Natural England Commissioned Report NECR298

MARINE BIODIVERSITY AND CLIMATE CHANGE MONITORING IN THE UK: A FIELD REPORT TO NATURAL ENGLAND ON THE MARCLIM ANNUAL SURVEY 2018

First published May 2020

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

This report summarizes the 2018 rocky intertidal survey work, data and analysis completed around the coastline of England as part of a long-term, sustained observation ecological and biological time-series carried out by The Marine Biological Association of the UK and academic collaborators for the MarClim Project.

This report should be cited as: MIESZKOWSKA, N. 2019 *Marine biodiversity and climate change in the UK: a field report to Natural England on the Marclim annual survey 2018*. Natural England Commissioned Reports, Number298.

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Keywords – Marclim, climate change, marine monitoring, rockyshore

Further information
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ISBN 978-1-78354-619-0

MARINE BIODIVERSITY AND CLIMATE CHANGE MONITORING IN THE UK: A FIELD REPORT TO NATURAL ENGLAND ON THE MARCLIM ANNUAL SURVEY 2018

CONTRACT REPORT FROM THE MARINE BIOLOGICAL ASSOCIATION OF THE UK TO NATURAL ENGLAND

March 2019

N. Mieszkowska

Summary:

This report summarizes the 2018 rocky intertidal survey work, data and analysis completed around the coastline of England as part of a long-term, sustained observation ecological and biological time-series carried out by The Marine Biological Association of the UK and academic collaborators for the MarClim Project. Details of the MarClim Project are described in the report by Mieszkowska (2005) http://www.mba.ac.uk/NMBL/publications/occpub/occasionalpub20.htm.

The annual survey in England forms part of a sustained, seventeen-year, continuous annual UK survey of long-term rocky intertidal survey sites as part of a long-term, sustained observation ecological and biological time-series carried out by The Marine Biological Association of the UK and academic collaborators for the MarClim Project. Geographical coverage includes sites around the English coastline, for which historical data dating back to the 1950s exist, and additional sites where range extensions have been predicted to occur. Most MarClim sustained observation sites are natural rocky shores, however, artificial coastal structures are included in areas where no rocky habitat occurs, and where artificial structures may act as 'stepping stones' for the range extension or gap-filling within the range for MarClim species. MarClim surveys were carried out at thirty sites around the English coastline in 2018 using the standard MarClim survey protocols, as part of the wider MarClim UK monitoring network.

Several extreme weather events occurred in 2018. Between late February and early March Britain experienced a severe spell of winter weather with very low temperatures. Known as the 'Beast from the East', anticyclone Hartmut coincided with storm Emma to cause some of the most extreme weather conditions in decades. These events caused a mass mortality of marine creatures along the east coast of England, however, no significant changes in the abundance of any of the fifty MarClim species of invertebrate were recorded at any MarClim site along the North Sea coastline during 2018. 2018 was one of the warmest years on record, with five of the warmest years happening since 2010. The joint hottest summer on record was recorded in 2018. Heatwaves occurred in April, June and July, with the Met Office reporting an average air temperature of 1.5°C above the long-term average. MarClim surveys around the UK found evidence of heat damage to the highshore fucoid species *Pelvetia canaliculata, Fucus spiralis* and *Fucus vesiculosus* at sites across UK regional seas.

The oceanic sea surface temperature has been increasing globally over the past few decades, however, a region of the northeast Atlantic to the west of the UK has actually undergone a cooling of the marine surface water temperatures, thought to be due to a slow-down in the Gulf Stream system, caused by a global-warming driven slow-down in the Atlantic meridional overturning circulation (AMOC).

This change in surface ocean circulation patterns has large potential implications for English marine ecosystems. The west coast ecosystems will continue to be subject to a cooling of the marine climate, favoring boreal, coldwater species, whereas the east coast ecosystems will continue to be subject to warming of the marine climate and favour the proliferation and range extensions of Lusitanian, warm water species. This may result in different coastal ecosystem responses to global climate warming if the west coast continues to cool in contrast to the east coast, which continues to warm. Such changes will have profound implications for national and EU level policy directives including the overarching Marine Strategy Framework Directive, where marine waters must be shown to maintain Good Ecological Status or Good Environmental Status against the shifting background of climate-driven changes to marine ecosystems. Correspondingly, in the UK Special Areas of Conservation, Sites of Special Scientific Interest and Marine Conservation Zones condition against baseline needs to be assessed.

The Lusitanian alga *Padina pavonica* was recorded at Lyme Regis for the first time in several years, and also appeared at Corbyn Head, south Devon in 2017. It was not found at either site in the 2018 surveys. This is a Species of Priority Importance.

Four Non Indigenous Species (NIS) were added to the MarClim list in 2017; the red algae *Caulacanthus ustulatus* and *Pikea californica,* and the tunicates *Botrylloides diegensis,* and *Perophora japonica.* None of these species were found in 2018 MarClim surveys. The MarClim sites in the northeast of England have the lowest number of Invasive Non Native Species records. Only three northeast sites had NIS present in 2018: the barnacle *Austrominius modestus* was recorded at Scalby Mills, and the brown alga *Colpomenia peregrine* was recorded at Filey Brig, Newton Point and Castlehead Rocks, Holy Island. NIS recordings from previous years were not found in 2018, demonstrating that in this region, NIS are not able to form long-term colonizations.

https://www.nasa.gov/feature/goddard/2016/climate-trends-continue-to-break-records.

The warmwater hermit crab, *Clibanarius erythropus* was recorded at shores along the south coasts of Devon and Cornwall in 2016 for the first time since 1985, when the leading range edge was trimmed back to northern France due to a combination of cooling climatic conditions and pollution from the Torrey Canyon oilspill. Populations of *C. erythropus* were still present at these sites in 2018.

Additionally, as a function of the length of time-series and depth of work carried out, the MarClim time-series was further developed for Defra/Joint Nature Conservation Committee (JNCC) by the team as rocky shore Indicators of Good Environmental Status for the Marine Strategy Framework Directive in 2014 http://jncc.defra.gov.uk/PDF/Report%20522_webv3.pdf with a second phase completed in 2017.

Natural England's funding contribution to MarClim is matched by staff time from the MBA (Mieszkowska, PI), University of Southampton (Hawkins) and University of Newcastle (Sugden).

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1. Introduction

1.1 Background to MarClim

Prof. A.J. Southward of The Marine Biological Association of the UK first spotted the link with climatic fluctuations, prompted in part by his own observations in changes in competing Boreal and Lusitanian species of barnacles along the coastline of the English Channel in the 1950s. The boreal 'coldwater' species *Semibalanus balanoides* was common in the 1930s and rarer in the warmer 1950s, when the lusitanian 'warmwater' species *Chthamalus stellatus* (split into two species, *C. stellatus* and *C.montagui* by Southward in the 1970s) increased in abundance. Following a switch to naturally colder climatic conditions in the 1960s, *S. balanoides* again became more dominant, whereas recent warming from the late 1980s onwards led to an increase in *Chthamalus species*. These changes in barnacles mirrored switches between herring and pilchard and changes in plankton, benthos and demersal fish, but the response of intertidal species was often far quicker than for other components of the marine ecosystem, making then early warning indicators of environmental change.

Southward and Prof. D. J. Crisp (Bangor University) carried out surveys of barnacles and other rocky intertidal invertebrates and macroalgae around UK coastlines in the 1950s, with ad-hoc resurveys during the 1960s-1980s. Prof. J. Lewis and his team at the Robin Hood's Bay Laboratory (Leeds University) undertook surveys on the distribution and abundance of rocky intertidal invertebrates in the 1980s, extending the scope to include newly developed quantitative surveys for topshells and limpets and investigations of reproductive cycles in these species. Lewis also realized that intertidal species were 'sentinels' of changes to the marine climate and resultant ecosystem-level shifts, and published a seminal scientific paper on how coastal species could be used to track global climate change (Lewis 1996).

The MarClim project was established at The Marine Biological Association of the UK in 2001 to rescue, centrally archive and analyze these unique long-term datasets, and to establish a current UK baseline on the distribution and abundance of keystone intertidal invertebrates and macroalgae. MarClim was consortium funded from 2001-2005 by Natural England (then English Nature), Natural Resources Wales (then Countryside Council for Wales), Scottish Natural Heritage, Scottish Government (then Scottish Executive), Defra, JNCC, The Crown Estate, States of Jersey and WWF. The MarClim project has carried out annual surveys at rocky intertidal survey sites where long-term data exists since 2002. MarClim established a low-cost network of survey sites covering England, Wales and Scotland, which provided subsequent annual updates to track how climate influences the marine biodiversity of the British Isles (Mieszkowska et al. 2005; Mieszkowska et al. 2014).

The MarClim survey site network currently has 30 funded survey sites located around the coastlines of England. MarClim was downsized at the end of MarClim Phase I in 2005 to a subset of thirty sites in England (due to cessation of funding) and 35 sites in Wales (in conjunction with Countryside Council for Wales). Natural England enabled the restart of eleven additional sites in northeast England in 2010, closing in a gap in the survey coverage, that have been resurveyed again in each subsequent year to date. Additional sites in the southeast of England are surveyed every few years to check on potential further range extensions of warmwater species, personally funded by Mieszkowska and Hawkins. The MarClim survey network, together with the baseline information provided by the MarClim project, are being used by scientific and policy communities at the national, European and global scales as key tools to track impacts on biodiversity from climate change, and separate these effects from those of additional, smaller-scale anthropogenic pressures on the marine environment. MarClim surveys around the English coastline are currently funded by Natural England with in-kind contributions from the Marine Biological Association of the UK, and academic staff from Newcastle University and the University of Southampton on their own time. These surveys form part of a wider network of long-term MarClim sites in Wales (funded by Natural Resources Wales) and France (funded as part of Mieszkowska's MBA Research Fellowship), providing long term, invaluable data. .

The project focuses on a robust set of eighty two temperature-sensitive, readily observed, intertidal climate indicator species of invertebrates and macroalgae for which long-term data sets and monitoring sites are available. The MarClim species list includes boreal coldwater and lusitanian warmwater origins, and invasive non-native species that are, or may pose a potential threat to native biodiversity (Appendix 1). Several species including the coldwater brown alga *Alaria esculenta* reach their southern limits, and warmwater species such as the barnacle *Chthamalus montagui* reach their northern limits in the northeast England/southeast Scotland region and in the eastern English Channel. Climate-driven shifts in the biogeographic ranges of these and other species are being tracked by Dr Mieszkowska around northern Europe using the MarClim protocols. Non-native species are also targeted due to their appearance and subsequent impacts on natural communities after introduction via escapes of associated spat from ports, marinas and aquaculture facilities. MarClim has shown major shifts in biogeographic distributions of both cold and warm water species around the coastline of the UK since the onset of climate warming in the mid-1980s, and associated changes in abundance, population structure and physiological responses across several taxanomic groups (Mieszkowska et al. 2005, 2006, Mieszkowska 2009, Mieszkowska & Sugden 2016). These changes are amongst the fastest recorded globally and up to ten times faster than those recorded in terrestrial systems. The methodology is therefore field-tested and proven as a suitable broadscale climate detection tool.

Additional species have been added since the start of the MarClim project in 2002 to encompass those shifting distributional ranges into the UK tracking a warming climate, and invasive non-native species identified as posing a risk to native rocky intertidal communities. To ensure comparability with the historical data the original methodology was retained for ACFOR (now SACFOR) scoring of species abundances and barnacle quadrat counts. Additional quantitative methodology to facilitate robust statistical analysis and modeling has been incorporated since 2002 and is detailed in the Survey Protocols section below.

1.2 Policy-relevance

The MarClim project and scientific data collected by MarClim are made available and communicated to government organizations, staff, conservation agencies, marine SAC and SSSI managers and the general public to increase the knowledge, understanding and reporting of scientifically, managerial and societally important questions relating to global climate change, ocean acidification and smaller-scale human impacts on the marine environment including development, habitation and exploitation of the coastal zone, component ecosystems and species. MarClim is used to assess and inform UK and EU policies and directives including the EU Marine Strategy Framework Directive (via contracted work and advice to Defra and JNCC), PEGASEAS (Promoting Effective Governance of the Channel Ecosystem) Governance Guide, Condition Assessments for EMS and SSSIs and as baseline data for the UK Marine Conservation Zone designation process, in addition to collecting further data to inform Condition Assessments.

The MarClim time-series dataset was developed by Mieszkowska, Burrows and Hawkins of the MarClim team as Good Environmental Status Indicators for the MSFD, with the full report published in 2014: http://jncc.defra.gov.uk/page-6813. A second phase of this work was completed in 2017.

MarClim is highlighted in a scientific assessment of climate-driven shifts of intertidal species across the major marine biogeographic transition zone between boreal cold water at higher latitudes and Lusitanian warm water area at lower latitudes in the northeast Atlantic (Mieszkowska & Sugden 2016). This paper details how anthropogenic climate change is causing unprecedented rapid responses in marine communities, with species across many different taxonomic groups showing faster shifts in biogeographic ranges than in any other ecosystem. Spatial and temporal trends for many marine species are difficult to quantify, however, due to the lack of long-term datasets across complete geographical distributions and the occurrence of small-scale variability from both natural and anthropogenic drivers. MarClim is highlighted as an essential time-series, demonstrating the importance of scientific research in providing fit-for-purpose information at relevant spatial and temporal scales useful to managers of protected areas, statutory bodies and policymakers. This peer-reviewed research paper demonstrates how groundbreaking the MarClim project and the long-term collaboration with Natural England and the Marine Biological Association of the UK have been in delivering relevant information on the Condition and Status of intertidal habitats against a backdrop of pervasive climate change.

The MarClim Project and associated research provide unique, essential, long-term monitoring and scientific research data and expertise. This is used by the UK government departments to address and input into major national and European policy directives including the EU Marine Strategy Framework Directive, EU Habitats Directive, EU Water Framework Directive, OSPAR Commission Assessments, and the UK Marine Conservation Zone designation process as part of the Marine and Coastal Access Act (2009).

1.3 The main aims of the MarClim project are:

1. Use data on intertidal indicator species from the last 50-100 years to develop and test hypotheses on the impact of climatic change on marine biodiversity in Britain and Ireland.
2. Forecast future marine community changes on the basis of the Met Office's Hadley Centre climate change models and the UKCIP's climate change scenarios.
3. Establish a low-cost, fit-for-purpose, network to provide subsequent regular updates and track how climate influences the marine biodiversity of Britain and Ireland.
4. Assess and report on the likely socio-economic consequences of the predicted changes in response to climate and the policies and frameworks that conserve, manage and protect marine biodiversity. It will assess whether more serious impacts can be mitigated.
5. Provide general contextual time series data to support reporting on the success or otherwise of marine aspects of Biodiversity Action Plans, European initiatives including the Habitats, Birds and Water Framework Directives, Water Framework Directive, Marine Strategy Framework Directive and the management and monitoring of marine activities and resources, including fisheries
6. Evaluate whether the climate indicator species used in this work have a wider contribution to underpin the UK sustainable development strategy and the MSFD.
7. Disseminate the results widely to governments, policymakers and practitioners, NGOs, scientists, stakeholders and members of the public, defining the known impact climate has had on marine biodiversity over the last 100 years, and predicting future changes.

2. Methods

2.1 Site Selection

Thirty sites were surveyed around the English coastline for the 2018 MarClim survey (Figure 1, Table 1) as part of the wider UK and European MarClim network. This number has been down-sized from 67 sites due to a reduction in funding. Seventeen were located in the southwest, four sites in the south, two in the southeast and seven sites in the northeast, providing coverage in both basins of the English Channel, the Celtic Sea and the southern and central North Sea.

All MarClim survey locations were chosen in areas of extensive, exposed intertidal rocky reef or artificial, hard, coastal structures/defences away from areas of coastline heavily developed or utilised for social or economic purposes, and avoiding riverine and estuarine outputs. This reduced the likelihood of acute anthropogenic factors skewing the data and masking any potential climate change signals. Sites were also selected to fall within, or adjacent to marine SACs, SSSIs and newly designated MCZs where possible to provide additional information for use by site managers. All existing MarClim sites were locations surveyed in the 1950s and/or in subsequent decades.

2.2 Survey Team

2018 surveys were led by Dr Mieszkowska and included Leoni Adams, Kathryn Pack (Research Assistants, Marine Biological Association), Dr Heather Sugden (University of Newcastle) and Prof. Steve Hawkins (University of Southampton) (time provided as added value). All surveyors have been extensively cross-calibrated with Mieszkowska during surveys across several previous years of MarClim research.

Dr Katrin Bohn (National Team) and Dr Catherine Scott, Lead Adviser (Marine) from the Northern North Sea Regional team assisted with surveys in 2017. Natural England staff members have been trained in MarClim methods during previous years with the MarClim team, and are cross-calibrated each subsequent year, and the availability of trained staff provides valuable assistance in the field.

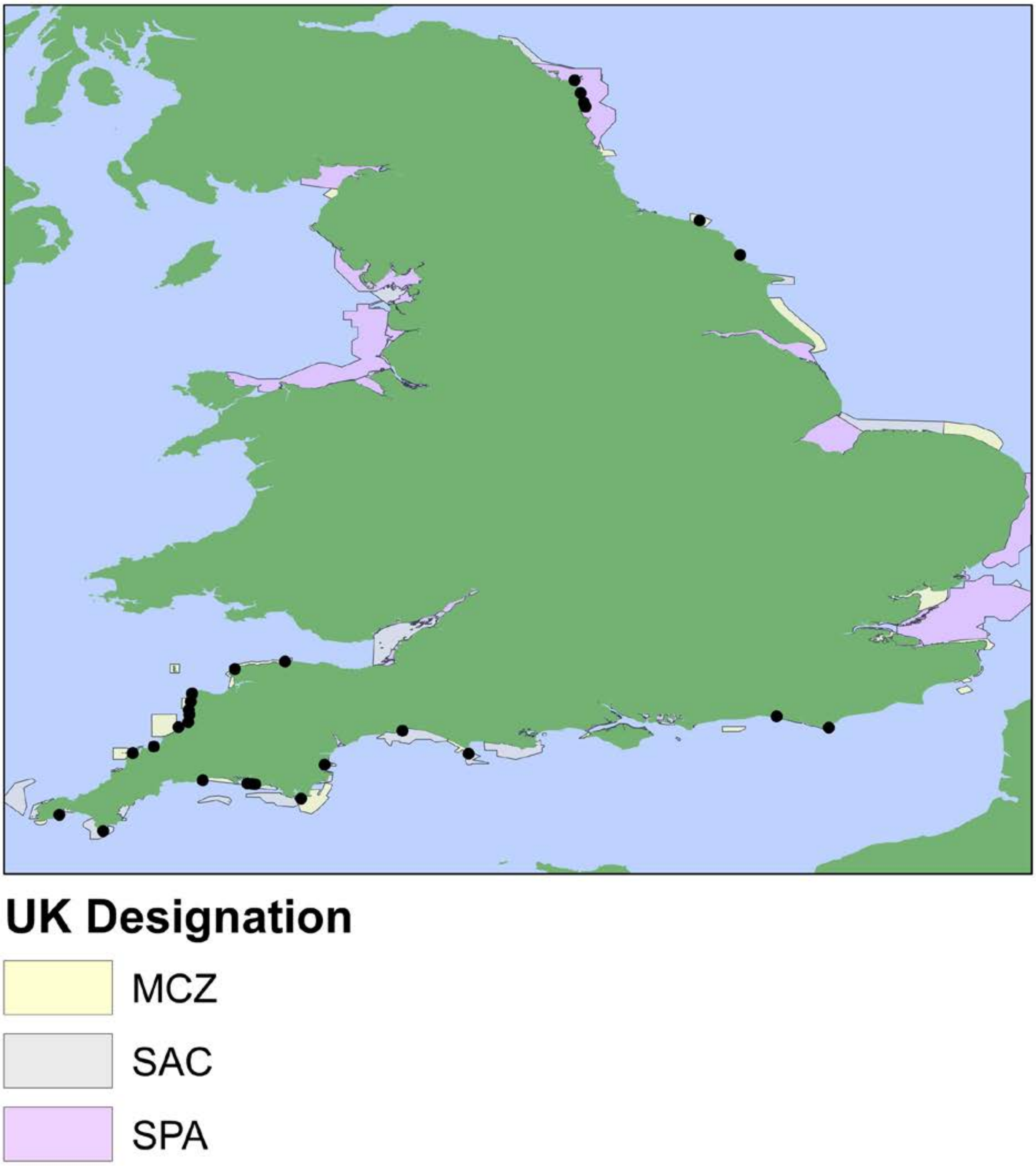

Figure 1. MarClim long-term sites surveyed in 2018 and UK MPAs.

Table 1. MarClim site locations for 2018 surveys.

Day	Month	Year	Site	Region	Grid	Lat (WGS84)	Long (WGS84)
17	3	2018	Wembury Church Reef	Southwest	SX518481	50.3140	-4.0830
19	3	2018	Renney Rocks	Southwest	SX491486	50.3179	-4.1210
21	3	2018	Portland (RJH)	South	SY67914	50.5414	-2.4544
29	3	2018	Looe SJH site	Southwest	SX251518	50.3410	-4.4580
30	3	2018	Prawle Point	Southwest	SX776351	50.2032	-3.7165
31	3	2018	Trevone	Southwest	SW886760	50.5450	-4.9850
1	4	2018	Bude	Southwest	SS199072	50.8362	-4.5592
2	4	2018	Woolacombe	Southwest	SS452446	51.1796	-4.2161
3	4	2018	Hartland Quay	Southwest	SS221248	50.9950	-4.5370
15	4	2018	Lyme Regis Broadledge	South	SY329909	50.7140	-2.9520
16	4	2018	Mousehole	Southwest	SW470261	50.0811	-5.5379
19	4	2018	Lizard Point	Southwest	SW700115	49.9590	-5.2080
1	5	2018	Port Gaverne	Southwest	SX001811	50.5952	-4.8259
2	5	2018	Corbyn Head	Southwest	SX908632	50.4586	-3.5400
14	5	2018	Welcombe Mouth	Southwest	SS210179	50.9330	-4.5490
14	5	2018	Widemouth Black Rock	Southwest	SS191010	50.7800	-4.5670
15	5	2018	Duckpool	Southwest	SS198111	50.8712	-4.5625
16	5	2018	Lynmouth	Southwest	SS718501	51.2356	-3.8378
17	5	2018	Hartland Quay	Southwest	SS221248	50.9950	-4.5370
17	5	2018	Crackington Haven	Southwest	SX138969	50.7417	-4.6405
1	6	2018	Bude	Southwest	SS199072	50.8362	-4.5592
28	8	2018	Scalby Mills	Northeast	TA037907	54.3013	-0.4079
28	8	2018	Staithes Cowbar	Northeast	NZ784192	54.5609	-0.7141
29	8	2018	Newton Point, Low-Newton-by-the-Sea	Northeast	NU247254	55.5221	-1.6097
29	8	2018	Rumbling Kern	Northeast	NU262172	55.4484	-1.5862
29	8	2018	Boulmer	Northeast	NU266140	55.4187	-1.5729
31	8	2018	Inner Farne	Northeast	NU216360	55.6178	-1.6558
9	10	2018	Beachy Head	Southeast	TV595956	50.7380	0.2590
11	10	2018	Brighton Marina East	Southeast	TQ315043	50.8232	-0.1343
25	10	2018	Cellar	Southwest	SX531477	50.3108	-4.0645

2.3 Survey Protocols

The MarClim methodologies (Appendix 1) were used for all site surveys in 2018. Categorical SACFOR abundance scores were recorded for a suite of 82 species including 49 species of ectothermic invertebrate and 33 species of macroalgae from boreal 'coldwater', Lusitanian 'warmwater' and invasive non-native geographic ranges. Replicate, quantitative quadrat counts were made for barnacles ($0.025m^2$) and limpets ($0.25m^2$). Replicated timed searches were made for topshells (5 x 3 minutes). All data is submitted to Natural England in electronic format.

A list of 23 Non Indigenous Species were also recorded in 2018 with the data being provided to the Great Britain Non-Native Species Portal https://secure.fera.defra.gov.uk/nonnativespecies/home/index.cfm. Some of these invasive non-native species are already established in natural rocky systems in the UK: *Sargassum muticum, Austrominius modestus, Undaria pinnatifida, Asparagopsis armata, Corella eumyota, Crepidula fornicata,* and *Crassostrea gigas*. Isolated records of *Botrylloides violaceus* and *Didemnum vexillum* have been recorded on natural substrate but there have been no sustained colonies. Three red algae were added to the MarClim list in 2013; *Heterosiphonia japonica* at the request of National Resources Wales, *Grateloupia turuturu,* identified by MBA researchers as an established INNS in southern England and Wales at risk of further spread within rockpools, and *Gracilaria vermiculophylla,* thought to be present in the UK and aggressively colonizing estuarine habitats in France. The ascidian *Asterocarpa humilis* has been recorded in marinas and is added as a horizon-scanning species that could invade natural intertidal communities. In 2014 two invasive shore crabs, *Hemigrapsus sanguineus* and *Hemigrapsus takanoi* were added to the MarClim species list. These species have aggressively invaded the Atlantic rocky shores of North America, outcompeting the green crab *Carcinus maenas* (native to the UK), and have begun to colonize the French coastline of the English Channel. Two records of individual sightings have been recorded in the UK to date, and these species are considered a risk for English natural rocky shore communities. Mieszkowska has studied live individuals of these crabs at the Nahant Marine Laboratory in the USA so is familiar with their identification and habitat selection.

Four Non Indigenous Species (NIS) were added to the MarClim list in 2017; the red algae *Caulacanthus ustulatus* and *Pikea californica,* and the tunicates *Botrylloides diegensis,* and *Perophora japonica,* upon consultation with Dr. John Bishop and the GBNNS secretariat database. MarClim now records six of NIS of macroalgae and twelve invertebrates as part of the MarClim surveys.

2.3.1. Barnacle density and species ratio and community composition

At each of the three shore levels, highshore (upper eulittoral), midshore (mid eulittoral) and lowshore (lower eulittoral) six digital photographs were taken of 5x5cm quadrats at each shore height on the flattest possible areas of bedrock. Species counts have been subsequently undertaken for all individuals > 2mm in the laboratory using digital image analysis (Figure 2). Note: statistical analyses and modeling has shown that six replicates at each shore height is the required number to permit multivariate analysis of species-level changes and use for general linear regression modeling (Burrows et al. 2006).

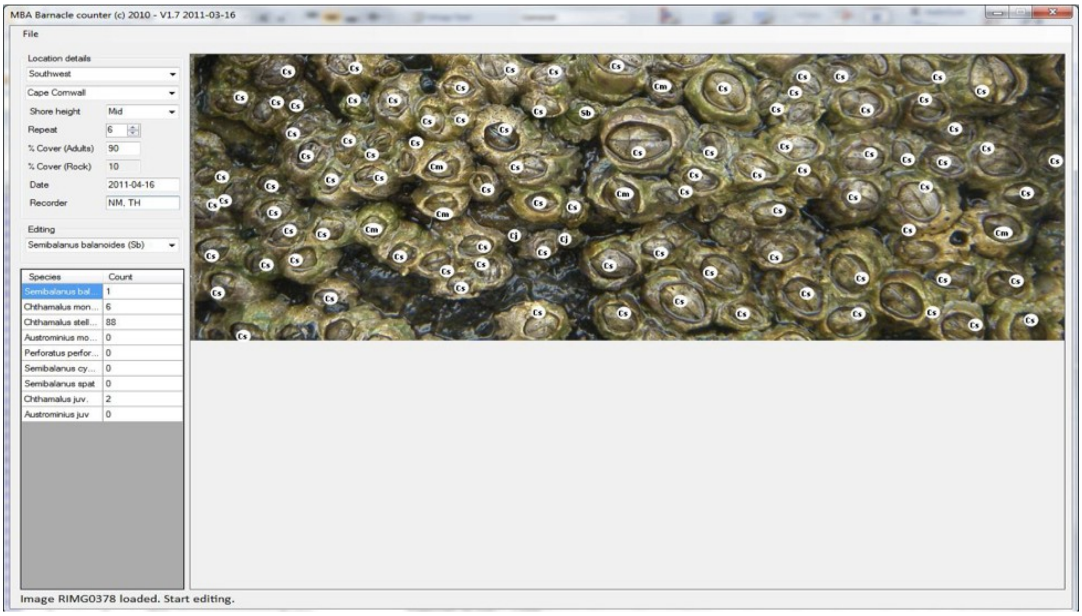

Figure 2. A 5x2cm subsection of the 5x5cm barnacle quadrat image being analysed using MarClim digital image software. The species are identified and marked by a unique code and the number of individual adult and juvenile barnacles for each species is recorded in a linked Access database.

2.3.2. Limpet species abundance and community composition

Ten replicate 0.25m^2 quadrats were randomly placed within the midshore zone on areas of bedrock or large boulders with homogeneous surfaces (Figure 3). Pools, cracks and crevices and patches of macroalgae were avoided. The slope of the rock, percentage cover of adult barnacles, algae and mussels were recorded in each quadrat. All limpets greater than 10 mm in size were counted and identified to species level.

Figure 3. MarClim 0.25m^2 limpet quadrat used for surveys.

2.3.3. Trochid population counts

Three replicate searches of three minutes duration were made separately for the Lusitanian warmwater species *Phorcus lineatus* and *Steromphala umbilicalis* in the area of the shore where each of the two warmwater indicator species were most abundant. Cobbles and small boulders were turned to ensure all individuals were collected, and returned to their original orientation after the search. The maximum basal diameter of every individual was measured in mm to 2 decimal places and population size frequencies calculated from the data. No counts were done at the northeast sites as neither species occurs that far north.

2.3.4. Data recording, QA and archive

Metadata and quantitative survey data were recorded on sheets in the field for all MarClim survey sites. The data were transferred to electronic datasheets in the laboratory and a rigorous QA check carried out by Mieszkowska. Digital photographs were set to record GPS in situ for each image, and were subsequently labelled by Mieszkowska to allow accurate interpretation and identification of features. Data analysis was carried out by Dr Mieszkowska, and the results are described in detail within this report. An electronic copy of data has been submitted to Natural England as part of this report and another copy lodged with the MEDIN accredited data centre DASSH (Data Archive for Seabed Species and Habitats) at the MBA. The MarClim master dataset is accessible through the NBN via Marine Recorder. Leoni Adams compiled the GIS-referenced MarClim survey map.

3. Results

3.1. Changes in the global and regional climate

The latest findings from the IPCC 5th Assessment Working Group I Report on the Physical Science Basis of Climate Change http://www.ipcc.ch/report/ar5/wg1/#.Uwt9YvYzmlI reveal that the earth's climate has not warmed as rapidly over the 2010s compared to the longer-term warming trend since the 1980s, due to non-anthropogenically mediated, natural variability in the earth's climate system. This recent slowdown must be placed into context; each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 and the northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years with 2016 being globally the warmest year on record http://www.bloomberg.com/graphics/hottest-year-on-record/, and the third warmest in the UK since 1910 http://www.metoffice.gov.uk/news/releases/2016/2016-a-year-in-weather-statistics (Figure 4).

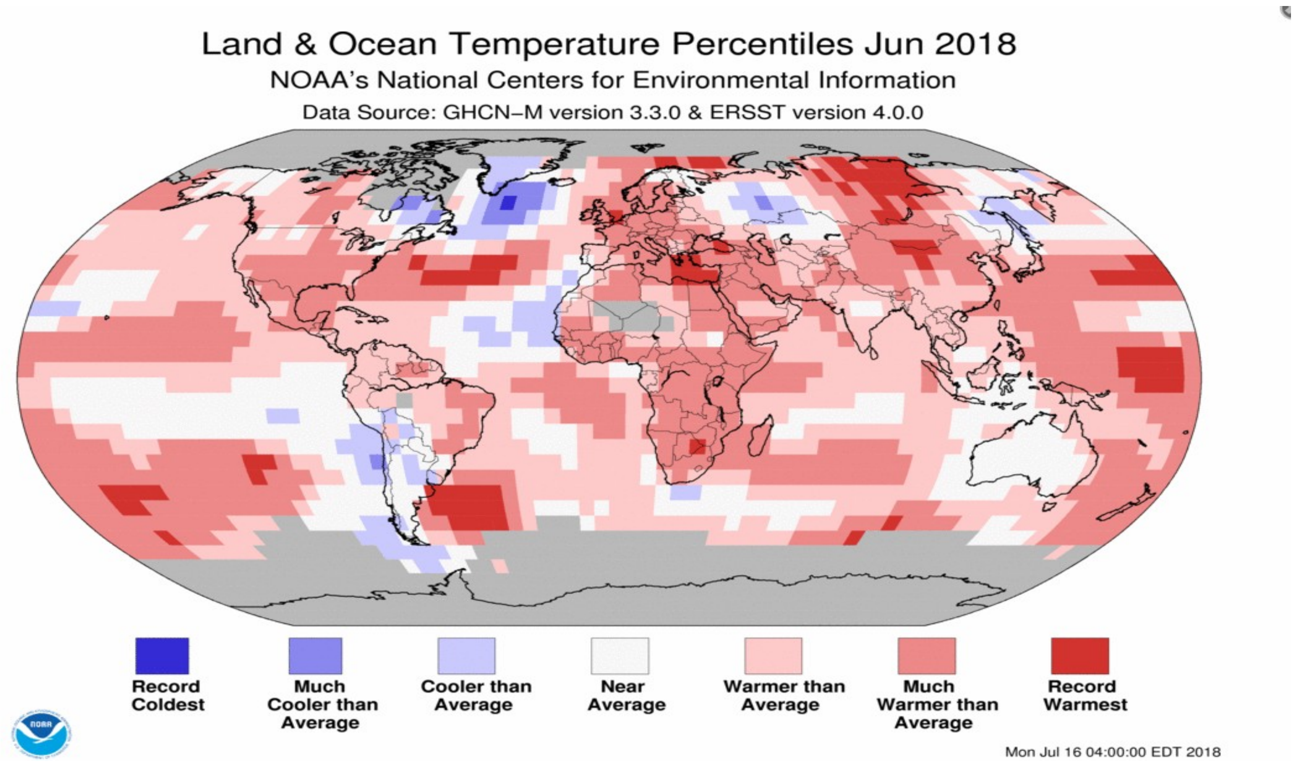

Figure 4. January to December 2016 blended land and sea surface temperature percentiles. Source: NOAA.

Sixteen of the hottest 17 years on record have occurred since 2000. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13]°C per decade over the period 1971 to 2010. The UK's National Oceanography Centres at Liverpool and Southampton provide online data on the marine climate and climate change at spatio-temporal scales relevant to the Welsh regional and national coastline http://noc.ac.uk/. The 2014/15, 2015/16 and 2016/17 winters were, in contrast to 2013/14, three of the warmest on record https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate.

Several extreme weather events occurred in 2018. Between late February and early March Britain experienced a severe spell of winter weather with very low temperatures. Known as the 'Beast from the East', anticyclone Hartmut coincided with storm Emma to cause some of the most extreme weather conditions in decades. These events caused a mass mortality of marine creatures along the east coast of England, however, no significant changes in the abundance of any of the fifty MarClim species of invertebrate were recorded at any MarClim site along the North Sea coastline during 2018. 2018 was one of the warmest years on record, with five of the warmest years happening since 2010. The joint hottest summer on record was recorded in 2018. Heatwaves occurred in April, June and July, with the Met Office reporting an average air temperature of 1.5°C above the long-term average.

The levels of carbon dioxide in the global atmosphere passed the 400ppm threshold permanently in 2016 (Figure 6). Increased CO_2 concentrations in the atmosphere raise the global temperature, and cause increased drawdown of CO_2 into the global oceans, exacerbating ocean acidification.

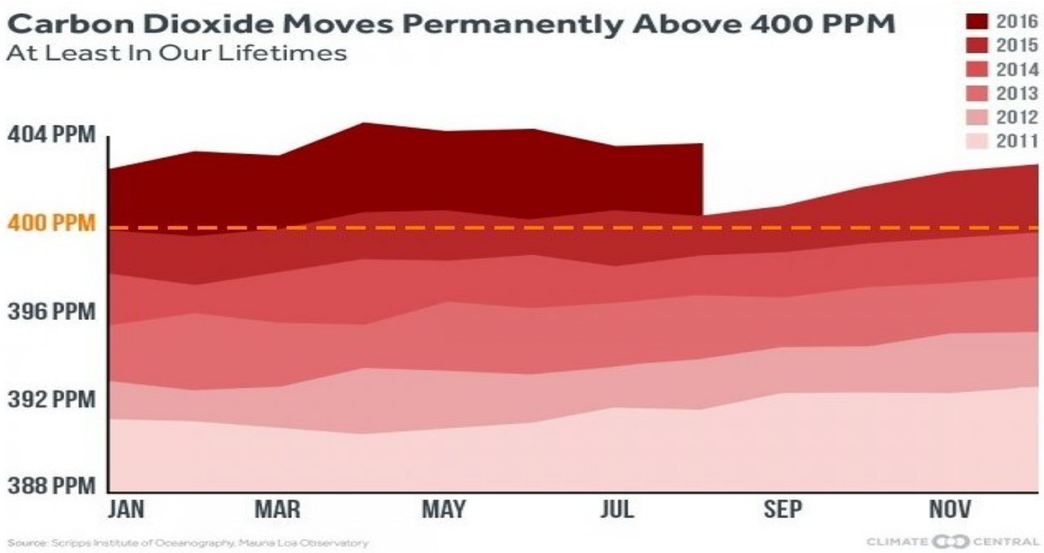

Figure 5. Atmospheric levels of carbon dioxide. Source: Scripps Institute of Oceanography

3.2 Regional and national trends

Most MarClim time-series sites in England were in a healthy condition in 2018 (no change against the baseline). The only evidence of anthropogenic impacts (other than climate change and storm damage) was small amounts of litter and fishing line on some shores.

Several extreme weather events occurred in 2018 (detailed above in 3.1). These events caused a mass mortality of marine creatures along the east coast of England, however, no significant changes in the abundance of any of the fifty MarClim species of invertebrate were recorded at any MarClim site along the North Sea coastline during 2018. 2018 was one of the warmest years on record, with five of the warmest years happening since 2010. The joint hottest summer on record was recorded in 2018. Heatwaves occurred in April, June and July, with the Met Office reporting an average air temperature of 1.5°C above the long-term average. MarClim surveys around the UK found evidence of heat damage to the highshore fucoid species *Pelvetia canaliculata, Fucus spiralis* and *Fucus vesiculosus* at sites across UK regional seas (Figure 6a,b), evident as desiccation and dieback of individuals.

Figure 6a. Heat damaged *F. vesiculosus* northeast England.

Figure 6b. Heat damaged *C. crispus,* Wembury, southwest England.

The oceanic sea surface temperature has been increasing globally over the past few decades, however, a region of the northeast Atlantic to the west of the UK has actually undergone a cooling of the marine surface water temperatures (Figure 4), thought to be due to a slow-down in the Gulf Stream system, caused by a global-warming driven slow-down in the Atlantic meridional overturning circulation (AMOC). Of concern are the NOAA model predictions that there is a 20% chance that the AMOC will completely break down at a “tipping point” under moderate warming (2-4 °C) and a 65% chance under strong global warming (4-8 °C). The moderate warming is within the predicted range of thermal increases due to global climate change by 2100 and if CO_2 emissions continue to increase, strong global warming is predicted to occur.

This change in surface ocean circulation patterns has large potential implications for English marine ecosystems. The west coast ecosystems will continue to be subject to a cooling of the marine climate, favouring boreal, coldwater species, whereas the east coast ecosystems will continue to be subject to warming of the marine climate and favour the proliferation and range extensions of Lusitanian, warm water species. This may result in different coastal ecosystem responses to global climate warming if the west coast continues to cool in contrast to the east coast, which continues to warm. Such changes will have profound implications for national and EU level policy directives including the overarching Marine Strategy Framework Directive marine waters must be shown to maintain Good Ecological Status or Good Environmental Status against the shifting background of climate-driven changes to marine ecosystems.

In 2017, the Lusitanian, warmwater species of ectothermic invertebrates and macroalgae continued to increase in abundance, or maintained their SACFOR abundance categories at MarClim long-term monitoring sites around the English coastline. Future annual surveys will be able to provide evidence of whether the long-term warming trend has resumed, or if the increase in population abundances was a short-term response to the milder winter thermal conditions experienced in 2013/14.

MarClim thus continues to assess a variety of coasts subject to different anthropogenic and non-anthropogenic factors now and in the future.

3.3 MarClim sites and MPAs

MarClim sites are located both within and outside SACs, SSSIs, SPAs, EMS and MCZs around the coastlines of England. The time-series data from these sites assist Natural England to work both at the landscape scale and to address smaller scale objectives in the context of the landscape scale ambition. MarClim data and expert knowledge contribute contributes to the monitoring and assessment of healthy and resilient coastal marine systems, which enhance the natural capital. The MarClim data can be used for **Ecological Network Guidance** as the time-series tracks changes to the biogeography of species within the MPA network, can be used for **Condition Assessments** of each attribute within MPAs as MarClim detects and tracks interannual changes in the condition of sites via attributes, such as:

- Distribution: of biological communities
- Structure: species composition of component communities
- Structure: non-native species
- Structure and function: presence and abundance of key structural and influential species

MarClim data can show when observed change is a local phenomenon resulting from an activity on a site, not inherent variability or a nation-wide trend due to some other factor. In addition, interpreting **Condition Monitoring** evidence requires contextual information from a wider geographical area, or over longer time scales. MarClim provides these data from inside and outside of MPAs on an annual frequency dating back to 2002, with historical data stretching back to the 1950s. MarClim data has been used by the MBA in conjunction with **Phase I and II biotope mapping** within MPAs to map species and habitats, and provide analyses of change to component species within habitats.

MarClim can be used to see if **Conservation Objectives** are being met and identify any changes. The annual survey frequency and wide spatial coverage of MarClim surveys enables the objectives to be consistently applied in a standard manner across sites to identify and track changes across sites, highlight any localized impacts and determine if protection levels ensure Favourable Conservation Status and that no further degradation occurs.

MarClim monitors changes of **FOCI** including the Broad-scale Habitats: Intertidal biogenic reefs, High, Moderate and Low energy intertidal rock, the Habitats of Principal Importance/Priority Habitats: Blue mussel beds, *Sabellaria alveolata* reefs (Annex I habitat Habitats Directive), Intertidal underboulder communities, Littoral chalk communities (patch size: Biotope & spp. mapping), and the Species FOCI *Pollicipes pollicipes* and *Padina pavonica*.

Conservation Strategy 21 creating resilient landscapes and seas and grow natural capital. MarClim data provides Natural England with sustained observations data around the UK regional seas to assist with CS21 aims of reversing biodiversity loss, sustain distinctive landscapes and enhance engagement with nature, in support of Defra’s ambitions for the environment. CS21 can utilize MarClim data for assessing resilience in marine ecosystems at 100 intertidal habitats spanning three UK regional seas, monitor patch size & connectivity of keystone and rare species, which is needed to build resilience, and address the likely long term impacts of climate change in the dynamic marine system using long-term, invaluable datasets.

MarClim data increase the Marine Evidence base, providing valuable data on the responses of intertidal organisms to climate change improving understanding thresholds and resistance/resilience in marine systems. The data can inform management as to the projected changes in community both inside and outside of marine protected areas, provide data to assist with the CS21 outcomes approach, deliver better long-term outcomes for the environment, restoring and recovering ecosystems, and ensure a rich and resilient natural environment.

3.3.1. Report cards on MarClim sites within MPAs

Multidimensional scaling of the annual survey data for sites within the Berwickshire and North Northumberland SAC in northeast England and Plymouth Sound and Estuaries SAC in southwest England (Figure 11 & 12). These figures show how similar the species abundances are at each site for each survey year. The closer the years are located to each other, the more similar the species abundances are between these years. Across all six SACs and MCZs surveyed by MarClim in 2018, the MarClim sites do not show any consistent patterns or trends since the surveys were started, which indicates natural variation in the abundance of the component species of invertebrate and macroalgae but no small-scale or larger scale changes within any of these MPAs.

3.3.1.1 Berwickshire and North Northumberland SAC

Four MarClim sites are located within the Berwickshire and North Northumberland SAC: Newton Point (exposed shore), Rumbling Kern (exposed shore), Boulmer (semi-exposed shore) and Inner Farne island (semi-exposed shore). Categorical SACFOR data for all sites are shown in Table 2.

Table 2. SACFOR data for Newton Point, Rumbling Kern, Boulmer & Inner Farne. Non Indigenous Species are highlighted in blue, rare/notable species are highlighted in green.

Day	29/08/2018	29/08/2018	29/08/2018	31/08/2018
MCZ	Berwickshire and North Northumberland SAC			
Site	Newton Point	Rumbling Kern	Boulmer	Inner Farne
Region	Northeast	Northeast	Northeast	Northeast
OS Grid	NU247254	NU262172	NU266140	NU216360
Latitude (WGS84)	55.5221	55.4484	55.4187	55.6178
Longitude (WGS84)	-1.6097	-1.5862	-1.5729	-1.6558

Recorder	NM, HS	NM, HS	NM, HS	NM, HS
Species				
Codium spp.	NS	NS	NS	NS
Laminaria hyperborea	NS	NS	NS	S
Laminaria digitata	S	NS	S	S
Saccharina latissima	NS	NS	NS	C
Laminaria ochroleuca	NS	NS	NS	NS
Alaria esculenta	NS	A	NS	NS
Himanthalia elongata	S	C	NS	A
Sargassum muticum	NS	NS	NS	NS
Ascophyllum nodosum	O	S	F	C
Pelvetia canaliculata	C	A	NS	A
Fucus spiralis	A	S	NS	S
Fucus vesiculosus	S	S	S	A
Fucus serratus	S	C	NS	O
Fucus distichus	NS	NS	NS	NS
Cystoceira spp.	NS	NS	NS	NS
Halidrys siliquosa	A	A	A	NS
Bifurcaria bifurcata	NS	NS	NS	NS
Mastocarpus stellatus	NS	NS	C	A
Chondrus crispus	C	NS	F	F
Lichina pygmaea	O	NS	NS	NS
Undaria pinnatifida	NS	NS	NS	NS
Dictyopteris polypodidoides	NS	NS	NS	NS
Calliblepharis jubata	NS	NS	NS	NS
Chondracanthus acicularis	NS	NS	NS	NS
Asparagopsis armata	NS	NS	NS	NS
Colpomenia peregrina	C	NS	NS	NS
Saccorhiza polyschides	NS	NS	NS	A
Grateloupia turuturu	NS	NS	NS	NS
Palmaria palmata	NS	O	NS	C
Caulacanthus ustulatus (okamurae)	NS	NS	NS	NS
Pikea californica	NS	NS	NS	NS
Heterosiphonia japonica	NS	NS	NS	NS
Padina pavonica	NS	NS	NS	NS
Halichondria panacea	NS	NS	NS	O
Hymeniacidon perlevis	NS	NS	NS	NS
Anemonia viridis	NS	NS	NS	NS
Aulactinia verrucosa	NS	NS	NS	NS
Actinia fragacea	NS	NS	NS	NS
Actinia equina	F	A	R	O
Diadumene lineata	NS	NS	NS	NS
Sabellaria alveolata	NS	NS	NS	NS
Chthamalus stellatus	NS	NS	NS	NS
Chthamalus montagui	NS	NS	NS	NS
Semibalanus balanoides	A	S	A	S
Balanus crenatus	NS	NS	NS	NS
Perforatus perforatus	NS	NS	NS	NS
Austrominius modestus	NS	NS	NS	NS
Pollicipes pollicipes	NS	NS	NS	NS
Mytilus spp.	NS	NS	NS	NS
Clibanarius erythropus	NS	NS	NS	NS
Haliotis tuberculata	NS	NS	NS	NS
Testudinalia testudinalis	NS	NS	NS	NS
Patella vulgata	A	A	C	C
Patella depressa	NS	NS	NS	NS
Patella ulyssiponensis	C	A	NS	C

Patella pellucida	NS	NS	NS	F
Steromphala (Gibbula) umbilicalis	NS	NS	NS	NS
Steromphala (Gibbula) pennanti	NS	NS	NS	NS
Steromphala (Gibbula) cineraria	NS	NS	A	NS
Phorcus lineatus	NS	NS	NS	NS
Calliostoma zizyphinum	NS	NS	NS	NS
Littorina littorea	F	NS	A	NS
Littorina saxatilis	A	NS	NS	NS
Melarhaphe neritoides	A	A	NS	NS
Nucella lapillus	C	NS	C	O
Onchidella celtica	NS	NS	NS	NS
Magallana gigas	NS	NS	NS	NS
Crepidula fornicata	NS	NS	NS	NS
Botrylloides violaceus	NS	NS	NS	NS
Botrylloides diegensis	NS	NS	NS	NS
Perophora japonica	NS	NS	NS	NS
Corella eumyota	NS	NS	NS	NS
Dendrodoa grossularia	NS	NS	NS	NS
Asterocarpa humilis	NS	NS	NS	NS
Didemnum vexillum	NS	NS	NS	NS
Asterias rubens	NS	NS	NS	R
Leptasterias muelleri	NS	NS	NS	NS
Paracentrotus lividus	NS	NS	NS	NS
Strongylocentrotus droebachiensis	NS	NS	NS	NS
Watersipora subtorquata	NS	NS	NS	NS
Hemigraspus sanguineus	NS	NS	NS	NS
Hemigraspus takanoi	NS	NS	NS	NS

Newton Point is an extensive rocky platform slope with a few large, shallow rockpools and a vertical wall running along the northern edge (Figure 7). There is clear vertical zonation of the fucoid algae from high to lowshore, with an extensive kelp bed in the infralittoral fringe. No visible pressures or threats were evident at this site in 2018, or in previous survey years. One Non Indigenous Species, the brown alga *Colpomenia peregrina* was recorded (Common) at Newton Point in 2018. No rare or notable species on the MarClim list were recorded in 2018. The Condition of Newton Point as assessed from the MarClim data was Favourable in 2018. Time-series analysis of the SACFOR data for each site show no persistent trends or Abrupt Community Shifts (regime shifts) have occurred since the surveys started in 2010 (Fig. 11).

Figure 7. Newton Point, Low Newton-By-The-Sea MarClim survey site.

Boulmer is a flat, algal dominated reef located in front of a stretch of sandy soft sediment that extents from the supralittoral to midlittoral zone (Fig. 8). No visible pressures or threats were evident at this site in 2018, or in previous survey years. No Non Indigenous Species were recorded at Boulmer. No rare or notable species on the MarClim list were recorded in 2018. The Condition of Boulmer as assessed from the MarClim data was Favourable in 2018. Time-series analysis of the SACFOR data for each site show no persistent trends or Abrupt Community Shifts (regime shifts) have occurred since the surveys started in 2010 (Fig. 11).

Figure 8. Boulmer MarClim survey site.

The survey site on Inner Farne is the shallow sloping rocky reef on the northeast of the island. Inner Farne is a moderately exposed, shallow sloping bedrock shore, comprised of an algal dominated reef platform that extents from the supralittoral to infralittoral zone (Fig. 9). No visible pressures or threats were evident at this site in 2018, or in previous survey years. No Non Indigenous Species were recorded at Inner Farne. No rare or notable species on the MarClim list were recorded in 2018. The Condition of Inner Farne as assessed from the MarClim data was Favourable in 2018. Time-series analysis of the SACFOR data for each site show no persistent trends or Abrupt Community Shifts (regime shifts) have occurred since the surveys started in 2010 (Fig. 11).

Figure 9. Inner Farne MarClim survey site.

The survey site at Rumbling Kern is an exposed, shallow sloping bedrock shore, comprised of a barnacle and limpet dominated reef platform that extents from the supralittoral to infralittoral zone on the seaward side, with vertical ledges on the landward side (Fig. 10). No visible pressures or threats were evident at this site in 2018, or in previous survey years. No Non Indigenous Species were recorded at Rumbling Kern. The kelp *Alaria esculenta* was Abundant in 2018. This trailing range edge of the distribution of this species in the North Sea is in northeast England. The Condition of Rumbling Kern as assessed from the MarClim data was Favourable in 2018. Time-series analysis of the SACFOR data for each site show no persistent trends or Abrupt Community Shifts (regime shifts) have occurred since the surveys started in 2010 (Fig. 11).

Figure 10. Rumbling Kern MarClim survey site.

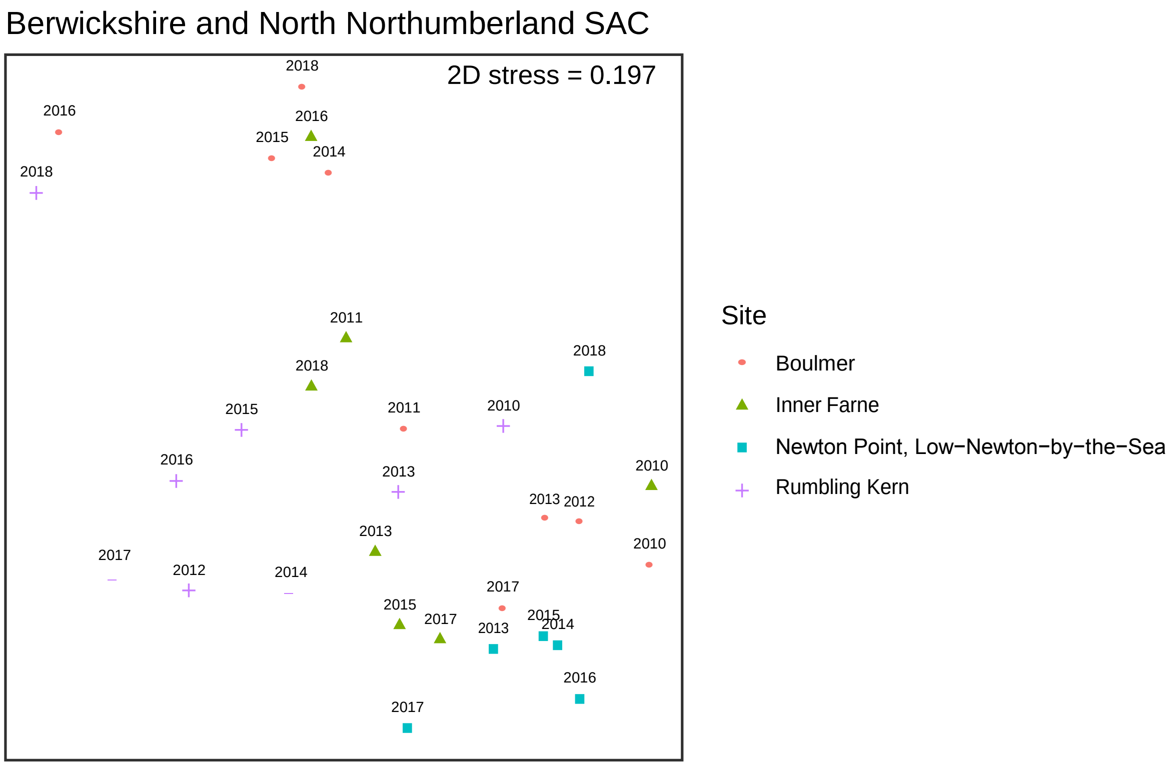

Figure 11. Northern North Sea: Berwickshire & North Northumberland SAC with MarClim site survey data for each year.

3.3.1.2 Plymouth Sound and Estuaries SAC

Four MarClim sites are located within the Plymouth Sound and Estuaries SAC: Wembury (exposed shore), Cellar Beach (semi-exposed shore), Renney Rocks (exposed shore) and Tinside (sheltered shore). Categorical SACFOR data for all sites are shown in Table 3.

Table 3. SACFOR data for Wembury, Cellar Beach, Renney Rocks and Tinside. Non Indigenous Species are highlighted in blue, rare/notable species are highlighted in green.

Day	17/03/2018	19/03/2018	25/10/2018	20/03/2018
MCZ	Plymouth Sound & Estuaries SAC			
Site	Wembury	Renney Rocks	Cellar	Tinside
Region	Southwest	Southwest	Southwest	Southwest
OS Grid	SX518481	SX491486	SX531477	SX479537
Latitude (WGS84)	50.3140	50.3179	50.3108	50.3633
Longitude (WGS84)	-4.0830	-4.1210	-4.0645	-4.1399
Recorder	NM, SJH, LA	NM, SJH	NM, LA	NM, LA
Species				
***Codium* spp.**	NR	NR	NR	NS
Laminaria hyperborea	A	S	NR	F
Laminaria digitata	A	NR	C	A
Saccharina latissima	F	A	C	C
Laminaria ochroleuca	NR	NR	NR	F
Alaria esculenta	NR	NR	NR	NS
Himanthalia elongata	A	A	S	A
Sargassum muticum	S	S	A	NS
Ascophyllum nodosum	C	NR	NR	NS
Pelvetia canaliculata	NR	F	F	NS
Fucus spiralis	NR	O	NS	NS
Fucus vesiculosus	A	C	NS	NS
Fucus serratus	A	A	A	S
Fucus distichus	NR	NR	NR	NS
Cystoceira spp.	NR	R	NR	NS
Halidrys siliquosa	NR	NR	NR	NS
Bifurcaria bifurcata	A	A	R	NS
Mastocarpus stellatus	A	A	A	C
Chondrus crispus	C	A	A	C
Lichina pygmaea	A	A	A	F
Undaria pinnatifida	NR	R	NR	NS
Dictyopteris polypodidoides	NR	NR	NR	NS
Calliblepharis jubata	NR	C	NR	NS
Chondracanthus acicularis	NR	NR	A	NS
Asparagopsis armata	NR	NR	NR	NS
Colpomenia peregrina	NR	NR	NR	NS
Saccorhiza polyschides	F	NR	C	C
Grateloupia turuturu	NR	NR	F	NS
Palmaria palmata	A	C	A	NS
Caulacanthus ustulatus (okamurae)	NR	NR	NR	NS
Pikea californica	NR	NR	NR	NS
Heterosiphonia japonica	NR	NR	NR	NS
Padina pavonica	NR	NR	NR	NS
Halichondria panacea	C	A	A	A
Hymeniacidon perlevis	A	C	A	NS

Anemonia viridis	NR	NS	O	NS
Aulactinia verrucosa	NR	R	NR	NS
Actinia fragacea	NR	NS	NS	NS
Actinia equina	F	A	F	O
Diadumene lineata	NR	NR	NR	NS
Sabellaria alveolata	NR	NR	NR	NS
Chthamalus stellatus	A	S	A	A
Chthamalus montagui	A	A	S	S
Semibalanus balanoides	F	F	F	O
Balanus crenatus	R	NS	R	A
Perforatus perforatus	A	A	A	A
Austrominius modestus	C	F	S	A
Pollicipes pollicipes	NR	NR	NR	NS
Mytilus spp.	NR	O	NS	F
Clibanarius erythropus	NR	NR	NR	NS
Haliotis tuberculata	NR	NR	NR	NS
Testudinalia testudinalis	NR	NR	NR	NS
Patella vulgata	A	A	A	A
Patella depressa	C	C	C	A
Patella ulyssiponensis	NR	A	C	C
Patella pellucida	NR	C	C	NS
Steromphala (Gibbula) umbilicalis	S	A	A	O
Steromphala (Gibbula) pennanti	NR	NR	NR	NS
Steromphala (Gibbula) cineraria	S	A	C	NS
Phorcus lineatus	A	A	C	NS
Calliostoma zizyphinum	C	R	C	NS
Littorina littorea	C	O	O	NS
Littorina saxatilis	NR	A	A	O
Melarhaphe neritoides	NR	S	A	A
Nucella lapillus	A	C	A	C
Onchidella celtica	NR	NR	NR	NS
Magallana gigas	R	F	C	R
Crepidula fornicata	NR	NR	NR	NS
Botrylloides violaceus	NR	NR	NR	NS
Botrylloides diegensis	NR	NR	NR	NR
Perophora japonica	NR	NR	NR	NR
Corella eumyota	NR	NR	NR	NS
Dendrodoa grossularia	NR	NR	NR	NS
Asterocarpa humilis	NR	NR	NR	NS
Didemnum vexillum	NR	NR	NR	NS
Asterias rubens	NR	NR	NR	NS
Leptasterias muelleri	NR	NR	NR	NS
Paracentrotus lividus	NR	NR	NR	NS
Strongylocentrotus droebachiensis	NR	NR	NR	NS
Watersipora subtorquata	NR	NR	C	NS
Hemigraspus sanguineus	NR	NR	NR	NS
Hemigraspus takanoi	NR	NR	NR	NS

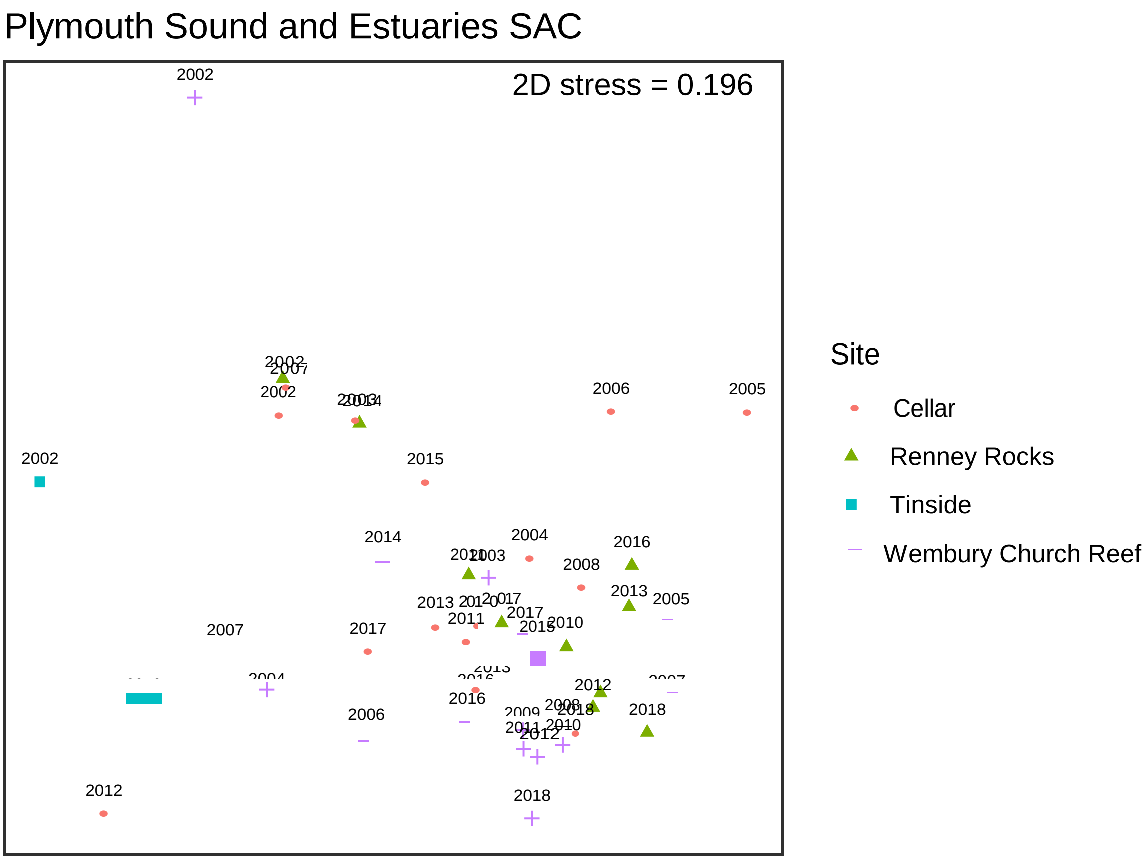

Figure 12. Western Channel & Celtic Sea: Plymouth Sound and Estuaries SAC with MarClim site survey data for each year.

The survey site at Church Reef, Wembury is also located in a voluntary Marine Conservation Area. It is an exposed shore comprised of a rocky reef with multiple peaks, gulleys, small boulderfields and ledges. The intertidal reef has a combination of barnacle and limpet dominated areas and fucoid patches (Fig. 13). No visible pressures or threats were evident at this site in 2018, or in previous survey years. The Non Indigenous Species *Sargassum muticum* (Superabundant), *Austrominius modestus* (Common), and *Magallana gigas* (Rare) were recorded in 2018. The Condition of Wembury as assessed from the MarClim data was

Favourable in 2018. Time-series analysis of the SACFOR data for each site show no persistent trends or Abrupt Community Shifts (regime shifts) have occurred since the surveys started in 2002 (Fig. 12).

Figure 13. Wembury MarClim site, Plymouth Sound & Estuaries SAC

Tinside (Fig. 14) is located within Plymouth Sound SAC. This sheltered site is comprised of a vertical wall extending from the supralittoral zone to the low water mark, with a horizontal rock outcrop from the mid eulittoral to the infralittoral region. The Lusitanian kelp *Laminaria ochroleuca* has an established population here. This is one of the few locations in the UK where this species occurs, and it is very close to the northern leading edge of the biogeographic distribution on Lundy Island. The Non Indigenous Species *Sargassum muticum* (Abundant), A*ustrominius modestus* (Abundant) and *Magallana (Crassostrea) gigas* (Rare) are all present at this site. The invasive kelp *Undaria pinnatifida* is not at Tinside, however, there are populations at several rocky shore locations in Plymouth Sound.

Figure 14. Tinside MarClim site, Plymouth Sound & Estuaries SAC

In the 2016 SAC Condition Assessment, Reefs (Feature H1170) was found to be in favourable condition in 2376.83 ha and unfavourable condition in 18.72 ha (Natural England, 2016). In 2018 99% of the feature was in favourable condition, with 1% in unfavourable condition due to Sub feature A1 – Intertidal Rock which was assessed as unfavourable/declining.(https://designatedsites.naturalengland.org.uk/Marine/MarineFeatureCondition.aspx?SiteCode=UK0013111&SiteName=plymouth&SiteNameDisplay=Plymouth+Sound+and+Estuaries+SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=). The three intertidal rock sites that were surveyed in 2018 as part of the MarClim surveys found all were in favourable condition.

3.4. Spatial synchrony of warmwater & coldwater species across regional seas

Spatial synchrony describes the unison of shifts in species abundance patterns across populations. This population synchrony may be driven by one of three mechanisms acting over local or broader regional spatial scales: (a) spatially correlated environmental variables, for example weather or climatic influences, (b) dispersal between populations, or (c) local biological interactions such as predation.

Understanding the biological mechanisms and the geographic scales at which population dynamics are affected by these drivers is a key ecological question of relevance to conservation and management of natural ecosystems. The magnitude of observed spatial synchrony for a species is correlated with global extinction rate, meaning that dispersal-driven spatial synchrony acting over small spatial scales may lead to “rescue effects”, allowing juveniles from one or more locations to replenish a damaged meta-population. In contrast, species with a high synchrony that is driven by stochastic environmental variables acting at a broad spatial scale have an increased risk of regional or global extinction from a large, detrimental climatic event. The occurrence of such events will have far reaching and potentially extreme negative impacts.

Both mean abundance and the degree of synchrony between populations is higher in the northeast than in the southwest of England, and it is expected that environmental drivers may have a more marked synchronizing impact on meta-populations in the southwest than in the northeast. Detailing synchrony in species population dynamics and shifts in the strength of synchrony over the distributional range will allow a better understanding of the potential impacts of climatic events, and enable appropriate mitigation measures to target the relevant spatial scale and/or locations within that species’ range. Analysis of spatial synchrony thus provides an affordable and tractable method of defining appropriate scales for conservation of species that play important roles in ecosystems functioning or services. The results are of direct applicability to Natural England’s management of MCZs, SSSIs and EMS across the UK regional seas.

4. Conclusions

All MarClim time-series sites in England were in a healthy condition in 2018 (no change against the baseline). The only evidence of anthropogenic impacts (other than climate change and storm damage) was small amounts of litter and fishing line on some shores. Several extreme weather events occurred in 2018. No damage was recorded after anticyclone Hartmut and storm Emma in February, however, the heatwaves in April and June-July caused damage to highshore fucoid algae around the English coastlines. Future MarClim surveys will track any mortality or recovery from these heatwaves.

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6. Appendix 1 MarClim Sampling Protocols 2018

Before you start at each site, record:

1. Site name and grid reference
2. County/Area
3. Date
4. Recorder
5. Lat long of access point (e.g. car park) and lat long of centre of survey area (e.g. midshore)
6. Exposure scale of the shore
7. Weather at the time of the survey, especially the visibility
8. Mark site on an OS Map

At each site: Semi-Quantitative Data

1. Identify area to be sampled (this might be up to 100 m or more in extent)
2. Photograph approach to site
3. Photograph general view of the sample site
4. Photograph specific features of interest and any rare organisms/new records
5. Walk the whole of the sampling area and using the checklist allocate each species listed to a SACFOR category. Use one or two quick quadrat counts to help in placing in the SACFOR category.
6. It is important to record *apparent* absences and the SACFOR category should be based on the locality in which the species is most abundant, this might be as small as 10 m x 10 m. DO NOT spend more than 30 minutes searching for species unless at a range edge. If more than 30 minutes is spent searching, record the time.
7. Use the notes section of the form for other species of interest.
8. Use GPS to record
   Midshore of the area sampled/searched
   Location of areas sampled for particular species (if different)
   Location of key features visible in the photographs
9. Note major features of the shore; bedrock, cobbles, boulders, sand scouring etc.

At each site: Quantitative Data

1. Replicated counts of limpets, barnacles, trochids will be made on each shore visit. If time is short and we are visiting a shore that has not been previously surveyed then trochids should only be recorded by ACFOR.
2. Avoid areas of heavy human disturbance.

At each site: Quantitative Barnacle Data Collection

1. Photograph at least ten replicate 5 cm x 5 cm quadrats containing barnacles at *low, mid* and *high* shore levels. High shore is defined as that area 1 m below the very top of the barnacle zone, mid shore in the middle of the barnacle zone, low 1m above the bottom of the barnacle zone
2. Use a 5 x 2 cm quadrat frame

Adults	Recruits
Semibalanus (1+ group)	*Semibalanus*
Chthamalus montagui	
Chthamalus stellatus	*Chthamalus* (Total)
Austrominius modestus	*Austrominius modestus*
Perforatus perforatus	
Balanus crenatus	

Counting Limpets and Associated Species

1. Count limpets at both *low* and *mid shore* levels
2. Use a 0.5 x 0.5 m quadrat. Where possible this should be strung at regular intervals to facilitate counting and estimation of % cover of barnacles.
3. Take at least 10 samples but not more than 20 at *each* shore height; the number should be consistent with habitat heterogeneity. True random sampling is unrealistic on a broken rocky shore hence samples should be stratified to encompass the full range of shore slopes
4. Areas with heavy shade, with pools and those that are heavily fissured should be avoided
5. Place the quadrat and record % cover of barnacles, mussels, dominant algae and bare rock. Record the number of individuals of *Osilinus lineatus, Steromphala umbilicalis* and *Nucella lapillus* present in the quadrat.
6. Count the total number of limpets >10 mm. Recount to estimate the abundance of the less common species. Ticking animals using chalk is a simple way to ensure that counts and species identification are accurate and consistent. Confirm the identity of *Patella depressa* through checking all features (white tentacles, black foot, shell morphology). Where rare (i.e. at range edges) take reference photographs.

Counting Trochids

1. Count *Phorcus lineatus* and *Steromphala umbilicalis* in the region of the shore that they are most abundant. *Phorcus lineatus* occurs **upshore** of *Gibbula umbilicalis* for a large part of the year.
2. The aim is to record abundance/ structure of populations. As adults and year classes 0-2 often live in slightly different habitats a detailed search is required.
3. Make 5 replicated timed counts of 3 minutes duration at each shore.

4. Select a small area in the region of the shore where the species is most abundant. Pick all individuals off visible surfaces and sample under stones and in cracks and crevices for the juveniles. Search using this method for 3 minutes and place all individuals into a bag. Remember to write the length of the search time on the form. Count the number of individuals and measure the basal diameter to the nearest 0.1 mm using dial calipers.
5. In shores where there is a relatively uniform distribution of rocks <30 cm it is possible to use a 1 m^2 quadrat to sample trochids. If this sampling method is used the operator moves across the quadrat and collects all animals on the visible surfaces. Once done, each rock is turned over and a separate search is undertaken for the younger animals that seldom move far from damp locations. A substantial proportion of the population may well be under stones. Again count the number of individuals and measure the basal diameter to the nearest 0.1 mm. In addition, up to five random 0.5 x 0.5 m quadrats can be thrown randomly to provide backup for SACFOR estimates.

Before leaving, have one last walk around the sample site to confirm first impressions and please check that all equipment and cameras have been collected from the shore

A: MarClim Recording Forms

Site name:	………………….	Grid reference:	………………….
County:	………………….	Lat long of access point:	………………….
Date:	………………….	Lat long of centre of survey area:	………………….
Recorder:	………………….	Exposure	………………….
Weather conditions:	………………….	Low shore availability	………………….

Species	S	A	C	F	O	R	Not seen	Comments
Codium spp.								
Laminaria hyperborea								
Laminaria digitata								
Saccharina latissima (L. saccharina)								
Laminaria ochroleuca								
Alaria esculenta								
Himanthalia elongata								
Sargassum (Bactrophycus) muticum								
Ascophyllum nodosum								
Pelvetia canaliculata								
Fucus spiralis								
Fucus vesiculosus								
Fucus serratus								
Fucus distichus								
Cystoseira spp.								
Halidrys siliquosa								
Bifurcaria bifurcata								
Mastocarpus stellatus								
Chondrus crispus								
Lichina pygmaea								
Undaria pinnatifida								
Dictyopteris polypodioides								
Calliblepharis jubata								
Chondracanthus acicularis								
Asparagopsis armata								
Colpomenia peregrina								
Sacchoriza polyschides								
Grateloupia turuturu								
Palmaria palmata								
Heterosiphonia japonica								
Caulacanthus ustulatus (okamurae)								
Pikea californica								
Halicondria panacea								
Hymeniacidon perlevis								
Anemonia viridis								
Aulactinia verrucosa								
Actinia fragacea								
Actinia equina								
Diadumene lineata								
Sabellaria alveolata								
Chthamalus stellatus								
Chthamalus montagui								
Semibalanus balanoides								
Balanus crenatus								
Perforatus (Balanus) perforatus								
Austrominus (Elminius) modestus								
Pollicipes pollicipes								
Mytilus spp.								
Clibanarius erythropus								
Haliotis tuberculata								
Testudinalia (Tectura) testudinalis								
Patella vulgata								
Patella depressa								
Patella ulyssiponensis								
Patella pellucida								
Steromphala umbilicalis								
Steromphala pennanti								
Steromphala cineraria								
Phorcus (Osilinus) lineatus								
Calliostoma zizyphinum								
Littorina littorea								
Littorina saxatilis agg.								
Melarhaphe neritoides								
Nucella lapillus								
Onchidella celtica								
Crassostrea gigas								
Crepidula fornicata								
Botrylloides violaceus								
Botrylloids diagensis								
Perophora japonica								
Corella eumyota								
Dendrodoa grossularia								
Asterocarpa humilis								
Didemnum vexillum								
Asterias rubens								
Leptasterias mulleri								
Paracentrotus lividus								
Strongylocentrotus droebachiensis								
Watersipora subtorquata								
Hemigrapsus sanguineus								
Hemigrapsus takanoi								

B: Barnacle count

Barnacle Count: Recorder: ………………….

Quadrat size: …………………. Lat long of centre of survey area: ………………….

Quadrat	Shore Height	% Cover barnacles	Adult count (1+)					Recruit count (O)			
			SB	CM	CS	EM	PP	SB		Total C	EM
								Cy	Sp		
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

Recorder: ………………….

Quadrat size: …………………. Lat long of centre of survey area: ………………….

Quadrat	Shore Height	% Cover barnacles	Adult count (1+)					Recruit count (O)			
			SB	CM	CS	EM	PP	SB		Total C	EM
								Cy	Sp		
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

Recorder: ………………….

Quadrat size: …………………. Lat long of centre of survey area: ………………….

Quadrat	Shore Height	% Cover barnacles	Adult count (1+)					Recruit count (O)			
			SB	CM	CS	EM	PP	SB		Total C	EM
								Cy	Sp		
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

C: Limpet Count

Shore height: …………………. Recorder: ………………….

Quadrat size: …………………. Lat long of centre of survey area: ………………….

Quadrat	x slope	% barnacles	% mussels	% algae	NL	OL	GU	Count		
								P. depressa	***P. vulgata***	***P. ulysipp***
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

D: Trochid Count: Recorder: ………………….

Quadrat/Timed Count: …………………. Lat long of centre of survey area: ………………….

Sample	Shore Height	Total Count	
		Phorcus lineatus	*Gibbula umbilicalis*
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Notes: