MARINE BIODIVERSITY AND CLIMATE CHANGE (MARCLIM)

PHASE 3 REPORT

MARCH 2002 - FEBRUARY 2004

THE MARINE BIOLOGICAL ASSOCIATION IN PARTNERSHIP WITH PLYMOUTH MARINE LABORATORY, SCOTTISH ASSOCIATION FOR MARINE SCIENCE, UNIVERSITY OF PLYMOUTH AND UNIVERSITY COLLEGE CORK

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PREFACE

The following report hereafter called Phase 3, details the MarClim project activities and outputs from April 2002 to February 2004. The report is divided into two sections. Section 1 details progress against the Project Specification (available on the project web site http://www.mba.ac.uk/marclim) according to the nine Project Modules. Section 2 provides a brief summary of research progress. The appendices provide information on project meetings, conferences attended and scientific output.

EXECUTIVE SUMMARY

The primary aim of Phase 3 was to, analyse the information collected during Phase 2, complete major re-surveys and begin modelling (hence predicting) possible effects of rapid climate change on marine biota.

Substantial person-hours have been spent cross checking the historical data extracted from notebooks and paper archives to electronic formats. Currently over 90% of the data collected and collated by MarClim have now been entered into a electronic databases in preparation for transfer to Marine Recorder, software developed by the National Biodiversity Network to archive data in a nationally consistent format. Three staff members have received training in Marine Recorder, the standard data input and archiving package used by NBN and national conservation agencies. New data is currently being entered directly into a 'Marine Recorder' format via Excel and Access whilst all older information is also being converted. Once complete it will be possible to make the data accessible on line at the close of the project when all scientific manuscripts have been submitted.

Analysis and interpretation of MarClim data has continued throughout the phase. Two manuscripts have been submitted for publication in peer-reviewed journals, whilst another three are in preparation.

In 2002 the MarClim team conducted nine major field trips surveying 242 sites including 56 of the broadscale sites surveyed by Crisp and Southward in 1958 along the English Channel. Survey of Crisp and Southwards Channel sites was restricted to the UK. Out of a possible 103 sites, 56 were surveyed. Because many of the sites first sampled in the 1950's were deemed unsuitable for re-survey, re-survey of the Channel sites was near enough completed in 2002. MarClim surveyed an additional 186 sites, sites chosen and sampled regularly since the 1960's by Crisp, Hawkins, Kendall, Lewis and Southward. The highest coverage was in Scotland, specifically, the Outer Hebrides, and northwest, north and east coasts, but at least 60 sites were re-surveyed in southwest England.

During 2003-2004 the MarClim UK and Ireland surveyed a total of 176 sites. MarClim UK conducted 5 major field trips surveying 125 sites including 19 of the broadscale sites surveyed by Crisp and Southward in 1958 along the English Channel. 7 of these sites were not sampled in 2002, whilst 12 were re-sampled from 2002. MarClim sampled an additional 106 sites, sites chosen and sampled regularly since the 1960's by Crisp, Hawkins, Kendall, Lewis and Southward. A subset of these sites was trialled for the Monitoring Network. The highest coverage was in Scotland specifically, the Inner Hebrides and east coast, but at least 35 sites were re-surveyed in southwest England and 21 sites in Northern Ireland. MarClim also visited Skomer Marine National Nature Reserve (a SPA and SSI). MarClim Ireland surveyed 54 sites in the Republic of Ireland and joined the UK team in Northern Ireland to survey 11 sites of the 21 completed in total.

A proposal for the establishment of a long-term climate change monitoring network was completed in October 2002 whilst in December 2002 a working list of sites was compiled for inclusion in the proposed monitoring network. Draft protocols were also included in this report and both the 2002 reports were circulated to the Advisory Group for comments. During the 2003 field season pilot trials of the network protocols were undertaken at a sub-set of sites around Britain. MarClim also submitted proposals to secure funding for a future long-term monitoring network.

No formal deliverables on Module 6 (Prediction and simulation) were scheduled for Phase 3 although a modeller has now been appointed to the project. Dr. Elvira Poloczanska, an employee of the MBA but based at SAMS in Oban, took up her post in September 2003, part time, and will work full time from February 2004 until the end of MarClim.

Communication of analysis and interpretation of data (Module 3) has continued throughout the phase. Two manuscripts have been submitted for publication in peer-reviewed journals, two semi-popular articles (one more than scheduled) have been published, one in the BIOMARE Newsletter (Autumn 2002), another in the MBA news (April 2003). In addition the MBA article has been circulated to Agency in house periodicals. Another major achievement of Phase 3 was the completion of the MarClim website. In addition to scheduled outputs, the activities of MarClim have also reached the BBC News Scotland website (April 2002) and a selection of articles in the Guernsey Press (June 2002 and June 2003). Members of the MarClim team have also disseminated information at five or more international conferences, notably The International Temperate Reefs Symposium, The 5th International Conference on Environmental Futures, The Tyndall Centre Global Climate Change and Biodiversity International Conference, The European Marine Biology Symposium and The Linnean Society Use of Long Term Data for Predicting Ecological Change Symposium.

The primary aim of the final Phase of MarClim (Phase 4, March 2004 - March 2005) will be the completion of the write up and dissemination of work conducted in the first three phases of the project, and the establishment of a monitoring network, including training of potential network staff. This phase of the project finishes with a conference to disseminate the results of Marclim in April 2005.

SECTION 1 - PROJECT PROGRESS AGAINST SPECIFICATION

Phase 3 of MarClim was scheduled from March 2002 to February 2004. During this phase of the project it was intended that:

- Data analysis of information collected during Phase 2 should be undertaken
- Major re-surveys be completed
- Predictions and modelling simulations should begin

Table 1.1 summarises the project progress against the specification in Years 2-3 (March 2002 - February 2004, but please note that the table begins in July as no deliverables were scheduled until this month). A detailed summary of progress in each module is given below, along with web links for the activity reports produced throughout Phase 3. All of these links can be found on the members page of the MarClim website at http://www.mba.ac.uk/marclim/members/memberframe.htm, under 'Project News'.

Table 1.1. Summary of Project Progress in Years 2-3 (July 2002 - February 2004). *To be incorporated into End of Phase Report. Note some tasks have been combined into one report.

Module	Project Tasks	Duration												Status	Document
		2002						2003							
		J	A	S	O	N	D	J	F	M	A	M	J		
		PHASE 3													
1. Identification & extraction of data	Secure access to priority data sets and assess quality													Completed	Update spreadsheet
2. Archiving databases	Transfer data onto databases and provide metadata													Completed	Activity Report
3. Analyses of data	Lewis and co-workers data													Slippage agreed	Manuscript
	Southward, Hawkins & Burrows barnacle and limpet datasets													Interim report	Manuscript
	Opportunistic analysis of other data													Completed	Activity report
4. Re-survey	Resurvey by MarClim team														
	Completion of broadscale Crisp and Southward survey													Completed	Activity report
	Annual census of Lewis sites													Completed	Activity report
5. Monitoring network	Planning future survey and low-cost monitoring													Completed	Activity report
	Targeted quantitative sampling at a selection of sites													Completed	Activity report
7. Providing data access	Establishment of data access vehicle on the website													Completed	Awareness report
8. Communication	Semi popular article in BBC Wildlife													See MBA newsletter	Manuscript
	Trochid data: manuscript for publication													Submitted	Manuscript
	Local and regional effects: manuscript for publication													Slippage agreed	Manuscript
	Summary of existing datasets													Completed	Link website to *MarLin*

Table 1.1. cont: Summary of Project Progress in Years 2-3 (July 2002 - February 2004)

Module	Project Tasks	Duration												Status	Document
		2003						2004							
		J	A	S	O	N	D	J	F	M	A	M	J		
		PHASE 3 cont:													
2. Archiving databases	Transfer data onto databases and provide metadata													Complete	Activity report
3. Analyses of data	SOTEAG, MBA, Southward & Lewis datasets													Complete	Manuscript
	Southward, Hawkins & Burrows barnacle and limpet datasets													Ongoing	Manuscript
4. Re-survey	Resurvey by MarClim team													Ongoing	
	Completion of broadscale Crisp and Southward survey													Complete	Activity report
	Completion of broadscale Crisp and Southward survey													Complete	Report*
	Annual census of Lewis sites													Complete	Report*
5. Monitoring network	Planning future survey and low-cost monitoring													Complete	Activity report
	Targeted quantitative sampling at a selection of sites													Complete	Activity report
	Planning future survey and low-cost monitoring													Delayed	Final report
8. Communication	Broadscale and limpets: manuscript for publication													Complete	Manuscript
	End of Phase III Report													Complete	Final report

Modules 1 & 2. Archiving and databases

This module was established to identify and secure access to historical data sets held by retired scientists or the heirs of deceased researchers that would otherwise have been lost.

Product	Due Date	Status	Web link
1. Update spreadsheets	September 2002	Complete	Not applicable
2. Data archive	February 2003	Complete	19_Data_archive_Feb_03
3. Data archive	February 2004	Complete	31_Data_archive_Feb_04

(Product 1) The major biological data holdings of UK MarClim are detailed in Table 1.2. MarClim also has access to a number of physical datasets, detailed in Table 1.3.

Table 1.2. Biological data sets secured by MarClim

Category	Locations	Data status		Time series	Original collector	Steward (s)	Access status	Entry status
		Broadscale	Quantitative					
Plankton	Plymouth, English Channel		✓	1903-1987	MBA	Southward Hawkins	Secured	Entered
Fish	Plymouth		✓	1903-1987	MBA	Southward Hawkins	Secured	Entered
Intertidal	UK, Isle of Man, Ireland	✓		1948-1986	Crisp	Crisp Southward	Secured	Entered
Intertidal	SW England Isle of Man, UK & Ireland	✓	✓	1950-1987	Southward	Southward	Secured	Entered
Intertidal	UK, N. France	✓		1964-1987	Rocky Shore Surveillance Group (Lewis)	Bowman Kendall Lewis	Trochid data secured	Entered
Intertidal	UK, France Portugal	✓	✓	1980-2002	Hawkins	Hawkins	Secured	Entered
Intertidal	Anglesey		✓	1974-1984	Coastal Surveillance Unit (Jones)	McMath CCW	Secured	On access database
Intertidal	Shetland		✓	1978-2001	Shetland Oil Terminal Advisory Group	Kingham Moore Ritchie	Agreed	On access database
Intertidal	Southern England	✓	✓	1989- 2001	Herbert	Herbert	Agreed	-
Intertidal	Orkney		✓	1970-2002	Orkney Marine Biology Unit	Jones Simpson	Agreed	-

Table 1.3. Physical data sets secured by MarClim and MECN

Category	Locations	Time series	Original collator	Steward (s)	Access status	Entry status
Sea Surface Temperature	Guernsey	1988-2000	Sendall	Sendall	Secured	Entered
Hydrography	Plymouth	1903-1987	MBA	Southward & Hawkins	Secured	Entered
Hydrography	Port Erin	1904-2004	Slinn, Allen, Hartnoll, Hawkins, Shammon	MECN, Hartnoll	Secured	Entered
Sea Surface Temperature	Port Erin	1904-2004	Slinn, Allen, Hartnoll, Hawkins, Shammon	MECN, Hartnoll	Secured	Entered
Sea Surface Temperature	Worldwide	1880-2004	The Hadley Centre	The British Atmospheric Data Centre	Secured	Entered
Air & Sea Surface Temperature	Plymouth	1967-2004	Richards, Southward, MECN	Richards, Southward, MECN	Secured	Entered

MECN: Marine Environmental Change Network based at the MBA.

(Products 2 & 3) Substantial person-hours have been spent cross checking the historical data extracted from notebooks and paper archives to electronic formats. Approximately over 2350 broadscale, 4500 barnacle, 4600 limpet and 2000 trochid records have been double checked by Rebecca Leaper in consultation with data gatherers. In addition, over 500 site locations have also been spatially referenced. Currently over 90% of the data collected and collated by MarClim have now been entered into a electronic databases in preparation for transfer to Marine Recorder, software developed by the National Biodiversity Network to archive data in a nationally consistent format. Data are currently being held in Excel® databases to facilitate transfer to statistical programmes such as S-PLUS©, whilst the analysis and interpretation of data (Module 3) is being conducted. Towards the end of Phase 4, Excel® and Access® formats will be converted to Marine Recorder and because the database uses Access® formats, we can modify forms to suit our specific needs. We currently have 3 trained users, who as core staff of the project will verify and enter data, however, Rebecca Leaper has taken overall responsibility for data entry and databases, and has completed all the data cross-checking. Once entered in Marine Recorder, data can be re-extracted to spreadsheet or database software (e.g. Excel® and Access®), GIS systems (e.g. ARC/INFO® 8.2) and if required, displayed dynamically on the Internet.

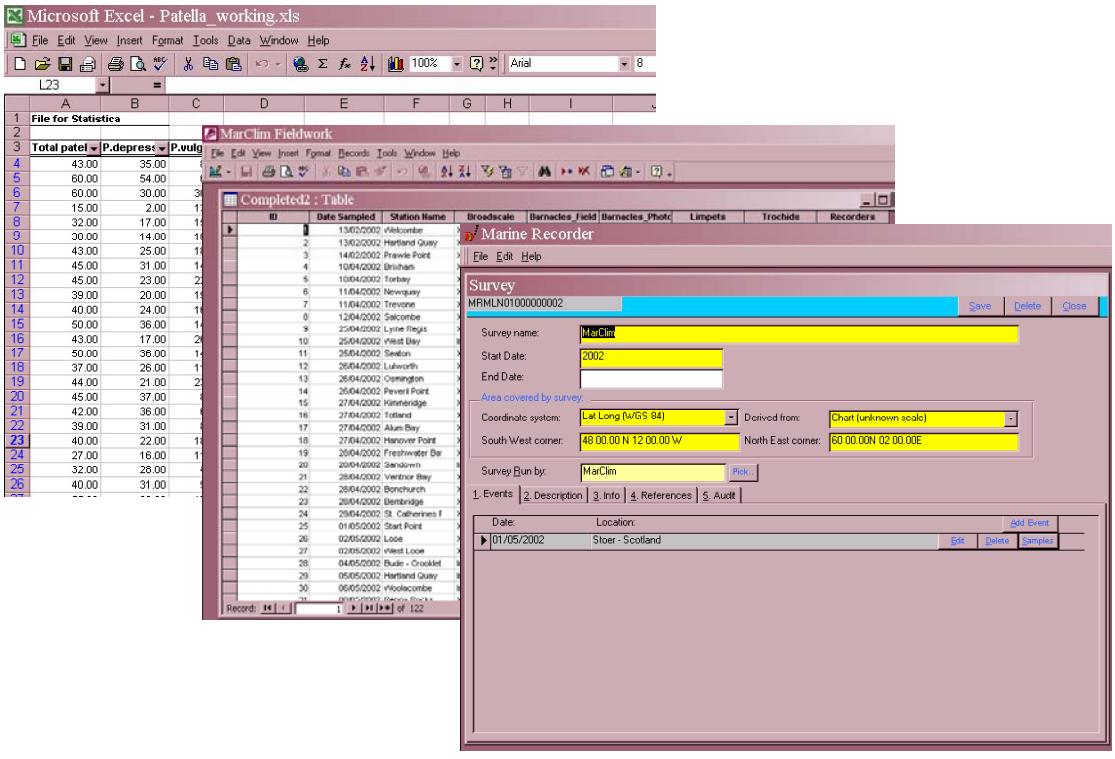

Figure 1.1. Transfer to electronic databases

The custodians of historical data from Ireland who have been contacted to date with the outcome of this contact are listed in Table 1.4. The datasets available to MarClim Ireland are shown in Table 1.5. Alan Southward has provided MarClim Ireland with his historical data for the Republic and Northern

Ireland in excel spreadsheets. Data from the Eurorock project collected at 9 shores in Co. Cork also exist in excel spreadsheets. Data in the form of unpublished reports (Bantry Bay Survey 1978; 1979; 1980 & Northern Ireland Littoral Survey 1988) exist in hardcopy but have been scanned with optical recognition software so that they will also be available in electronic format. Scanned pages will be complied to single files (probably in PDF format) before the end of the project when all electronic data be archived at the MBA. Efforts are ongoing to establish whether supplementary data holding facilities may be provided by The Irish Marine data Centre (Marine Institute, Galway).

Other data to which we have been given access are already available in the public domain as published research articles, online databases (AlgalBase), CD-ROM (BioMar survey) or as theses or published reports (Carnsore Point Survey can be found in Irish Fisheries Investigations (New Series) No. 2, 1998).

Jack Kitching's data from Lough Hyne is still in hardcopy and will possibly be archived in a dedicated Lough Hyne database. Raw data for selected species from the Bantry Bay Survey and the Carnsore Point Survey exist as yet, in original notebook form. The raw data from Denis Crisp's notebooks relating to Ireland are unavailable.

Table 1.4. Persons contacted and outcome with regard to accessing Irish intertidal data from 1950's to the present

Person Contacted	Outcome
Prof. Alan Southward	Provided raw data from 1952, 1953 and 1958 survey of Republic of Ireland and Northern Ireland
Dr Julia Nunn	helpful but unable to supply mollusc raw data
Dr Peter J. Hayward	Helpful but does not have raw data from his work in the 70's
Dr Colin Pybus	No raw data but published works
Dr Chris Emblow	BioMar (1993-96) raw data is on an access database on the BioMar CD
Prof. Mike Guiry	Referred us to AlgalBase.org, no raw data offered
Prof. J.S. Ryland	No raw data but published works
Prof. Brendan Keegan	No response
Dr Brenda Healy	Will provide raw data from Carnsore point (1980's) survey, Co. Wexford and possibly raw data from Dublin Bay area
Dr Padraig Whelan	Raw data on algal species from Ventry Bay, Co. Kerry and Carnsore Point, Co. Wexford (1980) contained in thesis
Dr Declan Looney	Provided a copy of the Northern Ireland Littoral Survey (1984-88), contains some raw data

Table 1.5. Data to which MarClim Ireland has been given access

Dataset	Archive Format
Southward & Crisp	Excel spreadsheet containing abundance scales of intertidal organisms for entire coastline of Ireland
Bantry Bay Survey	Unpublished reports plus raw data from the surveys conducted by various workers in Bantry Bay
BioMar	Access database on CD
Carnsore Point Survey	Published report (Irish Fisheries Investigations Series). Additional raw data as yet unavailable
Northern Ireland littoral survey	Contains some raw data
Eurorock	Excel spreadsheets available containing surveys of 9 shores in Cork in 1996-1997
Jack Kitching	Unpublished data on *Paracentrotus lividus* population densities at 2 locations in Lough Hyne Co. Cork during 1978

Module 3. Analyses and interpretation of data

This module was established to re-analyse historical data sets using modern statistical tools. The outputs of analysis will hopefully facilitate prediction and inform modern re-survey.

Product	Due Date	Status	Web link
1. Manuscript: trochid data	February 2003	Slippage agreed	20. Contact nova@mba.ac.uk
2. Manuscript: barnacle data	February 2003	Slippage agreed	21. Contact rleap@mba.ac.uk
3. Opportunistic data analysis	February 2003	Complete	22_Opportunistic_Feb_03
4. Manuscript: SOTEAG, MBA, AJS JRL data	December 2003	Submitted	32. Contact k.hiscocl@mba.ac.uk
5. Manuscript: barnacle & limpet data	February 2004	Ongoing	33. Contact rleap@mba.ac.uk

(Product 4) Analyses of some of the combined historical datasets (SOTEAG, MBA, AJS, JRL) have been incorporated into a publication:

Hiscock, K., Southward, A. J., Tittley, I. & Hawkins, S. J. (In press). Effect of changing temperature on benthic marine life in Britain and Ireland. *Aquatic Conservation*.

Work is currently ongoing on another three, two of which were granted slippage by the PMG on 27th May 2003.

(Product 1) It was originally hoped that analysis of the historical trochid dataset would yield a paper on effects of climate change on the distribution and abundance of the southern gastropod *Gibbula umbilicalis*. Although the project has detected clear range extensions since the mid 1980s, the historical data are not sufficiently complete to make possible the strong statistical comparison that was undertaken for *Osilinus lineatus* (see Module 8). At all sites that have been resurveyed close to the species northern limit in north west Scotland the species has increased in abundance but there are insufficient sites within the comparison for rigorous data analysis to be performed. The data is currently being analysed using multivariate techniques to determine if there are potential links between patterns in the population structure of *G. umbilicalis* at locations for which historical re-survey data is held and climatic variables. A manuscript will be ready for submission to a peer-reviewed journal in April 2004.

(Products 4 & 5) In the late 1940's, early 1950's Alan Southward and co-workers published a series of papers on the distribution of barnacles in Britain. As a direct result of this earlier work, Southward began a programme of regular surveys of barnacle populations in the whole of southwest Britain, starting in 1950. In all, 114 stations were chosen, the most northern station located at Clevedon (51.443^{o}N, -2.863^{o}W) in Somerset and the most eastern station located at Bembridge (50.702^{o}N, -1.066^{o}W) on the Isle of Wight; whilst six stations were located on the Scilly Isles. Of these 114 stations 17 were sampled on more or less a regular basis until 1987, the remainder perhaps being surveyed on only a couple of occasions. Of the 17 regular stations, one, Porthleven (50.080^{o}N, -5.320^{o}W), was continued until 1998. Abundance data from the 17 regular sites are currently being formally analysed using linear modelling techniques (ANOVA and mixed models). The analysis conducted thus far shows that shows that temporal change is a significant component of population density variation. At small spatial scales (the shore) population density can differ significantly over time, but at large spatial scales (the north and south coast) it does not. This suggests the widespread

nature of change over time. Work is currently underway to relate these spatial and temporal trends to climatic variables. More specifically, we have been extracting temporal trends in species abundance, compare trends across different spatial scales and relate trends to the regional mean annual sea surface temperature (SST), that itself has fluctuated within a range of 1.8ºC. Two manuscripts (February 2003, and 2004 deliverables) will be ready for submission to peer-reviewed journals in April 2004.

(Product 3) In addition to work conducted on the core MarClim datasets, analysis and synthesis of novel or additional archive data has led to one further paper being published during Phase 3, whilst another is in progress. Roger Herbert (based at The Medina Valley Field Centre), has been collecting data on intertidal organisms in the eastern English Channel since 1994. The eastern English Channel is an important area because many southern species are at the northeastern edge of their range. In the last 10 years the warm water barnacle *Balanus perforatus* has extended its range and is now found at Hastings (50.853^{o}N, 0.592^{o}W) 120km east from its previous range edge at Lyme Regis (50.723^{o}N, -2.928^{o}W). The results of this survey can be found in:

Herbert, R. J. H., Hawkins, S. J., Sheader, M. & Southward, A. J. (2003). Range extension and reproduction of the barnacle *Balanus perforatus* in the eastern English Channel. *Journal of the Marine Biological Association of the United Kingdom*, **83**, 73-82.

Range extensions along this part of the Channel have also been recorded in other species. The brown algae *Bifurcaria bifurcata* was found at Portland Bill (50.514^{o}N, -2.449^{o}W) on the English coast of the Channel in 2002. The eastern range edge was previously recorded at Start Point (50.223^{o}N, -3.639^{o}W) in Devon and this new population represents a range extension of approximately 150km. Nova Mieszkowska and Gerald Boalch are currently writing up this finding for submission to *Botanica Marina*.

Module 4. Re-survey of historical sites

This module supports the repetition of surveys whose outputs have been secured by Module 1 (see Table 1.2) and all current MarClim surveys are carried out in such a way that they will be amenable to repetition in the future. MarClim carry out re-survey work throughout the year, but the bulk of the fieldwork is conducted between March and October. MarClim UK have completed two full field seasons in Phase 3, whilst MarClim Ireland have completed one (in 2003) as this project only started in October 2002.

Product	Due Date	Status	Web link
1. Completion of broadscale Crisp and Southward survey	October 2002	Complete	23_Crisp_Oct_02
2. Annual census of Lewis sites	October 2002	Complete	24_Lewis_Oct_02
3. Completion of broadscale Crisp and Southward survey	October 2003	Complete	34_Crisp_Oct_03
4. Completion of broadscale Crisp and Southward survey	February 2004	Complete	35_Crisp_Feb_04
5. Annual census of Lewis sites	February 2004	Complete	36_Lewis_Feb_04

(Products 1, 3 & 4) For both UK and Irish teams the major aim of the both the 2002 and 2003 field seasons was to re-visit as many of the sites surveyed by Crisp and Southward in the 1950's as was possible. In the UK, field survey concentrated on a repeat of the published 1958 survey of the English Channel sites, whilst in the Republic of Ireland survey concentrated on sites all around the country, a repeat of the published 1954 survey. The Crisp and Southward sites originally surveyed in Northern Ireland were re-surveyed in a joint trip in September 2003. In addition, both teams visited sites in other areas that had also been subjected to broadscale survey on a regular basis. We felt that it was particularly important to cover other sites that were close to the edge of the recorded range of a target species. In the UK we were also able to re-survey limpet and barnacles sites of Hawkins, trochid sites of Kendall and Lewis and barnacles sites of Southward. The Irish team were also able to re-survey barnacle sites of O' Riordan. Over 23 personnel have been involved in field survey, 8 core MarClim staff, 6 Funding Agency staff, and the remainder biologists associated to the MarClim project. Figure 1.2 shows the location of sites surveyed by both teams to date, whilst Tables 1.4 and 1.5 details the actual number of sites visited in each MarClim sector.

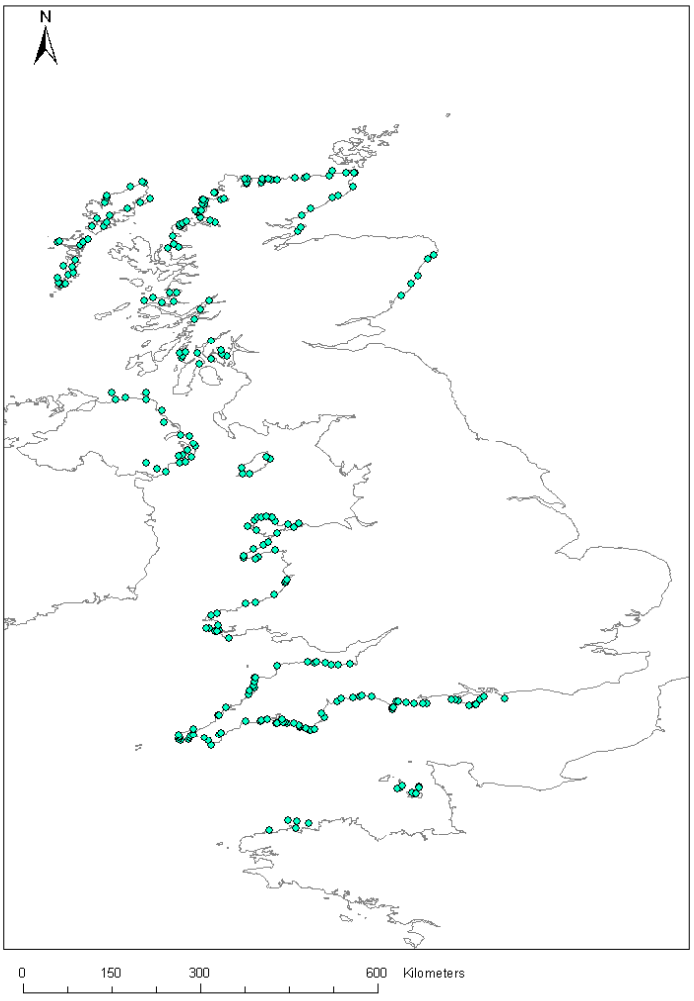

Figure 1.2. Location of all sites surveyed by MarClim UK and Ireland in 2002 and 2003.

Table 1.6. Summary of sites surveyed by MarClim in 2002.

Sector 2002	Sites completed
Scotland	105
IoM & NI	5
Wales	32
South West	62
South	24
Channel Islands	9
France	5
Total	**242**

Table 1.7. Summary of sites surveyed by MarClim UK and Ireland in 2003-2004.

Sector 2003-4	Sites completed
Scotland	38
IoM & NI	24
Wales	14
South West	35
South	5
Channel Islands	6
Ireland	54 (incl. 3 by UK team)
Total	**176**

In 2002 the MarClim team conducted nine major field trips surveying 242 sites including 56 of the broadscale sites surveyed by Crisp and Southward in 1958 along the English Channel. Survey of Crisp and Southwards Channel sites was restricted to the UK. Out of a possible 103 sites, 56 were surveyed. Because many of the sites first sampled in the 1950's were deemed unsuitable for re-survey, re-survey of the Channel sites was near enough completed in 2002. MarClim surveyed an additional 186 sites, sites chosen and sampled regularly since the 1960's by Crisp, Hawkins, Kendall, Lewis and Southward. The highest coverage was in Scotland, specifically, the Outer Hebrides, and northwest, north and east coasts, but at least 60 sites were re-surveyed in southwest England.

A number of key observations were made. Six species extended their range beyond historical limits, two of these are invasive species namely, *Sargassum muticum* and *Elminius modestus* whilst four are southern species namely, *Chthamalus montagui*, *Balanus perforatus*, *Osilinus lineatus* and *Gibbula umbilicalis*. Two other southern species, *Patella depressa* and *Laminaria ochroleuca* also showed increases in abundance in southwest England, as well as the sub littoral invasive barnacle *Solidobalanus fallax*. *Sabellaria alveolata* (a BAP species) was also found to have re-established itself in quantity on the Wirral after a gap of 80 years.

During 2003-2004 the MarClim UK and Ireland surveyed a total of 176 sites. MarClim UK conducted 5 major field trips surveying 125 sites including 19 of the broadscale sites surveyed by Crisp and Southward in 1958 along the English Channel. 7 of these sites were not sampled in 2002, whilst 12 were re-sampled from 2002. MarClim sampled an additional 106 sites, sites chosen and sampled regularly since the 1960's by Crisp, Hawkins, Kendall, Lewis and Southward. A subset of these sites was trialled for the Monitoring Network. The highest coverage was in Scotland specifically, the Inner Hebrides and east coast, but at least 35 sites were re-surveyed in southwest England and 21 sites in Northern Ireland. MarClim also visited Skomer Marine National Nature Reserve (a SPA and SSI). Although MarClim team members conducted most of the fieldwork, in total 18 different individuals were involved, including six staff from the Countryside Commission for Wales and two staff from The

Department of The Environment in Northern Ireland. MarClim Ireland surveyed 54 sites in the Republic of Ireland and joined the UK team in Northern Ireland to survey 11 sites of the 21 completed in total.

A number of key observations were made. Four species extended their range beyond historical limits; one of these is the invasive species *Sargassum muticum*, whilst three are southern species, namely, *Chthamalus montagui*, *Bifurcaria bifurcata*, and *Osilinus lineatus*. For three species these range extensions are in addition to those found in 2002; namely, *C. montagui* on the east coast of Scotland, *O. lineatus* and *S. muticum* in Lough Hyne, Ireland.

Two southern species, *O. lineatus* and *G. umbilicalis*, and the invasive species *S. muticum*, have shown increases in abundance in North Wales. *G. umbilicalis* is also now much more abundant than it was in the 1950's at many of the sites we surveyed in Northern Ireland. However, there are also some indications that two species, namely *Paracentrotus lividus* (an exploited southern species) and *Alaria esculenta* (a northern species) have declined in abundance in the Republic of Ireland.

(Products 2 & 5) In 2002 and 2003 all 16 sites close to the northern limit of distribution of *Osilinus lineatus* in southwest England and northern France that were surveyed by Kendall in 1986 were re-surveyed. The re-survey showed that in the past 15 years there have been small range extensions in the English Channel, North Wales and the Bristol Channel. Data analysis has also revealed that in all but one of the populations revisited *O. lineatus* has markedly increased in abundance. The size of individual adults and their growth rate has also declined indicating density dependent suppression. These changes appear to bring these northern limit populations closer to the population characteristics of animals towards the centre of the range.

In 2002 and 2003, seven sites close to the northern limit of distribution of *G. umbilicalis* in northwest Scotland, regularly visited by Lewis and Kendall in the period 1979-1987 have also been resurveyed. Clear range extensions have occurred since the mid 1980s and the species has increased in abundance at all but one of the seven locations. Roger Herbert has also recorded range extensions of this species in the eastern Channel.

Module 5. Establishment of a more detailed monitoring network

A major output of MarClim is to establish a more detailed monitoring network for climate change. It is designed to be a low cost, fit-for-purpose programme to provide policymakers and environmental managers with regular updates on the response of the marine biodiversity of Britain and Ireland to climate change following the completion of the MarClim project. The network will be established on the basis of experience gained during the MarClim project and on the availability of long-term data. It will be designed to maximise the scientific return on time and manpower invested and network sites will be selected from the existing catalogue of Southward, Crisp, Hawkins, Lewis and Kendall historical sites for which MarClim already holds the datasets. A small number of additional sites of scientific or

high conservation interest (statutory areas such as SAC's and MNR's) will also be added to integrate MarClim activities with those of any participating agencies and organisations.

Product	Due Date	Status	Web link
1. Planning future survey and low cost monitoring	October 2002	Complete	25_Network_Oct_02
2. Targeted quantitative sampling at a selection of sites	December 2002	Complete	26_Network_Dec_02
3. Planning future survey and low cost monitoring	October 2003	Complete	37_Network_Oct_03
4. Targeted quantitative sampling at a selection of sites	December 2003	Complete	38_Network_Dec_03
5. Planning future survey and low cost monitoring	February 2004	Delayed	

(Product 1) A proposal for the establishment of a long-term climate change monitoring network was completed in October 2002. The report detailed the criteria used to select potential sites from the existing datasets held by MarClim and made the recommendation that the sampling protocols be derived from the existing MarClim protocols, with the development of explicit instructions to ensure data collection is standardised between potential surveyors. (Product 2) In December 2002 a working list of sites was compiled for inclusion in the proposed monitoring network. The network has two survey categories, quantitative assessments of key indicator species at 85 selected sites, and semi-quantitative rapid assessments of distribution and abundance of key indicator species at 41 sites near to and beyond current distributional limits. Draft protocols were also included in this report and both the 2002 reports were circulated to the Advisory Group for comments.

(Products 3 & 4) During the 2003 field season pilot trials of the network protocols were undertaken at a sub-set of sites around Britain. MarClim also submitted proposals to secure funding for a future long-term monitoring network. These proposals were discussed at a preliminary meeting held between the MarClim team and the Joint Nature Conservancy Council (JNCC) (March 13th 2003) on the proposed context and content of the monitoring network. The October and December reports 2003 summarised these activities.

The development of the monitoring network following the MarClim model was discussed at the 5th Advisory Group Meeting and led to suggestion that a separate meeting of interested parties be organised. Many agency staff offered valuable input regarding the possible scope the network could take to fulfil both a climate change remit, and perhaps a broader, marine surveillance remit. Hence a meeting of key policy members from the core funding bodies has now been organised and will be held on March 25th 2004. A visit by Environment Agency (EA) staff on January 27th 2004 also discussed where MarClim related monitoring might fit into EA concerns, especially the Water Framework Directive. The primary aim of the meeting is to discuss the UK's requirements for an ongoing programme of marine climate change monitoring and to investigate the way in which such a programme might integrate with the existing plans of individual agencies. The main points for discussion are:

- UK requirements for marine climate change monitoring
- Existing and predicted agency obligations for marine surveillance and monitoring
- The role of a marine climate monitoring network within the existing UK marine monitoring framework
- The organisation and structure of a future marine climate monitoring network.

The conclusions of the meeting will be circulated to the Advisory Group as the final report, previously scheduled for February 2004, (Product 5).

Module 6. Prediction and simulation

Rule based qualitative predictions were developed in a small contract from SNH and submitted as a MarClim deliverable in Phase 1. The aim of this module is to extend these approaches to the whole of the British and Irish coasts. Predictions will be made based on analysis of past data sets (i.e. 1950s, and 1980s) and then tested with re-survey data from 2002-2004. After consultation with UKCIP, appropriately scaled, interactive models of population and community level responses to climatic change will be developed. These will enable longer-term predictions (2020s, 2050s and 2080s) to be made for subsequent generations to test. Predictions will be made in such a manner as to enable statistical testing via null hypotheses of lack of change in distribution and abundance. Furthermore, intensive modelling on the consequences of changes in composition of north–south species pairs (*Semibalanus balanoides/Chthamalus spp.*) will be the subject of separate, but linked applications to NERC.

No formal deliverables were scheduled for Phase 3 although a modeller has now been appointed to the project. Dr. Elvira Poloczanska, an employee of the MBA but based at SAMS in Oban, took up her post in September 2003, part time, and will work full time from February 2004 until the end of MarClim. She has already completed a NERC small project grant (awarded to Dr Burrows of SAMS in collaboration with Prof. Hawkins in 2002) on competitive interactions between two barnacle species. Using quantitative modelling Dr Burrows and Dr Poloczanska were able to incorporate processes of key environmental sensitivity into operational 2-species population models that ably reproduce changes in response to climatic fluctuations over the last 40 years. This work will now make it possible to forecast likely changes for these species as UK marine climate alters over the next 100 years, and lays the foundation for the modelling work under MarClim. It will also help inform the design of monitoring networks.

Module 7. Providing data access

MarClim has a commitment that data collected during the project are accessible by the National Biodiversity Network (NBN) but that the IPR of individual data owners is protected.

Product	Due Date	Status	Web link
1. Establishment of data access vehicle on the website	September 2002	Complete	27_Data_access_Sep_02

Three staff members have received training in Marine Recorder, the standard data input and archiving package used by NBN and national conservation agencies. New data is currently being entered directly into a 'Marine Recorder' format via Excel and Access whilst all older information is also being converted. Once complete it will be possible to make the data accessible on line at the close of the project when all scientific manuscripts have been submitted. At the 2nd PMG Meeting (October 16th 2002) the National Biodiversity Network data access agreements and their supporting documentation supplied to the project by Steve Wilkinson of JNCC, were accepted.

Module 8. Communication

The purpose of this module is to communicate MarClim outputs to professional and lay audiences. The major professional outputs will be in appropriate peer-reviewed journals, with some articles being sent to semi-popular magazines.

Product	Due Date	Status	Web link
1. Semi popular article	October 2002	Complete	28_Popular_Oct_02
2. Trochid data: manuscript for publication	December 2002	Submitted	29. Contact mak@pml.ac.uk
3. Local and regional effects: manuscript for publication	December 2002	Slippage granted	
4. Summary of existing datasets: Link website to *MarLin*	February 2003	Incomplete	
5. Broadscale and limpets: manuscript for publication	December 2003	Submitted	40_Broadscale_Dec_03
6. End of Phase III Report	February 2004	Complete	41_Phase3_04

A major achievement of Phase 3 was the completion of the MarClim website. It consists of two sections, the Public pages and the Members pages. Rebecca Leaper and Dan Lear maintain the web site.

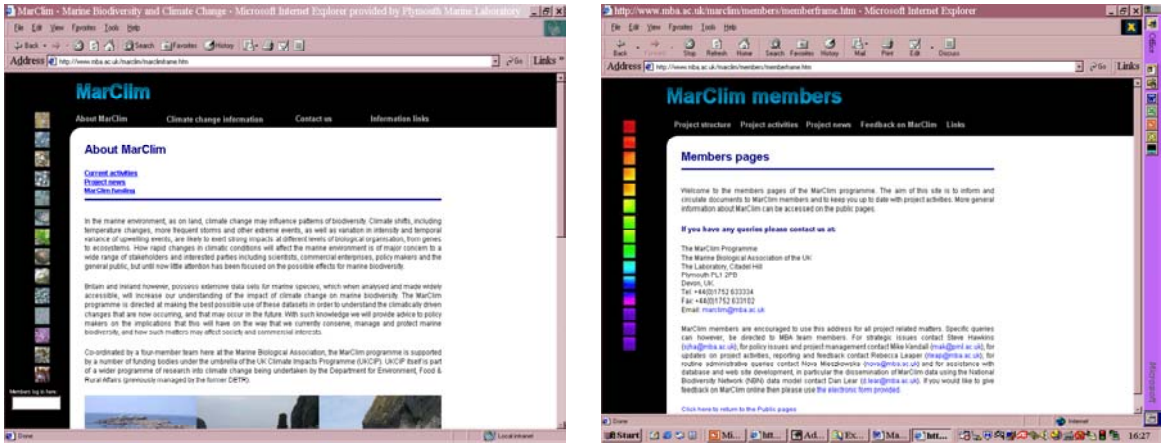

Figure 1.3. The MarClim website

The public pages are split into four sections: About MarClim, Climate change, Contact details and Information links. In the 'About MarClim' section we have provided information on the background to the project and the project aims:

- Synthesising and interpreting long-term and current data.
- Resurveying historical locations.
- Establishing a network of sites to monitor change.
- Forecasting future change using climate models.
- Informing policies on the marine environment.
- Addressing the implications for society.

Background information on climate change is given in the Climate change information section. This information is a summary of the findings from the latest IPCC and UKCIP reports. UKCIP have been particularly helpful in providing information and figures for these sections. There is information on how our climate is changing, the impacts of climate change and future climate change scenarios. We have kept this section general, as it is quite difficult to pull out specific "marine environment" facts and figures.

The member pages are split into five sections, providing information on Project structure, Project activities, Project news, Feedback and Links.

In the Project structure section you can link to the Advisory and Project Management Group details, the Project Specification and details of the Project Modules. Two sections Project activities and Project news are pages that will be continually updated. For example, on Project activities work in progress against the nine project modules is detailed. All documents relating to project management activities can be found on the Project activities page. PDF links are provided from the meetings table. These include agendas, minutes and reports presented at the meetings. Members can also keep up to date with progress against outputs using the PDF links to the Yearly timetables. Fieldwork protocols can also be found on this page. Project news is the same as project activities, but posts the latest information. Product (4) The members website will be updated at the start of Phase 4, but as yet operates as a stand-alone website and does not link to the *MarLin* site as scheduled for February 2003. This task will be best completed at the end of Phase 4.

(Products 2 & 5) Communication of analysis and interpretation of data (Module 3) has continued throughout the phase. Two manuscripts have been submitted for publication in peer-reviewed journals, two semi-popular articles (one more than scheduled) have been published, one in the BIOMARE Newsletter (Autumn 2002), another in the MBA news (April 2003). (Product 1) In addition the MBA article has been circulated to Agency in house periodicals.

(Product 2) Analysis of the historical trochid dataset (Module 3) has yielded a publication entitled 'Climate change prompts range extensions, denser populations and density dependant suppression of growth in the lusitanian Trochid gastropod *Osilinus lineatus*', which was submitted to The Journal of the Marine Biological Association of the UK in February 2003. The work shows that in the past 15 years there have been small range extensions in the English Channel, North Wales and the Bristol

Channel. In all but one of the populations revisited *O. lineatus* has markedly increased in abundance. The size of individual adults and their growth rate has declined indicating density dependent suppression. These changes bring these northern limit populations closer to the population characteristics of animals towards the centre of the range. Warmer sea temperatures have enhanced juvenile recruitment. The mechanism is likely to be some combination of increased reproductive period and post-larval survival. The use of *O. lineatus* as an indicator of climate change in UK is also proposed.

(Product 3) Due a later than anticipated start to Irish MarClim, and the fact that the Project Specification did not allow adequate time for data entry of historical records (Modules 1 & 2), the PMG (May 2003) granted slippage on the joint UK and Irish 'overview' manuscript on local and regional effects, originally scheduled for December 2002. A meeting of the projects science managers (November 17th 2003) enabled the team to determine the context and content of the manuscript and the peer-reviewed journal it should go to. A draft of the manuscript is underway and should be submitted to Marine Pollution Bulletin in April 2004.

(Product 5) Analyses (Module 3) of some of the combined historical datasets on broadscale and limpet data have been incorporated into a manuscript entitled 'Changes in the range of some common rocky shore species-a response to climate change' which was submitted to the Special EMBS 38 Edition of *Hydrobiologica* in September 2003, ahead of the December 2003 deadline.

In addition to scheduled outputs, the activities of MarClim have also reached the BBC News Scotland website (April 2002) and a selection of articles in the Guernsey Press (June 2002 and June 2003). Members of the MarClim team have also disseminated information at five or more international conferences, notably The International Temperate Reefs Symposium, The 5th International Conference on Environmental Futures, The Tyndall Centre Global Climate Change and Biodiversity International Conference, The European Marine Biology Symposium and The Linnean Society Use of Long Term Data for Predicting Ecological Change Symposium. More details can be found in Appendix 2.

Finally, MarClim were also able to secure a research contract (Contract: EPG 1/1/158) from the Department of the Environment Food and Rural Affairs to review and provide data for candidate marine indicators for the publication "Review of UK Climate Change Indicators 2003". Details can be found at http://www.nbu.ac.uk/iccuk/reportjune2003/Jan2004.htm

Phase 4 Programme (March 2004 – March 2005) (Modules 3, 5, 6, 8 & 9)

The primary aim of Phase 4 of MarClim is the completion of the write up and dissemination of work conducted in the first three phases of the project, and the establishment of a monitoring network, including training of potential network staff. This phase of the project finishes in March 2005 (but please note that three staff contracts are due to finish in December 2004).

Module 3. Analyses and interpretation of data

Analyses of the critical broadscale, barnacle, limpet and trochid datasets will be completed and final reports submitted in October.

Table 1.8. Summary of Project Progress in Year 4 (July 2004 - April 2005). * Incorporated into End of Phase Report

Module	Project Tasks	Duration										Document
		2004						2005				
		J	A	S	O	N	D	J	F	M	A	
		PHASE 4										
3. Analyses of data	Southward, Hawkins & Burrows barnacle and limpet datasets											Final report
	Opportunistic analysis of other data											Final report
5. Monitoring network	Planning future survey and low-cost monitoring											Workshop and report
	Planning future survey and low-cost monitoring											Mini - workshop and brief report
	Targeted quantitative sampling at a selection of sites											Final report
6. Prediction	Interactive model of population and community responses to long term predictions											Activity report
	Interactive model of population and community responses to long term predictions											Model and final report*
8. Communication	Manuscript for publication: major review											Manuscript
	Four manuscripts for publication											Manuscripts
	Joint SAFHOS/MBA/SAMS conference to disseminate results											Conference
9. Policy application	Strategic policy issues arising from data and climate change scenarios											Interim report
	Marine climate change indicator species and applications as sustainability indicators											Report
	Implications of predicted changes to marine biota of Britain and Ireland											Final report
	End of Phase IV Report											Final report

Module 5. Establishment of a more detailed monitoring network

The establishment and development of the monitoring network will continue under Phase 4. On the premise that future funding can be secured the MarClim team will host two training workshops (in July

and September respectively), on sampling methodologies and data archive and management. A final report on the network activities will be submitted in October.

Module 6. Prediction and simulation

Development of the interactive computer model of population and community responses to climatic variability and long term predictions will continue throughout Phase 4, led by the team at SAMS. The final report of this work will be submitted in March 2005.

Module 8. Communication

The final stage of the write up and dissemination of MarClim will include both a major scientific review paper (to be submitted in December) and the submission of at least four other scientific publications by the end of Phase 4 (March 2005).

Module 9. Policy Application

In preparation for the completion of MarClim, the Funding Agencies, Advisory and Project Management Groups will produce an interim report on strategic policy issues arising from the data and climate change scenarios (to be submitted in December).

Completion of MarClim

After Phase 4 has finished MarClim is scheduled to complete two remaining tasks. The first is to host a conference (Module 8: Communication), on the major findings of MarClim UK and Ireland. The UK and Irish governments have a range of national and international commitments to the conservation of species habitats and geological features. However, conservation policy will have to adapt to the effects of climate change and policy modifications need to be based upon the best possible scientific evidence and understanding of the implications of climate change on marine biota. The conference will cover the following topics in climate change context:

- Statutory frameworks for delivery of marine conservation and associated policies.
- Development of sustainability indicators - there are currently no marine indicators.
- Reporting on the health of the marine environment and protected sites.

The second task is for the Funding Agencies, Advisory and Project Management Groups to complete a report on strategic policy issues arising from the data and climate change scenarios (Module 9: Policy Application) with particular reference to climate change indicator species.

SECTION 2 – RESEARCH PROGRESS

The MarClim project employs two postdoctoral researchers, and two team members who are currently conducting research for PhD's. The postdoctoral work takes an analytical and modelling approach and is conducted under Modules 3, 6 and 8 of MarClim. The PhD research activities complement the analysis of historical datasets by developing experimental approaches to test hypotheses that may elucidate the underlying processes and mechanisms of cause change at the individual, population and community levels and at local and regional scales.

Postdoctoral Research

Analysis of MarClim historical datasets (R. Leaper)

A major challenge for current climate change research concerns the familiar problem of detecting signal from noise. For example, to attach any 'confidence' to a hypothesised climate effect, we must try to untangle natural variation from anthropogenic effects. This is often difficult to demonstrate unequivocally, because we simply cannot experimentally manipulate systems at temporal and spatial scales relevant to climatic forcing. Consequently, we rely on retrospective analysis of monitoring data. This approach yields weaker inferences, but offers the chance to capture system variability, providing data are collected over adequate scales. It may also help us generate testable hypotheses that provide evidence for cause-effect relationships. Retrospective analysis forms the basis of the analytical and modelling work on MarClim.

The analyses of four major datasets are now underway, those of Southward (barnacles), Hawkins (limpets and barnacles) and Crisp and Southward (broadscale). The Southward barnacle dataset is the most complete time series available to MarClim, monitored at a spatially extensive network of sites for a 33-year period (1955-1987) in SW Britain. Using advanced linear modelling approaches (ANOVA and Mixed Models), we are extracting temporal trends in species abundance, comparing trends across different spatial scales and relating trends to the regional mean annual sea surface temperature (SST), that itself has fluctuated within a range of 1.8ºC. In addition to the linear modelling approach, we are also investigating whether barnacle populations fluctuate synchronously across our sampling network over the 33-year period, using cross correlation techniques and Mantel tests. If we can quantify the domain (spatial extent) of synchrony in barnacle populations we may then be able to determine the relative roles of extrinsic, density independent processes, versus density-dependent forces in determining patterns of abundance. Results obtained from the Southward dataset will be compared to the independent data set of Hawkins collected at a subset of the Southward sites.

The limpet dataset covers a 23-year time period (1980-2003), but is not as complete (either spatially or temporally) as the Southward barnacle dataset; hence advanced linear modeling approaches are not as tractable. However, the dataset is complete enough to allow simple 'then' and 'now' comparisons between time periods when the marine climate has been quite different i.e. the 'cool' 1980's and the much 'warmer' 1950's or 2000's. Simple non-parametric methods (Binomial and Kruskall Wallis tests) are currently being used to determine whether significant change in population

abundance has occurred, whilst simple correlation analysis will determine whether change is (causally) related to changes in marine climate.

Powerful statistics cannot be easily applied to abundance category (ACFOR) datasets. This is because the abundance category is defined at the 'zone of most abundance' of the species in question and therefore no variance (in abundance) is measured. This semi-quantitative approach however, does reduce spatial variation at the local scale and increases the number of species (assemblages) that can be assessed at a site as well as providing the opportunity of sampling at many sites, thereby giving a regional perspective. Two analysis approaches are currently being employed. Multivariate methods (BIO-ENV) are being used to examine the relationship between species and physical variables, whilst simple non-parametric methods (Binomial and Kruskall Wallis tests) are being used to determine whether significant change in population abundance at the regional scale has occurred. We are also using the broadscale dataset to examine changes in the distribution of a number of species simultaneously at the regional scale using GIS (ARC/INFO® 8.2) mapping as well as providing data for the modelling work on future climate change (see below).

Prediction and modelling of climate change impact scenarios (E. Poloczanska)

Species ranges are determined by a number of interlinking factors such as climate, habitat, presence/absence of predators and competitors and dispersal ability. Using grid-based GIS maps of the UK and Irish coast, we are developing population models for key rocky shore species to predict responses to climate change. Historical data sets and data collected under the MarClim programme are being used to produce distribution maps based on rules such as response to sea surface temperature and wave exposure. Future climate change scenarios will be explored and it is expected species will disappear as conditions become less favourable or ranges may expand if future climate proves more favourable over larger areas. The dispersal process and presence of physical barriers will also be considered when predicting changes in ranges. For species with non-pelagic dispersal, the presence of unfavourable habitat may halt advancement along a coastline. A pelagic dispersal stage is dependant on inshore currents for colonisation of new areas so physical barriers such as headlines may prove to be an obstacle for range expansion.

The composition of rocky shore communities is strongly influenced by the degree of wave exposure (Lewis, 1964). Indeed, the most widely used index of wave exposure is based entirely on species composition (Ballantine, 1961). Use of biologically defined indices has the major drawback of potential circularity of logic – expectations of shore communities depend on the perceived wave exposure, partly defined by the kinds of animals and plants found at the site. From this point of view, preferable indices of wave exposure are based either on direct measurements of wave force, or on estimates of the openness and orientation of the site to the prevailing winds. Here we have adopted a simplified version of the map-based method of estimation of Thomas (1986). Wind energy in sixteen 22.5° angular sectors was calculated as the product of square of the average windspeed in knots (V_i^2) and the proportion of time that wind blew in that sector (p_i). Wave height and energy depends on the

fetch in a particular direction. Fetch is the distance across open sea to the nearest coastline. The wave exposure index we calculated for sites along UK coastline was the sum of the product of fetch (F_i) in km (truncated to a maximum of 50km) and the wind energy in the 16 angular sectors around the site. Thus:

$$W = \sum F_i \left(p_i V_i^2 \right)$$

For a synpotic view of the pattern of wave exposure along coastline, a grid of 500m squares was created for the area using the Ordnance Survey co-ordinate system with a GIS system (ArcView 3.2, ESRI). Grid squares were classified as land or sea by a majority area rule, and those land squares with at least one sea square as a neighbour were classed as coast squares. Fetch in the sixteen angular sectors was calculated for every coastal cell in the whole grid with a model that identified the nearest coastal cells at increasing distances in each sector. The resulting pattern (Figure 2.7) was in line with expected variation along the coastline.

Figure 2.7. Wave exposure map for Oban and Mull on the west coast of Scotland based on predictions of wind speed and fetch.

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PhD Research

Population structures and reproductive cycles of British Trochids in relation to climate change
(N. Mieszkowska: Supervised by: Kendall, Hawkins & Thompson)

This thesis focuses on the response to climate change of two 'southern' species of trochid Gastropods, *Osilinus lineatus* da Costa and *Gibbula umbilicalis* da Costa which both reach their northern limits of distribution in Britain and Ireland. The aim of the research is to understand and assess the effect of climate related temperature increases on the various components of the trochid reproductive cycle, and how this affects population dynamics along the biogeographic distribution range.

Resurveys of populations previously surveyed in the 1970s and 1980s have shown significant increases in abundance and corresponding decreases in adult size for both species at sites across Britain. Recruitment failure has become less common at populations close to the northern limits of distribution and these range edges have themselves been extended. Mixed age populations are now established beyond locations where historically only a few isolated individuals were found. These results form the basis of two MarClim manuscripts, one of which is in submission the other in final revision (Modules 3 & 8)

Population dynamics of intertidal invertebrates are usually controlled by juvenile recruitment, adult mortality, emigration and immigration. Adult mortality can be the dominant control of survival of a population in severe environmental conditions. In during the cold winter of 1962/63, adult *O. lineatus* from populations in Wales were emersed during the most severe snap frost of the twentieth century and were subsequently killed by the extreme low temperatures (Crisp 1964). However, in most years adult mortality is not the primary regulator of population size and success (Kendall & Lewis 1986), instead reproductive output and recruitment are the most sensitive of the life history stages (Vance 1973). These stages are regulated by exogenous factors, and the effects of climatic regime changes over a latitudinal or temporal scale are therefore likely to exert the strongest effects on this stage. If the range edges of geographic distribution are set by a failure to repopulate, populations close to distributional limits will have irregular age structures, missing year classes or a bias towards older animals (Lewis et al. 1986). Frequent recruitment failure was seen in populations of *O. lineatus* and *G. umbilicalis* close to northern range edges in the cooler period of the 1970s and 1980s (Kendall & Lewis 1986, Kendall 1987) whereas the same populations have had strong recruitment success in recent years where sea and air temperatures have been higher (Kendall *et al.* in prep, Mieszkowska *et al.* in prep). From historical and resurvey data collected to date, the north and north eastern range limits of both species appear to be set by the inability to reproduce successfully. Recruitment failure is more frequent in populations close to their range edge, although trends in recruitment strength are synchronous but less severe throughout the sites studied (Kendall & Lewis 1986, Lewis 1986, Kendall 1987, Kendall *et al.* in prep, Mieszkowska *et al.* in prep), indicating a latitudinal gradient in the environmental factor(s) affecting recruitment success. Variation in sea and air temperatures has been

shown to influence the distribution, physiological performance and reproductive success of marine species (Orton 1920, Hutchins 1947, Frank 1975, Bauer 1992, Sagarin *et al.* 1999, Helmuth & Hofmann 2001) and is suggested to be the main factor influencing the recruitment success of the trochid species *O. lineatus* and *G. umbilicalis* in Britain.

Understanding mechanistic links between changes in species range and abundance and climate change are essential in order to make quantitative forecasts of future distributional patterns. Field and laboratory experiments to determine these mechanisms are ongoing. Preliminary results suggest that the processes of reproduction and recruitment are the main drivers of the observed change through increased reproductive success due to warming in environmental temperatures.

A sample network was established in January 2003 to determine whether a latitudinal gradient in the timing of the gametogenic cycle and periodicity and frequency of spawning events existed. This hypothesised gradient may explain why populations reproduce more successfully towards the centre of the range whereas a high recruitment failure is observed at the northern range edges. Sample stations were set up in Wales, SW England, S England, Ireland and N France to monitor *O. lineatus* (Figure 2.1), and in Scotland, SW England, S England, Ireland and N France to monitor *G. umbilicalis* (Figure 2.2). Analysis of the samples is currently underway. Samples from the populations of *O. lineatus* in SW England and France are near to completion and the variation in gametogenic maturation between these sites can be seen in Figure 2.3. The sample network is being extended in 2004 to include a station close to the centre of the ranges of both species in Portugal.

Juvenile animals are the sole input of individuals into populations for species such as these as individuals have limited motility and do not move between adjacent populations. Few studies have investigated the dynamics of recruitment in trochid gastropods. In order to understand how recruitment is influenced by climate and the consequences of variation in recruitment success on a population, the timing of spawning, settlement, growth and the over winter survival of new recruits must be quantified. A research programme has been established to look at the recruitment process in populations of *O. lineatus* and *G. umbilicalis* and the linkages between the effects of temperature on timing of the reproductive cycle and on subsequent survival of the '0' class cohort over their first winter. Fortnightly assessments of the abundance and size distributions of '0' class juveniles have been carried out since October 2002 (Figure 2.4). The results show that the 2002 juveniles enter a period of winter growth cessation and then exhibit a linear trend of growth throughout the remainder of their first year. Juveniles settling in 2003 also stopped growing during the winter months but this phase occurred 3 weeks earlier than in 2002, indicating that an external environmental factor may be influencing the timing of this event. Data from temperature loggers deployed in microhabitats occupied by both species on the shore will be analysed to determine if any local temperature signal correlates with the period when growth ceases.

Figure 2.1. Distribution of *Osilinus lineatus* in Britain and Northern France (dark grey line) and location of sample stations (grey circles).

Figure 2.2. Distribution of *Gibbula umbilicalis* in Britain and Northern France (dark grey line) and location of sample stations (grey circles).

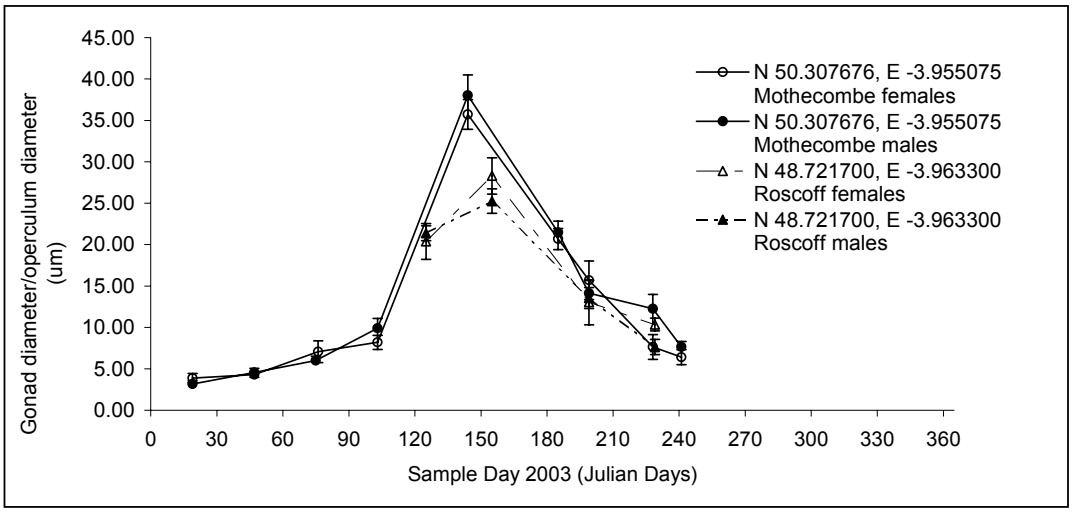

Figure 2.3. Seasonal Gonad Maturation of Female and Male *Osilinus lineatus* along a latitudinal gradient 2003

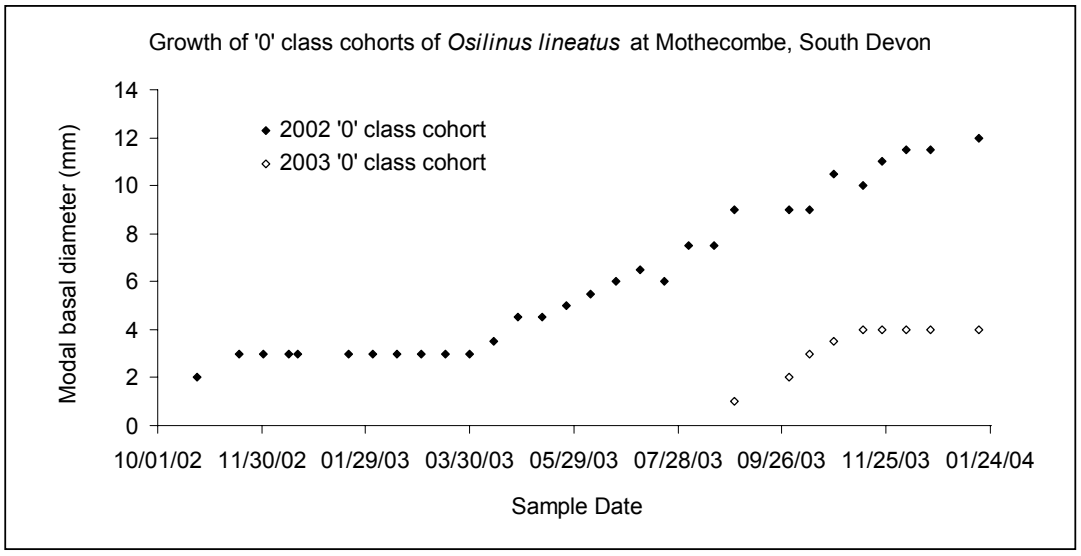

Figure 2.4. Modal basal diameter size class of *Osilinus lineatus* '0' class recruits from the 2002 and 2003 cohort between 2002 and 2004.

The mortality rates of recruiting juveniles during the winter and spring periods will also be determined. Ongoing laboratory experiments are examining the survival rates of newly settled juveniles under temperature regimes experienced during severe and mild winters. The results will show whether warmer temperatures enhance survival rates within populations close to northern range edges.

The use of *O. lineatus* and *G. umbilicalis* as indicators of climate change is proposed. At the current stage of research they have already been shown to be sensitive to fluctuations in climate at the population level. The experimental results of this thesis will determine whether either species also has a potential use as a physiological indicator of climate change, which can detect changes without the need for long-term data collection. The extent to which this approach can be applied to other species will also be discussed.

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The role of biological interactions in modifying the effects of climate change

(P. Moore: Supervised by Thompson, Leaper & Hawkins)

Recently, the importance of biotic interactions in influencing species responses to climate change has been highlighted (Brown et al. 1997, Davies *et al.* 1998a, Davies *et al.* 1998b, Bertness *et al.* 1999, Leonard 2000, Bertness and Ewanchuk 2002). Here rocky shores in south-west Britain are used as model systems to elucidate the role biotic of interactions in modulating species responses to climate change.

Limpets, particularly *Patella vulgata*, through their clumping behaviour beneath *Fucus* patches, have an important role in structuring many moderately-exposed shores in the NE Atlantic (Hawkins 1983, Hartnoll and Hawkins 1985, Hawkins *et al.* 1992, Burrows and Hawkins 1998). Little is known about the role *P. depressa* plays in structuring shores of the NE Atlantic, although it has been assumed that both species have the same role due to similarities in their physiology, ecology and behaviour.

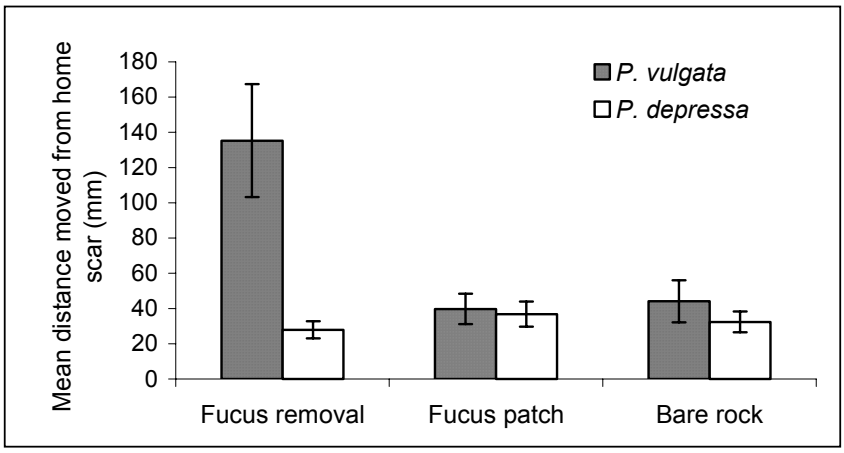
Quantitative surveys have found that *P. depressa* behaves in a different way to *P. vulgata* when *Fucus* patches are present. In contrast to *P. vulgata*, which preferentially clumps beneath *Fucus* patches, a higher proportion of *P. depressa* to total limpets were found on bare rock compared to beneath *Fucus* patches and as the percentage cover of *Fucus* increased the proportion of *P. depressa* to total limpets decreased.

Subsequently, manipulative field experiments were used to see how the two species of limpet would respond to the loss of *Fucus*, a predicted outcome on south-west shores as a result of climate change (Ballantine 1961, Barry *et al.* 1995, Franklin and Forster 1997, Coelho *et al.* 2000). Over two years and at two sites *P. vulgata* moved significantly further from its home scar and experienced higher mortality following *Fucus* removal than *P. depressa* in any treatment and *P. vulgata* in *Fucus* patch and bare rock treatments (Figures 2.5 and & 2.6). It is predicted that the loss of *Fucus* as a result of climate change will have little effect on the behaviour and mortality of *P. depressa*. In contrast, it is predicted that the positive interaction between *P. vulgata* and *Fucus* will strengthen as a result of climate change and if *Fucus* is lost from shores around the south-west *P. vulgata* will see its range movement northwards quicken or be limited to low and shaded microhabitats. *Fucus* patches are known to have a higher diversity beneath them compared to adjacent areas of exposed rock (Thompson *et al.* 1996), but the chance of *Fucus* escapes will decrease, because there will be fewer areas of reduced grazing due to *P. depressa* being randomly found across the mid-shore. Therefore the behaviour of *P. depressa* may indirectly change the community structure of NE Atlantic rocky shores.

It is unlikely that species range shifts will respond to climate change as a linear function. Factors such as biotic interactions will slow down or speed up range shifts, depending on whether interactions with new colonists or between present species in a community become positive, negative or facultative as a result of climate change. We agree with (Bertness and Ewanchuk 2002) exactly that how climate change influences the structure of natural communities will be extremely difficult and complex to predict.

Ongoing work is examining the migration of both limpet species into uncolonised *Fucus* species to elucidate the speed at which *P. vulgata* does colonise new patches of *Fucus* and the reasons why *P. depressa* does not preferentially clump beneath *Fucus* patches. To compare conditions inside and outside *Fucus* patches temperature data loggers are recording the temperature every fifteen minutes in these two habitats. A preliminary comparison of the temporal differences, particularly in terms of season and time of spawning, on the grazing activity of the two limpet species indicates that the *P. depressa* and *P. vulgata* do have different patterns of grazing which would appear to affect the settlement success of *Fucus* sporelings. The empirical data collected with the above two experiments will be used along with data from the *Fucus* removal experiment to produce a mathematical model to simulate changes in the interactions between the two limpet species and *Fucus* patches during a period of climatic warming.

a)



b)

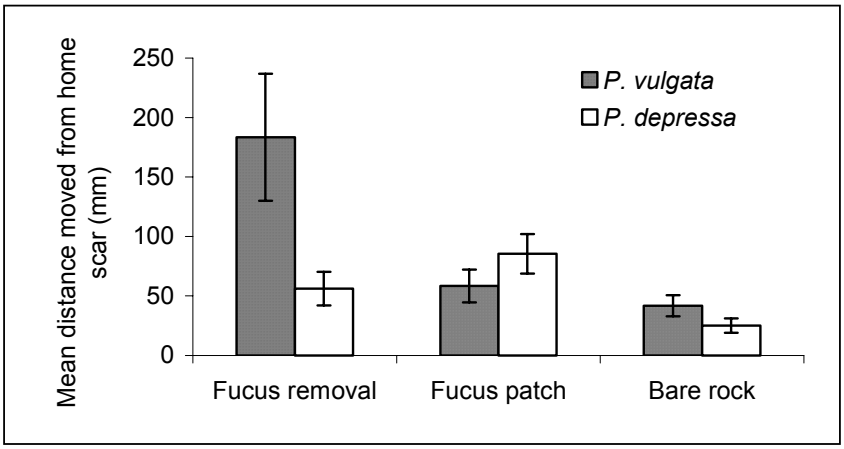
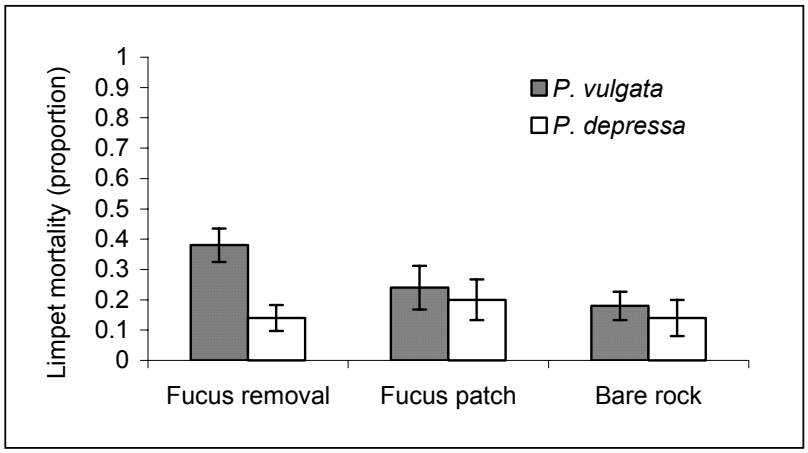


Figure 2.5. Mean distance moved from home scar for *P. depressa* and *P. vulgata* for three treatments, *Fucus* removal (FR), *Fucus* patch (FP) and Bare rock (BR). Error bars ± 1 SE. a) Treatment × species interaction at Trevone and Crackington Haven in 2003. Student-Newman Kuel (SNK) comparisons indicate for *P. vulgata* that movement away from home scar: FR > FP = BR. SNK tests for *P. depressa* indicate no difference in movement between the treatments. b) Treatment × species interaction at Crackington Haven in 2002 and 2003. SNK tests indicate that movement away from home scars for P. vulgata: FR > FP = BR. For P. depressa: FR = FP > BR.

a)



b)

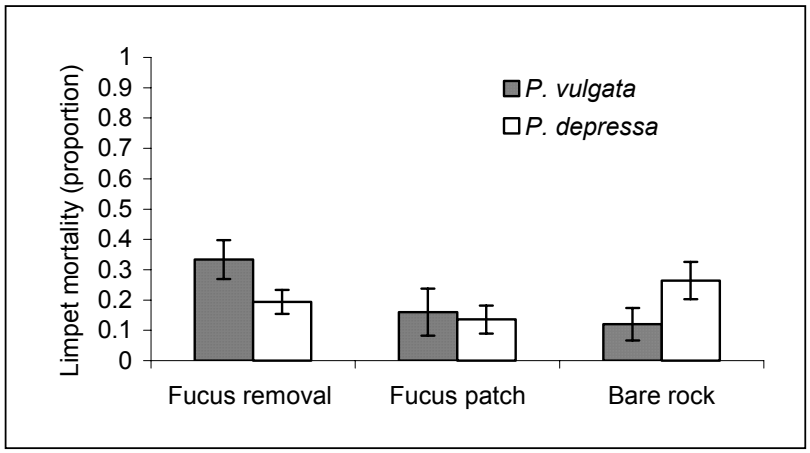


Figure 2.6. Proportional limpet mortality for three treatments, *Fucus* removal (FR), *Fucus* patch (FP) and Bare rock (BR). Error bars ± 1 SE. a) Treatment × species interaction for Crackington Haven in 2002 and 2003. SNK tests indicate that mortality for *P. vulgata* was: FR > FP = BR, there was no difference in the treatments for *P. depressa*. b) Treatment × species interaction at Trevone and Crackington Haven in 2003. SNK tests indicate no significant difference in the treatment × species interaction, although the trend is similar to Crackington Haven over the two years with *P. vulgata* suffering higher mortality in the *Fucus* removal treatments compared to *P. depressa* and *P. vulgata* in the *Fucus* patch and Bare rock treatments.

Climate influences the recruitment success of many species. Hence changes in climate can influence the balance between competing species, especially species that respond to climate change in different ways. Experiments using the gregariously settling barnacle *Semibalanus balanoides* will be used to examine the role adult conspecific abundance has on cyprid settlement. If cyprids are reliant on the presence of adult conspecifics to settle it can be hypothesised that during periods of low adult numbers on the rock there will also be low settlement success, irrespective of the number of cyprids in the water column. The effect of good and bad settlement years of *Chthamalus* on the settlement success of *Semibalanus* recruitment, and vice versa is also being investigating.

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APPENDIX 1

Project Meetings and Workshops

Meeting	Number	Date	Location	Chair
Advisory Group	2	19/10/2002	London	J. Baxter
	3	26/03/2002	Edinburgh	J. Baxter
	4	17/10/2002	Bristol	J. Baxter
	5	18/11/2003	Bristol	J. Baxter
Management Group	1	11/06/2002	Plymouth	D. Laffoley
	2	16/10/2002	Bristol	D. Laffoley
	3	27/05/2003	Dublin	D. Laffoley
Policy Group	1	05/09/2002	London	R. Connell

Agendas, Backing Papers and Minutes can be found on the 'Project Activities' page of the MarClim website.

APPENDIX 2

MarClim Team Conference Presentations

Invited Paper: *An overview of global change and temperate (?) reefs: patterns, processes and possibly predictions.* Temperate Reefs Symposium 2003 Canterbury, New Zealand (13-17 January 2003).

Invited Paper: *Can intertidal species be used as indicators of global climate change? Measuring and predicting responses of marine ecosystems in the North East Atlantic International*. Temperate Reefs Symposium 2003 Canterbury, New Zealand (13-17 January 2003).

Poster: *The role of biotic interactions in mediating species responses to climate change*. Temperate Reefs Symposium 2003 Canterbury, New Zealand (13-17 January 2003).

Poster: *Climate change and species interactions: The role of Fucus patches in influencing the distribution of northern and southern species of limpet.* The Malacological Society of London, Millport UK (28-30 March 2003).

Poster: *Does climate change drive temporal fluctuations in intertidal barnacles?* Global Climate Change and Biodiversity International Conference, Norwich UK (8-10 April 2003).

Poster: *The advance of a southern species in Britain: A response to rapid climate change?* Global Climate Change and Biodiversity International Conference, Norwich UK (8-10 April 2003).

Invited Paper: *Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years.* Environmental Future of Aquatic Ecosystems, Zurich, Switzerland (23-27 March 2003).

Paper: *Measuring and predicting responses of marine ecosystems to global climate change using intertidal indicators*. British Ecological Society, Annual Meeting, Manchester, UK (9-11 September 2003).

Paper: *Changes in the range of some common rocky shore species as a response to climate change.* EMBS Symposium Aveiro, Portugal (September 8-12 2003)

Poster: *Climate changes and biodiversity ranges: linking intertidal diversity distributions and global warming*. EMBS Symposium Aveiro, Portugal (September 8-12 2003)

Invited Paper: *Long term changes in the western English Channel by the Marine Biological Association: making the case for time series*. Looking back for the future; the use of long-term data for predicting ecological change. International Symposium of the Linnean Society (23-24 October 2003).

Paper: *Detecting the effects of climate change on intertidal diversity using long-term datasets*. Looking back for the future; the use of long-term data for predicting ecological change. International Symposium of the Linnean Society (23-24 October 2003).

APPENDIX 3

MarClim Scientific Output (Papers in Progress and Future Papers: DRAFT)

Scientific

Kendall, M. A., Hawkins, S. J., Burrows, M. T. & Southward, A. J. (In press). Predicting the effects of marine climate change on the invertebrate prey of the birds of rocky shores. *Ibis (Special Edition)*.

Herbert, R. J. H., **Hawkins, S. J.,** Sheader, M. & **Southward, A. J.** (2003). Range extension and reproduction of the barnacle *Balanus perforatus* in the eastern English Channel. *Journal of the Marine Biological Association of the United Kingdom*, **83**, 73-82.

Hiscock, K., Southward, A. J., Tittley, I. & **Hawkins, S. J.** (In press). Effect of changing temperature on benthic marine life in Britain and Ireland. *Aquatic Conservation*.

Kendall, M. A., Mieszkowska, N & Hawkins, S. J. (In submission). Climate change prompts range extensions, denser populations and density dependant suppression of growth in the lusitanian Trochid gastropod *Osilinus lineatus*. *Journal of the Marine Biological Association of the UK.*

Moore, P., Thompson, R. C. **& Hawkins, S. J**. (In submission). Climate change and species interactions: the role of *Fucus* patches in influencing the distribution of a northern and southern species of limpet.

Mieszkowska, N., Kendall, M. A, Hawkins, S. J., Leaper, R., Williamson, P., Hardman-Mountford, N.J. & **Southward, A. J.** (Under revision). Changes in the range of some common rocky shore species-a response to climate change? *Hydrobiologica Special Edition EMBS 38.*

Thompson, R. C., Crowe, T. P. & **Hawkins, S. J.** (2002). Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years. *Environmental Conservation*, **29**, 168-191.

Williamson, P. & **Kendall, M. A.** (In submission). Transplant experiments of *Osilinus lineatus* (Gastropoda: Trochacea) at the northern limits of its range. *Journal of the Marine Biological Association of the UK.*

Popular

Kendall, M. A. (2002). MarClim – Marine Biodiversity and Climate Change. *Report to BIOMARE Newsletter*, p10, Autumn 2002 Issue.

Leaper, R. (2003). Intertidal species as indicators responses of biodiversity to rapid climate change in UK marine ecosystems. *Report to the Marine Biological Association Newsletter*, p8, April 2003 Issue.

Simkanin, C. S., Power, A. M., Davenport, J., Myers, A. A., McGrath, D. (2003). Monitoring intertidal community change in a warming world. *The Irish Scientist 2003 Yearbook* May 2003. Samton Limited.

Technical Reports

Cannell, M., Brown, T., Sparks, T., Marsh, T., Parr, T., George, G., Palutikof, J., Lister, D., Dockerty, T. & **Leaper, R**. (2003). Review of UK Climate Change Indicators. *DEFRA Contract Report No. EPG 1/1/158.*

Papers in Progress (Provisional titles and authorship)

Leaper R., Burrows, M. T., Power, A. M. & Southward, A. J. (In preparation). Separating spatial and temporal components of population density fluctuation in intertidal barnacles over a 40-year period in the western English Channel. *Marine Ecology Progress Series.*

Leaper R., Burrows, M. T. & Southward, A. J. (In preparation). Spatial synchrony of population changes in intertidal barnacles over a 40-year period in the western English Channel. *Journal of Animal Ecology.*

Leaper R., Burrows, M. T., Hawkins, S. J. & Southward, A. J. (In preparation). Does climate change drive spatial and temporal fluctuations of intertidal barnacle populations in the western English Channel? *Journal of Animal Ecology.*

Mieszkowska, N., Boalch, G & Hawkins, S. J. (In preparation). The geographic range of a brown alga (*Bifurcaria bifurcata* Ross)- revisited. *Botanica Marina.*

Power, A. M., Delany, J., **McGrath, D., Myers, A. A. & O' Riordan, R. M.** (In preparation) Spatial variation in abundance of *Chthamalus stellatus* and *C. montagui* during early benthic life in SW Ireland. *Journal of Experimental Marine Biology and Ecology.*

Poloczanska, E. S., Burrows, M. T., Hawkins, S. J. (In preparation). Climate change and competitive interactions in intertidal barnacle populations: models built on 40 years of evidence. *Journal of Animal Ecology.*

Future Papers (Provisional titles and authorship)

Hawkins, S J., Southward, A. J., Crisp, D. J., Ballantine, W. J. & **Leaper, R.** (In preparation). Long-term change in the distribution and relative abundance of a northern and southern species of limpet in Britain: the effect of 50 years of climate fluctuation.

Leaper, R., Mieszkowska, N., Power, A. M., Simkanin, C. S., Davenport, J., Kendall, M. A., Hawkins, S.J., McGrath, D., Myers, A. A. & Southward, A. J. (In preparation). Long-term change in the distribution and relative abundance of intertidal organisms in the UK: the effect of 50 years of climate fluctuation.

Leaper, R., Mieszkowska, N., Hawkins, S .J. & Southward, A. J. (In preparation). Long-term change in the distribution and relative abundance of intertidal organisms in the English Channel: the effect of 50 years of climate fluctuation. *Journal of the Marine Biological Association of the UK.*

Mieszkowska, N., Kendall, M. A., & Hawkins, S.J. (In preparation). Latitudinal variation in the reproductive cycle of *Osilinus lineatus*.

Poloczanska, E. S., Burrows, M. T., Hawkins, S. J. (In preparation). Space-limited recruitment in intertidal barnacle populations: gregariousness or a constant settlement rate per unit area?

Simkanin, C. S., Power, A. M., McGrath, D., Myers, A. A. Davenport, J., & Southward, A. J. (In preparation). Long-term change in the distribution and relative abundance of intertidal organisms around the Irish coast: the effect of 50 years of climate fluctuation. *Journal of the Marine Biological Association of the UK.*