Cyfoeth Naturiol Cymru
Natural Resources Wales

MarClim Annual Welsh Intertidal Climate Monitoring Survey 2021

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Marine Biological Association & Newcastle University

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Dulliau

Caiff y dulliau eu disgrifio mewn manylder yn Adran 2.1.1. Cofnodir data SACFOR ar gyfer yr 82 rhywogaeth sydd ar restr MarClim. Cofnodir data meintiol cwadrat ar gyfer tair rhywogaeth o wystrys, pedair rhywogaeth o wyrain, a chwblheir chwiliadau meintiol wedi'u hamseru ar gyfer dwy rywogaeth o falwod.

Crynodeb o'r canlyniadau allweddol

- Arweiniodd symudiad helaeth gwaddodion yn Nhrwyn y Fuwch, Trefor, Llanbedrog, ac Aberdaron at orchuddio rhai rhannau o'r safleoedd a thynnu cregyn llong o rannau isaf yr wyneb fertigol ar glogwyn Trwyn y Fuwch yn sgil tywod a graean bras yn sgrafellu ac yn tynnu'r cregyn llong sefydledig o rannau allanol yr wyneb fertigol.
- Yn sgil symudiad gwaddodion ym Mhorth Ceiriad mae cynefin newydd o goblau wedi'i ddatgelu ger y safle MarClim. Yn y blynyddoedd nesaf, caiff y cynefin hwn ei fonitro i olrhain y rhywogaethau sy'n cytrefu yno.
- Mae amddiffynfeydd arfordirol artiffisial yn cael eu hadeiladu ar hyd y blaendraeth yn Y Rhyl. Nid oedd mynediad ar gael oherwydd y gwaith adeiladu, ond bydd yr ardal hon yn cael ei harolygu yn y blynyddoedd nesaf i olrhain unrhyw rywogaethau rhynglanw sy'n cytrefu yno.
- Unwaith eto, ar benrhyn Neyland y cofnodwyd y nifer fwyaf o rywogaethau anfrodorol yn unrhyw un o'r safleoedd MarClim, gydag *Undaria pinnatifida, Magallana gigas,* a *Botrylloides violaceus* oll yn bresennol. Ni welwyd dim un unigolyn o'r rhywogaeth *Crepidula fornicata*, yn wahanol i 2020.
- Roedd y rhywogaeth anfrodorol *Sargassum muticum* yn tyfu ar gobl mawr yn Llanbedrog. Dyma'r cofnod cyntaf o *S. muticum* ar y safle hwn, ac mae'n anarferol gweld y rhywogaeth yn tyfu ar garreg agored mor bell â hyn i'r gogledd yn y DU. Cofnodwyd un unigolyn o *S. muticum* yng ngorsaf bad achub Abersoch yn 2020 ond ni chafodd ei weld yn 2021, ac roedd y rhywogaeth hon unwaith eto Heb ei Gweld (yn absennol) yn y safle hwn.
- Cofnodwyd chwech o oedolion *P. depressa* ym Mhorth Oer. Dyma'r tro cyntaf i'r rhywogaeth Lwsitanaidd hon gael ei chofnodi yma ers canfod pump o unigolion yn 2003 a deg yn 2006.
- Gwelwyd niferoedd bychain (Prin) unwaith eto o *P. depressa* yn Aberdaron, sy'n dangos bod y boblogaeth hon wedi dal ati, mewn niferoedd bychain, dros y tair blynedd diwethaf.

Casgliadau a phwyntiau trafod

Mae arolygon MarClim yn synhwyro newidiadau blynyddol mewn mesurau o helaethrwydd sy'n deillio o ddefnydd ar gyfer rhywogaethau rhynglanwol creigiog. Mae'r rhain yn fetrig sensitif i dracio'r perygl a berir i rywogaethau gan newid treiddiol yn yr hinsawdd, digwyddiadau thermol eithafol sy'n digwydd yn yr hinsawdd forol, a gan fod nifer o safleoedd yn cael eu harolygu yn yr un rhanbarth, gellir synhwyro aflonyddwch ar raddfa fach fel difrod sgrafelliadau gan symudiadau lleol graean bras yn ystod digwyddiadau storm yn erbyn patrymau ar raddfa fwy o newid i rywogaethau morol a yrrir gan yr hinsawdd. Mae rhywogaethau rhynglanwol tymherus yn gallu goddef cyfnodau byr o wres eithafol neu dywydd oer, ac maent yn fwy ymatebol i newidiadau treiddiol yn yr hinsawdd sy'n digwydd ar draws amserlenni degawdol, gan ddylanwadu perfformiad yn y pen draw o ran twf ac allbwn atgynhyrchiol sy'n arwain at recriwtio.

Gellir tracio'r cytrefu a'r gyfradd ac ehangder lledaeniad rhywogaethau estron drwy arolygon blynyddol MarClim. Gellir hefyd fonitro'r effeithiau ar rywogaethau brodorol yn y gymuned sy'n cael eu cytrefu gan rywogaeth estron dros nifer o flynyddoedd er mwyn synhwyro unrhyw newidiadau i fioamrywiaeth ranbarthol a lleol.

Arwyddocâd canlyniadau ac ymarfer yn y dyfodol

Mae gwybodaeth am brosiect MarClim a'r data gwyddonol a gesglir ganddo'n cael eu trosglwyddo i sefydliadau'r llywodraeth, staff, asiantaethau cadwraeth, rheolwyr Ardaloedd Cadwraeth Arbennig (ACAau) a Safleoedd o Ddiddordeb Gwyddonol Arbennig (SoDdGAau) morol a'r cyhoedd er mwyn cynyddu gwybodaeth, dealltwriaeth ac adrodd ynghylch cwestiynau sy'n wyddonol, rheolaethol a chymdeithasol bwysig mewn perthynas â newid hinsawdd byd-eang, asideiddio'r cefnforoedd ac effeithiau dynol ar raddfa lai ar yr amgylchedd morol, gan gynnwys datblygu, anheddu ac ymelwa ar y parth morol, ecosystemau cydrannol a rhywogaethau. Defnyddir MarClim i asesu a llywio polisïau a chyfarwyddebau'r DU a'r UE, gan gynnwys Cyfarwyddeb Fframwaith Strategaeth Forol yr UE, Canllawiau Llywodraethu PEGASEAS, Asesiadau Cyflwr ar gyfer ACAau a SoDdGAau a Safleoedd Morol Ewropeaidd, ac fel data gwaelodlin ar gyfer proses dynodi Parthau Cadwraeth Morol y DU.

Cafodd set ddata cyfres-amser MarClim ei datblygu gan Mieszkowska, Burrows a Hawkins (2013) o dîm MarClim fel Dangosyddion Statws Amgylcheddol Da ar gyfer Cyfarwyddeb Fframwaith y Strategaeth Forol, gyda'r adroddiad cyntaf wedi'i gyhoeddi yn 2014: http://jncc.defra.gov.uk/page-6813. Datblygwyd ail gam o waith er mwyn datblygu cyfres-amser MarClim fel dangosyddion newid hinsawdd rhywogaethol (Mynegai Tymheredd Rhywogaethau) a chymunedol (Mynegai Tymheredd Cymunedau) fel rhan o'r broses datblygu dangosyddion Statws Ecolegol Da Cyfarwyddeb Fframwaith y Strategaeth Forol gan dîm MarClim yn 2017 (Burrows, Hawkins a Mieszkowska 2017). Mae prosiect a thîm ymchwil MarClim yn darparu monitro unigryw, hanfodol, tymor hir a data ymchwil ac arbenigedd gwyddonol. Mae'r rhain yn cael eu defnyddio gan gyrff cadwraeth natur statudol y DU i fynd i'r afael â chyfarwyddebau polisi cenedlaethol ac Ewropeaidd ar raddfa fawr, 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.

Mae'r tîm MarClim wedi cyhoeddi papur ar effeithiau digwyddiadau tywydd eithafol a newid treiddiol yng ngororau ecoleg morol (Mieszkowska ac eraill, 2021). Mae'r papur yn arddangos gwerth cyfres-dreigl tymor hir gydag ehangder daearyddol mawr yn synhwyro newidiadau tymor byr, llym yn erbyn symudiadau tymor hwy a yrrir gan yr hinsawdd mewn rhywogaethau o amgylch arfordir y DU. Mae'r papur hwn yn cynnwys gwybodaeth o safleoedd yr arolwg MarClim Cymru a'r rhywogaethau a gofnodwyd yno.

Executive summary

Background to the project

This report summarises the 2021 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, nineteen-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 thirty five sites in 2021. Twenty eight sites were surveyed in north Wales and seven sites in south Wales.

Methods

Methods are described in detail in Section 2.1.1. Categorical SACFOR data are recorded for all 82 species on the MarClim list. Quantitative quadrat data are recorded for three species of limpet, four species of barnacles, and quantitative timed searches are completed for two species of trochid.

Summary of key results

- Large scale movement of sediment at Little Orme, Trefor, Llanbedrog, and Aberdaron caused smothering of some areas of the sites and removal of barnacles from the lower areas of the vertical cliff face at Little Orme due to sand and shingle abrasion removing settled barnacles from the extremities of the vertical distributions.
- Movement of sediment at Porth Ceriad has resulted in a new cobble habitat being uncovered near the MarClim site. This will be monitored for species colonisations in future years.
- New artificial coastal defences are being built all along the foreshore at Y Rhyl. No access was available due to construction but this area will be surveyed in future years to track colonisation by intertidal species.
- Neyland Point again had the highest number of NNS recorded at any MarClim site, with *Undaria pinnatifida, Magallana gigas,* and *Botrylloides violaceous* all being present. No *Crepidula fornicata* individuals were found in contrast to 2020.
- The NNS *Sargassum muticum* was growing on a large cobble at Llanbedrog. This is the first record of *S. muticum* at this site, and it is unusual to find the species growing on open rock this far north in the UK. The one individual *S. muticum* recorded at Abersoch lifeboat station in 2020 was not found in 2021, with this species again being Not Seen (absent) from this site.
- Six adult *P. depressa* were recorded at Porth Oer. This is the first time this Lusitanian species has been recorded here since five individuals were found in 2003 and 10 individuals in 2006.
- *P. depressa* were again found in small numbers (Rare) at Aberdaron, showing this population has continued to persist in small numbers over the past three years.

Conclusions and discussion points

MarClim surveys detect annual changes in occupancy-derived measures of abundance for rocky intertidal species. These are a sensitive metric with which to track the vulnerability of species to pervasive climate change, extreme thermal events occurring in the marine climate, and because multiple sites are surveyed in the same region, small-scale disturbances such as scour damage from local movements of shingle during storm events can be detected against the larger patterns of climate-driven change to marine species. Temperate intertidal species are able to tolerate short periods of extreme heat or cold weather, and they are more responsive to pervasive changes in the climate that occur across decadal timescales, ultimately influencing performance in terms of growth and reproductive output leading to recruitment.

The colonisation and the rate and extent of spread of NNS can be tracked via MarClim annual surveys. The impacts on native species in the community that is colonised by a non-native species can also be monitored across multiple years to detect any changes to both local and regional biodiversity.

Significance of results and future practice

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.

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 was developed by the MarClim team in 2017 (Burrows, Hawkins & Mieszkowska 2017).The MarClim Project and research team provide unique, essential, long-term monitoring and scientific research data and expertise. This is used by the UK SNCBs 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.

The MarClim team have published a paper on the impacts of extreme weather events and pervasive change in Frontiers in Marine Ecology (Mieszkowska et al. 2021). The paper demonstrates the value of the long-term time-series with a large geographic extent in detecting both short-term, acute changes against longer time climate-driven shifts in species around the UK coastline. The paper includes information from the Welsh MarClim survey sites and species recorded there.

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 (non-indigenous) species (NIS) 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.

1.1. 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 Southampton 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-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 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.

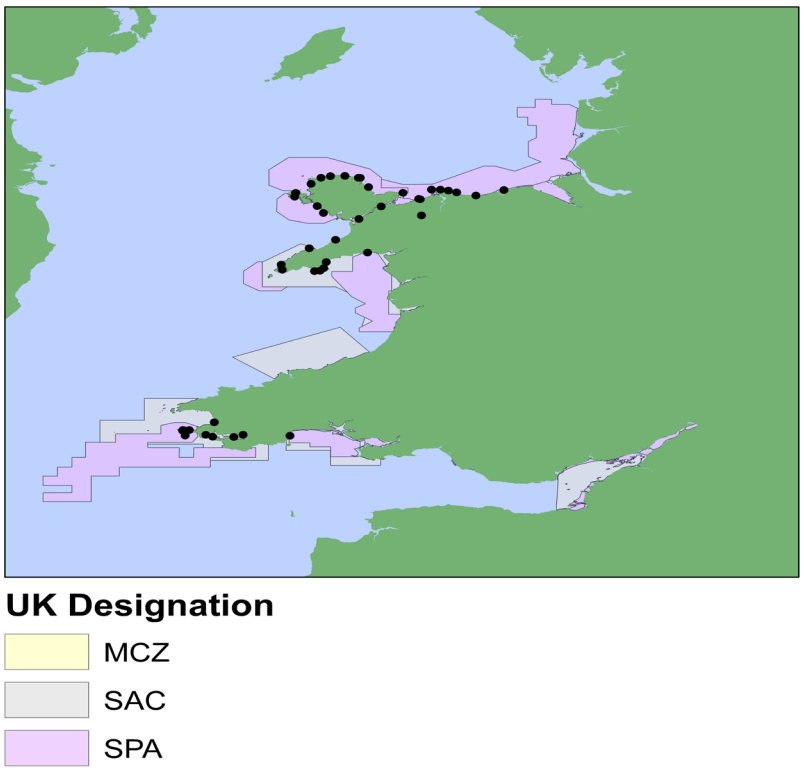
Climate-driven shifts in the biogeographic ranges of native and invasive species are also being tracked by Dr Mieszkowska around the wider northern European coastline using the MarClim protocols. These surveys provide geographically extensive, contextual evidence on distributions, abundances, biological 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).

2. Methods

The MarClim protocols (Appendix 1) were used as the standard survey methodology at all survey sites. These protocols include additional non-native 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 thirty-five sites in 2021 (Figure 1, Table 1).

Figure 1. MarClim sites surveyed in 2021.



Twenty eight rocky shores in north Wales were surveyed by Dr. Nova Mieszkowska from The Marine Biological Association, Dr. Heather Sugden from Newcastle University, Kathryn Birch and Gabe Wyn from Natural Resources Wales. Eight sites were surveyed in south Wales including seven on the mainland and one on Skokholm Island (see Figure 1). These surveys were carried out and cross-calibration exercises undertaken by Nova Mieszkowska and Mark Burton and Kate Lock of NRW, and John Archer-Thompson. Data entry was completed by Nova Mieszkowska with QA by Paul Brazier.

Semi-quantitative SACFOR abundance scores were recorded for a suite of 82 species of invertebrates and macroalgae, including nine non-native species of invertebrate and nine non-native species of macroalgae. 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, randomly placed within the midshore zone on areas of bedrock or large boulders with homogeneous surfaces (Figure 2). 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.

Three replicate searches, each of three minutes duration were made separately for *Phorcus lineatus* and *Steromphala 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 every 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 *Steromphala* (*Gibbula*) *umbilicalis* was found in 2012 and *Phorcus lineatus* in 2016, and is now surveyed each year. The Y Rhyl crescent seawall and groynes were surveyed in 2014 and again annually since 2017 to ensure further range extensions of the topshells are accurately located.

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 labelled 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 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.

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

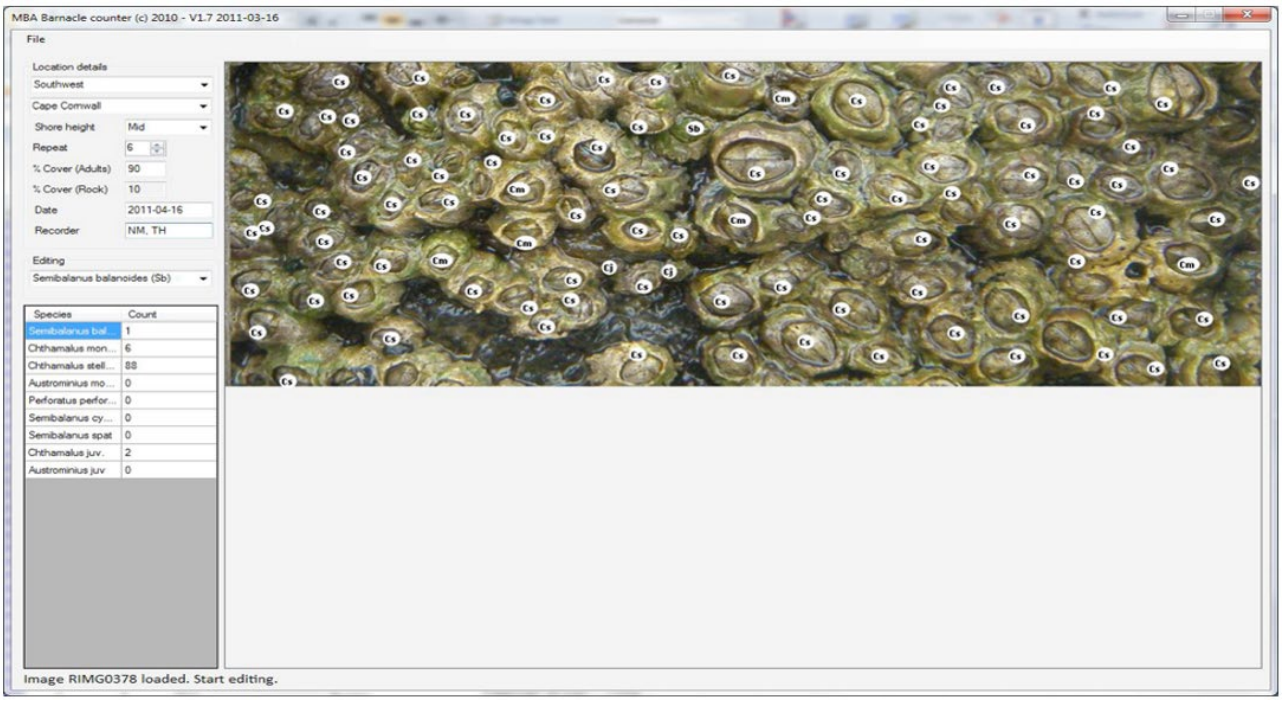


Table 1. MarClim survey site locations 2021.

Day	Month	Year	Site name	Recorder	OS grid ref	Lat (WGS84)	Long (WGS84)
30	3	2021	Pembroke Powerstation	MB	SM930032	51.6896	-4.9956
8	7	2021	Llanddulas	NM, HS	SM906787	53.2933	-3.6296
8	7	2021	Rhos-on-Sea	NM, HS	SH843805	53.3114	-3.7381
8	7	2021	Little Orme	NM, HS	SH812825	53.3260	-3.7852
8	7	2021	Great Orme East	NM, HS	SH782832	53.3321	-3.8297
9	7	2021	Great Orme Trwynygogarth	NM, HS	SH749834	53.3327	-3.8801
9	7	2021	Penmaenmawr Natural	NM, HS	SH704763	53.2674	-3.9440
9	7	2021	Trefor	NM, HS	SH376474	52.9992	-4.4215
9	7	2021	Caernarfon (Aber Foreshore Road)	NM, HS	SH521671	53.1374	-4.2897
9	7	2021	Penmon North	NM, HS, GW	SH641813	53.3111	-4.0413
9	7	2021	Menai Bridge	NM, HS, GW	SH555714	53.2207	-4.1643
10	7	2021	Bull Bay	NM, HS, KB	SH427945	53.4238	-4.3688
10	7	2021	Moelfre	NM, HS, KB	SH513859	53.3490	-4.2354
10	7	2021	Point Lynas	NM	SH477929	53.4109	-4.2928
10	7	2021	Porth Eilian	NM, HS, KB	SH484929	53.4111	-4.2823
10	7	2021	Holyhead	NM, HS	SH257825	53.3108	-4.6461
10	7	2021	Porth Swtan	NM, HS	SH298891	53.3713	-4.5598
11	7	2021	Rhosneigr	NM, HS	SH315725	53.2233	-4.5253
11	7	2021	Abberffraw (Briach-Lwyd)	NM, HS	SH337674	53.1776	-4.4899
11	7	2021	Cemlyn	NM, HS	SH337934	53.4146	-4.5112
12	7	2021	Porth Oer	NM, HS	SH163297	52.8344	-4.7256
12	7	2021	Nefyn	NM, HS	SH274415	52.9430	-4.5702
13	7	2021	Porth Neigwl	NM, HS	SH288245	52.7908	-4.5404
13	7	2021	Aberdaron	NM, HS	SH166260	52.8003	-4.7220
13	7	2021	Llanbedrog	NM, HS	SH335311	52.8516	-4.4742
14	7	2021	Porth Cariad	NM, HS	SH308247	52.7938	-4.5094
14	7	2021	Abersoch lifeboat station	NM, HS	SH323265	52.8107	-4.4881
14	7	2021	Criccieth (East)	NM, HS	SH308247	53.3490	-4.2354
14	7	2021	Criccieth Castle	NM, HS	SH494376	53.4109	-4.2928
23	8	2021	Neyland Natural (by Brunel Wall)	NM, MB	SM967047	51.7045	-4.9433
23	8	2021	Jetty Beach Dale	NM, MB	SM822053	51.7041	-5.1533
24	8	2021	Monkstone Point	NM, JAT	SN150033	51.6978	-4.6784
24	8	2021	West Angle Bay	MB	SM848038	51.6916	-5.1151
24	8	2021	Martin's Haven	NM, MB	SM759091	51.7357	-5.2471
25	8	2021	Broad Haven	NM, JAT	SM859144	51.7871	-5.1057

3. Results

3.1. Climate change and extreme events

The UK experienced the coldest January in 2020/21 since 2010, with exceptionally wet weather recorded (https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2021/2021-a-year-in-weather-a-review). The winter had colder than average conditions based on the updated 1991-2020 UK mean temperature data, whereas most months from June to December 2021 were warmer than average. The joint hottest summers on record were recorded in 2018 and 2020 and 2020 was the joint warmest year on record with 2016 (https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2019/2020-global-temperature-forecast). Five of the warmest years ever recorded in the UK occurred since 2010. Marine warm spells have become more frequent in both summer (heatwaves) and winter (anomalously warm temperatures) since 1982, whereas cold spells are becoming less frequent in both summer and winter across the same period. This evidences a shift away from seasonal patterns of extreme cold temperature in the marine environment towards a more widespread set of warmer events throughout the year.

Marine heatwaves are becoming more frequent since the 1980s, and possibly longer and more intense (Figure 4). The heatwave of 2018 stands out as being the longest (60 days) if not the most intense on record, and with the biggest cumulative 'degree x days' score in excess of 19°C (NOAA 2020; Reynolds et al. 2007). Heatwaves occur most frequently in June (11 events between 1982 and 2020), July (13 events) and August (10 events).

3.2. Community Composition across Wales

After the record heatwaves in the summers of 2018 and 2020, MarClim surveys recorded sublethal heat damage in macroalgae at some sites. The damage in 2018 did not result in any loss or noticeable reduction in algal cover at any MarClim site in 2019. Heat damage was again recorded in the 2021 surveys. Moderate heat damage was recorded for the high shore fucoid *P. canaliculata* at Point Lynas and Porth Swtan, but not at any other site in north or south Wales where it occurs. *F. spiralis* was also moderately heat damaged at Porth Swtan, but not at any other side. None of the other thirty two species of brown, red, and green macroalgae on the MarClim list showed signs of any heat damage in 2021. Heat damage data is available as comments in the MarClim Excel data sheet.

Analysis of the entire MarClim time-series data since 2002 showed that species of invertebrates and macroalgae generally declined in years of more frequent winter cold spells and summer heatwaves, whereas winter heatwaves and summer cold spells had similar numbers of positive and negative effects across species, and winter warm spells tended to have a more negative effect on cold-affinity species than on warm-affinity species (Figure 4) (Mieszkowska et al. 2021).

Figure 4. (A) Response to summer heatwaves, shown as the trend in annual abundance change relative to the annual frequency of heatwaves. (B) Response to winter heatwaves. Regression slopes for (A) Y = -0.064 (±0.035 SE) – 0.0012.STI (± 0.0027 SE), p = 0.65; (B) Y = -0.081 (±0.026SE) + 0.0047.STI (±0.0021 SE), p = 0.028 (Mieszkowska et al. 2021). MHW = marine heat waves.

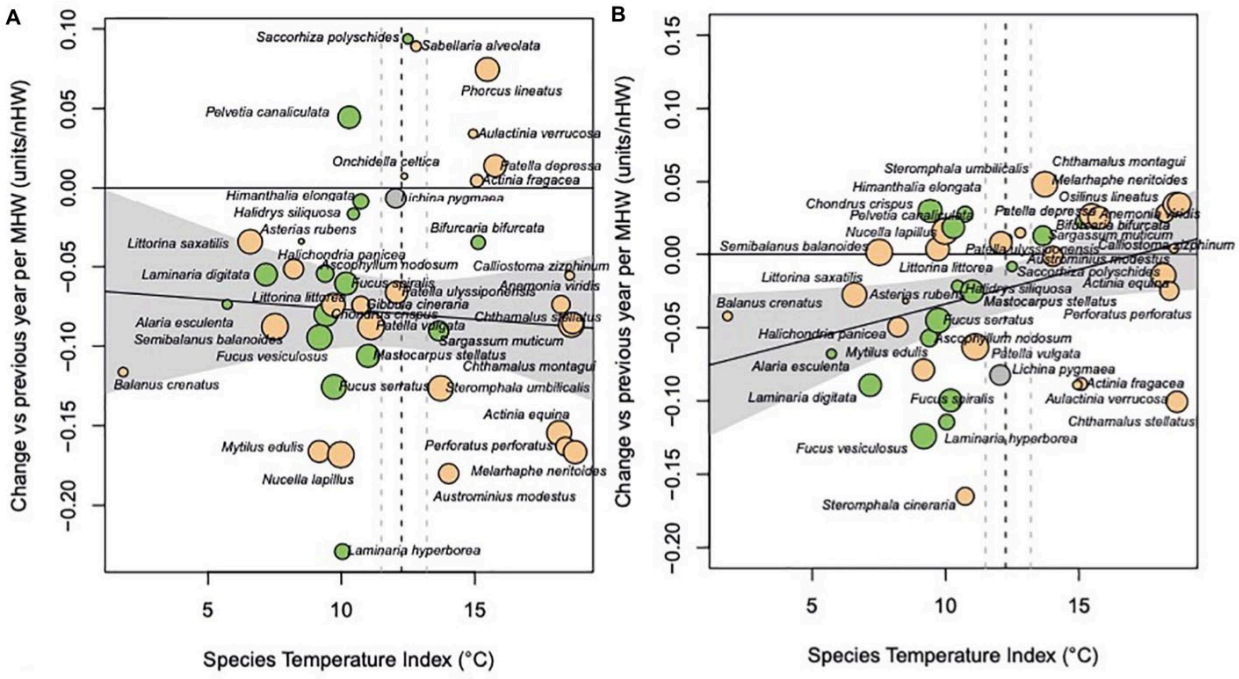
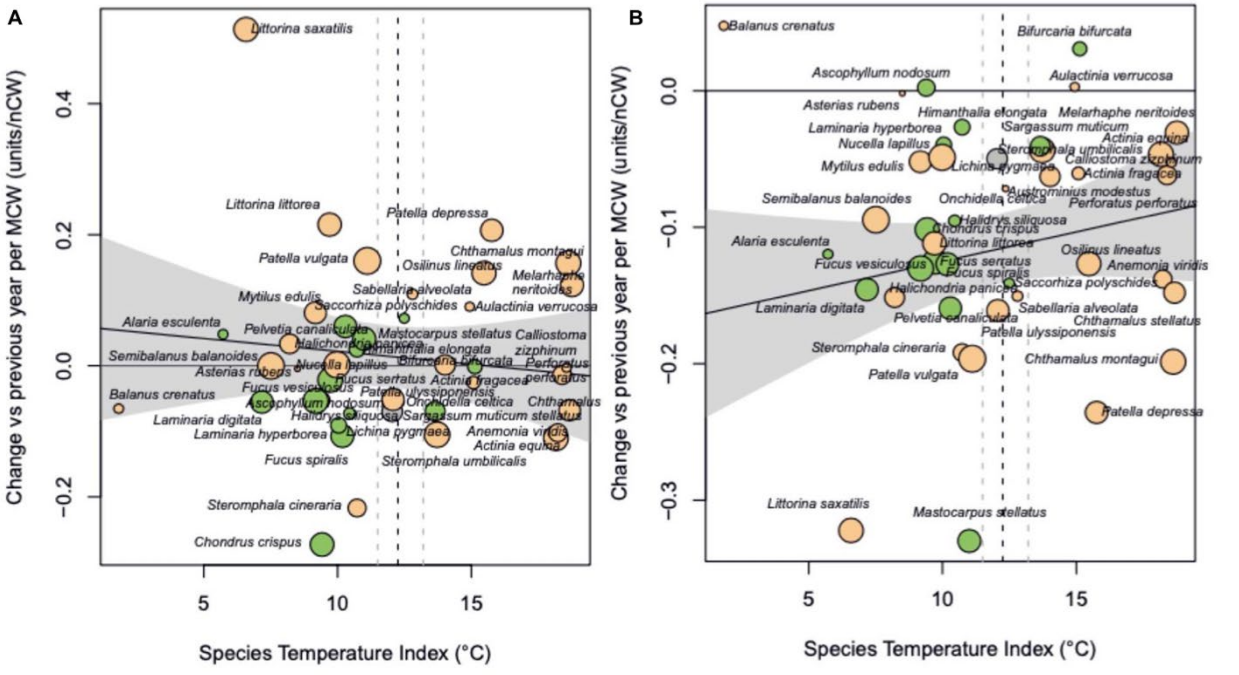


Figure 5. (A) Response to summer cold spells and (B) response to winter cold spells. Regression slopes for (A) Y = 0.049(±0.076DE) – 0.0024.STI(±0.0061SE), p = 0.70; (B) Y = -0.160 (±0.043 SE) + 0.0047.STI(±0.0021SE), p = 0.33. Regression intercept for (B) was significantly negative (p=0.000) (Mieszkowska et al. 2021). MCW = Marine cold spells.



Changes due to factors other than extreme temperature events were also seen in 2021. The MarClim 2020 and 2021 surveys showed evidence of local-scale removal of barnacles at a few shores in north Wales, which was probably due to storm events causing scouring of the rock by shingle. Almost complete loss of barnacle coverage from the high shore was recorded at Little Orme in both years. Porth Oer had a huge reduction in barnacle cover on the high shore in 2020, but some recruitment was evident in this zone in 2021. Llanbedrog and Aberdaron had sediment inundation across much of the survey sites in 2021, which at Aberdaron is likely due to alongshore transport as a boulder field had become uncovered in the middle of the sandy beach in 2021.

At Trefor there was a large amount of dead kelp that had been dumped just above the high water springs level. This is an unusual event in summer, as kelp dieback usually occurs in winter. This may have been the result of recent storm events in the region (Figure 6).

Figure 6. Dead macroalgae in piles above the high water mark at Trefor.

3.3. Range Extensions

MarClim tracks changes in the leading range edge of species that reach their distributional limits in Wales. Annual population surveys for all of the species on the MarClim list allow shifts to be tracked in real time, show how population dynamics change across longer time periods, identify established populations that are steadily increasing, as well as those that have fluctuating abundances. Such is the case for the Lusitanian ‘warm water’ species of limpet, *Patella depressa* at the most northerly leading range edge sites on the Llyn Peninsula.

Figure 7. A juvenile *Patella depressa* at Porth Oer in 2021.

Six *P. depressa* were recorded at Porth Oer on the north coast of the Llyn Peninsula in 2021 (Figure 7). This species was Not Recorded in 2002. Five individuals were found in 2003, but there were no individuals in 2004 or 2005. Since ten individuals were found in 2006 no individuals have been found until the 2021 survey (Figure 8). On the southern side of the Llyn Peninsula, two individuals were first recorded at Aberdaron in 2010, none recorded in 2011, and then a handful of individuals were recorded for the next three years, before disappearing in 2015, with isolated individuals not being recorded again until 2019 (Figure 9). The collection of annual quantitative data can show the temporal dynamics of range edge expansions and monitor when a population becomes established, as opposed to fluctuating low abundances and losses across a period of several years.

Figure 8. SACFOR population abundances of *Patella depressa* at Porth Oer from 2003-2021.

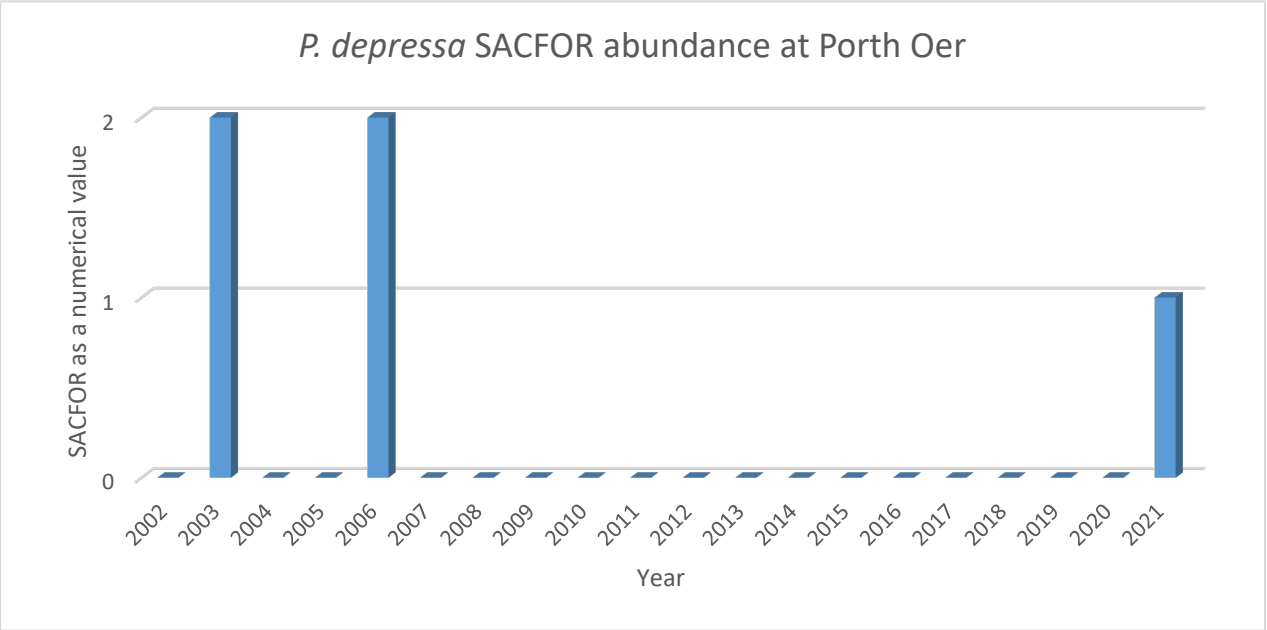
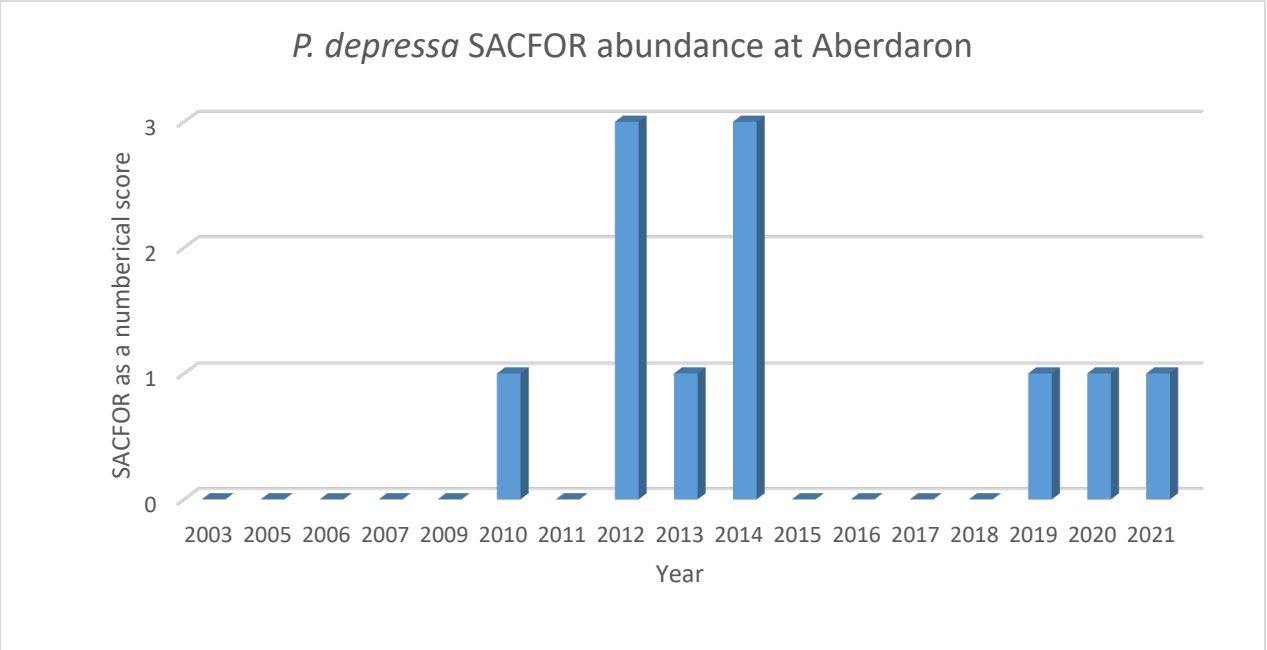


Figure 9. SACFOR population abundances of *Patella depressa* at Aberdaron from 2003-2021.



The time-series can also flag populations that have suffered from severe declines and are at risk of local extinction. *P. lineatus* experienced a range contraction of the leading range edge at Porth Eilian in the 1940s after the extreme cold winter of 1962/3. The leading range edge of *P. lineatus* has been extending along the coastline of north Wales since MarClim surveys started in 2002. The current range edge is located at Llanddulas, representing a geographic shift of approximately 75 miles in nineteen years.

3.4. Non Indigenous Species

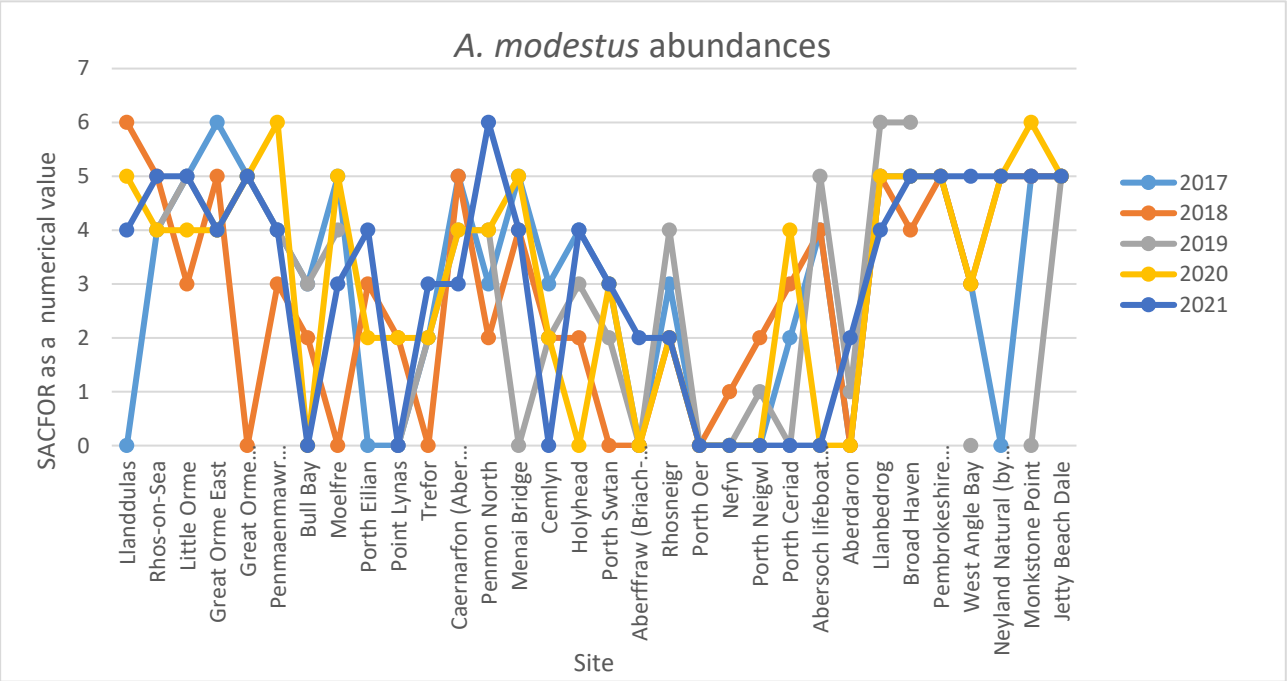
MarClim records eight species of macroalgae NNS and fourteen species of invertebrate NNS (Table 2). These include horizon scanning for species that have only been recorded at one or a few locations to date, e.g. the crabs *Hemigrapsus sanguineus* and *H. takanoi*, and the colonial ascidian *Didemnum vexillum* that invaded Holyhead marina in 2008 (Holt & Cordingley 2011).

Table 2. Non-Indigenous Species searched for during MarClim surveys.

Species
Sargassum muticum
Undaria pinnatifeida
Chondracanthus acicularis
Asparagopsis armata
Colpomenia peregrina
Grateloupia turuturu
Caulacanthus ustulatus (okamurae)
Pikea californica
Dasysiphonia (Heterosiphonia) japonica
Diadumene lineata
Austrominius modestus
Magallana gigas
Crepidula fornicata
Botrylloides violaceus
Botrylloides diegensis
Perophora japonica
Corella eumyota
Asterocarpa humilis
Didemnum vexillum
Watersipora subtorquata
Hemigrapsus takanoi

Most NNS on the MarClim list were not found at MarClim sites in Wales in 2021. Thirty sites had NNS recorded in 2021, most of which were the barnacle *Austrominius modestus*. The was the most prolific species, being recorded at 26 sites. Figure 10 shows how the population abundances of *A. modestus* have fluctuated across the last five years of MarClim surveys at sites in both north and south Wales. Only Porth Oer (no *A. modestus* ever recorded) and Nefyn (Rare in 2018, not found any other year) have had constantly low or no individuals present. *A. modestus* was recorded for the first time in 2021 at Aberffraw, where it was Occasional, having been Not Seen in previous years, and had disappeared from Porth Neigwl, Porth Ceriad, and Abersoch lifeboat station, where it had been recorded at quite high abundances in previous years up until 2019 or 2020. At sites where it has been present throughout the previous years, abundances have oscillated but not shown any directional trend, which is indicative of natural stochasticity in the system.

Figure 10. SACFOR population abundances of *Austrominius modestus* at MarClim sites across Wales from 2017-2021.



Neyland Point in Pembrokeshire again had the highest number of NNS recorded at any MarClim site, with *Undaria pinnatifida, Magallana gigas,* and *Botrylloides violaceous* all being present in 2021. The slipper limpet *Crepidula fornicata* was Common in 2018, declining to Occasional in 2019 and Rare in 2020, and was Not Seen in 2021. The red alga *Dasysiphonia japonica* was recorded for the first time in 2020 at Menai Bridge, but was Not Found at Menai Bridge or any other MarClim site in 2021.

The brown alga *Sargassum muticum* has been recorded in MarClim surveys across Wales since they began in 2002. In 2020 it was recorded for the first time at Abersoch lifeboat station, where instead of growing in rockpools, one individual was attached to open rock in the low shore. This species was Not Seen in 2021 at this site, however, it was recorded growing on a small cobble (mobile) at Llanbedrog in the next Bay to Abersoch (Figure 11). Surveys in future years will continue to track if/when this species appears at locations where it has not been previously recorded.

Figure 11. *Sargassum muticum* on a small cobble at Llanbedrog in 2021.

The slipper limpet *C. fornicata* was not recorded at any MarClim site in 2021. Surveys of NNS carried out by Bunker in 2021 did find *C. fornicata* at some sites on the Welsh coastline.

4. Relevance to NRW assessments of Annex I habitats

These data may also be used for the Natural Resources Wales assessments of vulnerability of Annex I marine habitats to climate change in Wales (Oaten et al. 2021). MarClim has data stretching back to the 1950s, and is able to provide long-term data on the abundance and distribution of species. MarClim data are used in conjunction with biotope mapping of MPAs in England to provide additional, quantitative information on the structure, and changes to rocky intertidal habitats along the coastline.

MarClim data collected on extreme events including heatwave impacts and storm events on rocky intertidal species at sites around the Welsh coastline may also be of use in these assessments.

The collection of abundance and recruitment data in MarClim surveys can ground-truth predictions such as those made in the Oaten et al. (2021) report, including the potential reduction in abundances of Boreal species such as *S. balanoides* and the low risk of impact to fucoid algae. To date, the abundance and recruitment of *S. balanoides* at MarClim sites in Wales has not declined. In addition, it is unlikely that the Lusitanian kelp *L. ochroleuca* will replace the Boreal *L. hyperborea* in Wales (or at any other site in the UK) over the next few decades. *L. ochroleuca* only occurs in a few sites in southwest England, and is not showing significant extensions of the leading biogeographical range edge. The MarClim project collects data on all of the rocky intertidal species mentioned in this report and tracks changes in abundance and distribution annually, being able to separate out small scale changes and impacts of extreme events from pervasive climate change.

5. Overview of MarClim surveys in England

Most MarClim time-series sites in England were in a healthy condition in 2021 (no change against the baseline). The only evidence of anthropogenic impacts (other than climate change and storm damage) was small amounts of litter and fishing line on some shores. In 2021, the Lusitanian, warm water species of ectothermic invertebrates and macroalgae continued to increase in abundance or maintained their SACFOR abundance categories at MarClim long-term monitoring sites around the English coastline. Boreal cold-water species did not show any significant reductions in abundance at any long-term survey site.

6. Conclusions

Lusitanian species of gastropod continue to show increases in abundance at populations close to, and at the leading range edges in north Wales. In 2021 higher than average numbers of new recruits were recorded at several populations in the vicinity of leading range edges, with multiple-year populations evidencing regular recruitment in the past few years.

7. References

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Appendices

MarClim Sampling Protocols 2021

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 *Phorcus lineatus, Steromphala 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 *Steromphala umbilicalis* in the region of the shore that they are most abundant. *Phorcus lineatus* occurs **upshore** of *Steromphala 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								
Laminaria ochroleuca								
Alaria esculenta								
Himanthalia elongata								
Sargassum 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								
Dictyopteris cyanoloma								
Calliblepharis jubata								
Chondracanthus acicularis								
Asparagopsis armata								
Colpomenia peregrina								
Saccorhiza polyschides								
Grateloupia turuturu								
Palmaria palmata								
Heterosiphonia japonica								
Caulacanthus ustulatus (okamurae)								
Pikea californica								
Halichondria panacea								
Hymeniacidon perlevis								
Anemonia viridis								
Aulactinia verrucosa								
Actinia fragacea								
Actinia equina								
Diadumene (Haliplanella) lineata								
Sabellaria alveolata								
Chthamalus stellatus								
Chthamalus montagui								
Semibalanus balanoides								
Balanus crenatus								
Perforatus perforatus								
Austrominius modestus								
Pollicipes pollicipes								
Mytilus spp.								
Clibanarius erythropus								
Haliotis tuberculata								
Testudinalia testudinalis								
Patella vulgata								
Patella depressa								
Patella ulyssiponensis								
Patella pellucida								
Steromphala umbilicalis								
Steromphala pennanti								
Steromphala cineraria								
Phorcus lineatus								
Calliostoma zizyphinum								
Littorina littorea								
Littorina saxatilis agg.								
Melarhaphe neritoides								
Nucella lapillus								
Onchidella celtica								
Magallana gigas								
Crepidula fornicata								
Botrylloides violaceus								
Botrylloides diegensis								
Perophora japonica								
Corella eumyota								
Dendrodoa grossularia								
Asterocarpa humilis								
Didemnum vexillum								
Asterias rubens								
Leptasterias mulleri								
Paracentrotus lividus								
Strongylocentrotus droebachiensis								
Watersipora subatra								
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	
		1.1.1.1.1.1.1.1 Phorcus lineatus	1.1.1.1.1.1.1.2 Steromphala umbilicalis
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Notes:

Data Archive Appendix

Data outputs associated with this project are archived in the NRW document management systems (MarClim - NRW View (sharepoint.com)) on server–based storage at Natural Resources Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] An spreadsheet named ‘MarClim data 2021’ in Excel format with metadata described.

Metadata for this project is publicly accessible through Natural Resources Wales’ Library Catalogue https://libcat.naturalresources.wales (English Version) and https://catllyfr.cyfoethnaturiol.cymru (Welsh Version) by searching ‘Dataset Titles’.

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Further copies of this report are available from the library

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