MarClim Annual Welsh Intertidal Climate Monitoring Survey 2016

Dr. N. Mieszkowska

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Crynodeb Gweithredol

Mae'r adroddiad hwn yn crynhoi gwaith arolwg rhynglanwol creigiog 2016 a'r data a gwaith dadansoddi cysylltiedig a gwblhawyd o amgylch morlin Cymru dan deitl prosiect MarClim, fel y disgrifir yn http://www.mba.ac.uk/NMBL/publications/occpub/occasionalpub20.htm Mieszkowska (2005). Mae'r arolwg blynyddol yng Nghymru yn ffurfio rhan o arolwg blynyddol parhaus, cynaledig y DU a gynhelir am 15 mlynedd i archwilio dros 100 o safleoedd arolwg rhynglanwol creigiog tymor hir. Mae'r mannau daearyddol yn cynnwys safleoedd trwy gydol gogledd a de-orllewin Cymru y mae data hanesyddol yn bodoli ar eu cyfer sy'n dyddio'n ôl i'r 1950au, a safleoedd ychwanegol lle rhagdybiwyd y bydd estyniadau o ran amrediad yn digwydd. Cynhaliwyd arolygon MarClim ar 42 safle yn 2016. Arolygwyd 36 safle yn y gogledd a chwe safle yn y de.

Mae cregyn crib Lwsitanaidd dŵr cynnes wedi cynyddu o ran amrediad a helaethrwydd mewn poblogaethau sefydledig yng Nghymru trwy gydol y 2000au mewn ymateb i gynhesu hinsawdd, a gwelwyd lleihad o ran helaethrwydd rhwng 2010 a 2013 oherwydd bwlch yn y cynhesu byd-eang a ganfuwyd yn ystod y 2000au. Yn 2016, canfuwyd cregyn crib danheddog *Phorcus lineatus* am y tro cyntaf yn Llanddulas, gan ddangos estyniad arall o ran amrediad arweiniol tua'r gogledd y rhywogaeth hon.

Mae helaethrwydd y sbwng dŵr oer *Halichondria panacea* a'r sbwng dŵr cynnes *Hymeniacidon perlevis* wedi disgyn yn ystod y 2010au ledled Cymru ar safleoedd MarClim. Dangosodd astudiaethau o gwadratau parhaol ar lannau Sir Benfro leihad o'r flwyddyn 2013 yng Nghei Lawrenni, Pembroke Ferry a South Hook, ac ychydig o newid o ran amledd helaethrwydd ym Monk Haven, Bae West Angle, Nolton Haven, Hazelbeach a Gorsaf Bŵer Penfro. Mae gan y ddau sbwng hyn wahanol darddiadau o ran esblygiad thermol, gan awgrymu bod ffactor ar wahân i newid hinsawdd yn ysgogi'r lleihad mewn helaethrwydd poblogaethau rhynglanwol.

Cofnodir sawl rhywogaeth o facroalgâu ac infertebrata goresgynnol, anfrodorol fel rhan o'r arolygon MarClim. Mae'r chwistrell fôr oresgynnol *Corella eumyota* wedi bod yn bresennol ar safle MarClim Porthaethwy ers pum mlynedd; fodd bynnag, mae helaethrwydd y rhywogaeth hon wedi codi a gostwng ac fe'i canfyddir mewn niferoedd bach yn unig ar ochr isaf cerrig crynion ar y lan isel. Mae gan y Rhwydwaith Bioamrywiaeth Cenedlaethol gofnodion o'r rhywogaeth hon o amgylch y DU, ond nid oes dosraniad daearyddol parhaus, gydag achosion o weld y rhywogaeth o gwmpas porthladdoedd, marinâu, harbwrs, ac ardaloedd yn y parthau arfordirol lle ceir gweithgaredd dynol uchel. Cofnodwyd bod presenoldeb yr alga brown goresgynnol *Colpomenia peregrina* yn 'gyffredin' yng Nghaergybi yn 2016. Dyma'r cofnod cyntaf o'r rhywogaeth hon ar y safle hwn, oherwydd fe'i cofnodwyd fel rhywogaeth 'nas welwyd' yn 2014 a 2015. Mae gwymon sargaso Siapan, *Sargassum muticum* wedi estyn ei gyrhaeddiad ledled safleoedd MarClim yng Nghymru ers dechrau'r arolygon cyfoes yn 2002, gyda phoblogaeth yn ymsefydlu ym Mhorth Oer yn 2011. Yn 2016, fodd bynnag, roedd dim ond yn bresennol ar safleoedd Aberffro a Phorth Oer, gan ddangos lleihad mewn rhai poblogaethau. Yn y de, roedd *Sargassum muticum* yn 'gyffredin' yn Aberllydan ac yn 'achlysurol' yn West Angle, ac mae wedi disgyn un categori SACFOR ers 2014 a 2015. Yn 2016, roedd yn 'achlysurol' yn Jetty Beach, Dale, ar ôl peidio â chael ei gofnodi yno yn ystod blynyddoedd blaenorol mewn arolygon MarClim.

Chwiliwyd am rywogaethau goresgynnol y macroalgâu *Undaria pinnatifida, Asparagopsis armata* a *Heterosiphonia japonica*; yr anemoni goresgynnol *Diadumene* (*Haliplanella*) *lineata*; y tiwnigogion *Didemnum vexillum* ac *Asterocarpa humilis*; y molysgiaid *Crassostrea gigas* a *Crepidula fornicata*; y bryosoad *Watersipora subtorquata*; a'r crancod *Hemigrapsus sanguineus* a *Hemigrapsus takanoi*. Fodd bynnag, ni chanfuwyd yr un ohonynt ar unrhyw un o safleoedd tymor hir MarClim yng Nghymru yn 2016.

Trosglwyddir prosiect MarClim a'r data gwyddonol canlyniadol i sefydliadau llywodraethol, asiantaethau cadwraeth, rheolwyr ACA a SoDdGA morol, a'r cyhoedd. Gwneir hyn i gynyddu gwybodaeth a dealltwriaeth o gwestiynau sy'n bwysig yn wyddonol, yn rheolaethol ac yn gymdeithasol mewn perthynas â newid hinsawdd byd-eang, asideiddio'r cefnfor, a rhywfaint o effeithiau dynol ar amgylchedd y môr gan gynnwys datblygu, preswylio a defnyddio'r parthau arfordirol, ecosystemau cyfansoddol a rhywogaethau, a'r gwaith o adrodd hyn oll. Defnyddir canlyniadau MarClim i asesu a llywio polisïau a chyfarwyddebau'r DU a'r UE, gan gynnwys Cyfarwyddeb Fframwaith Strategaeth Forol yr UE, Canllaw Llywodraethu PEGASEAS, ac asesiadau cyflwr ar gyfer SoDdGA a Safleoedd Morol Ewropeaidd. Defnyddir y canlyniadau hefyd fel data gwaelodlin ar gyfer proses dynodi Parthau Cadwraeth Morol y DU.

Datblygwyd set ddata cyfres amser MarClim gan Mieszkowska, Burrows a Hawkins (2013) o dîm MarClim fel dangosyddion Statws Amgylcheddol Da ar gyfer Cyfarwyddeb Fframwaith y Strategaeth Forol, a chyhoeddwyd yr adroddiad cyntaf yn 2014: http://jncc.defra.gov.uk/page-6813. Mae ail gam y gwaith o ddatblygu'r gyfres amser MarClim fel dangosyddion newid hinsawdd o ran rhywogaethau (Mynegai Tymheredd Rhywogaethau) a chymunedau (Mynegai Tymheredd Cymunedau) fel rhan o'r broses datblygu dangosyddion Statws Amgylcheddol Da Cyfarwyddeb Fframwaith y Strategaeth Forol wrthi'n cael ei gyflawni gan y tîm MarClim.

Amlygir gwerth cyfres amser a chanfyddiadau MarClim mewn asesiad gwyddonol gogledd Ewrop, 'Climate-Driven Range Shifts Within Benthic Habitats Across a Marine Biogeographic Transition Zone' (Newidiadau amrediad a ysgogir gan hinsawdd o fewn cynefinoedd dyfnforol ledled parth trawsnewid bioddaearyddol morol) yn y cyfnodolyn *Advances in Ecological Research*. Mae meintioli tueddiadau gofodol a thymhorol ar gyfer llawer o rywogaethau morol yn anodd oherwydd y diffyg setiau data tymor hir ledled gwasgariadau daearyddol cyflawn ac oherwydd digwyddiadau amrywioldeb ar raddfa fechan o ran ysgogyddion naturiol ac anthropogenig. Mae deall y newidiadau hyn yn mynnu dull amlddisgyblaethol i ddod â phatrymau a nodwyd o fewn setiau data at ei gilydd, ynghyd â'r prosesau sy'n gyrru'r patrymau hynny, gan ddefnyddio gwybodaeth fecanistig berthnasol i briodoli achos ac effaith yn gywir. http://www.sciencedirect.com/science/article/pii/S0065250416300228.

Mae prosiect a thîm ymchwil MarClim yn darparu gwaith monitro, data ymchwil ac arbenigedd gwyddonol unigryw, hanfodol a thymor hir. Defnyddir y rhain gan adrannau Llywodraeth y DU i fynd i'r afael â chyfarwyddebau polisi cenedlaethol ac Ewropeaidd pwysig, gan gynnwys Cyfarwyddeb Fframwaith Strategaeth Forol yr UE, Cyfarwyddeb Cynefinoedd yr UE, Cyfarwyddeb Fframwaith Dŵr yr UE, asesiadau Comisiwn OSPAR, a phroses dynodi Parthau Cadwraeth Morol y DU fel rhan o Ddeddf y Môr a Mynediad i'r Arfordir.

Executive Summary

This report summarizes the 2016 rocky intertidal survey work, data and analysis completed around the coastline of Wales under the project title of MarClim, as described in http://www.mba.ac.uk/NMBL/publications/occpub/occasionalpub20.htm Mieszkowska (2005). The annual survey in Wales forms part of a sustained, fifteen-year, continuous annual UK survey of over 100 long-term rocky intertidal survey sites. Geographical coverage includes sites throughout north and south west Wales for which historical data dating back to the 1950s exist, and additional sites where range extensions have been predicted to occur. MarClim surveys were carried out at forty two sites in 2016. Thirty four sites were surveyed in north Wales and eight sites in south Wales.

Lusitanian warm water topshells have shown increases in range and abundance at established populations in Wales throughout the 2000s in response to climate warming, and a reduction in abundance between 2010 and 2013 due to the hiatus in global warming detected during the 2000s. In 2016, individuals of toothed top shell *Phorcus lineatus* were found for the first time at Llanddulas, marking another extension of the northern, leading range edge for this species.

The abundance of both the cold water sponge *Halichondria panacea* and the warm water sponge *Hymeniacidon perlevis* have declined over the 2010s across Wales at MarClim sites. Studies of permanent quadrats on Pembrokeshire shores showed a decline from 2013 at Lawrenny Quay, Pembroke Ferry and South Hook, and little change in frequency of abundance at Monk Haven, West Angle Bay, Nolton Haven, Hazelbeach and Pembroke Power Station. These two sponges have differing thermal evolutionary origins, suggesting a factor other than climate change is driving the reduction in intertidal population abundance.

Several species of invasive, non-native macroalgae and invertebrates are recorded as part of the MarClim surveys. The invasive ascidian *Corella eumyota* has been present at the Menai Bridge MarClim site for five years, however, this species has fluctuated in abundance and is still found only in low numbers on the underside of cobbles in the low shore. The National Biodiversity Network has records of this species around the UK, although there is not a continuous geographic distribution, with sightings centred on ports, marinas, harbours and areas of high human activity in the coastal zone. The invasive brown alga *Colpomenia peregrina* was recorded as 'Frequent' at Holyhead in 2016. This is the first record of this species at the site, as it was 'Not Seen' in 2014 and 2015. Japanese wireweed *Sargassum muticum* has expanded coverage across MarClim sites in Wales since the start of modern surveys in 2002, with a population becoming established at Porth Oer in 2011. In 2016, however, it was only present at Aberffraw and Porth Oer sites, indicating a reduction in some populations. In south Wales, *S. muticum* was 'Frequent' at Broadhaven and 'Occasional' at West Angle, having reduced by a (S)ACFOR category since 2014 and 2015. In 2016 it was 'Occasional' at Jetty Beach Dale, having not been recorded there in previous years on MarClim surveys.

Invasive species of macroalgae *Undaria pinnatifida, Asparagopsis armata, Heterosiphonia japonica,* the invasive anemone *Diadumene* (*Haliplanella*) *lineata*, tunicates *Didemnum vexillum* and *Asterocarpa humilis*, molluscs *Crassostrea gigas* and *Crepidula fornicata,* bryozoan *Watersipora subtorquata,* the crabs *Hemigrapsus sanguineus* and *Hemigrapsus takanoi* were all looked for, but not found at any MarClim Wales long-term sites in 2016.

The MarClim project and resultant scientific data are communicated to government organisations, 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 some human impacts on the marine environment including development, habitation and exploitation of the coastal zone, component ecosystems and species. MarClim results are used to assess and inform UK and EU policies and directives including the EU Marine Strategy Framework Directive, PEGASEAS Governance Guide, condition assessments for SSSIs and European Marine Sites, and as baseline data for the UK Marine Conservation Zone designation process.

The MarClim time-series dataset was developed by Mieszkowska, Burrows and Hawkins (2013) of the MarClim team as Good Environmental Status Indicators for the MSFD, with the first report published in 2014: http://jncc.defra.gov.uk/page-6813. A second phase of work to develop the MarClim time-series as species (Species Temperature Index) and community indicators of climate change (Community Temperature Index) as part of the MSFD GES indicator development process is currently being undertaken by the MarClim team.

The value of the MarClim time-series and findings are highlighted in a northern European scientific assessment, 'Climate-Driven Range Shifts Within Benthic Habitats Across a Marine Biogeographic Transition Zone' in the journal *Advances in Ecological Research*. Spatial and temporal trends for many marine species are difficult to quantify 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. Understanding these changes requires a multidisciplinary approach to bring together patterns identified within long-term datasets and the processes driving those patterns using biologically relevant mechanistic information to accurately attribute cause and effect. http://www.sciencedirect.com/science/article/pii/S0065250416300228.

The MarClim Project and research team provide unique, essential, long-term monitoring and scientific research data and expertise. This is used by the UK government departments to address 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.

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1 INTRODUCTION

The MarClim project was established in 2001 to investigate changes that had occurred in rocky intertidal systems within the last 50 years around the UK. MarClim established a low-cost network of 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). In addition, a comprehensive survey of shores in Ireland and Northern Ireland was undertaken in 2003 (Simkanin *et al*. 2005). Natural Resources Wales (Countryside Council for Wales) has continued to fund annual surveys of the Welsh MarClim sites, including additional sites beyond species distributional limits to track range extensions as they occur.

The main aims at the outset of the MarClim project in 2001 remain as follows:

- To use existing historical information and collect new 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.
- To forecast future marine community changes on the basis of the Met Office's Hadley Centre climate change models and the United Kingdom Climate Impacts Partnership's climate change scenarios. The broad range of species known or likely to be temperature sensitive was covered.
- To establish low-cost, fit-for-purpose, methodologies and networks to provide subsequent regular updates and track how climate influences the marine biodiversity of Britain and Ireland.
- To provide general contextual time series data to support reporting on the success or otherwise of the Marine Strategy Framework Directive, marine aspects of Biodiversity Action Plans, European initiatives including the Habitats, Birds and Water Framework Directives, and management and monitoring of marine activities and resources, including fisheries and Special Areas of Conservation.
- To evaluate whether the climate indicator species used in this work have a wider contribution to make as part of the sustainability indicators that are needed to underpin the UK sustainable development strategy.
- To record the presence, abundance and spread of invasive non-native species on rocky intertidal ecosystems, and chart the impacts on native species.
- To disseminate the results widely, and accordingly elucidate the known impact climate has had on marine biodiversity over the last 100 years, and may have in the future.
- To provide a basis for the development of a proposal for European Commission funding to establish a pan-European network with related aims.
- To assess and report on the likely consequences of the predicted changes in response to climate for society, for commercial and non-commercial users of the marine environment and the policies and frameworks that conserve, manage and protect marine biodiversity. To assess whether any more serious impacts can be ameliorated or mitigated.

2 BACKGROUND

Prof. Alan J. Southward of The Marine Biological Association 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 cold water species *Semibalanus balanoides* was common in the 1930s and rarer in the warmer 1950s, when the southern species *Chthamalus stellatus* (split into two species, *C. stellatus* and *C. montagui* by Southward in the 1970s) increased in abundance. Following a switch to colder 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 marine ecosystem, making then early warning indicators of environmental change.

Southward and Prof. Denis Crisp (Bangor University) carried out surveys of barnacles and other rocky intertidal invertebrates and macroalgae around the coastline of Wales, England and Scotland in the 1950s, with ad-hoc resurveys during the 1960s-1980s. Prof. 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.

The MarClim project was established in 2001 to rescue, centrally archive and analyse these data, 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 exist since 2002. MarClim established a low cost network of 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. The network 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 England in 2010 that have been resurveyed again in each subsequent year to date. This network, together with the baseline information provided by the MarClim project, are being used by scientific and policy communities as key tools to track impacts on biodiversity as climate changes.

MarClim surveys around the Welsh coastline are currently funded by Natural Resources Wales with in-kind contributions from the Marine Biological Association of the UK, and academic staff from both Newcastle and Bangor Universities. These surveys form part of a wider network of long-term MarClim sites in England (funded by Natural England) and France.

The project focuses on a robust set of temperature-sensitive, readily observed, intertidal climate indicator species of invertebrates and macroalgae for which long-term datasets and monitoring sites are available. The MarClim species list includes boreal cold-water and lusitanian warm water origins, native to the UK intertidal ecosystems, and invasive non-native species that pose a potential threat to native biodiversity (Appendix 1) in collaboration with the UK Marine Aliens Project http://www.marlin.ac.uk/marine_aliens/. Other non-native species are also targeted due to their appearance and subsequent impacts on natural communities after introduction via escapes of associated spat from mussel and oyster aquaculture facilities and practices. MarClim data have 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 taxonomic groups (Mieszkowska *et al*. 2005, 2006, Mieszkowska 2009). 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 2002 to encompass those shifting distributional ranges into the UK tracking a warming climate, and invasive non-native species (INNS) 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 modelling has been incorporated since 2002 and is detailed in the Survey Protocols section below.

Climate-driven shifts in the biogeographic ranges of native and invasive species are also being tracked by Dr Mieszkowska around the wider northern European coastline using the MarClim protocols. These surveys provide geographically extensive, contextual evidence on distributions, abundances, biological mechanisms by which intertidal species respond to large-scale climate related changes and allow Welsh data to be placed into a European context, with special relevance to the EU Marine Strategy Framework Directive 'Good Environmental Status' indicators (http://jncc.defra.gov.uk/page-6813).

3 METHODS

The MarClim protocols (Appendix 1) were used as the standard survey methodology at all survey sites. These protocols include additional alien species of concern to NRW or pertinent to the Defra GB Non-Native Species Portal https://secure.fera.defra.gov.uk/nonnativespecies/home/index.cfm.

MarClim surveys were carried out at forty two long-term sites in 2016 (Table 1, Figure 1). Thirty four sites were surveyed in north Wales and eight sites in south Wales.

Rocky shores in north Wales were surveyed by Dr. Nova Mieszkowska and Leoni Adams from The Marine Biological Association, Paul Brazier, Gabrielle Wyn, Kathryn Birch, Jake Davies, Harriet Robinson, Laura Grant and Natasha Lough from Natural Resources Wales (Figure 2). Several NRW staff have been trained in MarClim methodology during previous annual surveys.

Eight sites were surveyed in south Wales including two sites on the Skomer Island Marine Conservation Zone, five on the mainland and one on Skokholm Island. These surveys were carried out and cross-calibration exercises undertaken by Mark Burton of NRW. All surveyors have been trained in MarClim methods and have carried out cross-calibrations with Mieszkowska in several previous years including on-site training to ensure accurate continuation of sample methodologies and protocols. Data entry was completed by Leoni Adams with QA by Nova Mieszkowska and Paul Brazier.

Semi-quantitative SACFOR abundance scores were recorded for a suite of 77 species of invertebrates and macroalgae, including nine non-native invertebrate and nine macroalgal species.

Replicate, quantitative quadrat counts were made for barnacles (0.1 m^2) (Figure 3) and population abundances for each species counted using bespoke digital image software. Ten replicate 0.25m^2 quadrats were counted at each site to record the abundance of limpet species were randomly placed within the midshore zone on areas of bedrock or large boulders with homogeneous surfaces (Figure 4). 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.

Five replicate searches, each of three minutes duration were made separately for *Phorcus lineatus* and *Gibbula umbilicalis* in the area of the shore where each of the two warm water 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 very individual was measured in mm to 1 decimal place and population size frequencies calculated from the data.

An additional site at Holyhead was added to the MarClim Wales site network in 2010 and has been re-surveyed annually to track any potential spread of the non-native ascidian *Didemnum vexillum* which has been the subject of an intense eradication program by NRW inside Holyhead marina (http://www.NRW.gov.uk/.../NRW-in-holyhead-harbour.aspx). An additional site at Llanddulas, which has been sporadically checked for absence of indicator species has been added to the list after the appearance of a population of *Gibbula umbilicalis* was found in 2012 for the first time, and was resurveyed in 2015 and 2016.

All data have been submitted to NRW in electronic format. Metadata and quantitative survey data were recorded on datasheets in the field. The data were transferred to electronic datasheets in the laboratory and a rigorous QA check carried out by Mieszkowska and Brazier. Photographs were labeled to allow accurate interpretation

and identification of features. Data analysis was carried out by Mieszkowska. The results are described in detail within this report. An electronic copy of data have been submitted to Natural Resources Wales 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.

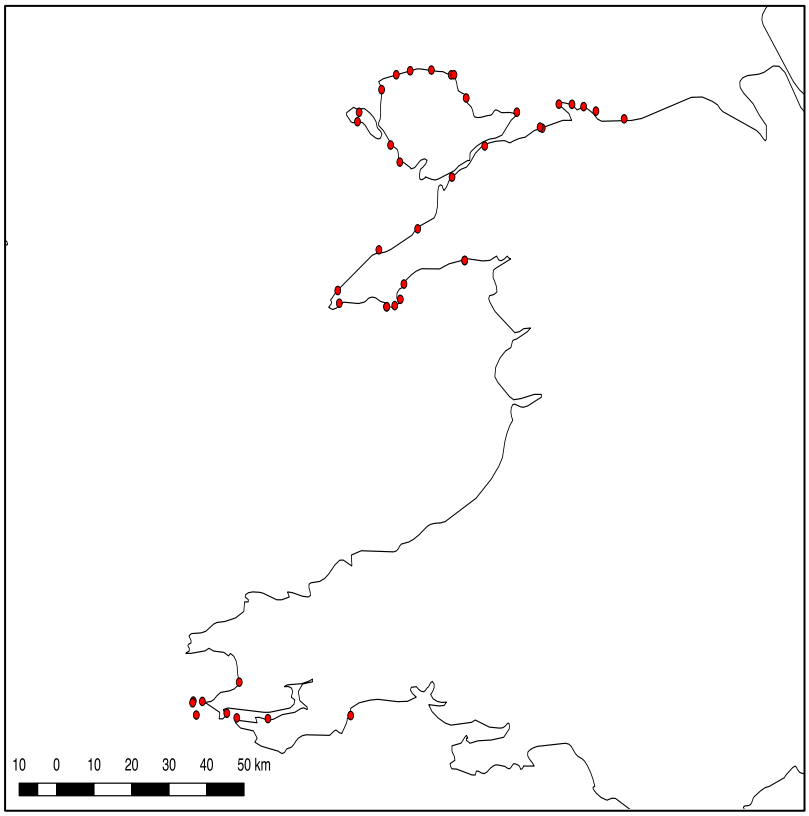

Figure 1. MarClim sites surveyed in 2016.

Figure 2a, b. NRW staff carrying out MarClim surveys.

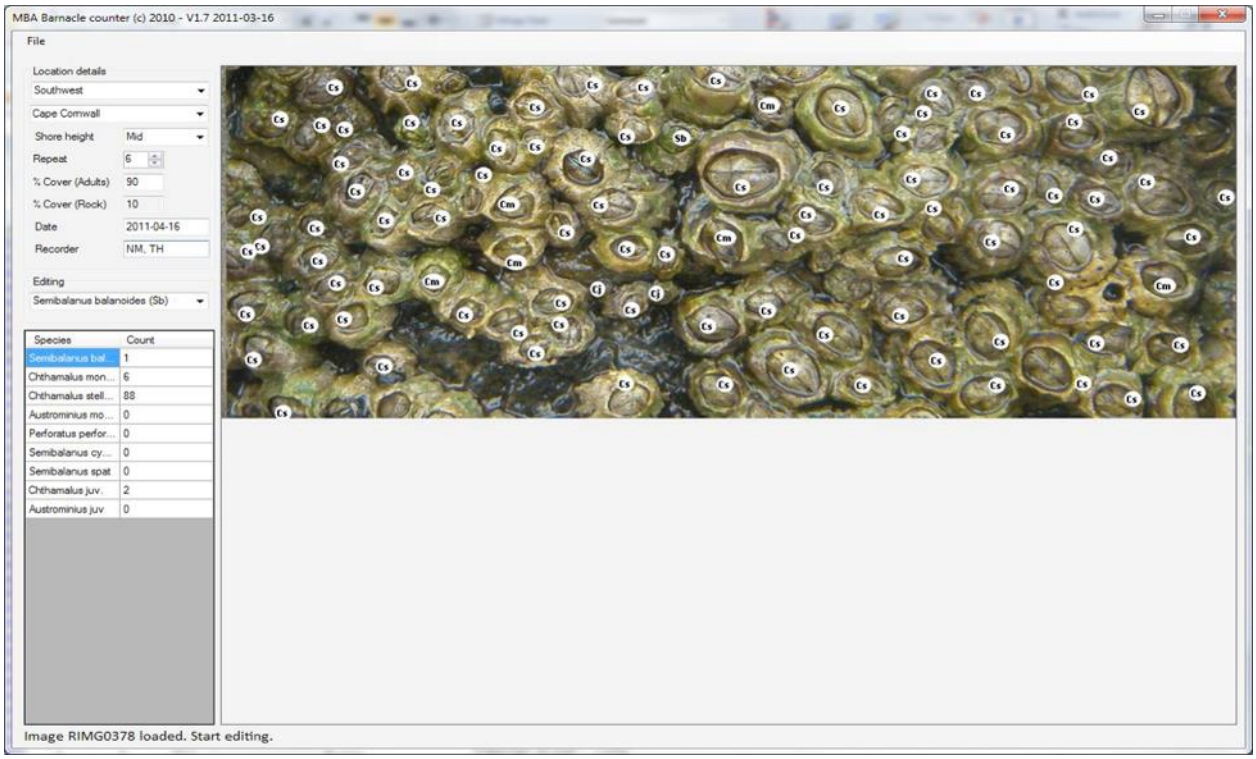

Figure 3. A 5cm x 2cm subsection of the 5x5cm barnacle quadrat images taken during MarClim surveys being analysed using MarClim digital image software. The species are identified and marked by a unique identifier code and the number of adult and juvenile barnacles for each species is recorded in a linked Access database.

Figure 4. MarClim 0.25m^2 limpet quadrat used for surveys.

Table 1. MarClim Survey Site Locations 2015

Day	Month	Year	Site	Grid	Lat	Long
1	8	2016	Llanddulas	SH906787	53.2933	-3.6296
1	8	2016	Rhos-on-Sea	SH843805	53.3140	-3.7381
1	8	2016	Little Orme	SH812825	53.3260	-3.7852
1	8	2016	Penmaenmawr Natural	SH704763	53.2683	-3.9440
1	8	2016	Penmaenmawr Artificial	SH709763	53.1613	-3.9369
1	8	2016	Penmaenmawr Slipway	SH699766	53.2712	-3.9521
2	8	2016	Great Orme Trwynygogarth	SH749834	53.3327	-3.8801
2	8	2016	Great Orme East	SH782832	53.3321	-3.8297
2	8	2016	Trefor	SH376474	52.9992	-4.4215
2	8	2016	Caernarfon	SH521671	53.1374	-4.2897
2	8	2016	Penmon North	SH641813	53.3111	-4.0413
2	8	2016	Menai Bridge	SH555714	53.2207	-4.1643
3	8	2016	Bull Bay	SH427945	53.4238	-4.3688
3	8	2016	Moelfre	SH513859	53.3490	-4.2354
3	8	2016	Point Lynas	SH484929	53.4111	-4.2823
3	8	2016	Porth Eilian	SH477929	53.4109	-4.2928
3	8	2016	Holyhead	SH257825	53.3108	-4.6461
3	8	2016	Porth Swtan	SH298891	53.3713	-4.5598
3	8	2016	Martin's Haven	SM759091	51.7357	-5.2471
4	8	2016	Cemlyn	SH337934	53.4111	-4.5035
4	8	2016	Cemaes	SH372944	53.4219	-4.4502
4	8	2016	Aberffraw (Braich-Lwyd)	SH337674	53.1776	-4.4899
4	8	2016	Rhosneigr	SH315725	53.2233	-4.5253
4	8	2016	Porth Dafarch	SH233798	53.2856	-4.6522
5	8	2016	Porth Neigwl	SH288245	52.7908	-4.5404
5	8	2016	Porth Neigwl boulder field	SH288245	52.7908	-4.5404
5	8	2016	Porth Oer B	SH163297	52.8343	-4.7279
5	8	2016	Nefyn	SH274415	52.9430	-4.5702
6	8	2016	Porth Ceiriad	SH308247	52.7938	-4.5094
6	8	2016	Abersoch Lifeboat Station	SH323265	52.8107	-4.4881
6	8	2016	Aberdaron	SH166260	52.8003	-4.7220
6	8	2016	Llanbedrog	SH335311	52.8516	-4.4742
7	8	2016	Criccieth (East)	SH494376	52.9146	-4.2412
7	8	2016	Criccieth Castle	SH494376	52.9146	-4.2412
1	9	2016	Skokholm South Haven	SM741051	51.6992	-5.2701
16	9	2016	Jetty Beach Dale	SM824052	51.7041	-5.1533
21	9	2016	Broadhaven	SM859144	51.7871	-5.1057
3	10	2016	West Angle	SM848038	51.6916	-5.1151
17	10	2016	Monkstone Point	SN150033	51.6978	-4.6784
18	10	2016	Pembrokeshire power station	SM930032	51.6896	-4.9956
4	8	2016	North Haven	SM735093	51.7365	-5.2819
4	8	2016	South Haven	SM733088	51.7319	-5.2845

4 RESULTS

4.1 2016 Findings

4.1.1 Recent 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. 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 http://www.metoffice.gov.uk/news/releases/2016/2016-a-year-in-weather-statistics. The levels of carbon dioxide in the global atmosphere passed the 400ppm threshold permanently in 2016 (Figure 5). 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.

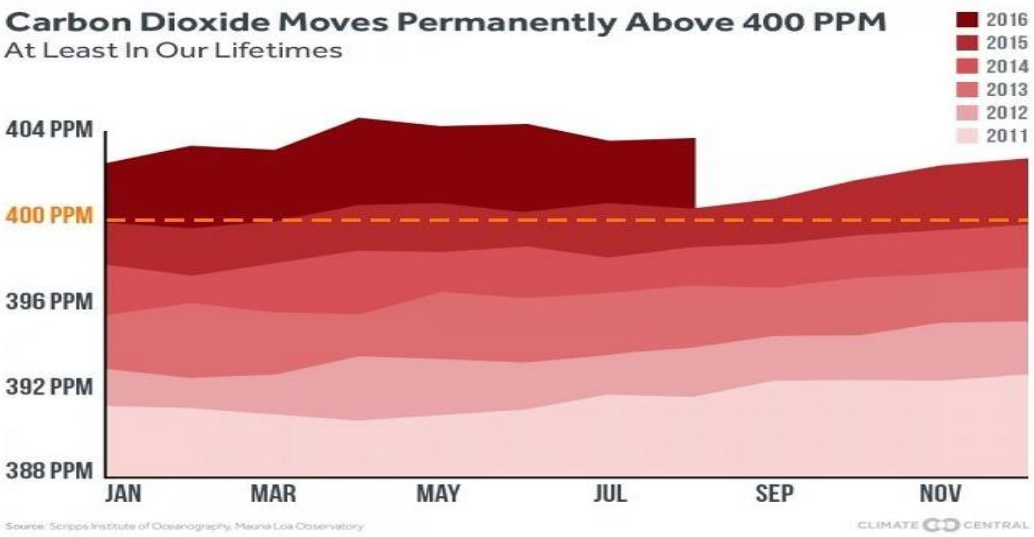

Figure 5. Atmospheric concentrations of carbon dioxide. Reproduced from Scripps Institute of Oceanography/Climate Central.

Storm events are predicted to reach such severe wind speeds, wave heights and precipitation levels more often with continuing climate change, although changes in storm frequency cannot yet be predicted with high confidence. The IPCC 5th Assessment Working Group I Report documents an apparent increase in the proportion of very intense storms since 1970, although the frequency of extreme weather events appears to be less predictable. Whilst UK government funding has been promised to tackle the damage to agricultural and domestic sectors, the natural coastline and the defensive and economic implications from the catastrophic storm damage is not being addressed.

The 2013/14 winter was characterised by the Met Office as a 'very severe' period of storms and associated wave conditions, unmatched in terms of intensity and duration for over 50 years. Biological impacts of these storm events were surveyed at all 42 MarClim sites in Wales six months afterwards during the annual surveys in July 2014. The 2015 and 2016 MarClim surveys have reassessed the effects on community structure following the 2013/14 storms after 18 and 30 month periods via analysis of those species that have resisted storm damage, those species that were able to return after the extreme storm events and invasive non-native species that opportunistically occupied vacant habitat after storm-induced species loss, colonising those shores affected by storm damage. Details are reported below in Section 4.1.2.

4.1.2 Storm impacts on Welsh rocky shores

An environmental audit was carried out by NRW after the 2014/14 storms (Duigan *et al*. 2014). Significant and highly variable impacts were recorded across a range of habitats and species, to the extent that ecosystem structure and functioning had changed, with algae, barnacles and molluscs being scoured from substrata or damaged and biogenic reefs were eroded in the intertidal zone. The nature and shape of the coastline was also markedly altered in several locations. Large volumes of beach sand were lost, exposing rock substrata, coarser material was driven inshore, and natural features, such as shingle ridges, were reshaped.

MarClim surveys around the Welsh coastline have tracked the changes in species and community composition annually since the 2013/14 storm event. The two sites that had significant changes in habitat structure were Porth Neigwl and Aberdaron, exposed rocky headlands on the southeast tip of the Llyn Peninsula where the prevailing Atlantic currents hit the land. These shores were subject to the highest wave forces during the storms around the north Wales coastline. At both shores, rocky habitat was uncovered by the storms and has remained uncovered since this time.

At Porth Neigwl, the main rocky reef and boulder field at the base of the cliff by Trwyn y Fostle (52.7908N, -4.5404E) showed no impacts, however, the boulder field situated approximately 100 m east in the sandy beach that is usually approximately 50 m in horizontal length was far larger, showing that previously covered sections of this boulder field had been uncovered by removal of sand from this area (Figure 5). This boulder field was covered in blue mussel *Mytilus* spp. and barnacles previous to the storm event, but sediment scouring and movement thought to be the result of higher wave action during the storm events than usually occurs in this bay is thought to have removed these sessile invertebrates, clearing the rock surface. This extensive boulder field was completely covered in early colonising ephemeral green *Ulva* spp. and red *Porphyra* spp. of algae in 2015 (Figure 6). The presence of ephemeral algae six months after the event is indicative of the first stages of succession on rocky intertidal habitat. By 2015 a large proportion of the boulder field was still covered by the ephemeral green algal species *Ulva intestinalis*. In addition fucoids were also present, a sign of some recovery towards a more stable community. In 2016, community

succession had continued (Figure 7), with a higher abundance of *Fucus vesiculosus* and *F. serratus* (both Superabundant). Barnacle abundance was also high on the top surfaces of boulders, with *Semibalanus balanoides* being Superabundant. Grazing gastropods *Littorina littorea* and *Phorcus lineatus* were also recorded in the boulder field in 2016, demonstrating additional trophic layers to the foodweb in this habitat.

These shifts indicate that the boulder field at Porth Neigwl is recovering to a more stable community state, the boulder field is still extensively covered with ephemeral early colonisers, with no apparent return to the *Mytilus* spp. and barnacles that characterised this area of the shore prior to the storms in 2013/2014. Continued monitoring through 2017 and onwards will enable further tracking of the community succession after a major physical disturbance event.

The headland at Aberdaron (52.8003N, -4.7220E) was also comprised of rocky cliff extending into the mid-eulittoral sandy beach, with small to large boulders. The boulder field was far more extensive in 2014 than in previous years, due to large movements of sediment within the bay (Figure 8). The boulder field remained uncovered in 2015 and 2016, without noticeable return of previously removed sediment and continued exposure. Succession to a *F. vesiculosus* and *S. balanoides* dominated community was recorded in 2014 (Figure 8), recorded again in 2015 (Figure 9), and remained in 2016 (Figure 11), demonstrating a shift towards more stable, later stage colonizing species.

No other major changes to habitat or community composition were recorded at the other 42 long-term MarClim sites in 2016. The MarClim data collected on post-storm impacts in 2014 and 2015 were used in the Natural Resources Wales report on storm damage (Duigan *et al*. 2014) (http://naturalresources.wales/media/1976/welsh-coastal-storms-december-2013-and-january-2014-an-assessment-of-environmental-change.pdf).

Figure 6. Ephemeral algae dominating the boulder shore at Porth Neigwl in July 2014

Figure 7. Boulder shore at Porth Neigwl, July 2015

Figure 8. Boulder shore at Porth Neigwl, August 2016

Figure 9. Boulder field uncovered by large movement of sediment at Aberdaron in July 2014

Figure 10. Boulder field at Aberdaron in July 2015

Figure 11. Boulder field at Aberdaron in August 2016

4.1.3 Lusitanian 'warm water' species

The leading range edge of the Lusitanian species of topshell *Phorcus lineatus* extended 16 km from Great Orme East to Llanddulas in 2016. Six adult individuals were found with the following maximum basal diameters and year classes; 24.3 mm (2006), 26.1 mm (2006), 20.7 mm (2008), 18.3 mm (2009), 20.4 mm (2009) and 20.0 mm (2010). The leading range edge extended from Great Orme Trwynygogarth to Great Orme East in 2008. A multi-age population, as opposed to isolated individuals was established in 2010, with abundances increasing to 5.8 per minute search in 2016. At Great Orme Trwynygogarth, 0.93 individuals per minute search were found in 2014, 0.2 individuals per minute in 2015 and 0.33 individuals per minute in 2016, showing that this very small population, close to the northern biogeographic range edge on the east side of the Great Orme had not increased in size significantly since the first MarClim survey at this site in 2007. It is likely that these small range edge populations at Great Orme are seeded by larvae from the Caernarfon and Anglesey populations.

Surveys at Llanddulas across the MarClim time-series also show how expansion of *Gibbula umbilicalis* from Rhos-on-Sea to this small cobble shore in 2008 marked the new most north-eastern population in Wales (there being a habitat-mediated gap in the biogeographic range until southern Scotland, with MarClim surveys funded by SNH tracking the northern range limit at Murkle Bay, northeast Scotland). In 2008 *G. umbilicalis* was Frequent (1.75 individuals per minute search). This population had increased to Common in 2012, with an average of 10.67 individuals per minute search but declined to Frequent in 2013 and 2014 with three and 3.26 individuals per minute search recorded respectively. The abundance of *G. umbilicalis* increased again in 2015 to Common, with 15.47 individuals per minute recorded in 2015 and 10.66 individuals per minute in 2016.

The Lusitanian, warm water kelp *Sacchoriza polyschides* has records from southern and northern subtidal sites around the Welsh coastline (https://data.nbn.org.uk/imt/?mode=SPECIES&species=NHMSYS0021058778#4-59.555,35.784,52.945,67.926!0951LDe!0851LDe). This species is recorded around the UK coastline, but there are few intertidal records from Wales. On 2014 *S. polyschides* was Rare at Porth Neigwl and Occasional at Porth Oer, it was Not Seen at either site in 2015, and Occasional at both sites in 2016. This species appears to colonise subtidal habitat initially, and then spread vertically upwards into the intertidal when thermal conditions are high enough to facilitate survival. If the marine climate of Wales continues to warm, higher abundances and colonisation of intertidal/shallow subtidal habitat at new locations in Wales is likely.

The honeycomb worm *Sabellaria alveolata* has a biogeographic range from southern limits in south Morocco to northern limits in the Shetland Isles. It has been recorded at 10 MarClim sites around the Welsh coastline, with Criccieth east being the only site where this species has been present over multiple years of the time-series, and was Abundant on 2016. It has been recorded in 2006 (Rare), 2008 (Common) and 2009 (Rare) at Rhosneigr, and at Llanddulas in 2008 (Abundant), 2015 (Abundant) and 2015 (Frequent), and records for only a single year (not the same year for each site) at Little Orme, Great Orme Trwynygogarth, Rhos on Sea, Porth Oer, Abersoch, Criccieth castle and Aberporth. The MarClim time-series for *S. alveolata* has been used in a UK-wide peer review publication documenting population declines following the recent cold winters of 2009/2010 and 2010/2011 (Firth et al. 2015). Extensive MarClim surveys revealed that *S. alveolata* had recolonised locations from which it had previously disappeared. Furthermore, it had increased in abundance at many locations, possibly in response to recent warming. *S. alveolata* was recorded on the majority of artificial coastal defence structures surveyed, suggesting that the proliferation of artificial coastal defence structures along this stretch of coastline may have enabled *S. alveolata* to spread across stretches of unsuitable natural habitat. Long-term and broadscale contextual monitoring such as the MarClim project is essential for monitoring responses of organisms to climate change.

4.1.4 Boreal ‘cold water’ species

Species of UK concern with respect to climate-driven declines in abundance and distribution include the kelp *Alaria esculenta*. *A. esculenta* was recorded as Common at Aberffraw, Frequent at Porth Oer and Occasional at Nefyn in 2014, was Not Seen at any MarClim site in 2015, and was only recorded at Nefyn in 2016, where it was Occasional. The individuals at Nefyn are smaller in length than at any other MarClim site in the UK. Populations of *A. esculenta* at MarClim sites around the English coastline have not undergone a reduction in abundance.

The high shore fucoid *Pelvetia canaliculata* has shown fluctuating abundances at MarClim sites, reflective of lifecycle dynamics across the 2000s and 2010s. In 2016, abundances had increased at several sites including Criccieth castle, and remained Superabundant at the sites where it was previously recorded at the highest abundance category in 2015 and 2014. *Halidrys siliquosa* is a pool-dwelling brown macroalga. It has only been recorded at Aberffraw (Braich-Lwyd) and Porth Oer across the years 2014-2016 of the MarClim time series, and at Menai Bridge (Rare), Rhosneigr (Abundant) in 2014, Cemlyn (Frequent) in 2015, and at Port Swtan (Rare) in 2016. The boreal kelp *Laminaria hyperborea* was not recorded at most MarClim sites in 2016 as in previous years due to the height of low water during the survey period not being as low as during previous annual surveys. *L. digitata* and *Saccharina latissima* were recorded at similar abundance in 2016 to previous years. These kelp species are located higher in the upper infralittoral zone than *L. hyperborea* and therefore 2016 records were not affected by tidal height. Analysis of similarity of abundance scores for all MarClim species within macroalgal assemblages across MarClim sites in Wales do not show any significant changes across recent years.

The Boreal, cold water barnacle *Semibalanus balanoides* shows little variation in population abundance at any MarClim Wales site across the 2002-2016 time period.

4.1.5 Invasive Non-Native Species

Several species of invasive, non-native macroalgae and invertebrates are searched for as part of the MarClim surveys. Invasive macroalgae *Undaria pinnatifida, Asparagopsis armata* and *Dasysiphonia* (*Heterosiphonia*) *japonica* have never been found at any Welsh MarClim sites. *Grateloupia turuturu* was recorded in Milford Haven marina in 2015. It has not been found at any MarClim site in Wales to date, although it is present in rockpools at several MarClim sites along the southern coastline of England. *Dasysiphonia* (*Heterosiphonia*) *japonica* was recorded by F. Bunker and J. Moore on NRW funded surveys in Milford Haven during studies on the maerl bed in September 2016, and in Tremadog Bay. The gametophyte Falkenbergia of *Asparagopsis armata* is pretty common in the shallow subtidal and pools in Pembrokeshire and it occurs in Tremadog Bay in north Wales (Old Oyster Bank and Sarn Badrig) (Bunker & Moore pers. comm).

The Japanese brown alga *Sargassum muticum* has been present in the UK since the 1970s. Analysis of MarClim sites where *S. muticum* was present across the 2002-2015 time-series show that this species has appeared for the first time at two sites in 2015; Penmon North and Nefyn, following on from new appearances at three sites for the first time in 2014: Cemlyn, Trearddur Bay and Aberffraw. Of these new colonisations in 2014, only the population at Aberffraw was maintained in 2015 with *S. muticum* recorded as Common for the second year running. Future MarClim surveys will continue to monitor for new introductions and successful survival at all sites. *S. muticum* had increased in abundance in recent years at sites where it was previously established up until 2015, but had disappeared Penmon North, Rhos on Sea or Martins Haven in 2016 and decreased in abundance at Aberffraw, Port Oer and Menai in north Wales, and Broadhaven and West Angle Bay in south Wales (Table 2).

Colpomenia peregrina is an invasive brown alga that has been sporadically recorded at several MarClim sites over the time-series, however, no established populations have been recorded over multiple years at these sites (Table 3). The National Biodiversity Network has records of this species around the UK, although there is not a continuous geographic distribution, with sightings centred on ports, marinas, harbours and areas of high human activity in the coastal zone. The invasive brown alga *Colpomenia peregrina*

was recorded as Frequent at Holyhead in 2016. It has also been recorded in Milford Haven, and in low shore rockpools on Rhosneigr in 2011 by Francis Bunker.

The invasive ascidian *Corella eumyota* was again found in low numbers on the undersides of boulders by Menai Bridge each year since 2011, but this population has not increased in size. *C. eumyota* has been present at the Menai Bridge MarClim site since 2012, with abundances fluctuating between Rare and Common. In 2016, only Rare individuals were recorded on the underside of cobbles in the low shore (Figure 12). *C. eumyota* has been recorded at Trefor in 2012, Great Orme Trwynygogarth in 2013 and Holyhead in 2012 and 2014. *C. eumyota* was recorded in low numbers for the first time in 2015 at the Dale site in south Wales and is occasionally recorded at the NRW Lawrenny Quay monitoring site in the Daugleddau.

Table 2. SACFOR abundance categories for *Sargassum muticum* when it was present at a MarClim site.

Site	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Penmon North	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	F	NS
Cemlyn	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	R	NS	NS
Trearddur Bay	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	A	NS	NS
Rhosneigr	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	R	NS	C	F	NS
Aberffraw	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	C	C	F
Porth Oer	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	R	A	A	S	A
Menai Bridge	NR	NR	NR	NR	NR	NS	NS	NS	R	R	R	NS	F	R	NS
Broadhaven	A	C	NS	NR	NS	NS	NS	O	F	A	F	F	C	C	F
Dale	NR	NR	NR	NR	NR	O	NS	NS	NS	F	R	NS	NR	NR	O
Martin's Haven	NS	NS	NS	NS	NS	NS	R	NS	R	NS	NS	NS	R	R	NS
South Haven	NS	NS	NS	NS	NS	NS	R	NS	NS	NS	NS	NS	NS	NS	NS
West Angle Bay	F	NS	O	NS	NS	O	NS	NS	F	NS	NS	NS	NS	F	O

Table 3. SACFOR abundance categories for *Colpomenia peregrina* when it was present at a MarClim site.

Site	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Bull Bay	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cemaes Bay	NS	NS	NS	R	NS	NS	NS	NS	NS	NS
Cemlyn	NS	R	NS	R	R	F	NS	NS	NS	NS
Porth Swtan	NS	NS	NS	NS	NS	F	NS	NS	NS	NS
Holyhead	NS	NS	NS	NS	NS	NS	NS	NS	NS	F
Trearddur Bay	NS	NS	C	NS	NS	NS	NS	NS	NS	NS
Rhosneigr	NS	C	C	NS	R	F	NS	C	NS	NS
Aberffraw (Braich-Lwyd)	C	C	F	NS	F	NS	NS	NS	NS	NS
Trefor	NS	NS	O	NS	F	NS	NS	R	NS	NS
Nefyn	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Porth Oer	NS	NS	NS	NS	NS	NS	NS	NS	NS	0

Figure 12. *Corella eumyota* at Menai Bridge

The invasive anemone *Diadumene* (*Haliplanella) lineata*, tunicates *Didemnum vexillum* and *Asterocarpa humilis*, molluscs *Crassostrea gigas* and *Crepidula fornicata,* bryozoan *Watersipora subtorquata,* the crabs *Hemigrapsus sanguineus* and *Hemigrapsus takanoi* were all looked for, but not found at any MarClim Wales long-term sites in 2016. *Diadumene lineata* has been found in the Daugleddau, is regularly recorded at Pembroke Ferry in the lower and middle shore of Bunker & Moore's NRW monitoring site and has been recorded both on the shore and nearby in the shallow subtidal (the NRW Warrior monitoring site) in 2016.

MarClim survey sites are located at exposed or semi-exposed sites away from direct influences of human activities. Whilst limited numbers of non-native invasive species were recorded during MarClim surveys, a number of these are found at nearby marinas and aquaculture sites in higher abundances than nearby natural shores, including *Corella eumyota* and *Asterocarpa humilis* http://www.nonnativespecies.org/downloadDocument.cfm?id=136. Given the close proximity of these marinas to MarClim natural rocky shore sites continued monitoring will enable tracking of any arrivals and increases in abundance of non-native species into local natural shores. The solitary tunicate *Styela clava* is not on the MarClim list, but the team found it again to be present in low densities on the concrete supports of the old lifeboat slipway at Abersoch in 2016.

Whilst limited numbers of non-native invasive species were recorded during MarClim surveys, a number of these are found at nearby marinas and aquaculture sites in higher abundances than nearby natural shores, including *Corella eumyota* and *Asterocarpa humilis* http://www.nonnativespecies.org/downloadDocument.cfm?id=136. Given the close proximity of these marinas to MarClim natural rocky shore sites continued monitoring will enable tracking of any arrivals and increases in abundance of non-native species into local natural shores.

4.2 Spatio-temporal trends

The MarClim time-series shows that many species recorded for the project have responded to both climate warming and cooling of the marine climate across this century. Lusitanian gastropods have shown the fastest range extensions around the north Wales coastline in response to warming of sea temperatures. The community composition and abundance of component species has not shown large shifts, as climate change impacts are species specific, and therefore the effects are more subtle than those caused by regime shifts upon ecosystem structure and functioning.

4.2.1 North east & Llyn coastlines

Both Boreal cold water and Lusitanian warm water sponges have shown a decline in abundance at sites across the north east and Llyn coastlines of Wales. The cold water sponge *Halichondria panacea* declined at ten sites, and increased at two sites across the 2010s. The warm water sponge *Hymeniacidon perlevis* also declined in abundance, with lower SACFOR scores across the 2010s at eleven sites, and no increases at any site.

4.2.2 Anglesey

The same declining trend in abundance of both sponges was recorded around the Anglesey coastline, with a decline in abundance of *H. panacea* at ten sites, no changes at one site and an increase at two sites, and a decline in *H. perlevis* at

seven sites and an increase at two sites. The same declining abundance trend in both a warm water and a cold water species of sponge at the same sites suggests a factor other than climate change is driving this national trend.

4.2.4 Pembrokeshire

Most species have not fluctuated more than 1-2 SACFOR categories across the time-series indicating natural stochasticity but no acute impacts or pervasive changes. *Mytilus* spp. appears sporadically at sites, remains for a few years and then disappears again. This is typical of mussel beds that are often the result of a single spat fall that does not successfully recruit in subsequent years. A new survey station added at the new Pembroke power station in 2013 to monitor the potential impacts of warm water outflow on adjacent intertidal habitats and this site is now resurveyed each year.

4.2.5 Additional species records

The brown alga *Leathesia difformis* was recorded in high abundances at most MarClim sites in 2016. Whilst not a MarClim species, the unusually high densities at long-term sites was noted. The free floating, pelagic hydrozoan *Velella velella* was washed up on Aberdaron beach in 2016 (Figure 13).

Figure 13. *Velella velella* at Aberdaron.

4.3 Relevance to policy drivers and conservation objectives

The MarClim long-term sustained observation time-series dataset has been used to develop indicators for Good Environmental Status under the Descriptors 1: Biodiversity, 2: Non-indigenous Species, 4: Foodwebs, and 6: Seafloor Integrity for the European Union Marine Strategy Framework Directive (http://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm; http://jncc.defra.gov.uk/page-6813). This establishes MarClim as an official,

standardised monitoring project and methodology for the European MSFD assessment and policy-delivering progress. A second phase of work to develop the MarClim time-series as species (Species Temperature Index) and community indicators of climate change (Community Temperature Index) as part of the MSFD GES indicator development process is currently being undertaken by the MarClim team.

5 SUMMARY

All 42 rocky shores surveyed by the MarClim team were in good condition in 2016. The community composition at the majority of long-term sites did not show major changes in abundance in 2016 compared to recent years. Cold water macroalgae have not changed in abundance across the sites. Warm water topshells, limpets and barnacles prior to 2014 had shown a slight slowdown in the decadal increasing trend, 2014 and 2015 data indicate that abundances of these species may now be back on a an upward with an extension of the northern, leading range edge of *P. lineatus* recorded in 2016. Invasive non-native species have shown a decline in abundance at those MarClim sites where they have been previously recorded.

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APPENDIX 1. MarClim Sampling Protocols 2016

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 100m 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 of listed 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 10m x 10m. 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 and 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 SACFOR.
2. Avoid areas of heavy human disturbance.

At each site: Quantitative Barnacle Data Collection

1. Photograph at least ten replicate 5cm x 5cm quadrats containing barnacles at *low, mid* and *high* shore levels. High shore is defined as that area 1m 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 2cm 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, Gibbula umbilicalis* and *Nucella lapillus* present in the quadrat.
6. Count the total number of limpets >10mm. 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 *Gibbula 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 0.1mm using dial callipers.
5. In shores where there is a relatively uniform distribution of rocks < 30cm it is possible to use a $1m^2$ 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 0.1mm. In addition, up to five random 0.5x0.5m 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

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								
Dasysiphonia japonica (Heterosiphonia japonica)								
Halichondria panacea								
Hymeniacidon perlevis								
Anemonia viridis								
Aulactinia verrucosa								
Actinia fragacea								
Actinia equina								
Diadumene lineata (Haliplanella lineata)								
Sabellaria alveolata								
Chthamalus stellatus								
Chthamalus montagui								
Semibalanus balanoides								
Balanus crenatus								
Perforatus (Balanus) perforatus								
Austrominius (Elminius) modestus								
Pollicipes pollicipes								
Mytilus spp.								
Clibanarius erythropus								
Haliotis tuberculata								
Testudinalia (Tectura) testudinalis								
Patella vulgata								
Patella depressa								
Patella ulyssiponensis								
Patella (Ansates) pellucida								
Gibbula umbilicalis								
Gibbula pennanti								
Gibbula cineraria								
Phorcus (Osilinus) lineatus								
Calliostoma zizyphinum								
Littorina littorea								
Littorina saxatilis agg.								
Melarhaphe neritoides								
Nucella lapillus								
Onchidella celtica								
Crassostrea gigas								
Crepidula fornicata								
Botrylloides violaceus								
Corella eumyota								
Dendrodoa grossularia								
Asterocarpa humilis (cerea)								
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:

APPENDIX 2: Data Archive

The report and data collected under Natural Resources Wales Memorandum of Understanding MOA 0070 is archived as Project No 443 Media No 1483 and is maintained on a backed-up server based storage at NRW headquarters.

The data archive consists of:

[A] Digital versions of the contract report: Microsoft Word document(s); and an equivalent Adobe Portable Document Format version

[B] Excel spreadsheets of species records

[C]. Marine Recorder file that is held by DASSH

File Path for data: (DMS link)

File path for the report: (DMS link)

Metadata for this project is publicly accessible through the Natural Resources Wales Library Catalogue https://libcat.naturalresources.wales/webview/ by searching 'Dataset Titles'.

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