MarClim Annual Welsh Intertidal Climate Monitoring Survey 2015

Dr. N. Mieszkowska, L. Adams, Dr. H. Sugden

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Crynodeb Gweithredol

Mae'r adroddiad hwn yn crynhoi gwaith arolygu, gwaith dadansoddi a data creigiau rhynglanwol 2015 a gwblhawyd o amgylch arfordir Cymru fel rhan o brosiect MarClim, a ddisgrifir yn yr adroddiad gan Mieszkowska (2005) http://www.mba.ac.uk/NMBL/publications/occpub/occasionalpub20.htm. Mae'r arolwg blynyddol yng Nghymru yn rhan o arolwg blynyddol rheolaidd sydd wedi bod yn cael ei gynnal yn ddi-dor ers pedair blynedd ar ddeg yn y DU mewn dros 100 o safleoedd creigiau rhynglanwol sy'n rhan o'r arolwg hirdymor. Mae'r cwmpas daearyddol yn cynnwys safleoedd ledled y gogledd a'r de-orllewin y mae data hanesyddol sy'n dyddio'n ôl i'r 1950au ar gael ar eu cyfer, a safleoedd ychwanegol lle rhagwelwyd y byddai eu cwmpas yn ymestyn. Cynhaliwyd arolygon MarClim mewn dau safle a deugain yn 2015. Arolygwyd tri deg a thri o safleoedd yn y gogledd a naw yn y de.

Cynyddodd poblogaeth morwiail a thopiau môr dŵr cynnes Lwsitanaidd o amgylch Cymru gydol y 2000au mewn ymateb i gynhesu byd eang yr hinsawdd forol a achoswyd gan ddyn. Fodd bynnag, cofnodwyd bod gwyrdroi i'r tuedd cynyddol rhwng 2010-2013, a oedd yn debygol o fod yn ymateb i'r toriad a gafwyd mewn cynhesu byd-eang a ganfuwyd yn ystod y 2000au (Mieszkowska 2014). Roedd arolygon yn y safleoedd hirdymor hyn yn 2014 yn dangos nad oedd dirywiad yn y niferoedd rhagor, a bod nifer cynyddol o unigolion o fewn y boblogaeth o bellafion gogledd Cymru ac o amgylch arfordir Cymru a Lloegr ac ar hyd y Sianel (a arolygwyd gan dîm MarClim gyda chyllid Natural England) i bellafion y gogledd-ddwyrain. Mae'r data a gasglwyd yn ystod arolygon 2015 yn dangos niferoedd y topiau môr mewn safleoedd hirdymor yn parhau â'r tuedd cynyddol pob degawd, gan gefnogi dull o ddychwelyd o bosibl i duedd o gynhesu tymor hwy mewn ymateb i gynhesu byd-eang yr amgylchedd morol. Bydd arolygon blynyddol yn y dyfodol yn darparu tystiolaeth a fydd yn dangos a yw'r tuedd o gynhesu tymor hwy wedi ailgychwyn, neu a yw'r cynnydd yn niferoedd y poblogaethau yn ymateb tymor byr, mecanistig, is-angheuol rhywogaethau topiau môr Lwsitanaidd *Phorcus lineatus* a *Gibbula umbilicalis* i amodau thermol mwynach gaeafau 2013/14 a 2014/2015.

Cofnodir sawl rhywogaeth o algâu macro a rhywogaethau di-asgwrn cefn ymledol, anfrodorol fel rhan o arolygon MarClim. Yn 2015, cofnodwyd yr algâu coch ymledol *Grateloupia turuturu* yn safle marina Aberdaugleddau, a gofnodwyd yn flaenorol gan CNC (Jennings a Wray 2013) ac a gofnodwyd yn 2015 yn ystod arolygon MarClim. Cymerwyd sampl o feinwe i gymharu moleciwlau â samplau o'r rhywogaeth ymledol hwn ar hyd a lled Lloegr a Ffrainc, er mwyn egluro ffynonellau a'r ffyrdd y mae'r algae ymledol hwn yn ymledu. Mae'r rhywogaeth hon wedi bod yn ymledu o amgylch arfordir y DU, fodd bynnag, nid oes llawer o wybodaeth ar gael o hyd am y ffactorau sy'n gwneud iddi ymledu na'r effaith ar rywogaethau brodorol.

Mae prosiect MarClim a'r data gwyddonol a gasglwyd gan MarClim yn cael eu cyfathrebu i sefydliadau'r llywodraeth, staff, asiantaethau gwarchod, Ardaloedd Cadwraeth Morol Arbennig, a rheolwyr Safleoedd o Ddiddordeb Gwyddonol Arbennig a'r cyhoedd er mwyn cynyddu gwybodaeth, dealltwriaeth ac unrhyw adrodd ar gwestiynau pwysig o ran gwyddoniaeth, rheolaeth a chymdeithas sy'n gysylltiedig â newid yn yr hinsawdd fyd-eang, asideiddio'r cefnfor a'r effeithiau dynol graddfa is ar yr amgylchedd morol gan gynnwys datblygiad, cynefinoedd, ac achosion o ecsbloetio'r parth arfordirol, yr ecosystemau sy'n rhan ohonynt a'r rhywogaethau. Mae MarClim wedi arfer asesu a llywio polisïau a chyfarwyddebau'r DU a'r UE gan gynnwys Cyfarwyddeb Fframwaith Strategaeth Forol yr Undeb Ewropeaidd, Canllaw

Llywodraethu PEGASEAS, Asesiadau o Amodau ar gyfer Ardaloedd Cadwraeth Arbennig, Safleoedd o Ddiddordeb Gwyddonol Arbennig a Safleoedd Marina Ewropeaidd ac fel data llinell sylfaen ar gyfer proses ddynodi Parth Cadwraeth Morol y DU.

Enwyd protocolau MarClim fel enghraifft o arfer gorau ar gyfer casglu data dros gyfnod o amser ac maen nhw ar gael yn y PEGASEAS Governance Guide for Policymakers in the EU https://www.pegaseas.eu/wp-content/uploads/2015/01/PEGASEAS-Compendium-English-Version.pdf.

Datblygwyd y set ddata ar gyfer y data a gasglwyd dros amser gan Mieszkowska, Burrows a Hawkins (2013) o dîm MarClim fel Dangosyddion Statws Amgylcheddol Da ar gyfer Cyfarwyddeb Fframwaith y Strategaeth Forol, gyda'r adroddiad llawn yn cael ei gyhoeddi yn 2014: http://jncc.defra.gov.uk/page-6813. Mae llinell amser MarClim yn cael ei mabwysiadu hefyd gan yr International Network for the Study of Rocky Shore Ecosystems (INSHORE) fel yr hyn sy'n safonol yn fyd-eang http://rockyinshore.org/about/.

Tynnwyd sylw at MarClim mewn asesiad gwyddonol byd-eang, gan fanylu ar bwysigrwydd sicrhau bod gwaith ymchwil gwyddonol yn cael ei gynllunio'n briodol er mwyn darparu gwybodaeth addas i'r diben ar raddfeydd gofodol a thymhorol perthnasol sy'n ddefnyddiol i reolwyr ardaloedd gwarchodedig, cyrff statudol a gwneuthurwyr polisi. Mae'r papur ymchwil hwn a adolygir gan gymheiriaid yn dangos pa mor arloesol oedd prosiect MarClim a'r cydweithredu tymor hir rhwng Cyfoeth Naturiol Cymru a Chymdeithas Fiolegol Forol y DU wrth ddarparu gwybodaeth berthnasol ar Amodau a Statws cynefinoedd rhynglanwol yn erbyn cyd-destun o newid hinsawdd sy'n treiddio i bob rhan. http://www.biomedcentral.com/content/pdf/s40665-014-0006-0.pdf.

Mae Prosiect a thîm ymchwil MarClim yn darparu gwaith monitro, data ar ymchwil gwyddonol ac arbenigedd unigryw, hanfodol, tymor hir. Defnyddir eu hadnoddau gan adrannau llywodraeth y DU er mwyn mynd i'r afael â chyfarwyddebau polisi cenedlaethol ac Ewropeaidd pwysig gan gynnwys Cyfarwyddeb Fframwaith Strategaeth Forol y DU, Cyfarwyddeb Cynefinoedd y DU, Cyfarwyddeb Fframwaith Dŵr y DU, Asesiadau Comisiwn OSPAR, a phroses ddynodi Parth Cadwraeth Morol y DU fel rhan o Ddeddf y Môr a Mynediad i'r Arfordir.

Executive Summary

This report summarizes the 2015 rocky intertidal survey work, data and analysis completed around the coastline of Wales under the project title of MarClim, as described in the report by Mieszkowska (2005) http://www.mba.ac.uk/NMBL/publications/occpub/occasionalpub20.htm. The annual survey in Wales forms part of a sustained, fourteen-year, continuous annual UK survey of over 100 long-term rocky intertidal survey sites. Geographical coverage includes sites throughout north and southwest 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 2015. Thirty three sites were surveyed in north Wales and nine sites in south Wales.

Population abundances of Lusitanian warm water kelps and topshells around Wales increased throughout the 2000s in response to anthropogenically mediated global warming of the marine climate, however, a reversal to the increasing trend was recorded from 2010-2013, a likely response to the hiatus in global warming detected during the 2000s (Mieszkowska 2014). Surveys at these long-term sites in 2014 showed that these declines in abundance were no longer occurring, with increased numbers of individuals within populations from northern range limits in north Wales right around the Welsh and English coastlines and along the English Channel (surveyed by the MarClim team with funding from Natural England) to the northeast range limit. The data collected during the 2015 surveys showed topshell abundances at long-term sites resuming the decadal-scale increasing trend, supporting a potential return to a longer-term warming trend in response to global warming of the marine environment. Future annual surveys will provide evidence of whether the long-term warming trend has resumed, or if the increase in population abundances was a short-term, mechanistic, sub-lethal response of the Lusitanian topshell species *Phorcus lineatus* and *Gibbula umbilicalis* to the milder winter thermal conditions experienced in 2013/14 and 2014/2015.

Several species of invasive, non-native macroalgae and invertebrates are recorded as part of the MarClim surveys. In 2015, the invasive red alga *Grateloupia turuturu* was recorded at the Milford Haven marina site, which had been previously recorded by NRW (Jennings & Wray 2013) and was recorded in 2015 during MarClim surveys. A tissue sample was taken for molecular comparison with samples from this invasive species across England and France, to elucidate the sources and modes of spread of this invasive alga. This species has been spreading around the UK coastline, however, little is still known about the vectors of spread, or impacts on native species.

The MarClim project and scientific data collected by MarClim is communicated to government organisations, 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, PEGASEAS Governance Guide, Condition Assessments for SACs, SSSIs and European Marine Sites and as baseline data for the UK Marine Conservation Zone designation process.

MarClim protocols have been cited as an example of best practice for time-series collection in the PEGASEAS Governance Guide for Policymakers in the EU https://www.pegaseas.eu/wp-content/uploads/2015/01/PEGASEAS-Compendium-English-Version.pdf.

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 full report published in 2014: http://jncc.defra.gov.uk/page-6813. The MarClim time-series is additionally being adopted by the INSHORE International Network for the Study of Rocky Shore Ecosystems as the global standard http://rockyinshore.org/about/.

MarClim has been highlighted in a global scientific assessment, detailing the importance of scientific research to be appropriately designed in order to provide 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 ground-breaking the MarClim project and the long-term collaboration with Natural Resources Wales 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 http://www.biomedcentral.com/content/pdf/s40665-014-0006-0.pdf.

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 exists 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 data sets 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/. Non-natives 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 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 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 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 2015 (Table 1, Figure 1). Thirty three sites were surveyed in north Wales and nine sites in south Wales.

Rocky shores in north Wales were surveyed by Dr. Nova Mieszkowska from The Marine Biological Association, Paul Brazier and Kathryn Birch from Natural Resources Wales and Dr. Heather Sugden from Newcastle University. Nine sites were surveyed in south Wales including two sites on the Skomer Island Marine Conservation Zone, five on the mainland and one new site on Skokholm Island. These surveys were carried out and cross-calibration exercises undertaken by Mark Burton of NRW and Leoni Adams of The Marine Biological Association. All surveyors 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 a QA by Nova Mieszkowska, Heather Sugden 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. Non-native species added to the list in 2014 were the shore crabs *Hemigrapsus sanguineus* and *Hemigrapsus takanoi*, both species having had a single record of a potential sighting in the UK, with rapid colonisation of rocky shores on the French coastline of the English Channel. *Hemigrapsus sanguineus* has also invaded the US coastline of the North Atlantic in recent years, outcompeting the green crab *Carcinus maenas* that is native to the UK, and therefore poses a potential risk for invasion of natural rocky intertidal communities.

Replicate, quantitative quadrat counts were made for barnacles (0.1 m^2) (Figure 2) 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 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.

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.

All data have been submitted to NRW in electronic format. All surveyors had been trained in MarClim methodology and cross-calibrated in the field with Dr Mieszkowska. 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.

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, Sugden and Brazier. Photographs were labeled to allow accurate interpretation and identification of features. Data analysis was carried out by Mieszkowska and Adams, the results are described in detail within this report. An electronic copy of data has 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. Leoni Adams compiled the GIS-referenced MarClim survey map.

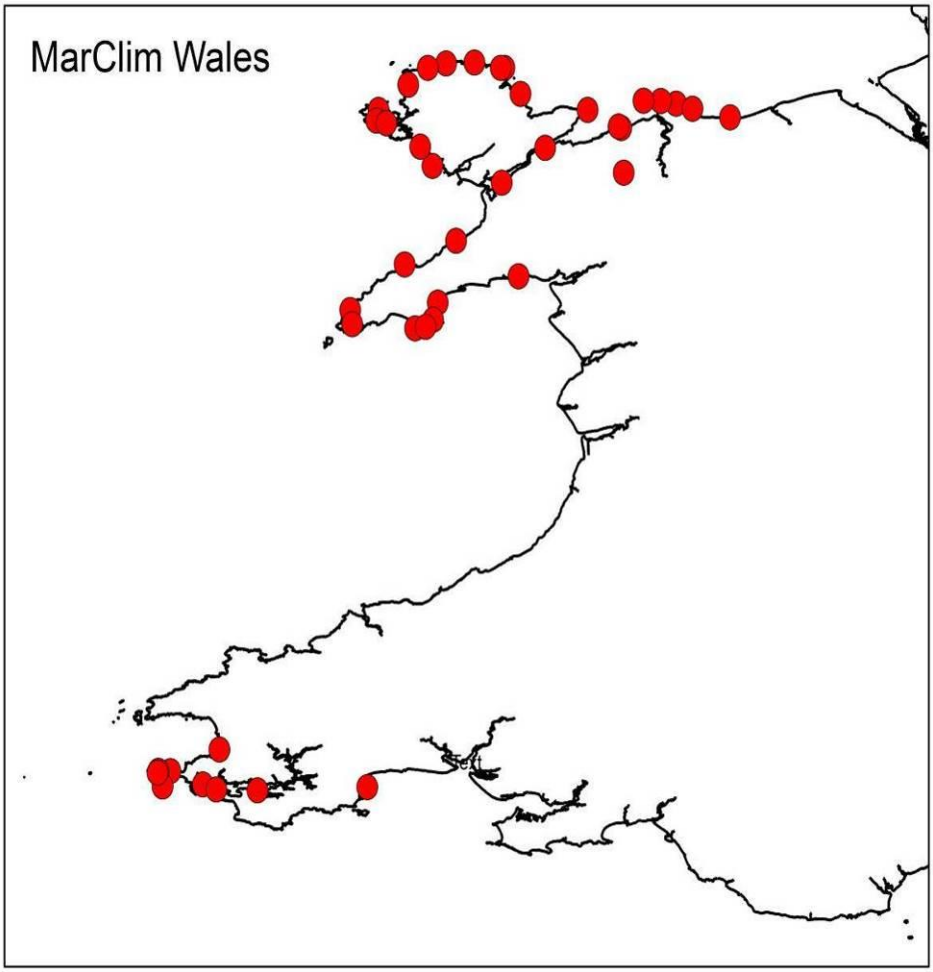

Figure 1. Sites surveyed by MarClim for NRW in 2015

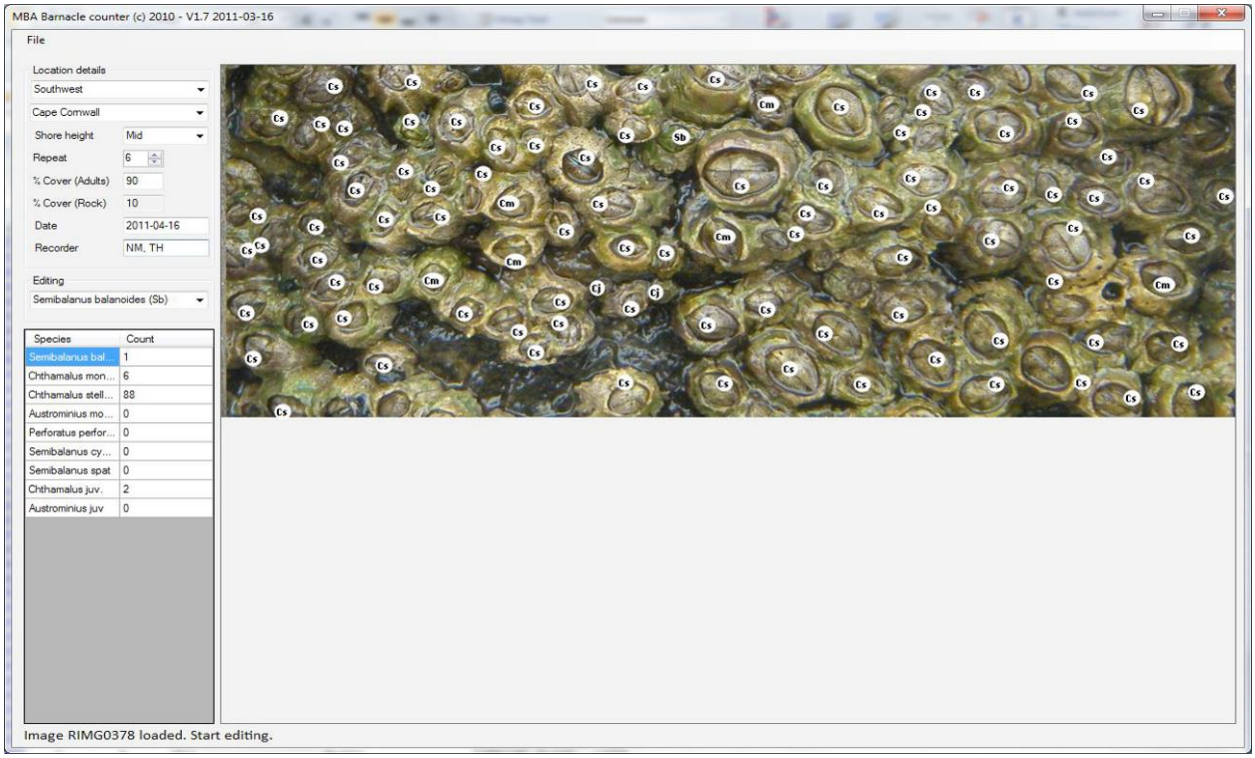

Figure 2. A 5cm x 2cm subsection of the 5x5cm barnacle quadrat images taken during MarClim surveys being analysed using MarClim digital image software. The species are identified and marked by a unique identifier code and the number of adult and juvenile barnacles for each species is recorded in a linked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

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

Table 1. MarClim Survey Site Locations 2015: NM: Nova Mieszkowska (MBA), HS: Heather Sugden (Newcastle University), LA: Leoni Adams (MBA), MO: Mauricio Orostica (Bangor University), KW: Kringpaka Wangkulangkul (Bangor University), PB: Paul Brazier (NRW), KB: Kathryn Birch (NRW), MB: Mark Burton (NRW), JJ: Jennifer Jones (NRW), JAT: Jon Archer Thompson (Dale Fort), KL: Kate Lock (NRW)

Day	Month	Year	Site	Region	Recorder	Grid	Lat	Long
17	7	2015	Little Orme	North Wales	NM, HS	SH812825	53.3260	-3.7852
17	7	2015	Llanddulas	north Wales	NM, HS	SH906787	53.2933	-3.6296
17	7	2015	Penmaenmawr artificial	north Wales	NM, HS	SH709763	53.1613	-3.9369
17	7	2015	Penmaenmawr natural	north Wales	NM, HS	SH704763	53.2683	-3.9440
17	7	2015	Penmaenmawr slipway	north Wales	NM, HS	SH699766	53.2712	-3.9521
17	7	2015	Rhos-on-sea	north Wales	NM, HS	SH843805	53.3140	-3.7381
18	7	2015	Caernarfon	north Wales	NM, HS, MO, KW	SH521671	53.1374	-4.2897
18	7	2015	Cemaes	north Wales	NM, HS, MO, KW, KB	SH372944	53.4219	-4.4502
18	7	2015	Great Orme East	north Wales	NM, HS, PB	SH782832	53.3321	-3.8297
18	7	2015	Great Orme Trwynygogarth	north Wales	NM, HS, PB	SH749834	53.3327	-3.8801
18	7	2015	Menai Bridge	north Wales	NM, HS, MO, KW	SH555714	53.2207	-4.1643
18	7	2015	Penmon North	north Wales	NM, HS, MO, KW	SH641813	53.3111	-4.0413
18	7	2015	Trefor	north Wales	NM, HS, MO, KW	SH376474	52.9992	-4.4215
19	7	2015	Bull Bay	north Wales	NM, HS	SH427945	53.4238	-4.3688
19	7	2015	Holyhead	north Wales	NM, HS, MO, KW	SH257825	53.3108	-4.6461
19	7	2015	Moelfre	north Wales	NM, HS	SH513859	53.3490	-4.2354
19	7	2015	Point Lynas	north Wales	NM, HS	SH484929	53.4111	-4.2823
19	7	2015	Porth Dafarch	north Wales	NM, HS, MO, KW, KB	SH233798	53.2856	-4.6522
19	7	2015	Porth Eilian	north Wales	NM, HS	SH477929	53.4109	-4.2928
19	7	2015	Porth Swtan	north Wales	NM, HS, MO, KW	SH298891	53.3713	-4.5598
20	7	2015	Aberffraw	north Wales	NM, HS	SH337674	53.1776	-4.4899
20	7	2015	Cemlyn	north Wales	NM, HS, MO, KW, KB	SH337934	53.4111	-4.5035
20	7	2015	Rhosneigr	north Wales	NM, HS	SH315725	53.2233	-4.5253
20	7	2015	Trearddur Bay	north Wales	NM, HS, MO, KW, KB	SH252789	53.2790	-4.6231
21	7	2015	Nefyn	north Wales	NM, HS	SH274415	52.9430	-4.5702
21	7	2015	Porth Neigwl	north Wales	NM, HS	SH288245	52.7908	-4.5404
21	7	2015	Porth Oer	north Wales	NM, HS	SH163297	52.8343	-4.7279
22	7	2015	Aberdaron	north	NM, HS	SH166260	52.8003	-4.7220

Day	Month	Year	Site	Region	Recorder	Grid	Lat	Long
				Wales				
22	7	2015	Llanbedrog	north Wales	NM, HS	SH335311	52.8516	-4.4742
23	7	2015	Abersoch Lighthouse	north Wales	NM, HS	SH323265	52.8107	-4.4881
23	7	2015	Criccieth Castle	north Wales	NM, HS	SH494376	52.9146	-4.2412
23	7	2015	Criccieth East	north Wales	NM, HS	SH494376	52.9146	-4.2412
23	7	2015	Porth Ceiriad	north Wales	NM, HS	SH308247	52.7938	-4.5094
17	8	2015	Martin's Haven	south Wales	MB, LA	SM759091	51.7357	-5.2471
18	8	2015	Skokholm	south Wales	MB, LA, JAT	SM741051	51.6992	-5.2701
19	8	2015	North Haven	south Wales	MB, LA, JAT	SM735093	51.7365	-5.2819
2	9	2015	South Haven	south Wales	MB, JJ, KL	SM733088	51.7319	-5.2845
3	9	2015	Dale	south Wales	MB, JJ, KL	SM822053	51.7041	-5.1533
14	9	2015	West Angle Bay	south Wales	MB, JJ, KL	SM848038	51.6916	-5.1151
15	9	2015	Monkstone Point	south Wales	MB, JJ, KL	SN150033	51.6978	-4.6784
16	9	2015	Broadhaven	south Wales	MB, JJ, KL	SM859144	51.7871	-5.1057
1	10	2015	Pembrokeshire power station	south Wales	MB, JJ, KL	SM930032	51.6896	-4.9956

4 RESULTS

4.1 2015 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 both 2014 and 2015 successively recorded as globally being the warmest year on record http://www.bloomberg.com/graphics/hottest-year-on-record/. 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/ .

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. These sea conditions resulted in the bulk of the ocean wave energy from the North Atlantic being driven onto the coastlines of Wales repeatedly between December 2013 and February 2014. The size and intensity of the storms generated some of the largest waves ever recorded to hit land in Western Europe, reaching 16 metres in height. These storms coincided with some of the highest spring tides of the year and record-breaking precipitation levels for the UK dating back 248 years, leading to saturated coastal ecosystems and an exacerbation of the physical impacts of storm wave forces. The 2014/15 and 2015/16 winters were, in contrast to 2013/14, two of the warmest on record.

Biological impacts of these storm events were surveyed at all 44 MarClim sites in Wales six months afterwards during the annual surveys in July 2014. The 2015 MarClim surveys have reassessed the effects on community structure following the 2013/14 storms after an 18 month period 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.

Ongoing research led by Mieszkowska is building new 'dynamic species distribution' models and 'dynamic energy budget' DEB mechanistically-derived models that use physical data at a spatial and temporal resolution suitable to analyse the MarClim site-specific data, associated experimentally derived information and knowledge to determine biological mechanisms, individual, population, species and community level responses to recent change, and to forecast future changes based on new IPCC and Met Office/Hadley Centre climate forecasts.

4.1.2 Storm impacts on Welsh rocky shores

Six months after the storm events of winter 2013/14, MarClim surveys around the Welsh coastline found little evidence of damage to intertidal rock habitat or to rocky intertidal communities. Only two sites had significant changes to the long-term community structure: Porth Neigwl and Aberdaron. Both shores are exposed rocky headlands on the southeast tip of the Llyn Peninsula where the prevailing Atlantic currents hit the land, and thus were likely to have been subject to the highest wave forces during the storms around the north Wales coastline.

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 4). This extensive boulder field was completely covered in early colonising ephemeral green *Ulva* spp. and red *Porphyra* spp. of algae (Figure 5). This boulder field is usually covered in blue mussel *Mytilus* spp. and barnacles, 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. 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. 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 2016 and onwards will enable further tracking of the recovery of this shore.

Figure 4. Ephemeral algae dominating the boulder shore at Porth Neigwl in July 2014

Figure 5. Boulder shore at Porth Neigwl by July 2015

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. Again, evidence of sediment movement was observed, with the boulder field in 2014 being far more extensive than in previous years (Figure 6). In 2015 the boulder field remains, without noticeable return of previously removed sediment and continued exposure (Figure 7). In 2014 this boulder field was characterised by a band approximately 0.5 m in height above the beach level where only the ephemeral green alga *Ulva intestinalis* was present, above which another band approximately 0.5 m in height was colonised by new recruits of the barnacle *S. balanoides* that had settled in the spring of 2014 (Figure 8). These observations are strongly indicative of large amounts of sediment movement and scour in the bay in excess of that seen in previous years. The same boulders in 2015 were dominated with fucoid algae, with some ephemeral green *Ulva intestinalis* present. In the band of only *S. balanoides* recruitment described in 2014, individuals of two age classes (new recruits and over one year old) were observed in 2015 (Figure 9). This demonstrates a shift towards more stable, later stage colonizing species. Both the presence of two year-classes of the barnacle *S. balanoides* and the presence of fucoids suggest that the substrate has not been re-covered with sediment since removal during the 2013-2014 storms, nor has the same scale of scouring occurred. In other areas of the UK sediment removed during the 2013-2014 winter, has slowly returned. Future monitoring will allow tracking of the continuing recovery or change of this intertidal community.

No other major changes to habitat or community composition were recorded at the other 42 long-term MarClim sites in 2015. The MarClim data collected on post-storm impacts in 2014 and 2015 were used in the Natural Resources Wales report on storm damage (Duigan, Rimington & Howe 2014) (http://naturalresources.wales/media/1976/welsh-

coastal-storms-december-2013-and-january-2014-an-assessment-of-environmental-change.pdf).

Figure 6. Boulder field uncovered by large movement of sediment at Aberdaron in July 2014

Figure 7. Boulder field at Aberdaron in July 2015

Figure 8. Ephemeral algal coverage and barnacle new recruitment on boulders at Aberdaron in July 2014

Figure 9. Recovery on boulders at Aberdaron by July 2015

4.1.3 Lusitanian 'warm water' species

Great Orme East still marks the northern range limit of the Lusitanian species of topshell *Phorcus lineatus*, which was first recorded as a multi-age population (as opposed to isolated individuals) in 2010, with abundances increasing from Occasional (1 per minute search), 2011 (1.47 per minute search), to Frequent (7 per minute) in 2012 but decreasing back to Occasional (1.4 per minute search) in 2013. Fewer individuals were present on the west coastline of the Great Orme (0.67 per minute search, 2013) but abundances had increased again in 2014 (2.067 per minute search). This trend has

continued in 2015 with abundances increasing to 2.8 individuals recorded per minute of search.

At Great Orme Trwynygogarth, 0.93 individuals per minute search were found in 2014. The density of this population had decreased in 2015 to 0.2 individuals per minute, 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 (Figure 10). 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 showed 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* has now increased once more to Common in 2015, with abundances of 15.47 individuals per minute recorded (Figure 11).

Population abundances of Lusitanian warm water kelps and topshells around the UK increased throughout the 2000s in response to warming of the marine climate, but began to decline from 2010-2013 in likely response to the hiatus in global surface warming detected during the 2000s (Figure 10), (Mieszkowska 2013 Report to Natural England). Surveys at these long-term sites in 2014 showed that the recent declining trend had stopped, with increased numbers of individuals within populations from northern range limits in north Wales, right around the Welsh and English coastlines and along the English Channel to the northeast range limit. In 2015, numbers have remained higher than those prior to 2014. 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 and 2014/2015.

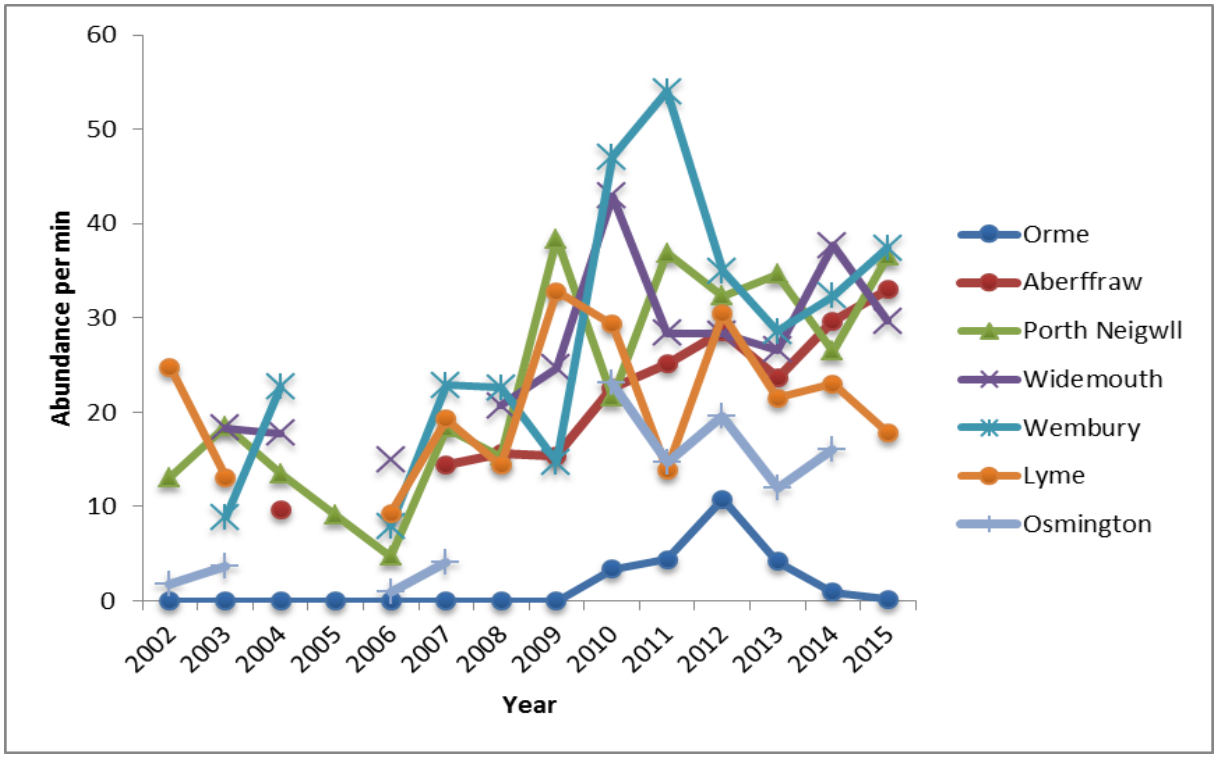

Figure 10. *Phorcus lineatus* abundances at selected sites from the northern range edge at Great Orme East to the north-eastern range edge in south England at Osmington

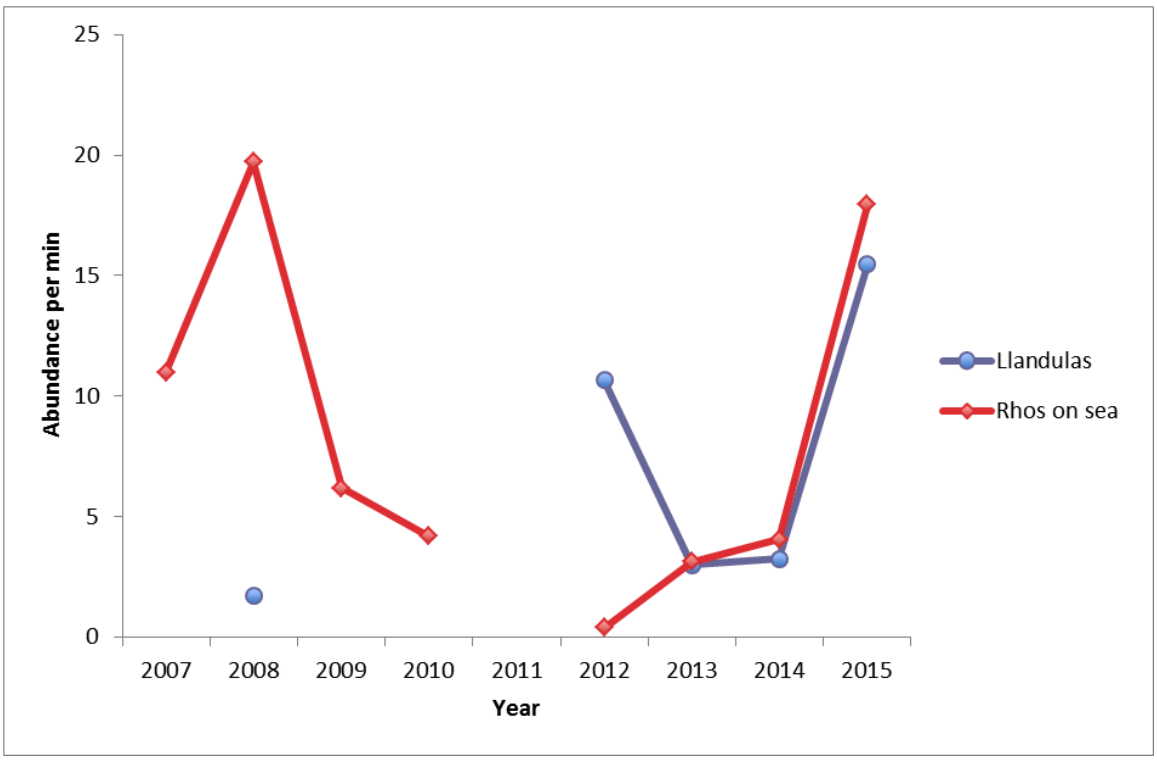

Figure 11. *Gibbula umbilicalis* abundances at Welsh range-edge and near range-edge site

The MarClim time-series has tracked the increase in abundance of the warm water kelp *Saccorhiza polyschides* around the UK coastline in line with warming temperatures during the early 2000s. Since 2009, intertidal populations in Wales have declined in abundance or disappeared, likely due to the colder winters experienced in recent years. In 2015, for the first time since 2009 this species has disappeared from almost all of the MarClim sites in Wales, except on Skokholm Island (new site in 2015), off of

Pembrokeshire (Table 2). Observations from subtidal dive surveys carried out by the Skomer MNR team and MRes student projects in Plymouth supervised by Mieszkowska in recent years indicate that *S. polyschides* has been increasing in abundance far more rapidly in subtidal kelp beds along the Atlantic coastline of France and the southern coastline of England during the 2000s. These observations suggest that the colonisation and dominance of kelp forests in the UK is driven by subtidal populations where environmental temperatures are more stable and do not approach lower lethal temperatures, whereas intertidal populations are subject to cold winter air temperatures likely to result in juvenile mortalities within the intertidal fringe.

Table 2. SACFOR abundance categories for intertidal populations of the warm water kelp *Saccorhiza polyschides*

Site	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cemaes Bay	NS	NS	NS	NS	R	NS	NS	NS	NS
Porth Swtan	NS	NS	F	NS	NS	R	NS	NS	NS
Rhosneigr	NS	C	C	NS	NS	NS	NS	NS	NS
Aberffraw	NS	NS	O	R	NS	NS	NS	NS	NS
Nefyn	NS	NS	A	NS	NS	NS	NS	NS	NS
Porth Oer	NS	A	A	R	NS	R	R	O	NS
Aberdaron	NS	NS	O	NS	NS	C	NS	NS	NS
Porth Neigwl	NS	NS	F	NS	NS	O	NS	R	NS
West Angle Bay	NS	NS	NS	NS	NS	NS	O	NS	NS

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*, fucoid *Pelvetia canaliculata* and the barnacle *Semibalanus balanoides*. None of these species have southern distributional limits currently in Wales and the Welsh MarClim sites show little variation in population abundance across the 2002-2015 time period.

4.1.5 Invasive Non-Native Species

MarClim survey sites are located at exposed or semi-exposed sites away from direct influences of human activities. Few records of INNS were found in 2015, similar to previous years. The red alga *Grateloupia turuturu* (Figure 12) has been recorded on natural rocky shores in northern France and southern England for several years in MarClim surveys. Based on information provided by NRW staff, a survey for *G. turuturu* was carried out at Milford Haven marina in 2015. This species was present at this location, and tissue samples removed for genetic analysis by the team.

The invasive ascidian *Corella eumyota* was again found in low numbers on the undersides of boulders by Menai Bridge in 2015, but this population has not increased in size. Both *Corella eumyota* and *Botrylloides violaceus* were recorded in low numbers for the first time in 2015 at the Dale site in South Wales.

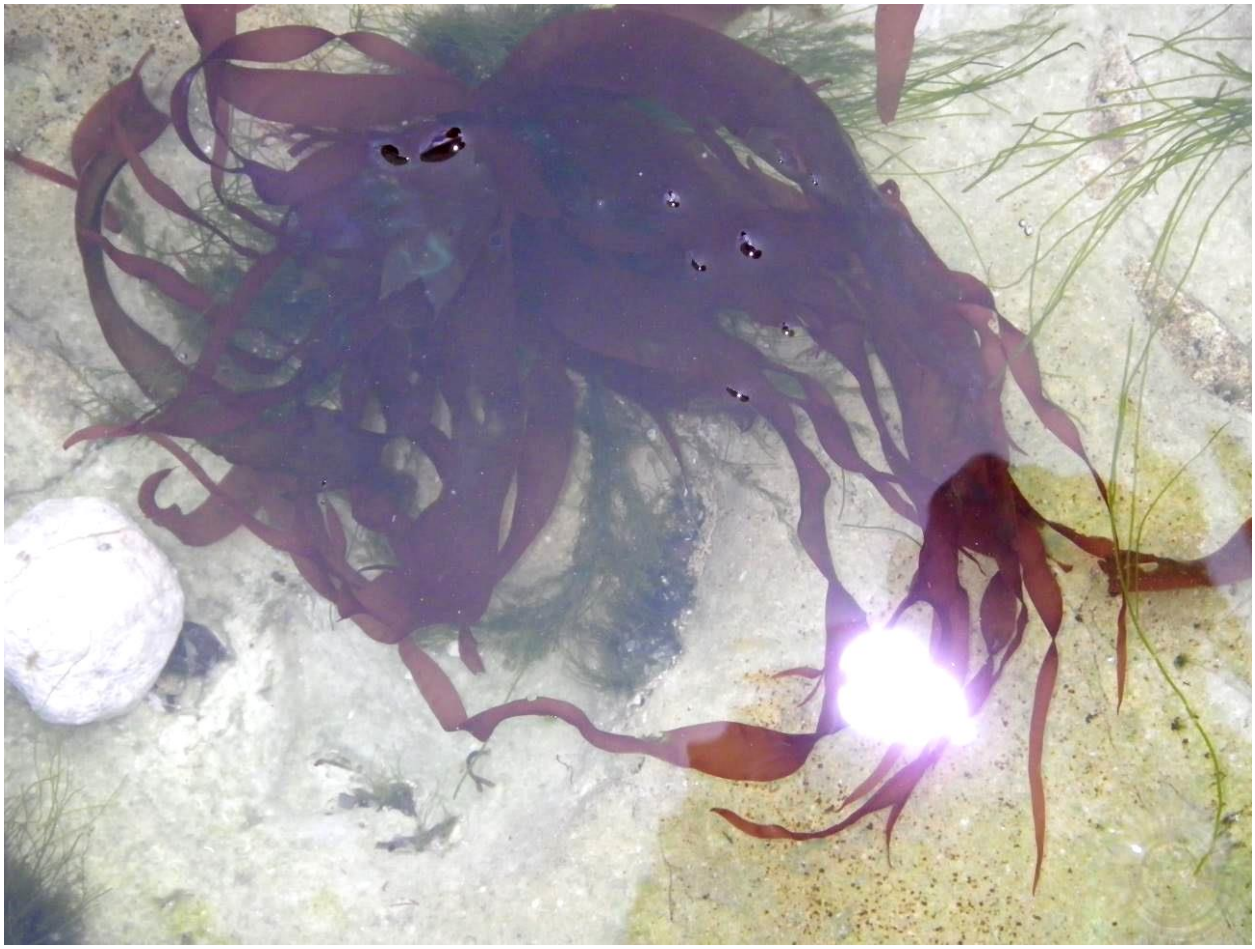

Figure 12. The non-native invasive species *Grateloupia turuturu*

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* has increased in abundance in recent years at sites where it was previously established (Table 3).

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 2015.

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.

Table 3. SACFOR abundances for the invasive alga *Sargassum muticum*

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

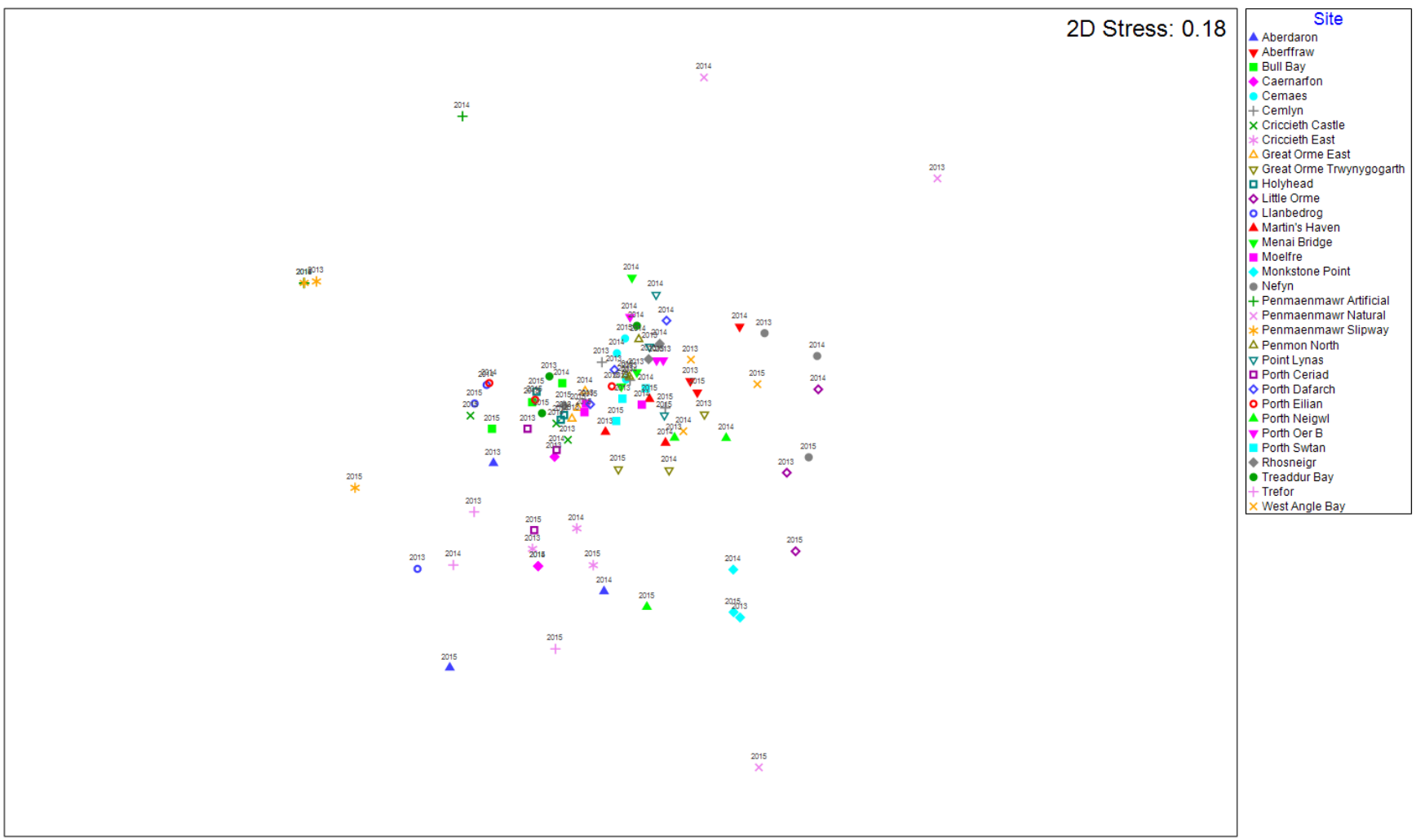

Figure 13. Multidimensional scaling analysis of algal assemblages at Welsh sites. ANOSIM analysis reveals no significant changes in algal assemblages between 2013-2015.

4.2 Spatio-temporal trends

Multidimensional scaling analyses were performed for the macroalgal assemblages present at five sites around the Welsh coastline; Penmon North and Rhosneigr on Anglesey, Porth Oer and Porth Neigwl on the Llyn Peninsula in north Wales, Martin's Haven and West Angle Bay in Pembrokeshire in south Wales for the 2013 report (Mieszkowska 2014). These community assemblages have not changed significantly in 2014 or 2015 (Figure 13).

4.2.1 Northeast coastline

The abundance of *P. lineatus* and *G. umbilicalis* in recent years in north Wales at, and close to northern range limits has shown a slow-down in the increasing trend recorded across the previous decade, with the northern range edge for *P. lineatus* remaining at Great Orme East since the first record of a multi-age population in 2010. The regional decline in abundances recorded from 2010-2013 was not observed in 2014, with abundances continuing to increase again in 2015 (Figure 10 and 11).

Comparison with SST at these locations shows a drop in sea temperatures in 2008 that may be reflected in the reduction in densities of both *P. lineatus* and *G. umbilicalis*. This may be due to either individuals at these locations moving to more cryptic habitat in cracks and crevices further down the shore where they were not found during the standard searches, or a decline in recruitment, however, detailed analysis of the individual size data for the entire topshell datasets is beyond the scope of the current contract.

4.2.2 Anglesey

Following declines of the blue mussel *Mytilus* spp. at several sites including Penmon North, Moelfre, Porth Swtan and Porth Dafarch in 2014, population recovery has had mixed success. *Mytilus* spp. was still absent from Porth Dafarch, Menai Bridge and Moelfre in 2015, all sites at which this species was found prior 2014. Other sites, however, such as Penmon North have been recolonised by *Mytilus* spp. Abundances of both Boreal and Lusitanian limpets and barnacles have remained at similar densities in 2015 to previous years in the 2010s.

4.2.3 Llyn Peninsula

Mytilus spp. has also declined at several sites on the Llyn over the past three years. Mussel beds are temporally variable and the recent decline may be part of a natural fluctuating cycle. The former Countryside Council for Wales SAC monitoring program identified a considerable wide-scale spat fall of Mytilus edulis throughout Cardigan and Tremadog Bays in 2010, the resultant dense cover of M. edulis has been decreasing year on year since then (pers comm R. Holt, NRW). Abundances of both Boreal and Lusitanian limpets and barnacles have remained at similar densities in 2015 to previous years in the 2010s.

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. The warm water kelp *Saccorhiza polyschides* was recorded for the first time at West Angle Bay in 2013 as Occasional, but was not seen in 2014, in 2015 this species was found at Skokholm Island in Pembrokeshire. *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 was resurveyed in 2014 and again in 2015. The invasive alga *G. turuturu* was found in 2015 at this location on the MarClim survey.

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 the official, standardised monitoring project and methodology for the European MSFD assessment and policy-delivering progress.

MarClim protocols have been cited as an example of best practice for time-series collection in the PEGASEAS Governance Guide for Policymakers in the EU https://www.pegaseas.eu/wp-content/uploads/2015/01/PEGASEAS-Compendium-English-Version.pdf. This EU Interreg Project aims to provide 'effective governance of the Channel Ecosystem' and the incorporation of MarClim protocols into this initiative is testament to the robust, widely applicable methodology and resultant data to a wide range of issues regarding status and governance of coastal ecosystems in Europe.

MarClim has been highlighted in a global scientific assessment of the need for scientific research to be appropriately designed to provide fit-for-purpose information at relevant spatial and temporal scales useful to managers of protected areas, statutory bodies and policymakers. This paper demonstrates how groundbreaking the MarClim project and the long-term collaboration with Natural Resources Wales and the Marine Biological Association of the UK has been in delivering relevant information on the Condition and Status of intertidal habitats in Wales against a backdrop of pervasive climate change http://www.biomedcentral.com/content/pdf/s40665-014-0006-0.pdf.

MarClim has also been selected as the test time-series for the INSHORE International Network for Research in Rocky Intertidal Systems http://rockyinshore.org/about/ demonstrating the global impact of this project.

5 SUMMARY

All 42 rocky shores surveyed by the MarClim team were considered to be in good condition in 2015. The community composition at the majority of long-term sites did not show major changes in abundance in 2015 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 trend. This will be monitored in future years.

During the 2000's global surface warming entered a so-called hiatus period of reduced warming. The restart of increasing abundances for the lusitanian species mentioned above coincided with two of the warmest years in recent climate records (NASA, 2016), with the MET office showing that 2015 was 0.75^{o}C warmer than the long term average between 1961 and 1990. These meteorological data suggest that climate warming is driving this increase in abundance.

It is crucial to maintain continued long-term regular monitoring to detect changes in species distributions and community structure in the marine environment. These changes can then be linked to either large scale stressors such as climate change or smaller scale natural or human induced pressures such as pollution. Long-term sustained monitoring programmes, such as MarClim, are essential for the UK to deliver assessments for national and European level policy directives e.g. Marine Strategy Framework Directive, Water Framework Directive and the Habitats Directive and the UK Marine and Coastal Access Act.

6 REFERENCES

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Surveyors:

NM Nova Mieszkowska, MBA
LA Leoni Adams, MBA
HS Heather Sugden, Newcastle University
MO Mauricio Orostica, Bangor University
KW Kringpaka Wangkulangkul, Bangor University
PB Paul Brazier, NRW
KB Kathryn Birch NRW
MB Mark Burton, NRW Skomer MCZ
JJ Jennifer Jones, NRW Skomer MCZ
JAT Jon Archer-Thompson
KL Kate Lock NRW Skomer MCZ

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APPENDIX 1. MarClim Sampling Protocols 2015

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, 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 calipers.
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)								
Halicondria 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								
Austrominus (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

Citation:

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The report and data collected under Natural Resources Wales contract FC 73-02-359 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] Some site photographs from each location.

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

File Path for data:

File path for the report:

File path for the archive:

Metadata for this project is publicly accessible through the Natural Resources Wales Library Catalogue http://194.83.155.90/olibcgi/ by searching 'Dataset Titles'. The metadata is held as record no 109815.

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