compiled for further cross reference with site and species abundance data.

3. ANALYSIS

Abundance and distributions of the MarClim species were compared with those in the previous MarClim surveys and with earlier records, predominantly from the biogeographical work of Alan Southward and Dennis Crisp from the 1950s to the 1970s.

3.1 Environmental context for surveys, and climatic change from 1940 to the present day (2016)

Two climate datasets were used to give the context for this study: sea surface temperature and the North Atlantic Oscillation index (NAO). Sea surface temperatures (SST) were derived from the UK Met Office's Hadley Centre HadISST v1.1 global sea-ice and SST dataset (Rayner *et al.*, 2003) which are based on *in situ* observations and satellite-derived estimates, and were obtained from the British Atmospheric Data Centre. Data are available as monthly 1° grids from January 1870 to May 2014. The North Atlantic Oscillation index values were obtained from the US National Center for Atmospheric Research (NCAS, 2016). The NAO index is a good indicator of weather patterns across northern Europe, especially in winter when positive values are associated with milder, wetter and often more stormy weather and negative values with calmer, settled and colder conditions (Figure 5).

Winter NAO values were positive in 12 of the 15 years before the millennium but there appears to have been more negative years (6/15) since that time. Greater NAO values are associated with stormy weather in northern Europe (Matulla *et al.*, 2008).

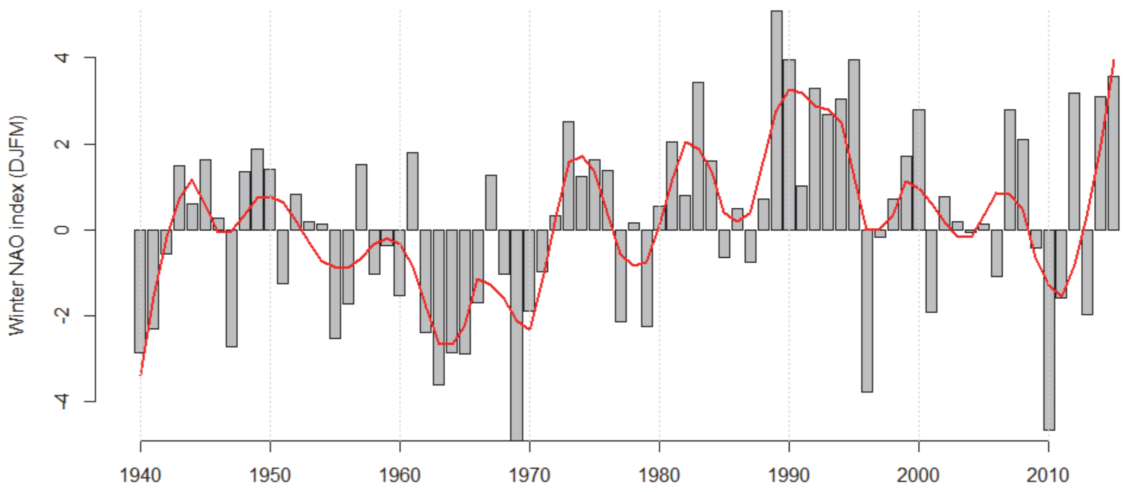


Figure 5: Changes in climate in Scotland since 1940: Winter values for the North Atlantic Oscillation index, the standardised difference in atmospheric pressure between Portugal and Iceland, with a smoothed line showing decadal changes (Loess smoother (span=10/75 years)). Positive values indicate wet, stormy conditions and negative values indicate dry, cold and settled conditions, evident in the winter of 2010.

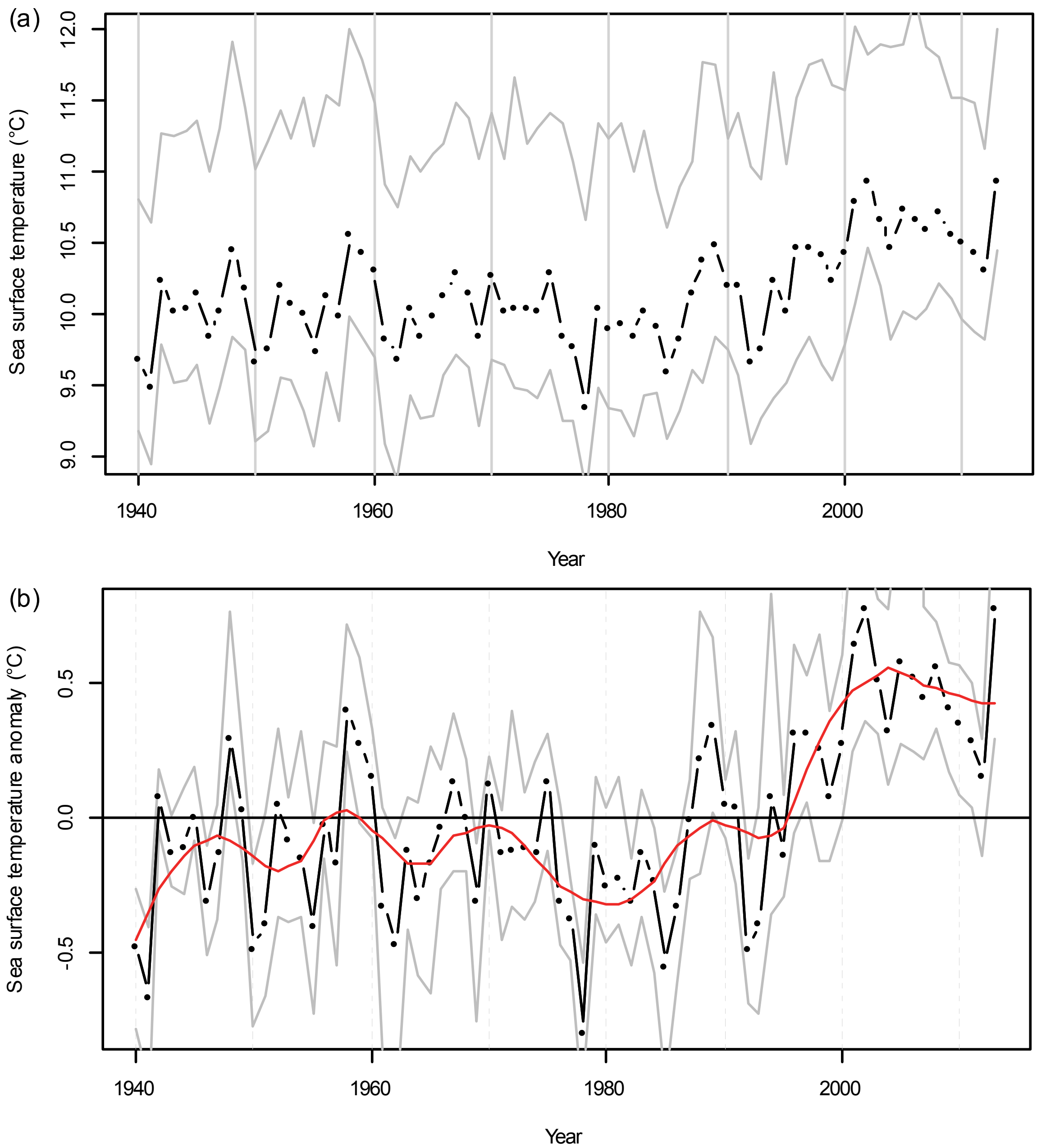


Figure 6: Changes in climate in Scotland's seas since 1940: (a) Sea surface temperature from the Hadley Centre HadISST1.1 dataset, extracted for the region (8°W to 1°E, 54°N to 61°N) and shown as the overall average annual temperature of the region (solid symbols and black lines) and the maximum and minimum (upper and lower grey lines) average annual temperatures in 1° areas (62km EW by 111km NS), (b) SST anomalies as differences from the 1940 to 2013 average shown as mean, minimum and maximum values across the region, with a smoothed line showing decadal changes (Loess smoother (span=20/75 years)).

MarClim surveys between 2002 and 2010 had been preceded by two decades of rapid temperature increases through the 1980s and 1990s (Figure 6) during which average annual sea surface temperatures around Scotland rose by around 0.6°C. Since 2000, however, temperatures remained relatively stable at around 0.5°C above the 75-year average, with no obvious upward trend (Figure 6b).

More complex analyses of seasonal weather patterns (rainfall, wind speed and direction, sunshine hours, air temperatures including the incidence of high and low extremes) have not been attempted, but each aspect of weather is likely to have an influence on the survival and performance of intertidal species on short- (such as the effects on foraging success of predators and grazers (Burrows and Hughes, 1989)) and long-term time scales (such as the effects of heatwaves on the vertical distribution of macroalgae (Harley and Paine, 2009)).

3.2 Surveyor variation: cross-validation of estimated categorical species abundance

Analysis of data from the 50 sites in 2014 where both surveyors estimated abundance for the same species showed a high degree of consistency among the two sets of estimates, with 66% of estimates being the same, 83% differing by one category or less and 92% within two categories (Figure 7 right). Both surveyors produced a similar distribution of abundance categories, but Surveyor 1 was more likely than Surveyor 2 to report species as 'not seen' (NS, a true absence, Figure 7 left), implying that a search had been made for that species in its habitat as opposed to 'not recorded' (NR), implying that no search was attempted or that searching was prevented by lack of or inaccessibility of suitable habitat. The combined proportion of NS and NR records were similar for both surveyors: Surveyor 1 recorded 69% of abundance estimates as NS or NR and Surveyor 2 67%. All surveys in 2015 were done by a single surveyor.

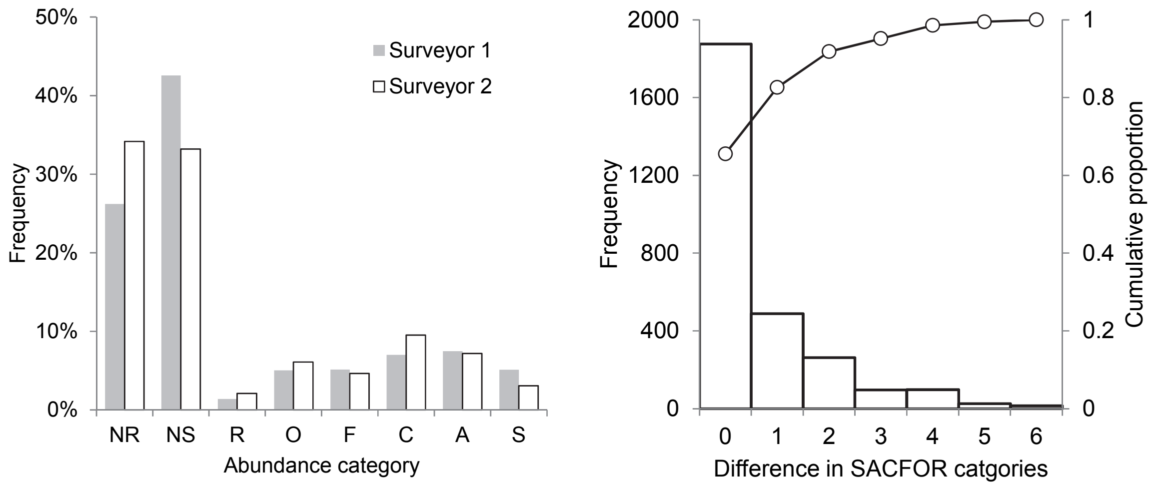


Figure 7: (left) Frequencies of matched abundance estimates for categorical abundance scores (NR, not recorded; NS, not seen; R, rare; O, occasional; F, frequent; C, common; A, abundant; S, superabundant). (right) Differences in SACFOR categories between the two surveyors are shown as frequencies of each difference (bars, values on left axis) and as cumulative proportions (line, right axis). Plots are based on 4499 matched abundance estimates.

3.3 Changes in species ranges since 2002-2010

The MarClim project recognises some species as cold-water species (e.g. *Alaria esculenta*, dabberlocks, *Semibalanus balanoides*, acorn barnacle; *Littorina littorea*, common periwinkle) (Burrows *et al.*, 2014) and others as warm-water ones. Of the warm-water species, some are present in Scotland (such as *Actinia equina,* beadlet anemone; *Anemonia viridis*, snakelocks anemone; *Chondrus crispus*, carrageen; *Chthamalus montagui,* Montague's barnacle; *Melarhaphe neritoides,* small periwinkle; *Gibbula umbilicalis,* purple topshell; *Himanthalia elongata*, thongweed), while others are only present further south and west in England, Wales and Ireland (including *Bifurcaria bifurcata,* brown alga; *Perforatus*

perforatus, volcano barnacle; *Patella depressa*, black-footed limpet; *Phorcus (Osilinus) lineatus,* toothed topshell). Range extensions in both groups of warm-water species are possible, but those in the second group are likely to result in species appearing on Scottish coasts for the first time. However, at this time, of these only *Phorcus (Osilinus) lineatus* is remotely likely to extend into Scotland, being present on Northern Irish rocky shores.

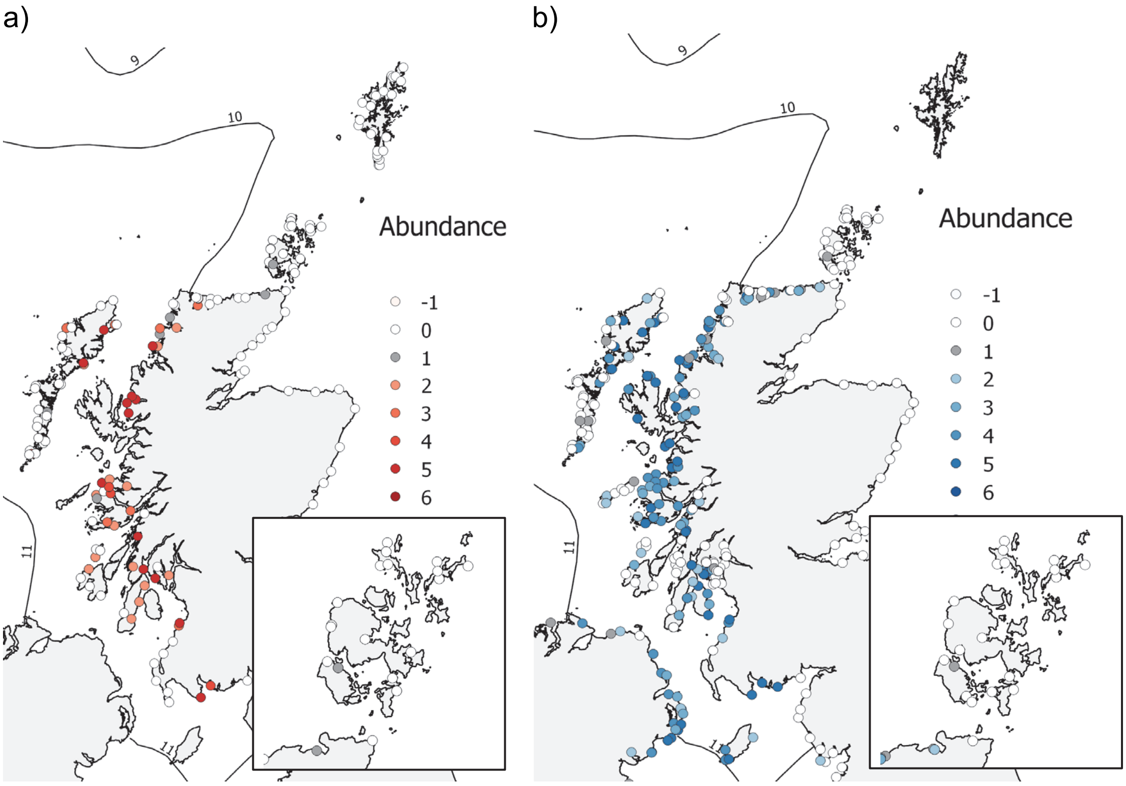


Figure 8: (a) Purple topshell, Gibbula umbilicalis*, distribution in 2014 - 2015, (b) same in 2002 -2010. Numbers correspond to ranked abundance categories (-1, Not Recorded; 0, Not Seen; 1, Rare; 2, Occasional, 3, Frequent; 4, Common; 5, Abundant; 6, Super Abundant). Inset maps show distributions around Orkney. (Contains OS data © Crown copyright and database right (2015)).*

Comparison of the MarClim surveys around Scotland between 2002 and 2010 with earlier records showed that a few species had extended their ranges northwards and eastwards into colder waters (Mieszkowska *et al*., 2006). Of these species, Mieszkowska *et al.* (2006) reported that the purple topshell, *Gibbula umbilicalis*, had extended its breeding range 55km further east from Skerray (58.44°N, 4.30°W, but with isolated individuals 45km further east) in 1985 (Kendall and Lewis, 1986). An isolated individual was seen at Quoyness on the Scapa Flow shore of Hoy during a further survey of Orkney sites in 2004. Surveys of the north coast in September 2014 found scattered individuals at similar places to those where *Gibbula umbilicalis* was recorded by Mieszkowska *et al.* (2006): at Murkle (11/9/2014), at Quoyness on Hoy (31/7/2015), and several individuals during two informal surveys of the Brough of Birsay (30/7/2014, 1/8/2015). However, these topshells were not markedly more abundant at mainland sites than they had been 10 years or so previously, and the species remained absent at sites along the Caithness coast. We conclude that there is no evidence for a further change in range of this species.

The other two conspicuous rocky shore species with northern distribution ranges that lie within the survey domain are the high-shore acorn barnacles *Chthamalus montagui*

(Southward) and *Chthamalus stellatus* (Poli). Crisp *et al.* (1981) reported the northern and eastern limits of these species as around the north-eastern tip of the Scottish mainland, with a couple of records of populations of *Chthamalus stellatus* in southern Shetland without corresponding *Chthamalus montagui*. Both species were reported as having sporadic populations along the north-eastern coast of Scotland from Caithness to Aberdeenshire in the late 1970s. Revisits to these areas in 2002-2010 showed the same patterns, but with isolated individuals of *Chthamalus montagui* further south than previously reported, at Johnshaven and Pittenweem. Surveys in 2014 and 2015 showed the same patterns, with a suggestion that more sites were occupied beyond the main range of each species, along the east coast (Figure 9, Figure 10). The survey of Shetland in July 2015 confirmed the suggestion by Crisp *et al.* (1981) that the range of *Chthamalus stellatus* in Europe extends as far as the northern extremity of Shetland, but that the northern limit of *Chthamalus montagui* is in Orkney. This agrees with other studies of Shetland, such as Hiscock (1981) who found only occasional *Chthamalus stellatus* on a single wave-exposed west coast site, and no *Chthamalus montagui* at any otherwise potentially suitable sites. The rocky shore monitoring programme of the Shetland Oil Terminal Environmental Advisory Group (SOTEAG) has surveyed 20-30 shores around Sullom Voe and Yell Sound annually since the late 1970s, and in that time has only recorded *Chthamalus stellatus* in Shetland and then only since 2011 at 3 sites (Moore and Howson, 2015). The appearance of *Chthamalus stellatus* in Yell Sound since 2011 and its becoming apparently more widespread in Shetland since Hiscock's (1981) earlier study suggests that this species may be increasing in abundance towards its northern range edge, in line with expectations from climate warming in the area since the 1970s.

The surveys also confirmed the regional absence of *Chthamalus stellatus* from enclosed areas on the west coast where *Chthamalus montagui* was present. The species was absent from the sheltered areas of most sea lochs and not found at all in the Clyde Sea in either 2002/2010 or 2014/2015 surveys.

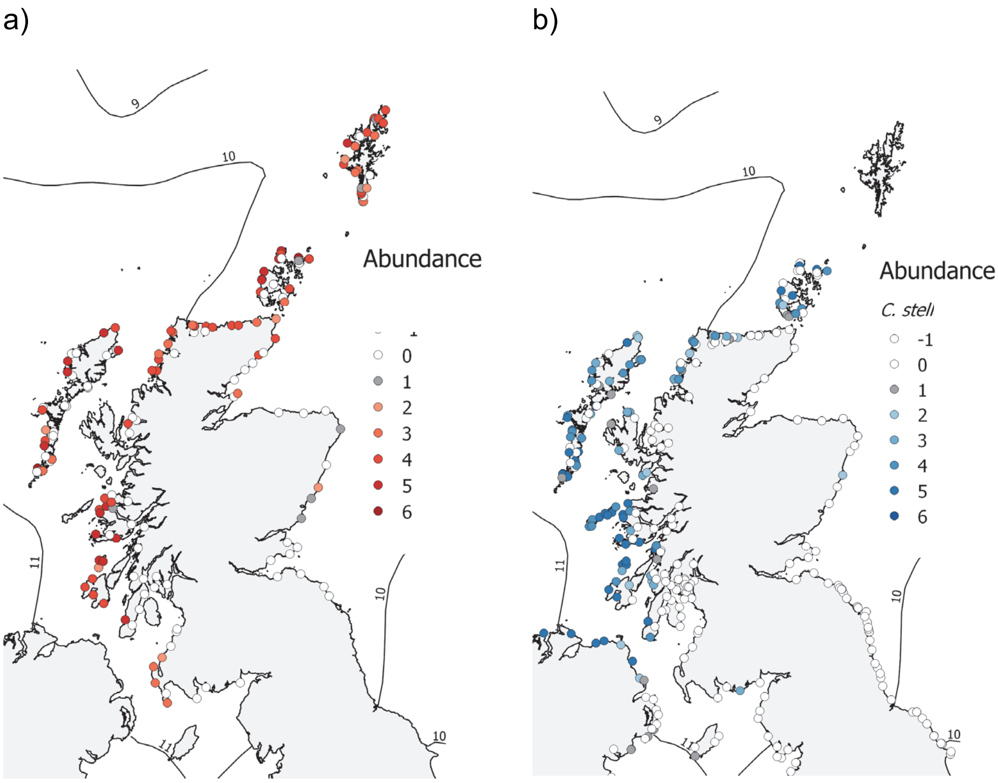


Figure 9: (a) Chthamalus stellatus *distribution in 2014 - 2015, (b) same in 2002 - 2010. Numbers correspond to ranked abundance categories (For key see Figure 8) (Contains OS data © Crown copyright and database right (2015))*

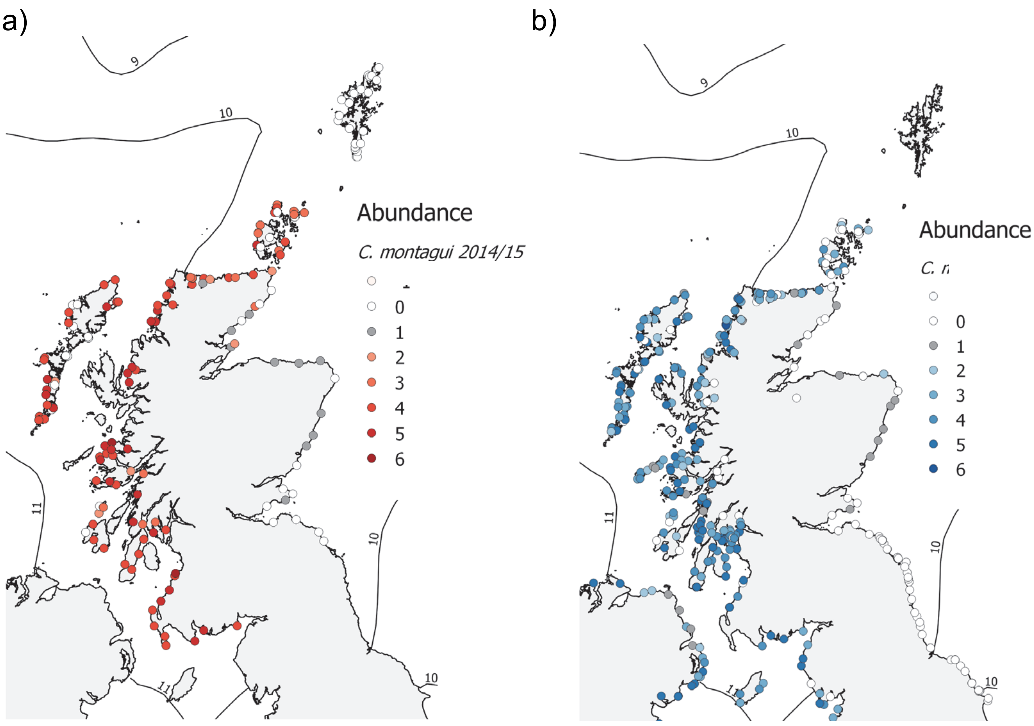


Figure 10: (a) Chthamalus montagui *distribution in 2014 - 2015, (b) same in 2002 - 2010. Numbers correspond to ranked abundance categories (For key see Figure 8) (Contains OS data © Crown copyright and database right (2015))*

Of the other MarClim species that could conceivably have extended their ranges into Scotland's waters, particularly *Phorcus lineatus* from Northern Irish rocky shores, none were observed at any of the sites surveyed in 2014 and 2015, despite extensive searches. Only a non-native seaweed (*Sargassum muticum*) showed any dramatic change in distribution: a change unlikely to be driven solely by climate change since in the UK the species is well within the thermal limits of its native geographical distribution (see Section 3.3.1).

3.3.1 Range extension of a non-native species

The most noticeable change since surveys of the same areas in the early 2000s was the spread of *Sargassum muticum* (wireweed) in western Scotland. This brown alga spread from the Firth of Clyde to sites on the west coast and was found as far north as Skye by 2008 (Trendall *et al.*, 2010a). Surveys in July 2014 showed that the species has since become well established in the south of Mull (Carsaig Bay, Figure 11a), and in Colonsay (Rubha Caol, Oronsay, Figure 11b), as well as being found at sites in the Clyde (such as Carradale) and in the south of the Kintyre peninsula (Westport) where the species had been previously recorded.

Sargassum muticum has formed abundant populations in mid to high shore rock pools, in a similar habitat to that occupied by the sea oak weed, *Halidrys siliquosa*. Elsewhere, plants were found in the shallow subtidal, often attached to small mobile rocks (the stonewalker plants referred to by Trendall *et al.* (2010a)). Combining previous observations with this new set of records will give the current rate of spread of the species and some indication of how widespread the weed may become over the next decade. In the Eastern Pacific *Sargassum muticum* is present (Phillips, 1995) from British Columbia (annual average SST 9-10°C) to Mexico (22-24°C), while in East Asia the species is found in southern and eastern Japan (9-23°C) (Critchley, 1983). Scottish coasts have average sea surface temperatures (9-11°C) towards the lower limit of the temperatures experienced by the species elsewhere, but the current known limit of *Sargassum* north of Ardnamurchan (Trendall *et al.*, 2010b) and as far as Ardtoe and Glenuig (M. T. Burrows, personal observations) is within its native temperature range. Climate warming may facilitate the spread of the species, since the species is generally found in warmer waters, but recent warming, most of which took place before 2000 (Figure 6b), is unlikely to be the direct cause of the spread over the last 15 years.

a) b)

Figure 11: (a) Sargassum muticum in a high shore pool at Carsaig Bay, South Mull 15:25 17/7/2014 amongst Halidrys siliquosa; (b) Widespread Sargassum muticum in a mid to high shore pool on Oronsay 14:50 16/7/2014.

3.4 Change in abundance of individual species since 2002-2010

Changes in distribution, unless pronounced, can be difficult to detect and are easily confounded by changes in the distribution of sampling effort in space and time (Bates *et al.*, 2015). Abundance change on the other hand is generally fairly easy to detect, and relatively unequivocally demonstrated especially where the same sites are visited repeatedly. The previous set of MarClim surveys in 2002 to 2010 attempted to revisit sites that had been surveyed by Dennis Crisp and Alan Southward in the 1950s and 1960s. In Ireland, Simkanin *et al*. (2005) were able to show how the abundance of intertidal species had changed between 1958 and 2003. Where a change was detectable, the abundance category ascribed tended to decrease, with five out of 12 northerly species declining (*Alaria esculenta*, *Balanus crenatus*, *Laminaria hyperborea*, *Saccharina latissima* and *Littorina littorea*) and one increasing (*Semibalaunus balanoides*) and only one out of nine southerly species (*Paracentrotus lividus*) showing a decline.

Most of the surveys in 2014-2015 were return visits to sites visited at least once in 2002-2010. Two hundred and twenty-three surveys were made at 156 sites in 2014-2015, with 91 single-survey sites and 63 two-survey sites (for cross-validation of SACFOR scores, see section 3.2). Of these 156 sites, 111 were exactly matched or were within 2km of surveys in 2002-2010 on shores of similar exposure, composition and aspect. Every 2002-2010 survey was matched with one of the 111 resurveys, giving up to 369 comparisons of abundance per MarClim species in Scotland (site-specific comparison of species abundance where the species was recorded in each period). A subset of these data where the same sites were surveyed by the same surveyor (RH, surveyor-site-specific comparison) was also analysed for changes, giving up to 354 comparisons. This latter comparison gave essentially the same results as the wider comparison so is not considered further here.

Changes in abundance between the two periods were analysed in two ways: (1) the frequency of sites at which abundance increased, decreased or stayed the same (Annex B, Table 2 and plotted as a bar chart in Figure 12), and (2) the change in distribution of abundance values (SACFOR scores) by species (Annex B Table 3).

Whether compared by site-specific increases and decreases (Table 2) or by changes in average abundance (Table 3), patterns of changes among species were similar. The greatest decline was recorded for the blue mussel *Mytilus edulis* that decreased in abundance at 54% of sites and by an average of 0.76 categories. The decline in intertidal mussel beds was especially marked at some sites, including a particularly dramatic change at Caolas an Scarp on Harris where a shore previously dominated by mussels in 2004 became one where continuous mussel beds were absent (Figure 13).

Four species showed an average decline in matched abundance values (*Mytilus edulis, Melaraphe neritoides, Gibbula umbilicalis* and *Gibbula cineraria*, (Annex B Table 2), with the first three as statistically significant changes) while six species showing a decline in average abundance across the sites (*Gibbula umbilicalis, Mytilus edulis, Littorina littorea, Melaraphe neritoides, Elminius modestus* all at $P<0.05$ and *Patella ulyssiponensis,* Annex B Table 3). Many more species showed increases, with 31 species showing increases in average overall abundance (24 species $P<0.05$) and 31 species showing more increases than decreases in abundance across paired sites (24 species $P<0.05$). While the possibility exists that surveyors have erred on the generous side in estimating abundance categories, repeated photography (see example in b) Figure 14) suggests that the recorded changes are real. The tendency for most species to have increased in abundance is likely to have resulted from amelioration of environmental conditions for those species. Conditions may have favoured better recruitment and survival of settling larvae and algal sporelings in 2014-2015 and the years immediately preceding the resurveys.

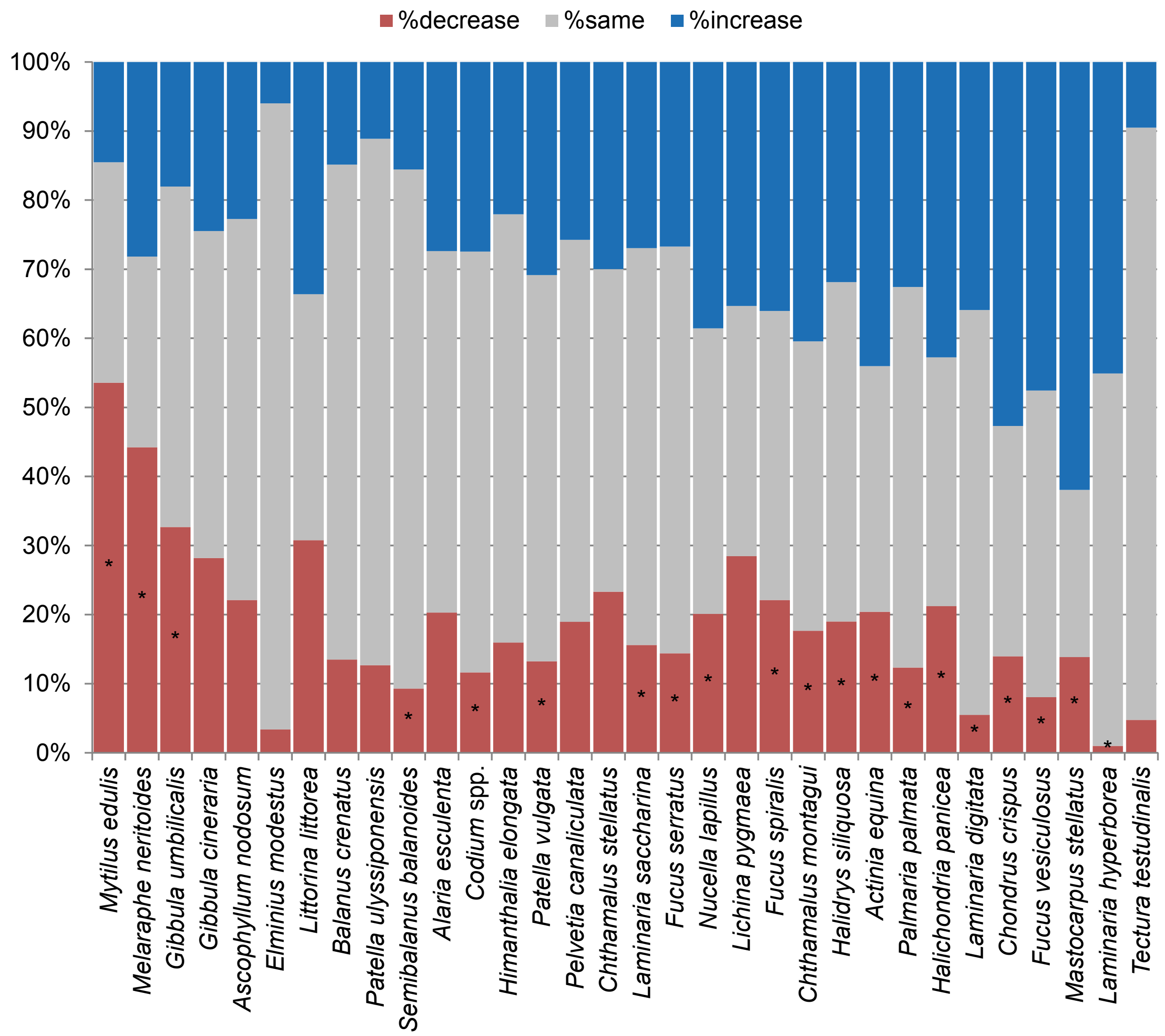


Figure 12: Changes in species abundance since previous surveys in 2002-2010 for all sites re-surveyed in 2014 and 2015, expressed as the percentage of sites where abundance decreased by one or more SACFOR category (red bars), where abundance remained the same (grey bars), and the percentage of sites where abundance increased (blue bars). Species are arranged in order from those showing the greatest decline in abundance to those showing the greatest increase in abundance. Asterisks indicate where the proportion of sites differs from an expectation of 1:1 ratio of sites with decreased abundance to those where abundance increased, ($p<0.05$ using chi-squared tests). Values are provided in Annex B.

A noteworthy aspect of the pattern of changes in species abundance is the disproportionate representation of macroalgae among those showing an increase. All species of macroalgae increased in abundance. The ranking of all species by the average magnitude of change at paired sites (Annex B Table 2) shows that the 8 most-increased species are all macroalgae, with no algae in the bottom 8 species either declining or remaining the same.

a)

b)

Figure 13: Loss of intertidal mussels at Caolas an Scarp, Harris. (a) 2/7/2004, (b) same view on 11/8/2014.

a)

b)

Figure 14: Increase in intertidal macroalgae at Eriskay Outer. (a) 6/7/2006, (b) same view on 14/8/2014. Photos were taken from different viewpoints; the arrows indicate the same part of the reef in each photo. Fucoids increased particularly in the upper intertidal to the right of the arrowed area.

Changes in abundance among species were not related to the thermal preference of each species. We have recently defined thermal preference as the median temperature experienced throughout the species' range (Burrows and others, in preparation), a measure also known as the Species Temperature Index (STI, Devictor *et al*., 2008, 2012). Indices of community response to changing temperature can be constructed from multiple STI measures, and we use this approach in Section 3.5 to evaluate the response of rocky shore communities around Scotland to climate change. Here, the STI measures can be used to compare abundance changes among warm water and cold water species (Figure 15).

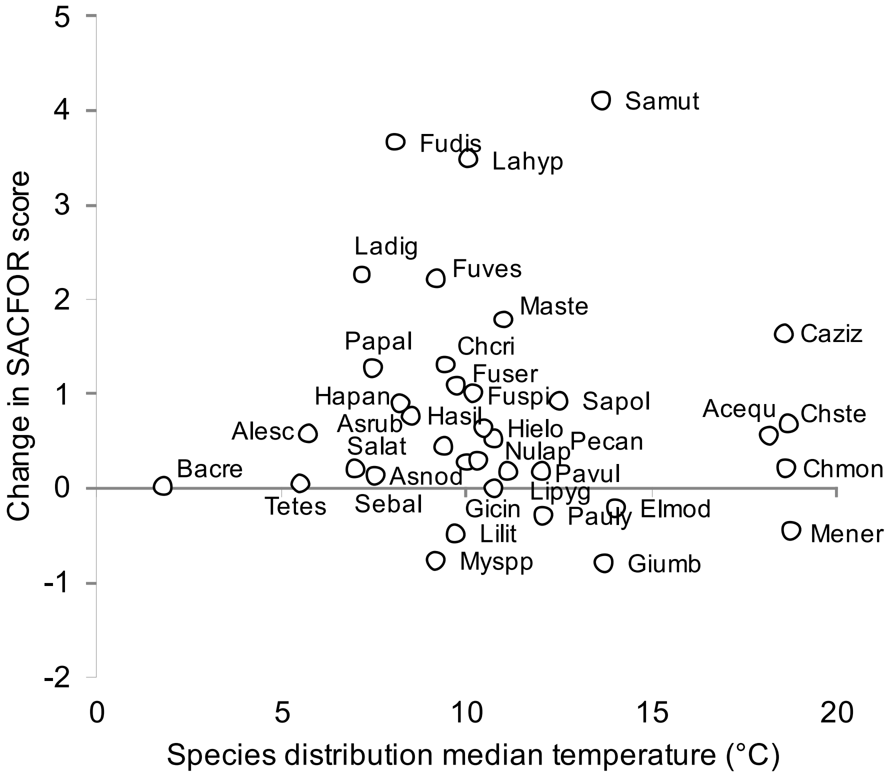


Figure 15: Changes in SACFOR score for resurveyed MarClim species in Scotland between 2002-2010 and 2014-2015 plotted against each species' median temperature (Species Temperature Index, STI). Symbols show change in average abundance across all sites. NR (Not recorded) values are omitted from calculations. Species abbreviations: Gibbula umbilicalis, *Giumb;* Mytilus edulis, *Myspp;* Littorina littorea, *Lilit;* Melaraphe neritoides, *Mener;* Patella ulyssiponensis, *Pauly;* Elminius modestus, *Elmod;* Gibbula cineraria, *Gicin;* Balanus crenatus, *Bacre;* Tectura testudinalis, *Tetes;* Semibalanus balanoides, *Sebal;* Patella vulgata, *Pavul;* Lichina pygmaea, *Lipyg;* Saccharina latissima, *Salat;* Chthamalus montagui, *Chmon;* Codium *spp, Cospp;* Nucella lapillus, *Nulap;* Pelvetia canaliculata, *Pecan;* Ascophyllum nodosum, *Asnod;* Himanthalia elongata, *Hielo;* Actinia equina, *Acequ;* Alaria esculenta, *Alesc;* Halidrys siliquosa, *Hasil;* Chthamalus stellatus, *Chste;* Asterias rubens, *Asrub;* Halichondria panicea, *Hapan;* Saccharina polyschides, *Sapol;* Fucus spiralis, *Fuspi;* Fucus serratus, *Fuser;* Palmaria palmata, *Papal;* Chondrus crispus, *Chcri;* Calliostoma zizyphinum, *Caziz;* Mastocarpus stellatus, *Maste;* Fucus vesiculosus, *Fuves;* Laminaria digitata, *Ladig;* Laminaria hyperborea, *Lahyp;* Fucus distichus anceps, *Fudis;* Cystoseira tamariscifolia, *Cytam;* Sargassum muticum, *Samut.*

No statistically significant relationship exists between the magnitude and direction of change in abundance and species temperature index (STI): cold-water species were no more likely to decrease than warm-water species were to increase. Large increases in average abundance per site for species that were previously not recorded, notably *Sargassum muticum*, reflect only the method of calculation. *Sargassum* became more abundant at those sites where the species had been recorded in either period, going from Rare at one site and not seen at 69 sites to being Rare to Superabundant at eight sites in 2014-2015. This effect only applies to those species recorded at fewer than 10 sites (*Asterias rubens*, *Saccharina polyschides*, *Calliostoma zizyphinum*, *Fucus distichus anceps*, *Cystoseira tamariscifolia* and *Sargassum muticum*). Treating 'Not Recorded' values as 'Not Seen' values (i.e. true absences) would remove this discrepancy, but would introduce a further assumption.

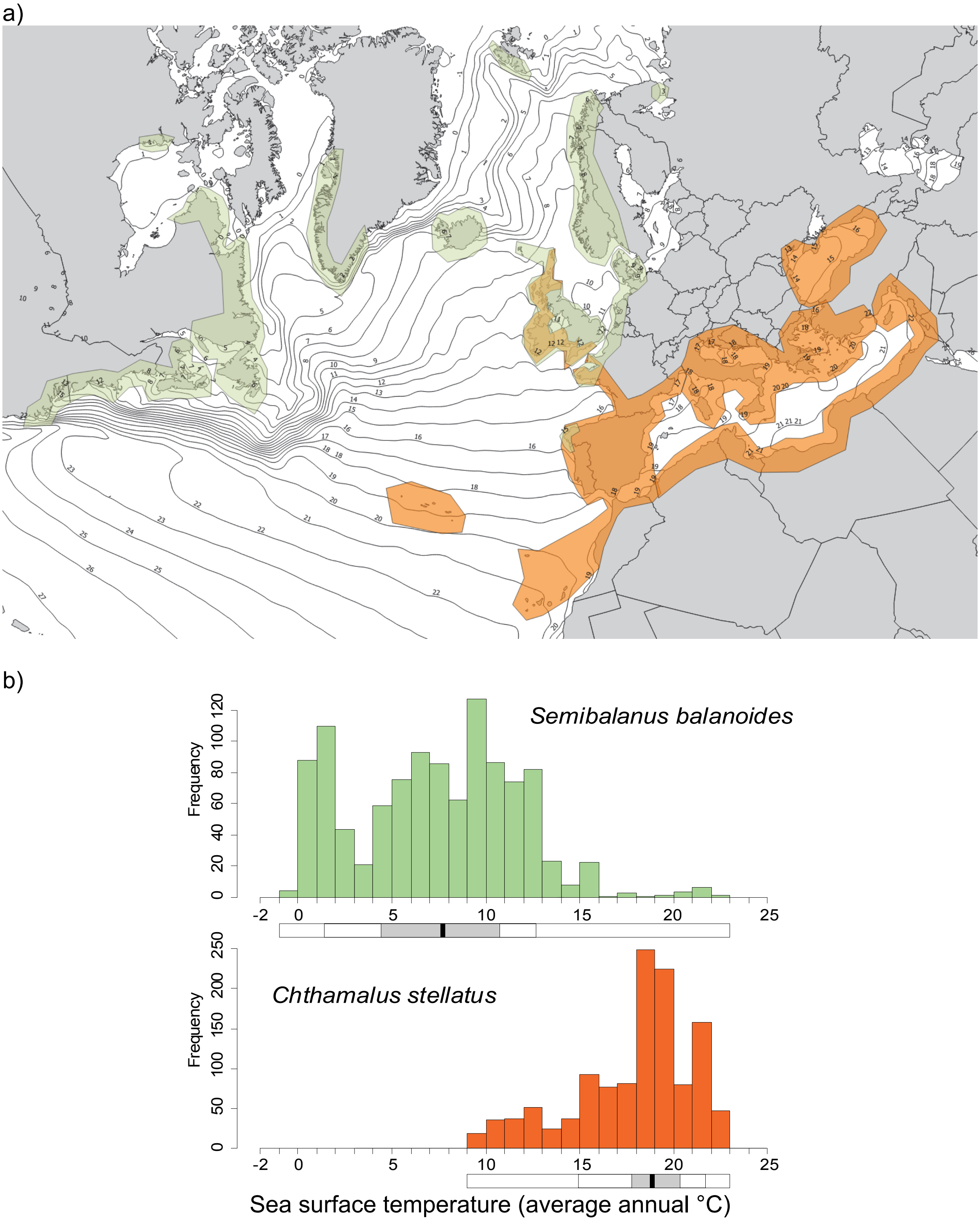
3.5 Community response to climate-change

A recent approach to measuring community-wide responses to temperature involves the calculation of a Community Temperature Index (CTI): the average 'temperature preference' of all the species in a community weighted by their abundance (Devictor *et al*., 2008, 2012) . CTI uses the global distributions of species to define their thermal niches, and takes the average of the species temperature midpoints (T_i , the temperature in the middle of the geographical range of the species) weighted (w_i) by their abundance or presence in a community of *n* species to produce index values, thus:

$$CTI = \sum_i^n T_i w_i \Big/ \sum_i^n w_i$$

A species' thermal niche is described here by the median or average of the temperatures experienced throughout its range (Species Temperature Index, STI, T_i above), with stenothermy (i.e. narrow temperature range)/ eurythermy (i.e. variable temperature range) given by the standard deviation or interquartile range (hereafter Species Temperature Range, STR), comparable with physiologically derived thermal ranges that generally match their ambient temperature ranges. Geographical ranges for MarClim species were derived from literature records and drawn as polygons (Figure 16a). The polygons were then used to extract values for average sea surface temperature over the period 1982-2011 for coastal 0.25 degree latitude/longitude cells. The percentiles of the distribution of those average SST values were then used to describe the species thermal range, with the 50%ile (median) value giving the Species Temperature Index (Figure 16b). This process has been completed for 58 MarClim species to produce STI values (Figure 17).

Burrows *et al.* (2014) proposed a similar measure based on the ratio between the abundance of warm-water species and the abundance of a combined selection of cold water and warm water species, in a recent report for JNCC on the development of Good Environmental Status indicators for the implementation of the European Marine Strategy Framework Directive (Burrows *et al.,* 2014). The Community Temperature Index offers an alternative to that approach and its use is recommended in future assessments of the climate change responses of rocky shore communities, and for assessing climate-related community change in general.



Horizontal bars show thermal niches as minimum, 10%ile, interquartile range (grey), median (thick line), 90%ile and maximum.

Figure 16: (a) North Atlantic distributions of two UK barnacles: Lusitanian Chthamalus stellatus *(orange polygons) and boreal* Semibalanus balanoides *(light green polygons) from literature records. (b) Frequency distribution of temperature in 0.25dg coastal cells within each species range. Temperatures are from the NOAA Optimal Interpolation Sea Surface Temperature (SST) dataset (OISST HR), showing the average annual SST for 1982-2011.*

Figure 17: Thermal ranges for MarClim species as defined by percentiles of average sea surface temperatures throughout their global distributions. Species are arranged in order of their Species Temperature Index values; the 50%ile or median average sea surface temperature across their range.

3.5.1 Site-specific Community Temperature Index values for 2014-2015

Site specific CTI values were calculated for every survey in 2014-2015 and, despite some variability, showed the expected pattern of communities with a greater dominance of warm-water species in the west of Scotland than in the east (Figure 18), with values ranging from 8.7 to 12.9°C. East coast sites showed relatively consistent values between 9.5 and 10.5°C. West coast and island sites were much more variable, with shifts between cold-water and warm-water dominance over relatively small spatial scales. The causes of these shifts are not yet known, but experience has shown that species richness has a strong influence: sites with fewer species tend to have 'noisier' CTI values, and species abundance may be influenced more strongly by habitat specific factors such as local wave exposure or lack of suitable substratum at some shore levels. Local variability in CTI values is most likely driven by habitat-related changes in species composition.

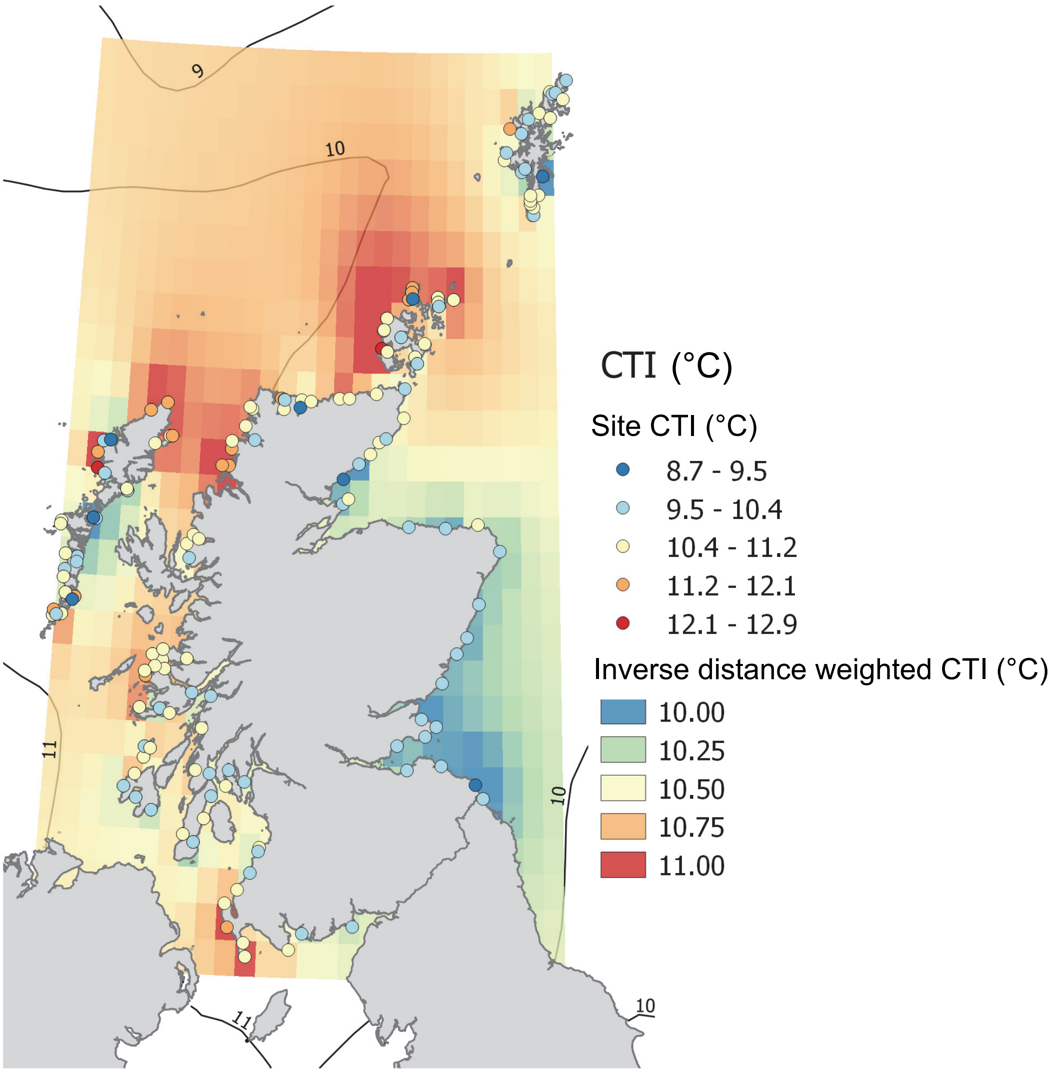


Figure 18: Community Temperature Index values from rocky shore survey sites in 2014-2015. Regional patterns are highlighted by gridded local average CTI values (CTI 2014-2015 above) calculated from site values by inverse distance weighting (IDW). Contours show average SST values from the NOAA OISSTHR 1982-2011 climatology. (Contains OS data © Crown copyright and database right (2015))

3.5.2 *Climate-related change in community composition between 2002-2010 and 2014-2015*

a) b)

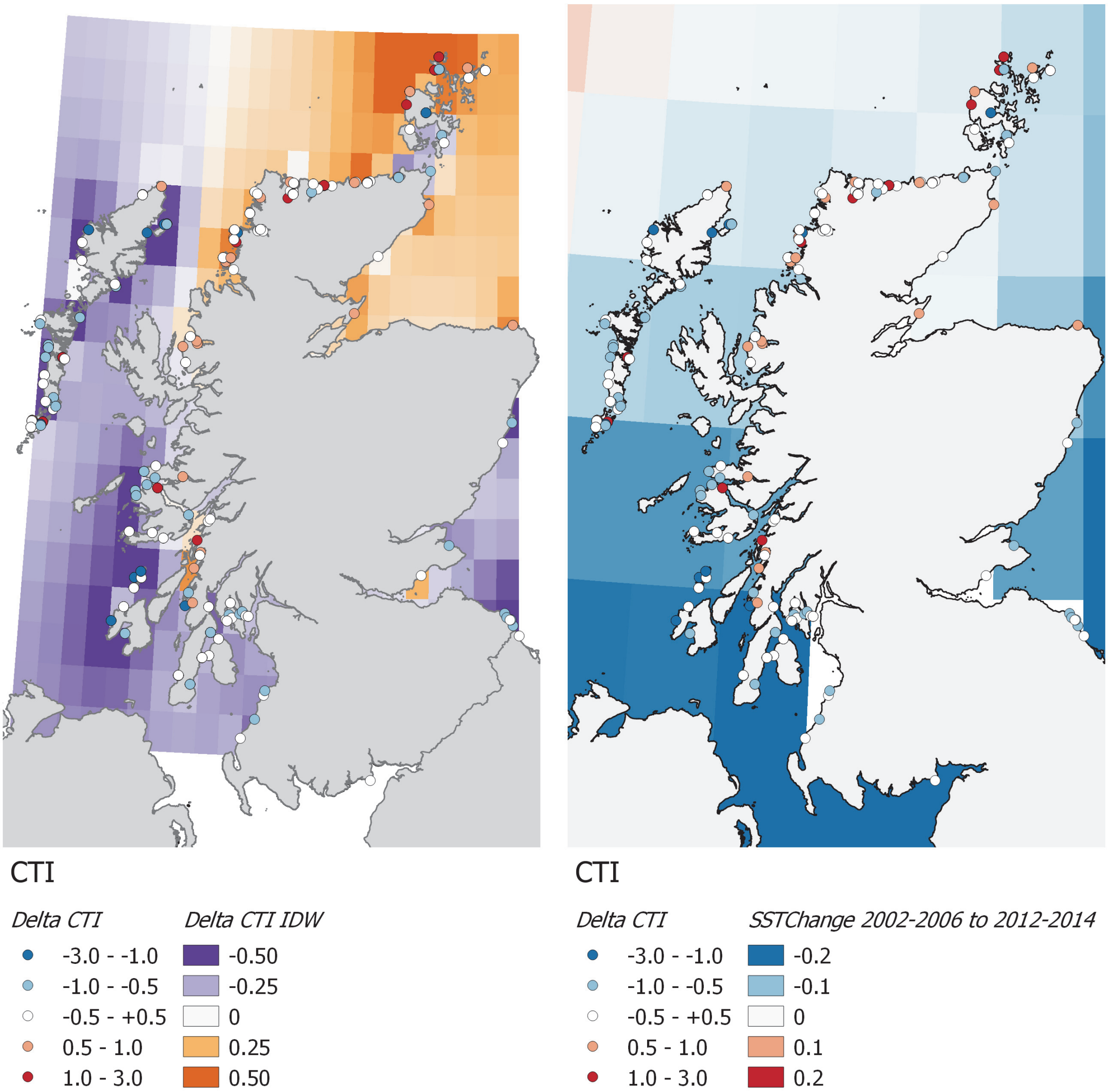


Figure 19: Change in Community Temperature Index values at rocky shore sites from 2002-2010 to 2014-2015. (a) Regional patterns shown by gridded local average change in CTI values calculated by inverse distance weighting (IDW: Delta CTI IDW in the plot legend). (b) Site-specific CTI changes overlaid on calculated changes in sea surface temperature for comparable and influential periods around the two sets of surveys based on differences in averages for 2002-2006 and 2012-2014 from the HadISST v1.1 1-degree monthly dataset. (Contains OS data © Crown copyright and database right (2015))

There were regional differences in the pattern of change in Community Temperature Index between the two periods (Figure 19a). Changes in west and south-east Scotland were generally negative by up to -0.5°C while those in north and in Orkney were generally positive up to +0.5°C. Sea surface temperatures were on the whole similar in the two reference periods (2002-2006 and 2012-2014, Figure 19b). In the south, temperatures were slightly lower in 2012-2014 than in 2002-2006 where as in the north there was little difference.

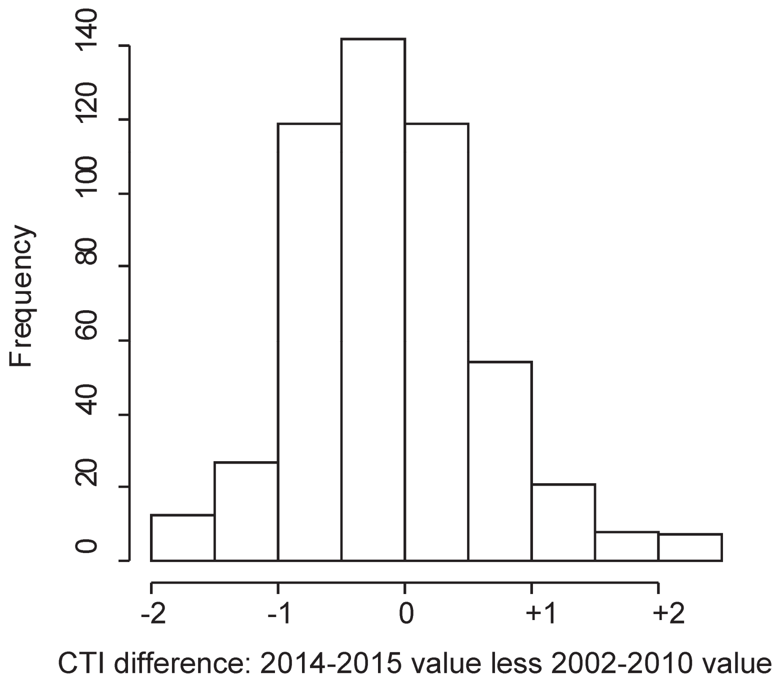


Figure 20: Change in Community Temperature Index values at rocky shore sites from 2002-2010 to 2014-2015: Frequency distribution of site-specific differences in CTI.

Changes in community composition related to temperature can be shown by changes in Community Temperature Index across those survey sites visited in 2002-2010 and again in 2014-2015 (Section 3.4). CTI values were calculated for every site survey in each period and the difference between these two values obtained (Figure 20). Site-specific changes in CTI varied from -1.9°C to +2.4°C. The mean site-specific difference in CTI values between 2002-2010 and 2014-2015 was -0.104°C and the standard deviation of this difference was 0.749°C (Figure 20). A t-test of the hypothesis that the difference was not different from zero was highly significant at $P<0.05$ ($t= -3.12$, $n=510$ comparisons). Across all sites it can therefore be concluded that there was a slight 0.1°C shift towards a colder-water assemblage between the two sampling periods. The significance of this change is discussed in Section 4.3.

4. DISCUSSION

Changes in rocky shore communities around Scotland over the last decade and the potential causes of the observed changes are discussed here, particularly in relation to climate change. Unlike the preceding decade, the period from 2002 to 2014 in Scotland was not characterised by an increase in sea surface temperature (Figure 6). Temperatures stayed around the level reached at the end of the 1990s at about 0.5°C above the long term average for the period since 1940. Most of the temperature increase in the last 75 years happened between 1980 and 2000, immediately prior to the first set of MarClim surveys beginning in 2002.

4.1 Species range changes

Early surveys of rocky shore species in the 1950s, 1960s and 1970s targeted a smaller number of species that reached their range limits in the UK and were aimed at establishing the location of these ranges edges. Alan Southward from the Marine Biological Association (MBA) in Plymouth surveyed shores along the north coast of Scotland in September 1953 and showed that the northern limits of *Gibbula umbilicalis* and *Chthamalus* species occurred in the area. Rocky shores were surveyed again in Scotland in the second half of the 1970s by the Scottish Marine Biological Association – Marine Biological Association Intertidal Survey Unit (SMBA/MBA ISU, Powell *et al.*, 1979; Bartrop *et al.*, 1980; Harvey *et al.*, 1980; Powell *et al.*, 1980, data available at BODC). These surveys were primarily descriptive and although species lists were compiled from each site, the species recorded were not consistent between surveys and the assessment of abundance followed variable and informal methods. The standard of taxonomic identification on these surveys was very high and records of presence of species at locations from this period can be treated with high confidence. Special attention was not paid to range-edge species and the recording of those species of interest (such as *Gibbula umbilicalis, Chthamalus montagui* and *Chthamalus stellatus*) was not sufficient to establish definitive range edges prior to the most recent phase of warming. After this period, the NERC-funded Rocky Shore Surveillance Group based at Leeds and Newcastle Universities focused on populations of species near their range edges, and in particular the topshell *Gibbula umbilicalis* in northern Scotland. This work was enough to allow the first MarClim surveys to establish that a shift in distribution in this species had occurred between 1986 and 2003 (Mieszkowska *et al.*, 2006). For the barnacle species, a revision of the taxonomic status of the genus *Chthamalus* in the UK (Southward, 1976) prompted a fresh look at the range edges of the two then-new species *Chthamalus montagui* and *Chthamalus stellatus* (Crisp *et al.*, 1981).

Analysis of the MarClim surveys in the same areas in 2002-2010 and 2014-2015 showed that the ranges of these species had not altered since the 1970s and 1980s. Increasing numbers of records suggest that the sporadic isolated populations of *Chthamalus stellatus* down the east coast may currently be slowly increasing.

4.2 Changes in species abundance

As noted in Section 4.1, prior to the MarClim project the form of earlier records of abundance and presence make difficult a rigorous comparison with the last two decades (2002-2010 and 2014-2015). With the same methods and largely the same personnel, a comparison of species-specific abundance changes over the last 10 years is possible and has been done here (see Section 3.4). These changes are dominated by the overall increases in macroalgae and marked decline in mussels *Mytilus edulis*, with smaller declines in other invertebrates (*Melaraphe neritoides, Gibbula umbilicalis, Gibbula cineraria*). The pattern of change in abundance among the species over the decade was not related to their thermal affinities (Figure 15).

Without implying a link between the observed changes and other aspects of climate change, and in the absence of strong evidence, it is, however, worth noting that the pattern of increases in macroalgae and decreases in shell-forming mussels has been seen elsewhere (Wootton *et al.*, 2008). The effects of ocean acidification on marine species including many of those represented here has been an active area of research since the mid-2000s, and a variety of positive and negative responses have been observed to combinations of increased temperature and increased CO_2. Among ocean taxa, fleshy macroalgae may benefit from high CO_2 conditions (Kroeker *et al.*, 2013; Brodie *et al.*, 2014) in terms of enhanced growth and reproduction. Shell-building invertebrates, including molluscs and crustacea, on the other hand show mostly negative effects of high CO_2 conditions on calcification and growth if not reproduction (Whiteley, 2011). A high CO_2 environment for *Mytilus edulis* mussels reduces health during short-term exposure (Beesley *et al.*, 2008), reduces size and thickness of larval shells (Gazeau *et al.*, 2010), although field experiments suggest that other influences such as food availability may have a bigger influence than CO_2 (Thomsen *et al.*, 2013).

On the Pacific west coast of North America, similar changes in intertidal communities have been shown to be accompanied by a decadal decline in nearshore pH levels (Wootton *et al.*, 2008). Intertidal communities on Tatoosh Island monitored between 2000 and 2007 showed that declining pH was associated with reductions in large dominant calcifying species, including *Mytilus californianus*, and increases in fleshy macroalgae. The study also showed that interactions were also important and that removal of dominant species may allow others to increase following reductions in pH. This region has been hit strongly by the effects of ocean acidification with significant impacts on the local oyster industry (Barton *et al.*, 2015). However, at present there is no supporting evidence to suggest similar problems in the Scottish shellfish industry with production relatively stable over the same period as these surveys (Munro and Wallace, 2015). There is no baseline measurement of pH, inorganic carbonate and alkalinity that covers the current period but measurements have been taken at coastal sites by Marine Scotland Science since 2012.

Finally, mussels have been known to fluctuate in abundance over the same sorts of timescales in the past. The early French intertidal ecologist Fischer-Piette (1935) found a heavy spatfall of mussels in a single year dominated that shore for the next few years and was finally eliminated by predatory dogwhelks over the next decade. Recruitment of mussels in the Pacific Northwest shows a similarly variable pattern of recruitment (Menge *et al.*, 2009). This evidence suggests that attribution of decadal changes in abundance to a long-term climatic effect, albeit when those changes occur over a scale of several 100s of km, should be approached with caution.

Weather patterns may have played a role in shaping the changes observed. The short-term variability in climate indicated by the North Atlantic Oscillation (NAO) index may influence the abundance of rocky shore species. Species characteristic of sheltered shores may fare less well during or immediately after periods of stormy weather, for example, with macroalgae species such as *Fucus vesiculosus* being removed by storm events. The winters preceding the 2014-2015 surveys had been particularly stormy, while those prior to the 2002-2010 surveys (and the high effort years of 2002, 2003 and 2004) were characterised by near zero NAO values, suggesting less stormy winters. These differences might be expected to result in greater removal of attached algae in the second set of surveys, which is the opposite of the observed increases in this group of species between the two survey periods.

4.3 Changes in community composition

The Community Temperature Index (CTI) analysis presented in Section 3.5 showed a small, statistically significant 0.1°C shift towards dominance by cold water species. This is in line with the lack of a clear trend in sea surface temperature in the region over the same period.

Although the association of species-level changes with their thermal affinities (Figure 15) was weak or absent, collectively the positive changes in cold-water species (e.g. *Fucus distichus, Alaraia esculenta* and *Asterias* rubens) outweighed those of warm-water species such as *Gibbula umbilicalis* and *Patella ulyssiponensis*.

It is not surprising therefore that climate-related shifts in species distributions, patterns of abundance or community composition have not emerged in the comparisons of rocky shore communities over the last decade. The CTI approach has proved useful, however, for communities in other habitats and is a good indicator of how the whole community has shifted. The early data from the 1950s, 1960s, 1970s and 1980s focused on the changes in a much smaller subset of the rocky shore biota. The surveyors were not wrong in addressing the abundance of contrasting cold-water and warm-water species at the expense of a broader view of the whole community, since changes in species with contrasting affinities are likely to be most informative in relation to improving our understanding of responses to changing temperatures. The approach to future monitoring of rocky shore communities is the focus of current research efforts and is likely to further yield policy relevant indices of change, particularly in interpreting spatial patterns (Stuart-Smith *et al.*, 2015) and changes in community composition over time (Burrows and others, in preparation).

4.4 Recommendations for further work

This set of return surveys and extensions to other areas has proved successful in detecting both site-level and coastwide change in rocky shore species across Scotland. While the period between this current intensive effort and the previous countrywide surveys has been a time of relatively little climate change, this situation is unlikely to persist in the coming decades. The so-called 'climate hiatus' since 1998 has proved not to be a long-lived phenomenon and (http://data.giss.nasa.gov/gistemp/) further change in temperature is highly likely to be upwards alongside a gradual decrease in seawater pH (IPCC, 2013). Further repeated surveys will be needed to track the responses of coastal species to changes in anthropogenic climate change and other human impacts. While rocky shore species may not be economically important, many studies have shown their responsiveness to changes in the environment, be they natural or man-made. Ease of access, and a growing capacity for public engagement in data collection (such as http://www.capturingourcoast.co.uk/), makes these marine habitats a good choice for low cost and frequent assessment of change.

A drawback of decadal resurveys of the coastline is that little is known of changes in the intervening period. The timescale of the observed changes is not known: observed differences may have come about as a result of gradual change over the whole period, or may have happened immediately before the second set of surveys. A programme of surveys that revisited a smaller selection of 30-40 sites at least every 2-3 years would give a clearer picture of shorter term variability in species abundance and community composition, and would give much earlier indications of any marked responses and more confidence in the conclusions of longer-term change. The whole set of sites should be resurveyed at least every 10 years for a complete picture of coastwide change. Where appropriate this could be undertaken as part of other survey and monitoring work following the MarClim protocol, supplemented by targeted surveys at key nodal sites around the coast.

Interpretation of and attribution of the causes of change in abundance and distribution ranges of rocky shore species could benefit from more targeted research. The possibility of ocean acidification being responsible for some of the changes seen suggests the need for better coverage in the measurement of temporal and spatial patterns in physical and chemical properties of the seas around Scotland. When implemented alongside more regular monitoring of rocky coastal species, increased data will make clearer the associations between environmental change and observed responses.

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ANNEX A: SURVEY SITE LOCATIONS

Table 1: Sites surveyed in 2014 and 2015, showing planned times of arrival and departure and actual times of arrival. NA in actual time of arrival column denotes the planned site was not surveyed, while missing planned times show sites that were not included in the original plan. Expected height and time of low water are given for the nearest tidal reference location. 'Order' denotes the sequence of photography (H, high; U, upper; M, mid; W, lower; L, low) with asterisks showing where shore levels were not photographed or were unusually inaccessible.

Date	Area	Lat	Long	Site	TimeLW	Height LW	Time Arrived	Order	Weather1	Weather2
Friday 11/07/2014	Cowal	55.86129595	-4.97949799	Toward	17:34	0.34	15:25	HMUWL	Sunny	L. breeze
		55.93925695	-5.18300397	Fearnoch	17:34	0.34	17:20	LMHUW	Sunny	
		55.82710097	-5.21051195	Ardlamont	17:34	0.34	18:50	LMHWU	Overcast	Dry
Saturday 12/07/2014	Kintyre	55.75122798	-5.38578099	Claonaig	18:29	0.34	16:10	HMUWL	Rain	
		55.59275796	-5.46525895	Carradale	18:29	0.34	17:30	LMHWU	Heavy rain	
		55.42461296	-5.58156397	Campbeltown	18:29	0.45	18:45	LMHWU	Overcast	Occ. rain, W. breeze
		55.47643499	-5.71333696	Machrihanish	21:40	0.61	20:20	HL/MUW	Heavy heavy rain	Swell to midshore
Sunday 13/07/2014	North Mull	56.57105598	-6.29534799	Lainne Sgeir	13:34	0.36	11:50	HMLWU	Sun	Warm
		56.60399593	-6.30901694	Caillich	13:34	0.36	12:56	HMLWU	Sun	
		56.64230492	-6.18185098	Glengorm	13:34	0.36	14:45	LMWUH	Sunny	
		56.62620798	-6.05999496	Tobermory	13:34	0.36	16:04	LMWUH	Clouds/sun	
Monday 14/07/2014	Ardnamurchan	56.72356999	-6.22322498	Ardnamurchan Point	14:20	0.43	11:55	HMUWL	Rain	Wind
		56.68848996	-6.09460996	Mingary Pier			13:10	HMLWU	Rain	Wind
		56.76176297	-6.09272093	Fascadale	14:20	0.43	14:15	LMHWU	Light rain	Wind
		56.70550296	-5.78289494	Salen	14:16	0.25	15:45	LMHWU	Occ. drizzle	Wind
Tuesday 15/07/2014	Islay	55.63352502	-6.12340397	Dunyvaig Castle			12:35	HMUWL	Sunny	Scattered clouds
		55.71558293	-6.32328395	Laggan Point	13:44	-0.09	13:40	LMHLW		L. breeze
		55.78934393	-6.48409495	Coul Point	14:12	0.25	15:15	LMHLW	Sun	L. breeze
		55.88017182	-6.35582744	Ardnave	14:51	0.32	16:45	LWMUH	Hazy sun	
Wednesday 16/07/2014	Colonsay	56.07510061	-6.25335323	Port Mor North			12:30	HMUWL	Sun, clouds	Breezy

Date	Area	Lat	Long	Site	TimeLW	Height LW	Time Arrived	Order	Weather1	Weather2
		55.999882	-6.25658093	Rubha Caol Oronsay	15:24	0.28	14:47	LMWUH	Hazy sun	Breezy
		56.06632493	-6.18125193	Scalasaig	15:24	0.28	16:30	LMHLW	Hazy sun	Breezy
Thursday 17/07/2014	South Mull	56.3473268	-6.34763313	Kintra	16:14	0.5	13:40	HMUWL	Sun	L. breeze
		56.34805595	-6.09024793	Gortein Driseach			15:00	HMLWU	Sun	L. breeze
		56.31846598	-5.96339696	Carsaig Bay	16:08	0.6	16:10	LMHWU	Sun	No wind
		56.47051522	-5.69572172	Craignure			17:55	LMHWU	Sun	No wind
Friday 18/07/2014	Mid Argyll	55.90897799	-5.42052297	Tarbert	11:07	0.09	11:15	LMHWU	Sun	L. breeze
		55.92903094	-5.60064395	Columba's Cave	16:27	0.43	13:05	LMHWU	Hazy sun	L. breeze
		56.22455698	-5.54764593	Melfort	16:39	0.78	14:50	HMLWU	Overcast	Spots of rain
Saturday 09/08/2014	Lewis	58.48918495	-6.22553235	Port Nis	12:22	0.87	10:00	HMUWL	Hazy sun	L. breeze
		58.42911696	-6.44363056	Borve Melbost	12:22	0.87	11:10	HMUWL	Hazy sun	breeze
		58.25820962	-6.13700311	Tiumpan Head	12:45	1.05	12:55	LMHLW	Hazy sun	L. breeze
		58.25589823	-6.16757526	Port Nan Giuran	12:45	1.05	13:45	LWUMH	Hazy sun	Mod. breeze
		58.1982366	-6.36052215	Lower Sandwick			14:50	LWMUH	Occ. sun	Mod/strong breeze
Sunday 10/08/2014	Harris N	58.11008555	-7.11093969	Mealastair	13:04	0.64	10:50	HMUWL	Sunny	Mod. breeze
		58.19124861	-7.04606485	Crowlista	13:04	0.64	12:20	LMHWU	Hazy sun	Breeze
		58.20131888	-6.95277879	Miavaig Pier	13:04	0.64	13:15	LMHWU	Overcast	Still
Monday 11/08/2014	Harris S	57.99912726	-7.09906857	Caolas an Scarp	13:31	0.59	11:10	HMUW	Heavy rain	Strong wind, waves
		57.96533134	-6.99935812	Abhainn Suidhe	13:31	0.59	12:15	HMUWL	Heavy rain	Strong wind
Monday 11/08/2014	Harris S	57.85417649	-6.68294362	Aird Adhanais	14:05	0.62	14:00	LMHWU	Heavy rain	Sheltered
		57.86746147	-6.69406842	Scalpay Village	14:05	0.62	15:20	LMHWU	Light rain	Windy
Tuesday 12/08/2014	N Uist	57.58772082	-7.52643985	Rubha na Port Scolpaig	14:21	0.52	12:20	HMUWL	Overcast	Mod. breeze
		57.61113575	-7.51839071	Hogha Gearraigh	14:21	0.52	13:45	LMHWU	Drizzle, Light rain	Wind
		57.64558093	-7.07049399	Bagh a Chaise	14:44	0.42	15:40	LMHWU	Drizzle	Windy

Date	Area	Lat	Long	Site	TimeLW	Height LW	Time Arrived	Order	Weather1	Weather2
				Exposed						
		57.64957541	-7.10600283	Loch Amhlasaraidh	14:44	0.42	16:30	LMHWU	Rain	Wind
Wednesday 13/08/2014	South Uist N	57.36811671	-7.27546463	Loch Carnan	15:24	0.33	12:00	HMUW	Overcast, drizzle	Breeze/wind
		57.38401626	-7.43103552	Rubha Aird na Machrach	15:04	0.53	13:30	HMLWU	Overcast, fine rain	Windy
		57.2746735	-7.42674608	Rubha Aird Mhicheal	15:04	0.53	15:00	LWMUH	Fine rain	Windy
		57.33187873	-7.27990318	Loch Sgioport	15:24	0.33	17:20	LMHWU	Occ. rain	Mod. breeze
Thursday 14/08/2014	South Uist S	57.22035952	-7.4346332	Trollasgeir	15:48	0.64	13:45	MWUH	Hazy sun	Breeze
		57.11220506	-7.39186982	Smeircleit	15:48	0.64	15:10	HLWUM	Hazy sun	Breeze
		57.08716915	-7.27004732	Eriskay Outer	16:08	0.41	16:40	LMHWU	Cloudy	L. breeze
		57.06722039	-7.29855166	Eriskay Sheltered	16:08	0.41	17:50	LMWUH	Hazy sun	Breeze
Friday 15/08/2014	Barra	56.94618864	-7.53417442	Vatersay Causeway West	16:38	0.79	14:10	HMUWL	Hazy sun	Calm
		56.96234342	-7.42469972	Leinis	16:38	0.79	15:15	HMLWU	Overcast, bright	Breeze
		56.98531151	-7.5279936	Borve Point Outer	16:38	0.79	16:35	LMHWU		
		56.95507044	-7.48999416	Castlebay	16:38	0.79	17:40	LMHWU	Bright, but overcast	L. breeze
Sunday 07/09/2014	Assynt	58.070486	-5.45574741	Reiff (MTB)	12:32	1.21	10:10	HMUWL	Overcast, occ. rain	NW wind
		58.07026782	-5.36499864	Achnahaird (MTB)	12:32	1.21	11:15	HMUWL	Overcast	L. breeze
		58.18930711	-5.33946125	Clachtoll	12:32	1.21	13:10	LMHWU	Overcast	Breeze
Sunday 07/09/2014	Assynt	58.24465717	-5.34062407	Culkein			14:15	LMWUH	Bright, but overcast	Breeze
Monday 08/09/2014	NW	58.48845941	-5.12053851	Sheigra North	13:36	0.73	11:30	HMUWL	Hazy sun	L. breeze
		58.47600868	-5.08827707	Oldshoremore	13:36	0.73	12:35	HMULW	Overcast	Breezy
		58.35315328	-5.1680862	Scourie (MTB)	13:36	0.73	14:00	LMHWU	Hazy sun	Breeze
		58.25793872	-5.03814742	Kylescu W of Bridge			15:05	LWMUH	Sunny	Breeze
Tuesday 09/09/2014	Loch Eriboll	58.55755001	-4.7039135	Sangobeg	14:51	0.34	11:50	HMUWL	Hazy sun	Breeze
		58.54832095	-4.65832198	Rispond Outer			12:50	HMUWL	Hazy sun	L. breeze

Date	Area	Lat	Long	Site	TimeLW	Height LW	Time Arrived	Order	Weather1	Weather2
		58.5479954	-4.66070739	Rispond Inner	14:51	0.34	13:40	HMLWU	Hazy sun	Breeze
		58.48247021	-4.66674613	An-T-Sron	14:51	0.34	15:30	LMHWU	Hazy sun	Still
Wednesday 10/09/2014	Tongue	58.55088397	-4.43246196	Port Vasgo	15:52	0.77	13:10	HMUWL	Sunny	Warm
		58.49857695	-4.44858598	Causeway	15:52	0.77	14:10	HMUWL	Sunny	Breeze
		58.54337865	-4.30544134	Skerray (MTB)	15:52	0.77	15:30	LMHWU	Sunny	Light air
		58.56739799	-3.94437594	Portskerra			17:10	LMWUH	Overcast	L. breeze
Thursday 11/09/2014	N Coast	58.6474854	-3.04925591	Ness of Duncansby			14:20	HMUW	Sunny	No wind
		58.63972099	-3.16274696	Gills Bay	17:29	0.74	15:50	none	Sunny	
		58.60720374	-3.42999162	Murkle Bay West	17:01	0.69	16:45	LWMUH	Sun, haze	
		58.56692492	-3.79130898	Fresgoe	17:01	0.69	18:20	LWMUH	Twilight/Sunset	Calm, swell
Friday 12/09/2014	Caithness	58.44273998	-3.05763387	Wick (North Head)	07:59	0.39	07:10	HMLUW	Misty	
		58.29540599	-3.28792096	Lybster N of Harbour	08:29	0.41	08:45	LMWUH	Misty	Difficult access
		58.26930131	-3.38089186	Latheronwheel S of Harbour	08:29	0.41	10:00	LMHUW	Misty	
		58.18435642	-3.49376072	Berridale	08:29	0.41	11:15	WMHU	Misty	
Saturday 13/09/2014	Sutherland and S	58.11416334	-3.64319321	Helmsdale	09:09	0.63	07:45	HMUWL	Sun, mist	
Saturday 13/09/2014	Sutherland and S	58.0063346	-3.84529104	Brora	09:09	0.63	09:00	HUMLW	Sunny	
		57.8672329	-3.77121094	Tarbat Ness	09:35	0.78	11:00	LMWUH	Hazy sun	No breeze
		57.83265277	-3.84276004	Portmahomack Balnaburach	09:35	0.78	12:00	WMUH	Hazy sun, misty	
Thursday 14/05/2015	Oban	56.451531	-5.451773	Dunbeg NW	09:26	1.14	10:00	LMHLU	Sunny	
Monday 18/05/2015	Applecross and Torridon	57.41097967	-5.82448754	Camusteel	13:59	0.64	12:10	HMLLU	Sunny	
		57.50844033	-5.86568718	Lonbain	13:59	0.64	13:40	LLMUH	Sunny	showers
		57.547524	-5.710881	Ardheslaig	13:59	0.64	14:15	*MH	Sunny	
		57.574016	-5.784533	Fearnbeg	13:59	0.64	14:55	LLMUH	Sunny	light breeze
Tuesday	Moray/North	57.67932362	-2.96993863	Buckie	07:09	0.59	06:10	HUMLL	Sun	cloud

Date	Area	Lat	Long	Site	TimeLW	Height LW	Time Arrived	Order	Weather1	Weather2
19/05/2015	Aberdeenshire									
		57.67240042	-2.48811423	Macduff	07:48	0.71	07:40	LMHLU	Showers	sun
		57.51201857	-1.77699524	Roanhead	07:37	0.5	09:15	LLMUH	Sun/cloud	windy
		57.69895479	-2.06353672	Sandhaven	08:07	0.59	10:30	LLMUH	Hazy sun	
Wednesday 20/05/2015	South Aberdeenshire/ Angus	57.140603	-2.048824	Girdle Ness	09:30	0.5	07:40	LULMH	Hazy sun	windy
		56.906722	-2.201132	Crawton	09:30	0.5	09:05	LMLUH	Sun	clouds
		56.79326248	-2.33228588	Johnshaven	10:09	0.48	10:20	LLMUH	Sunny	breezy
		56.586399	-2.516998	Auchmithie	10:09	0.48	12:05	LLMUH	Sunny	
Thursday 21/05/2015	Fife	56.33299283	-2.77445706	East Sands	11:42	0.81	09:20	HMULL	Drizzle	breezy
		56.28091849	-2.58734071	Fife Ness	11:42	0.81	10:40	LLMUH	Hazy sun, drizzle	windy
		56.21133453	-2.72631207	Pittenweem	11:28	0.69	12:00	LLMUH	Hazy sun, drizzle	windy
		56.144266	-3.07885	West Wemyss	11:28	0.69	13:40	none		
Sunday 14/06/2015	South Ayshire	55.405724	-4.762685	Dunure Castle	16:38	0.26	14:00	HMULL	Sunny	
Sunday 14/06/2015	South Ayshire	55.378926	-4.773821	Croy	16:38	0.26	15:15	LLMUH	Sunny	
		55.225663	-4.864164	Girvan	16:40	0.18	16:45	LLMUH	Sunny	
		55.10412598	-5.01282215	Ballantrae	16:40	0.18	17:55	LMHLU	Sunshine	
Monday 15/06/2015	Galloway	55.006201	-5.160496	Corsewall Lighthouse	17:33	0.5	14:45	HMULL	Hazy sun	
		54.637623	-4.884701	Mull of Galloway	17:33	0.5	16:30	HMLLU	Hazy sun	
		54.734262	-4.913407	Myroch Point	17:33	0.5	17:40	LLMUH	Hazy sun	
		54.838719	-5.116885	Portpatrick	17:33	0.5	19:00	LMHLU	Overcast	
Tuesday 16/06/2015	Solway	54.69569433	-4.36058052	Isle of Whithorn	18:46	0.8	15:10	HMULL	Overcast	
		54.81264962	-4.203951	Corseyard	18:46	0.8	17:40	HMLLU	Overcast	
		54.870205	-3.591841	Southerness	18:46	0.8	19:55	LLMUH	Overcast	windy
Wednesday 17/06/2015	Borders/East Lothian	55.77855617	-1.99626365	Berwick on Tweed	10:06	1.14	8:15	HUMLL	Rain	

Date	Area	Lat	Long	Site	TimeLW	Height LW	Time Arrived	Order	Weather1	Weather2
		55.874855	-2.091736	Eyemouth	10:01	0.77	9:40	LLMUH	Drizzle	
		56.005753	-2.521217	Dunbar	10:06	1.14	11:25	LLMUH	Drizzle	Occasional rain, sun
		55.97432306	-2.95029664	Cockenzie	09:54	0.66	12:35	*LMUH	Windy	
Wednesday 01/07/2015	Shetland south	59.945838	-1.331263	Spiggie Bay N	15:23	0.51	14:50	LMHLU	Sunny	
		59.866999	-1.305752	Inner Tumble Wick	15:23	0.51	16:00	LMHLU	Hazy sun	wind
		59.867408	-1.288631	Jarlshof	17:13	0.44	17:00	LMHLU	Sunny	wind
		59.920601	-1.289428	Northvoe	17:13	0.44	18:00	LMHLU	Hazy sun	wind
Thursday 02/07/2015	Shetland south	60.005468	-1.330105	Claver W	16:05	0.51	13:55	HUMLL	Sun	breeze
		59.968642	-1.33173	Bigton	16:05	0.51	15:10	LMHLU	Sun	light breeze
Thursday 02/07/2015	Shetland south	60.006454	-1.217015	Sand Lodge	17:54	0.53	16:20	LMHLU	Hazy sun	
Thursday 02/07/2015	Shetland south	60.138147	-1.155839	Skarfa Skerry	17:54	0.53	17:35	LMHLU	Overcast	light breeze
Friday 03/07/2015	Shetland west	60.253707	-1.692432	Clett	16:49	0.49	13:45	HMULL	Sun	light breeze
		60.305839	-1.663681	Ness of Melby	16:49	0.49	15:05	LMHLU	Sunny	no wind
		60.192562	-1.403945	Roesound Skerry	16:49	0.49	16:30	LMHLU	Sun	no wind
		60.168852	-1.451085	South of Badni Taing	16:49	0.49	17:30	LMHLU		
Saturday 04/07/2015	Shetland west	60.473293	-1.612378	Utstabi Stenness	17:22	0.38	13:55	HMULL*	Overcast	strong wind
		60.539333	-1.346994	Voe of the Brig	17:39	0.44	15:25	HMULL	Overcast	light rain
		60.43885	-1.4503	Nibon	17:22	0.38	17:00	LMHLU	Light rain	
Sunday 05/07/2015	Shetland Yell	60.730099	-1.035251	Ness of Houlland	18:12	0.54	15:40	HUMLL	Hazy sun	
		60.715174	-1.004662	Papil Bay	18:12	0.54	17:05	LMHLU	Overcast	
Monday 06/07/2015	Shetland Yell	60.547478	-1.037358	Haroldswick	08:15	0.34	7:20	LMHLU	Low cloud	breezy
		60.809065	-0.800894	The Taing	07:55	0.24	8:40	LMHLU	Low cloud	breeze
		60.676449	-0.852504	Ramnageo	18:00	0.61	17:15	HMULL	Overcast	light breeze
		60.723308	-0.955969	Point of Coppister	18:00	0.61	18:15	LMHLU	Hazy sun	light breeze

Date	Area	Lat	Long	Site	TimeLW	Height LW	Time Arrived	Order	Weather1	Weather2
Tuesday 07/07/2015	Shetland Yell	60.581209	-1.194351	West Sandwick Bay	07:16	0.27	7:10	LMHLU	Sun	breeze
		60.547482	-1.037353	White Wife	09:06	0.23	8:40	LMHLU	Hazy sun	light breeze
Friday 31/07/2015	Orkney Hoy	58.905607	-3.294563	Quoyness	15:53	0.71	13:00	HUMLL*	Rain	
		58.92689896	-3.37041831	Muckle Head	15:53	0.71	14:45	HMLLU	Rain	
Saturday 01/08/2015	Orkney Mainland west	59.057829	-3.345334	Bay of Skaill	16:38	0.61	14:35	HMULL	Sun	showers
		59.139143	-3.307499	Banks	16:38	0.61	15:55	HMLLU	Rain	
		59.009161	-3.110913	Skarva Taing	16:38	0.61	17:25	LLMUH	Light rain	
Sunday 02/08/2015	Orkney Mainland east	58.825971	-2.886961	Kirk Geo	07:27	0.17	6:00	HMLLU	Clear	showers
		58.87163544	-2.91731787	Churchill Barrier No. 3	07:27	0.17	7:10	HMLLU	Clear	
Sunday 02/08/2015	Orkney Westray	59.27906418	-2.95984721	Tuquoy	17:41	0.46	14:45	HMULL	Sunny	
		59.274216	-3.013626	Kirbist	17:41	0.46	15:55	HMLLU	Light cloud	breeze
		59.356118	-2.966279	Bow Head	17:41	0.46	17:20	LMHLU	Sunny	breeze
		59.32387543	-2.97340369	Gill Pier	17:41	0.46	18:25	LMHLU	Haze	breezy
Monday 03/08/2015	Orkney Sanday	59.25636	-2.611623	Noust of Ayre	08:18	0.52	15:30	HMUL*	Sun	
		59.290211	-2.615922	Muckle Kiln	19:45	0.45	16:45	HMLUL		
		59.27562	-2.399223	Bight of Lotheran	19:45	0.45	18:10	HMLLU	Hazy sun	wind
		59.228806	-2.600539	Kettletoft	08:18	0.52	19:30	LLMUH	Sunny	wind

ANNEX B: COMPARISONS OF SPECIES ABUNDANCE BETWEEN 2002-2010 AND 2014-2015

Table 2: Changes in abundance of rocky shore species between 2002-2010 and 2014-2015 around Scotland, using all possible comparisons between site-specific estimates of abundance. Column headings as numbers give the magnitude of change and the values beneath the frequency of comparisons showing this change by species. Abbreviations: N comp, number of comparisons; Avg, average change in levels; % decr, % same and % inc give the percentage of comparisons where abundance declined, stayed the same or increased; Inc, Dec, and Exp are the frequencies of increases, declines and the expected frequency of both if the changes were symmetrical. Chi is the chi-squared test statistic on the expectation that increases and declines would be equal, and P is the probability of this statistic: the likelihood that the species abundance has remained the same. Species are ordered by the average change in abundance level (Avg).

Species \ Change in SACFOR score	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	N comp	Avg	% decr	%same	%inc	Inc	Dec	Exp	Chi	P
Mytilus edulis	0	0	10	25	39	61	53	109	22	11	7	11	3	0	0	351	-0.91	54%	31%	15%	188	54	121	74.20	<0.001
Melaraphe neritoides	0	0	11	16	9	14	19	43	9	8	2	23	2	0	0	156	-0.38	44%	28%	28%	69	44	56.5	5.53	0.019
Gibbula umbilicalis	0	0	3	14	18	29	52	175	28	24	3	0	9	0	0	355	-0.30	33%	49%	18%	116	64	90	15.02	<0.001
Gibbula cineraria	0	0	12	4	7	16	14	89	13	17	6	5	5	0	0	188	-0.18	28%	47%	24%	53	46	49.5	0.49	0.482
Elminius modestus	0	0	0	3	2	3	1	241	12	1	0	4	0	0	0	267	0.02	3%	90%	6%	9	17	13	2.46	0.117
Balanus crenatus	0	0	0	4	1	3	2	53	2	1	6	2	0	0	0	74	0.04	14%	72%	15%	10	11	10.5	0.05	0.827
Patella ulyssiponensis	0	0	8	1	1	3	3	96	1	0	1	1	10	1	0	126	0.06	13%	76%	11%	16	14	15	0.13	0.715
Littorina littorea	0	0	10	13	9	38	42	94	69	39	19	9	12	0	0	354	0.15	32%	27%	42%	112	148	130	4.98	0.026
Codium spp.	0	0	2	1	4	8	10	131	44	5	8	2	0	0	0	215	0.16	12%	61%	27%	25	59	42	13.76	<0.001
Himanthalia elongata	0	0	6	9	7	13	15	188	27	12	7	20	3	5	1	313	0.24	16%	60%	24%	50	75	62.5	5.00	0.025
Alaria esculenta	0	0	19	5	11	13	19	148	39	26	13	19	6	6	1	325	0.26	21%	46%	34%	67	110	88.5	10.45	0.001
Semibalanus balanoides	0	0	4	0	0	6	49	168	103	30	3	1	2	0	0	366	0.29	16%	46%	38%	59	139	99	32.32	<0.001
Laminaria saccharina	0	0	7	7	7	8	11	147	8	23	22	13	3	0	0	256	0.30	16%	57%	27%	40	69	54.5	7.72	0.005
Chthamalus stellatus	0	0	3	9	13	15	30	135	35	12	19	21	8	0	0	300	0.30	23%	45%	32%	70	95	82.5	3.79	0.052
Ascophyllum nodosum	0	1	20	12	7	14	21	123	50	54	11	11	2	3	10	339	0.32	22%	36%	42%	75	141	108	20.17	<0.001
Patella vulgata	0	0	0	1	5	10	33	151	114	23	8	1	1	0	0	347	0.35	14%	44%	42%	49	147	98	49.00	<0.001
Lichina pygmaea	0	0	1	11	16	40	27	121	32	28	6	27	25	0	0	334	0.40	28%	36%	35%	95	118	106.5	2.48	0.115
Pelvetia canaliculata	0	0	3	4	9	19	48	129	91	23	16	13	11	2	1	369	0.45	22%	35%	43%	83	157	120	22.82	<0.001
Chthamalus montagui	0	0	5	8	6	8	36	144	57	40	26	19	2	0	0	351	0.50	18%	41%	41%	63	144	103.5	31.70	<0.001

Species \ Change in SACFOR score	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	N comp	Avg	% decr	%same	%inc	Inc	Dec	Exp	Chi	P
Halidrys siliquosa	0	0	5	8	6	16	30	160	43	16	7	21	28	2	0	342	0.57	19%	47%	34%	65	117	91	14.86	<0.001
Nucella lapillus	0	0	2	4	5	17	46	108	91	53	22	9	4	2	0	363	0.58	20%	30%	50%	74	181	127.5	44.90	<0.001
Actinia equina	0	0	1	3	8	19	41	109	70	43	32	5	9	1	2	343	0.63	21%	32%	47%	72	162	117	34.62	<0.001
Halichondria panicea	0	0	2	5	9	22	28	112	40	28	19	38	8	0	0	311	0.69	21%	36%	43%	66	133	99.5	22.56	<0.001
Palmaria palmata	0	0	0	3	3	3	2	48	5	7	5	9	3	1	0	89	0.70	12%	54%	34%	11	30	20.5	8.80	0.003
Fucus spiralis	0	2	4	7	12	16	35	73	75	52	15	12	16	7	4	330	0.78	23%	22%	55%	76	181	128.5	42.90	<0.001
Fucus serratus	0	3	13	6	5	8	25	54	79	79	19	8	9	16	9	333	1.10	18%	16%	66%	60	219	139.5	90.61	<0.001
Chondrus crispus	0	0	1	5	9	12	12	92	32	23	36	36	15	6	0	279	1.27	14%	33%	53%	39	148	93.5	63.53	<0.001
Mastocarpus stellatus	0	0	1	3	7	11	22	62	49	51	27	38	27	11	1	310	1.65	14%	20%	66%	44	204	124	103.23	<0.001
Fucus vesiculosus	0	1	8	6	0	4	13	59	68	60	28	13	40	38	9	347	2.09	9%	17%	74%	32	256	144	174.22	<0.001
Laminaria digitata	1	0	6	1	2	5	9	54	43	87	17	16	20	14	34	309	2.23	8%	17%	75%	24	231	127.5	168.04	<0.001
Laminaria hyperborea	0	0	1	0	0	0	0	49	1	5	3	2	1	8	32	102	2.94	1%	48%	51%	1	52	26.5	49.08	<0.001
Tectura testudinalis	0	0	0	0	0	0	1	18	2	0	0	0	0	0	0	21	0.05	5%	86%	10%	1	2	1.5	0.33	0.564

Table 3: Frequencies of occurrence of rocky shore species in each abundance category in 2002-2010 and 2014-2015 at paired survey sites around Scotland, using all site-specific and sometimes repeated estimates of abundance in the two periods. T-tests of the difference in average level are shown in the rightmost columns. Abundance categories: NR, not recorded; NS, not seen; R, Rare; O, Occasional; F, Frequent; C, Common; A, Abundant; S, Superabundant; Ex, Extremely Abundant. Abbreviations: Avg, average abundance category (0-8, equivalent to NS(0) to EX(8); SD, standard deviation of average abundance category; n, number of estimates; Diff, difference in average abundance category between 2002-2010 and 2014-2015; t, t-statistic of the difference in abundance categories; P(t), probability of the t-statistic, giving the likelihood of the difference arising by chance.

	SACFOR 2002-2010												**SACFOR 2014-2015**														
Species	**NR**	**NS**	**R**	**O**	**F**	**C**	**A**	**S**	**EX**	**Avg**	**SD**	**n**	**NR**	**NS**	**R**	**O**	**F**	**C**	**A**	**S**	**EX**	**Avg**	**SD**	**n**	**Diff**	**t**	**P(t)**
Gibbula umbilicalis	21	124	14	12	42	38	34	0	0	1.841	1.95	264	8	107	10	18	12	6	14	0	0	1.054	1.64	167	-0.79	-4.50	<0.001
Mytilus edulis	23	82	19	39	30	38	54	0	0	2.324	1.94	262	9	73	22	23	20	12	14	1	1	1.56	1.76	166	-0.76	-4.20	<0.001
Littorina littorea	20	42	6	37	29	67	79	4	1	3.249	1.80	265	8	52	4	16	18	33	29	11	4	2.76	2.19	167	-0.49	-2.41	0.008
Melaraphe neritoides	172	58	0	3	8	23	21	0	0	2.009	2.15	113	8	97	3	11	12	29	6	9	0	1.563	2.03	167	-0.45	-1.74	0.041
Patella ulyssiponensis	63	164	3	0	9	16	30	0	0	1.099	1.92	222	83	75	1	0	3	1	11	1	0	0.815	1.79	92	-0.28	-1.25	0.106
Elminius modestus	96	168	1	3	9	7	1	0	0	0.354	1.05	189	6	160	4	0	1	3	0	1	0	0.148	0.74	169	-0.21	-2.17	0.016
Gibbula cineraria	86	125	14	27	11	7	15	0	0	1.025	1.58	199	47	82	9	13	7	10	7	0	0	1.023	1.59	128	0.00	-0.01	0.496
Balanus crenatus	195	78	2	4	2	4	0	0	0	0.356	0.99	90	63	99	1	2	3	7	0	0	0	0.375	1.09	112	0.02	0.13	0.447
Tectura testudinalis	189	92	3	0	0	0	1	0	0	0.083	0.53	96	108	61	3	3	0	0	0	0	0	0.134	0.45	67	0.05	0.66	0.256
Semibalanus balanoides	19	2	2	0	6	34	204	15	3	4.838	0.78	266	2	6	0	0	3	24	90	44	6	4.977	1.21	173	0.14	1.34	0.092
Patella vulgata	27	1	1	6	10	93	140	7	0	4.484	0.80	258	2	2	1	8	7	43	79	30	3	4.659	1.16	173	0.17	1.73	0.043
Lichina pygmaea	38	125	7	18	33	50	14	0	0	1.668	1.84	247	12	72	3	32	9	28	19	0	0	1.847	1.88	163	0.18	0.95	0.172
Laminaria saccharina	68	181	7	9	7	4	9	0	0	0.493	1.26	217	31	110	7	8	8	4	5	2	0	0.694	1.45	144	0.20	1.36	0.087
Chthamalus montagui	31	45	22	26	43	71	47	0	0	2.843	1.74	254	4	36	6	7	26	60	31	5	0	3.058	1.85	171	0.22	1.21	0.114
Codium spp.	138	109	17	8	9	2	2	0	0	0.531	1.08	147	14	108	25	7	7	8	5	1	0	0.764	1.39	161	0.23	1.65	0.050
Nucella lapillus	18	15	5	31	45	64	105	1	1	3.73	1.44	267	4	12	4	14	24	32	59	24	2	4.006	1.68	171	0.28	1.77	0.039
Pelvetia canaliculata	17	28	2	8	17	60	136	15	2	4.078	1.65	268	5	16	0	7	20	19	63	36	9	4.376	1.83	170	0.30	1.73	0.043
Ascophyllum nodosum	28	99	11	17	17	24	84	4	1	2.502	2.25	257	7	72	9	4	4	15	15	13	36	2.94	2.94	168	0.44	1.64	0.051
Himanthalia elongata	45	153	0	11	20	33	21	2	0	1.379	1.93	240	13	96	3	3	4	23	9	19	5	1.895	2.47	162	0.52	2.24	0.013
Actinia equina	27	39	12	51	46	58	48	4	0	2.899	1.69	258	6	20	6	21	29	36	40	13	4	3.462	1.83	169	0.56	3.20	0.001
Alaria esculenta	41	147	7	11	16	11	50	1	1	1.574	2.12	244	9	82	6	10	8	19	20	16	5	2.151	2.42	166	0.58	2.48	0.007
Halidrys siliquosa	29	139	12	27	19	38	21	0	0	1.484	1.83	256	10	84	3	3	11	24	28	12	0	2.121	2.32	165	0.64	2.98	0.002
Chthamalus stellatus	73	122	12	12	17	22	27	0	0	1.462	1.93	212	4	80	3	7	11	35	33	2	0	2.146	2.16	171	0.68	3.23	0.001
Asterias rubens	94	173	5	7	0	4	2	0	0	0.236	0.85	191	174	0	1	0	0	0	0	0	0	1	0.00	1	0.76	12.50	<0.001
Halichondria panicea	52	125	11	30	26	26	14	1	0	1.412	1.74	233	4	63	5	13	22	43	24	1	0	2.31	1.97	171	0.90	4.75	<0.001
Saccharina polyschides	272	12	1	0	0	0	0	0	0	0.077	0.27	13	174	0	1	0	0	0	0	0	0	1	0.00	1	0.92	12.49	<0.001
Fucus spiralis	37	48	5	18	26	48	89	11	3	3.399	1.99	248	7	22	5	4	8	25	43	39	22	4.405	2.17	168	1.01	4.80	<0.001
Fucus serratus	28	33	5	4	9	37	136	17	16	4.21	1.91	257	12	18	1	2	5	5	27	46	59	5.301	2.18	163	1.09	5.24	<0.001

	SACFOR 2002-2010											SACFOR 2014-2015														
Species	**NR**	**NS**	**R**	**O**	**F**	**C**	**A**	**S**	**EX**	**Avg**	**SD**	**n**	**NR**	**NS**	**R**	**O**	**F**	**C**	**A**	**S**	**EX**	**Avg**	**SD**	**n**	**Diff**	**t**	**P(t)**
Palmaria palmata	219	39	1	7	8	10	1	0	0	1.273	1.65	66	30	59	2	12	5	24	25	18	0	2.552	2.36	145	1.28	4.54	<0.001
Chondrus crispus	58	150	6	26	26	15	4	0	0	0.952	1.45	227	22	61	2	13	21	33	15	8	0	2.261	2.06	153	1.31	6.80	<0.001
Calliostoma zizyphinum	214	66	4	0	0	1	0	0	0	0.113	0.52	71	171	1	1	1	0	1	0	0	0	1.75	1.48	4	1.64	2.21	0.014
Mastocarpus stellatus	50	88	9	21	40	49	26	2	0	2.166	1.91	235	9	21	1	9	16	39	49	29	2	3.952	1.87	166	1.79	9.34	<0.001
Fucus vesiculosus	25	82	2	13	3	45	102	11	2	3.104	2.27	260	11	15	0	0	3	8	35	65	38	5.317	1.91	164	2.21	10.80	<0.001
Laminaria digitata	36	70	8	5	8	18	107	12	21	3.486	2.45	249	24	16	0	3	0	5	15	17	95	5.748	2.22	151	2.26	9.49	<0.001
Laminaria hyperborea	73	193	0	1	1	2	14	0	1	0.425	1.38	212	111	25	0	1	1	1	1	9	26	3.906	3.25	64	3.48	8.35	<0.001
Fucus distichus anceps	199	86	0	0	0	0	0	0	0	0	0.00	86	172	0	0	1	0	1	1	0	0	3.667	1.25	3	3.67	5.09	<0.001
Cystoseira tamariscifolia	234	50	0	0	0	1	0	0	0	0.078	0.55	51	173	0	0	0	1	0	1	0	0	4	1.00	2	3.92	5.51	<0.001
Sargassum muticum	215	69	1	0	0	0	0	0	0	0.014	0.12	70	167	0	2	0	0	1	3	2	0	4.125	1.90	8	4.11	6.12	<0.001
Paracentrotus lividus	215	70	0	0	0	0	0	0	0	0	0.00	70	175	0	0	0	0	0	0	0	0						

ANNEX C: ABUNDANCE CATEGORIES USED FOR SURVEYS

Table 4: Abundance scales used for intertidal organisms, after Crisp and Southward (1958) modified by Hiscock (1981). Abbreviations: Ex, Extremely abundant; S, Super abundant; A, Abundant; C, Common; F, Frequent; O, Occasional; R, Rare. Organisms not seen during a site visit despite searching recorded as N, Absent.

1. Barnacles, *Melaraphe neritoides* Ex: >500 per 10×10 cm, 5+ per cm^2 S: 300 - 499 per 10×10 cm, 3 - 4 cm^2 A: 100 - 299 per 10×10 cm, 1 - 2 per cm^2 C: 10 - 99 per 10×10 cm F: 1-9 per 10×10 cm O: 1-99 per m^2 R: <1 per m^2	2. *Patella* spp. 10 mm+, *Littorina littorea* (juveniles & adults), *Littorina mariae /obtusata* (adults) Ex: 200 or more per m^2 S: 100 - 199 per m^2 A: 50 - 99 per m^2 C: 10 - 49 per m^2 F: 5 - 9 per m^2 O: 1 - 4 per m^2 R: <1 per m^2	3. *Littorina* '*saxatilis*', *Patella* <10 mm, *Littorina mariae/obtusata* juv. Ex: 500 or more per m^2 S: 200 - 499 per m^2 A: 100 - 199 per m^2 C: 50 - 99 per m^2 F: 10 - 49 per m^2 O: 1 - 9 per m^2 R: Less than 1 per m^2
5. *Nucella lapillus* (>3 mm), *Gibbula* spp., *Actinia* Ex: 100 or more per m^2 S: 50 - 90 per m^2 A: 10 - 49 per m^2 C: 5 - 9 per m^2, sometimes more F: 1 - 4 per m^2, locally sometimes more O: <1 per m^2, locally sometimes more R: Always less than 1 per m^2	6. *Mytilus edulis* Ex: 80% or more cover S: 50 - 79% cover A: 20 - 49% cover C: 5 - 19% cover F: Small patches, 5%, 100+ small individuals per m^2, 10 or more large per m^2 O: 10 - 99 small per m^2 1 - 9 large per m^2; no patches except small in crevices R: <1 per m^2	7. *Pomatoceros* sp. A: 50 or more tubes per 10×10 cm C: 1 - 49 tubes per 10×10 cm F: 10 - 99 tubes per m^2 O: 1 - 9 tubes per m^2 R: <1 tube per m^2
8. Spirorbinidae A: 5 or more per cm^2 on appropriate substrata; more than 100 per 10×10 cm generally C: Patches of 5 or more per cm^2; 100-1000 per m^2 generally F: Widely scattered small groups; 10-99 per m^2 generally O: Widely scattered small groups; less than 10 per m^2 generally R: Less than 1 per m^2	9. Sponges, hydroids, bryozoa A: Present on 20% or more of suitable surfaces. C: Present on 5-19% of suitable surfaces F: Scattered patches; <5% cover O: Small patch or single sprig in 0.1 m^2 R: Less than 1 patch over strip; 1 small patch or sprig per 0.1 m^2	10. Lichens, lithothamnia Ex: More than 80% cover S: 50 - 79% cover A: 20 - 49% cover C: 1 - 19% cover F: Large scattered patches O: Widely scattered patches all small R: Only 1 or 2 patches
11. Algae Ex: More than 90% cover S: 60 - 89% cover A: 30 - 59% cover C: 5 - 29% cover F: Less than 5% cover, zone still apparent O: Scattered plants, zone indistinct R: Only 1 or 2 plants		

ANNEX D: EXAMPLE DATA SHEETS

Table 5: Categorical abundance recording – an example datasheet. Here abundance has been estimated independently by two surveyors to allow cross validation of estimates. S refers to the abundance scale (Table 4) used for each species. Absence despite a search was recorded as 'NS' (not seen), while 'NR' means absence of a record (not recorded), in some cases due to inaccessibility, lack of appropriate habitat, or if shore levels where species were usually found were inundated.

SITE & DATE: Tiumpan Head 09/08/14 12.55-13.30

SPECIES	S	AB G	AB R	SPECIES	S	AB G	AB R
Lecanora spp	10	A	S	Palmaria palmata	11	O	O
Lichina pygmaea	10	O	F	Polysiphonia lanosa	11	NS	NS
Verrucaria maura	10	S	S	Porphyra sp	11	A	A
Verrucaria mucosa	10	NS	NS				
Xanthoria parietina	10	F	F				
				Halichondria panicea	9	R	O
Blidingia' type	11	NS	NS	Hymeniacidon sp.	9	NS	O
Cladophora rupestris	11	C	A				
Cladophora sericea	11	NS	O	Actinia equina	5	S	S
Codium spp	11	NS	NS	Anemonia sulcata	5	NS	NS
Ulva compressa / intestinalis	11	A	F	Dynamena pumila	9	NS	NS
Ulva lactuca	11	O	O				
				Pomatoceros triqueter	8	R	R
Alaria esculenta	11	Ex	C	Spirorbis spirorbis	8	NS	NS
Ascophyllum nodosum	11	NS	NS				
Chorda filum	11	NS	NS	Balanus crenatus	1	NS	NS
Dictyota dichotoma	11	NS	NS	Carcinus maenas	1	NS	NS
Fucus serratus	11	NS	NS	Chthamalus montagui	1	C	C
Fucus spiralis	11	A	NR	Chthamalus. stellatus	1	NS	A
Fucus vesiculosus	11	A	A	Elminius modestus	1	NS	NS
Fucus vesiculosus linearis	11	NS	NS	Semibalanus balanoides	1	Ex	S
Halidrys siliquosa	11	NS	NS				
Himanthalia elongata	11	NS	NS				
Laminaria digitata	11	Ex	Ex	Gibbula cineraria	5	NS	NS
Laminaria hyperborea	11	NR	NR	Gibbula umbilicalis	5	NS	NS
Laminaria saccharina	11	NS	NS	Littorina littorea	2	NS	NS
Leathesia difformis	11	NS	NS	Littorina neritoides in Lichina	1	C	C
Pelvetia canaliculata	11	O	O	Littorina obtusata	3	NS	NS
Pilayella littoralis	11	NS	NS	Littorina rudis	3	NS	NS
Scytosiphon lomentaria	11	F	NR	Mytilus edulis	6	S	A
				Nucella lapillus	5	NS	S
Ceramium / Polysiphonia / Callothamnion turf	11	A	A	Patella ulyssiponensis	2	NS	NR
Chondrus crispus	11	NS	NS	Patella vulgata	2	A	A
Corallina officinalis	11	A	C	Tectura testudinalis			NR
Coralline crusts (High pools)	10	A	Ex				
Coralline crusts (Low rock)	10	C	Ex	Electra pilosa	9	NS	O
Dilsea carnosa	11	NS	NS	Flustrellidra hispida	9	NS	NS
Dumontia incrassata	11	NS	NS	Membranipora membranacea	9	NS	NR
Lomentaria articulata	11	F	NS				
Mastocarpus stellatus	11	F	F	Lipophrys pholis	na	NS	O
Membranoptera alata	11	NS	NS	Pholis gunnellus	na	NS	NR
Osmundia spp	11	NS	NS				
Other filamentous reds	11	NS	NS				
Other finely branched reds	11	F	C				
Other foliaceous reds	11	NS	NS				

Ceramium on mussels C. Callithamnion A

Sagartia (elegans var. venusta?) 7 specimens in 2 pools

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