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Recommendations for Intertidal Biodiversity Surveillance

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Contents

Executive Summary

Surveillance monitoring is essential to meet both UK and international targets of halting the loss of biodiversity. To achieve this goal effective surveillance strategies need to be implemented. The aims of this project, therefore, were to provide recommendations for surveillance of intertidal marine biodiversity to enable progress to meet UK and EU targets of reversing declines in biodiversity by 2010. In particular, this project identified intertidal species that are likely to respond to environmental change and therefore could act as potential indicator species for change to the community as a whole; provided bioclimatic models to predict species range shifts in response to global climate change; recommended scales at which intertidal surveillance programmes need to be undertaken to meet best and worst case scenarios for survey design; and identified locations, at a variety of scales, in which surveillance monitoring of the rocky intertidal could be undertaken.

Findings

1. Fifty-seven rocky intertidal species have been identified as potential indicator species. The species were identified because they have previously been identified as Environment Agency 'exposure pressure' species (Hiscock *et al.* 2005), climate indicator species (Simkanin *et al.* 2005), characteristic species of key intertidal biotopes (Grosholz *et al.* 2000) and/or non-native species.

2. Neighbourhood occupancy predictive models were created for 28 of the 57 indicator species to forecast the likely species range changes under different UKCIP02 climate models. We were unable to create models for all species due to a lack of information on the distribution and abundance of some and the rarity of others.

3. The use of biotopes as indicators of environmental change was shown to be poor at the EUNIS level 3 classification. However, modelling changes in the distribution of characteristic species of key biotopes, at EUNIS level 5, to global climate change showed that many of these species are likely to retreat or expand their ranges, which is likely to alter the balance of intertidal biotopes. Bioclimate envelope predictions of future species ranges have been created for ten characteristic species of intertidal biotopes.

4. Power analysis of the broadscale data collected during the MarClim project has given an indication of the best and worst case scenarios for undertaking surveillance programmes. To just meet UK obligations under the Habitats Directive i.e. changes in species abundance of an order of magnitude, 50 sites would need to be surveyed to detect a decrease and 20 sites to detect an increase in species abundance. To meet targets over and above UK and international targets 85 sites and 40 sites would need to be surveyed to detect a decrease and increase in species abundance of one SACFOR category. However, to detect the predicted change in abundance of the most temperature sensitive species for the High 2020s scenario over 200 sites would need to be surveyed.

5. ESRI Shape files have been created for 20, 30, 50, 100, 200 and 400km spaced survey schemes for intertidal areas.

Recommendations

Annual surveys of approximately 100 sites would meet targets over and above UK and international obligations to undertake surveillance as well providing enough information to separate noise from signal. Larger surveys, such as those to detect changes in the abundance of, for example, the most climate sensitive species, need only be undertaken every ten years. Both these survey strategies would meet UK and EU aims of reducing the loss of biodiversity and be deemed cost effective by both managers and the general public.

Further work

The findings of this pilot project are limited to the rocky intertidal. Further work needs to be done to extend this project to other intertidal habitats and the subtidal. In addition the predictive models are based on observed data collected during the MarClim project. Unfortunately there are some areas of the UK that were not surveyed during the MarClim project e.g. north-east England and it is imperative, to validate these models, that data on species distributions and abundances are collected from where there are gaps in our knowledge. Our findings show that up to 200 sites will need to be surveyed to observe changes in species abundance under some environmental change scenarios. Therefore, work started during the MarClim project, to establish a low cost UK wide monitoring network, needs to be addressed.

1. Introduction

Information on the condition and changes in the condition of the marine environment are of major concern to government and non-government organisations, as well as the general public. The World Summit on Sustainable Development stated that '*halting the loss of marine biodiversity*' was imperative. At an EU and pan-European level the objective is to protect and restore the structure and functioning of natural systems and halt the loss of biodiversity both in the European Union and on a global scale by 2010 (European Commission 2001). There is therefore a growing need for better information on the state of marine biodiversity to guide management and regulatory decisions, verify the efficiency of existing programmes and help shape policy on marine environmental protection.

Surveillance (or trend monitoring) needs to be designed to identify and quantify long-term environmental changes as a result of anthropogenic change from naturally occurring fluctuations. In particular, to ensure an ecosystem approach to marine stewardship, the influence of global environmental change (i.e. anthropogenically forced warming and introduction of non-native species) needs to be separated from regional (e.g. fishing, eutrophication and modification of coastal processes) and local impacts (e.g. point sources, acute pollution incidents, specific sea defence schemes, habitat loss due to coastal development and recreational activities). This can only be done via broadscale and long-term research networked over appropriate spatial and temporal scales. Surveillance programmes carried out over such spatial and temporal scales will be able to detect changes in habitats and species, signalling areas where declines in diversity are occurring and enable hypotheses to be developed to understand the causes of these declines. In addition surveillance undertaken both within and outside protected (designated) areas will provide information on the condition of protected areas and the contribution they make to maintain the wealth of the UK's biodiversity. Such surveillance programmes also ensure that national and international obligations for undertaking of surveillance and monitoring are met, as well as contributing to European and global audits of the state of biodiversity and its contribution to ecosystem processes.

Effective trend monitoring should provide a rationale for setting standards and priorities that not only provides effective management of marine ecosystems, but also resonates with the general public. Therefore an effectively designed surveillance programme should provide:

- a potential early warning of future problems, especially if the surveys can be carried out in a way that is not solely reliant on an identified 'need' by decision makers;

- an enhanced knowledge of marine ecosystems, their variability, and societal impacts on them – thus allowing the targeting of resources;

- a rationale for setting standards and priorities. When surveillance shows a clear change or trend, for example, a reduction in fish abundance, public confidence in the decision maker's limits on catches is enhanced;

- a better understanding of the health of the marine environment;

- information for generating hypotheses to inform process orientated research on the underlying mechanisms behind the alteration in species distributions to provide a better understanding of the processes structuring marine communities and ecosystems; and

- information to construct, adjust and verify quantitative predictive models to predict rates and scales of future changes in species ranges and population structure and to provide a basic tool in evaluating and selecting management strategies.

Any surveillance programme should aim to detect changes in the status of biodiversity, the impacts of different factors upon biodiversity and the effects of policy and management responses taken to counteract the causes of changes in biodiversity. It is, however, impossible to undertake surveillance of all biodiversity directly due to constraints of time, biological knowledge and perhaps more importantly cost. Therefore attempts should be made, wherever possible, to use species that can act as indicators of change for the community as a whole. In particular surveillance programmes need to ensure that enough sampling is undertaken to detect more than just catastrophic change, but not sample far in excess of what is necessary.

The aim of this pilot project was to provide recommendations for surveillance in the intertidal zone. The intertidal was specifically chosen for this project as considerable amounts of quantitative and semi-quantitative time-series data, collected over a fifty-year period and covering much of the UK, has been collated enabling re-survey as part of the recently completed Marine Biodiversity and Climate Change (MarClim) project. The rocky intertidal is also an ideal system in which to undertake this pilot project as it is the most studied of marine habitats due to ease of access, most of the organisms being either sedentary or sessile, resulting in a good understanding of the biology and ecology of the species. More recently a suite of intertidal species have been shown to be good indicators of changes in species abundance and range in response to climatic warming, mirroring changes that are occurring offshore (Simkanin *et al.* 2005). Intertidal species have therefore been suggested as cheap indicators of more general responses to climate change of marine biodiversity (Laffoley *et al.* 2005, Simkanin *et al.* 2005).

1.1. Policy drivers and commitments

A key driver for surveillance is the need to set priorities for nature conservation action. Many of these priorities have been set through our need to comply with national and international obligations for surveillance. Obligations to detect changes in the status of biodiversity, and the causes of change, arise primarily from the EC Habitats and Birds Directives, Convention on Biological Diversity, Ramsar Convention, OSPAR and the requirement by Government to monitor and report on the condition of designated sites. There are a number of other Directives currently being considered that may also affect the need and scope of a marine biodiversity surveillance programme.

The UK Governments' vision of "*clean, safe, healthy, productive* and *biologically diverse oceans and seas*" (as set out in the first Marine Stewardship Report *Safeguarding our Seas*, published in May 2002), is central to the development of a surveillance programme that is likely to be implemented through the new UK Marine Monitoring and Assessment Strategy, currently undergoing consultation.

1.2 Project aims and objectives

The aims of this pilot project (26 funded days of scientist time) were to provide recommendations for surveillance of intertidal biodiversity, to enable progress to EU and UK targets of reversing the decline of biodiversity by 2010. In particular, we aimed to provide information on how to measure biodiversity in the marine environment using intertidal indicator species and the spatial and temporal scale at which monitoring studies need to be undertaken to meet different national and international agreements.

The specific objectives of this report were to:

- identify indicators key for measuring changes in biodiversity in intertidal biotopes;
- provide projected changes in species ranges using a bioclimate envelope model, incorporating species which are diagnostic of particular biotopes;
- recommend comprehensive and minimalist intertidal sampling designs suitable for detecting changes in biodiversity;
- identify appropriate sampling locations and methodologies, as appropriate; and
- provision of pilot GIS polygon shape files that can be used as a template for locating sampling stations.

This report stems from the work of the JNCC-part-funded MarClim project (MarClim 2001), the main aims of which were to understand and predict likely change in intertidal fauna and flora in a changing climate, by reference to earlier survey work done in the 1950s and intervening period. In this context therefore, much of the analysis presented here derives from methods developed for detection of climate-related change. These methods are, however, largely portable to other environmental drivers of change, and should be interpreted with this in mind.

2. Intertidal indicators to measure biodiversity

It is unrealistic in terms of time and hence cost to undertake monitoring of all marine biodiversity directly. A more realistic alternative is to identify indicator species or sensitive biotopes that are known to respond to changes in environmental conditions and are likely to act as indicators of changes in biodiversity. Using the rocky intertidal as an example we have created a list of candidate indicator species for monitoring the effects of changes in marine biodiversity (Appendix 1).

The species chosen have been selected because they are easily identifiable and represent species that are likely to respond to environmental change because they have been identified as Environment Agency 'exposure pressure' species (Hiscock *et al.* 2005), climate indicator species (Simkanin *et al.* 2005), and/or key non-native species (see Appendix 1). Characteristic species of key intertidal biotopes (Grosholz *et al.* 2000) have also been proposed as indicator species as changes in the presence or abundance of these species are likely to track wider changes in marine biodiversity and have knock-on effects if they are habitat forming species (ecosystem engineers) or important consumers (keystone species).

3. Predicted range extensions of indicator species

3.1 Models developed in the MarClim project

A major goal of the MarClim project was the resurvey of the intertidal rocky coastlines of the UK and Ireland 50 years after the last major surveys by Alan Southward and Dennis Crisp in the 1950s, using methods comparable with the earlier work and compatible with those in use today. 617 sites were surveyed up to October 2005, forming the ‘observed’ set of categorical abundance data for the development of statistical models used in forecasting the changes presented in this report. The spatial extent of the MarClim surveys had some gaps in coverage, and to extend model predictions to the entire UK coastline we have added 126 further sites in areas not yet surveyed. ‘Predicted’ data in maps shown in this Report thus covers 743 sites around the UK.

Abundance categories used by Crisp and Southward (1958) spanned six categories from Abundant (corresponding to ecologically dominant), Common, Frequent, Occasional, Rare and Absent, a sequence that has become known as the ACFOR scale. While these categories represent the loss of some numerical information in terms of counts of organisms, particularly at the higher ranges of abundance, they are well suited to capture the lower range of abundance when individuals may occur in scattered patches or as isolated individuals. At the upper end of the abundance scale, a better ability to capture numbers of organisms by direct counts in quadrats has led to the addition of extra categories: Extremely Abundant and Super Abundant. The latter is included in the now-standard SACFOR scale. Most of the data collected in the MarClim project was collected as SACFOR data. To detect change since the 1950s, however, for the modelling the Super Abundant and Abundant categories were collapsed into a single Abundant class. This has no effect on the changes in distributions projected by the models, since forecast changes are based on changes in the likelihood of Abundant or Common categories. Likewise, use of the ACFOR scale in this modelling exercise does not undermine the adoption of the SACFOR scale as the presently accepted standard.

Models of species distributions were developed during the MarClim project based on ordinal logistic regression of ACFOR categorical abundance scores. Two predictor variables were found to give good prediction of species abundance for a wide range of species recorded during surveys. The best predictions of the distributions of warm-water species, generally restricted to western and south-western coasts, was achieved using February sea surface temperature, averaged between 1961 and 1990. An index of wave exposure developed during the project, the summed fetch up to a maximum of 200km in 16 angular sectors, successfully distinguished distributions of exposed-shore species (e.g. *Laminaria hyperborea*, *Alaria esculenta*, *Chthamalus stellatus*) from those of species generally restricted to shelter (*Elminius modestus*, *Ascophyllum nodosum*, *Fucus spiralis*, *Pelvetia canaliculata*). Models were produced for 55 species using data from 617 sites surveyed by MarClim teams in the UK and Ireland mostly between 2002 and 2004.

These ‘bioclimate envelope’ models (hereafter BE models) are a useful first step in establishing the nature of the association between species distributions and the major environmental variables in a region. Making forecasts of changes in distributions as a result of environmental changes using this class of models is not without difficulty (Davis *et al.* 1998), since such models take no account of the underlying processes determining population spread, including any potential barriers to dispersal, connectivity and availability of suitable habitat.

We attempted to account for the effects of limits to population spread by modifying our original models to include the effect of occupancy of nearby sites. If the species were absent from an area yet environmental conditions were apparently favourable, such as for *Patella depressa* in southern Ireland, the modified model predicts much-reduced abundance in such areas. The incorporation of the neighbourhood occupancy rate into models was achieved by fitting ordinal logistic regressions to the ACFOR data using February SST, wave fetch and a single index of the proportion of sites occupied in a 100km neighbourhood around each site (henceforth PO models).

The models themselves predict the likelihood that the ACFOR category at each site will be at least a particular category. To use these models to determine changes in species ranges, it is necessary to set a criterion for whether the predicted 'likelihood of a category' defines the site as being inside or outside the species range. For most species, mere presence defines the range so the appropriate category to consider is **at least RARE**. The critical likelihood of being rare that may define the species range is less easy to set but experimentation suggests a value of P(at least Rare)>0.3 is sufficient to delineate the range of the species (Figure 1).

UKCIP recommend (Hulme *et al.* 2002) that models that make forecasts from climate projections should present the results from several forecasts for comparison. To this end we have predicted range changes for three scenarios: High CO_2 emissions for the 2020s (High 2020s), Medium-Low CO_2 emissions for the 2080s (Medium-Low 2080s), and High CO_2 emissions for the 2080s (High 2080s). Table 1 gives the expected range of February SST increases for each scenario.

Table 1. Projected changes in average sea surface temperature for February under UKCIP02 scenarios. Values shown are the minimum and maximum for all sites around the UK and Ireland. * shows scenarios used in predictions of range changes (Section 4 below and Appendix Fig. A3)

	Min	Max
Low 2020s	0.34	0.67
Medium-Low 2020s	0.38	0.74
Medium-High 2020s	0.38	0.74
High 2020s*	0.41	0.8
Low 2080s	0.86	1.69
Medium-Low 2080s*	1.01	1.98
Medium-High 2080s	1.42	2.78
High 2080s*	1.67	3.28

Examples of forecast changes in species distribution are shown in Figures 2 and 3. The topshell *Osilinius lineatus* is currently restricted to southwest England, south and west Wales and southern and western Ireland. With a 0.4 to 0.8°C change in February SST (Figure 2), the species is predicted to extend eastwards in the Channel to mid Kent, northwards along the Irish coast and across into southern and western Scotland. With a further 0.6 to 1.2°C increase in the long-term average of February SST, the species is expected to continue its expansion eastwards into the southern North Sea and northwards along the west coast of Scotland (Figure 3).

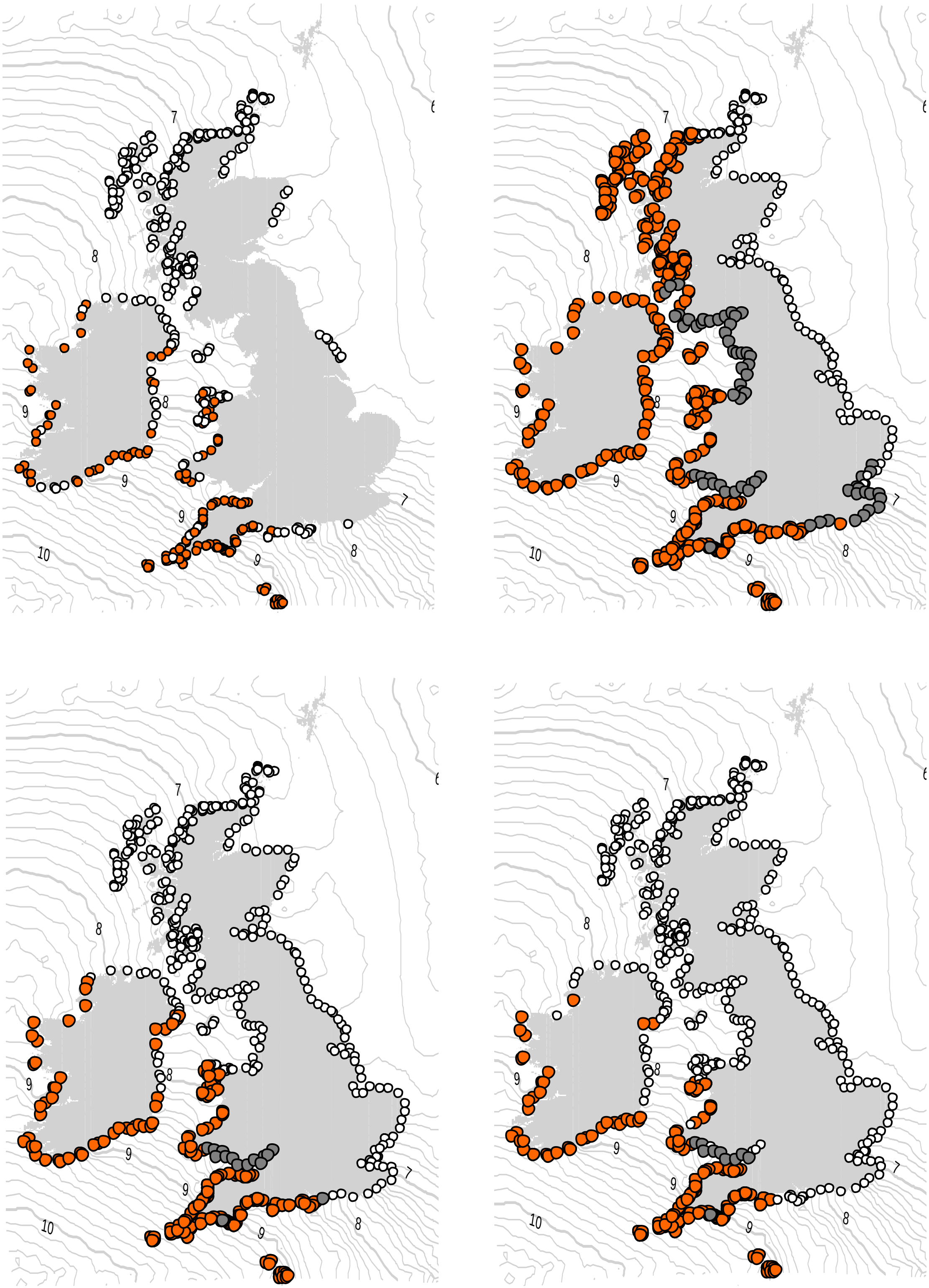

Figure 1. Observed (top left) and predicted (top right, bottom left and right) species range for the topshell, *Osilinus lineatus*, using the criterion P(R)>*x* where *x*=0.1 (top right), 0.3 (bottom left), 0.5 (bottom left). For observed distributions (top left), orange and grey filled circles indicate sites where the species is at least rare and white open circles show where the species is absent. For species ranges predicted using present day conditions of temperature and wave exposure, filled circles show sites where the likelihood of the species being rare is greater than the threshold value, *x*. Grey lines indicate February sea surface temperature isotherms, here and in successive Figures.

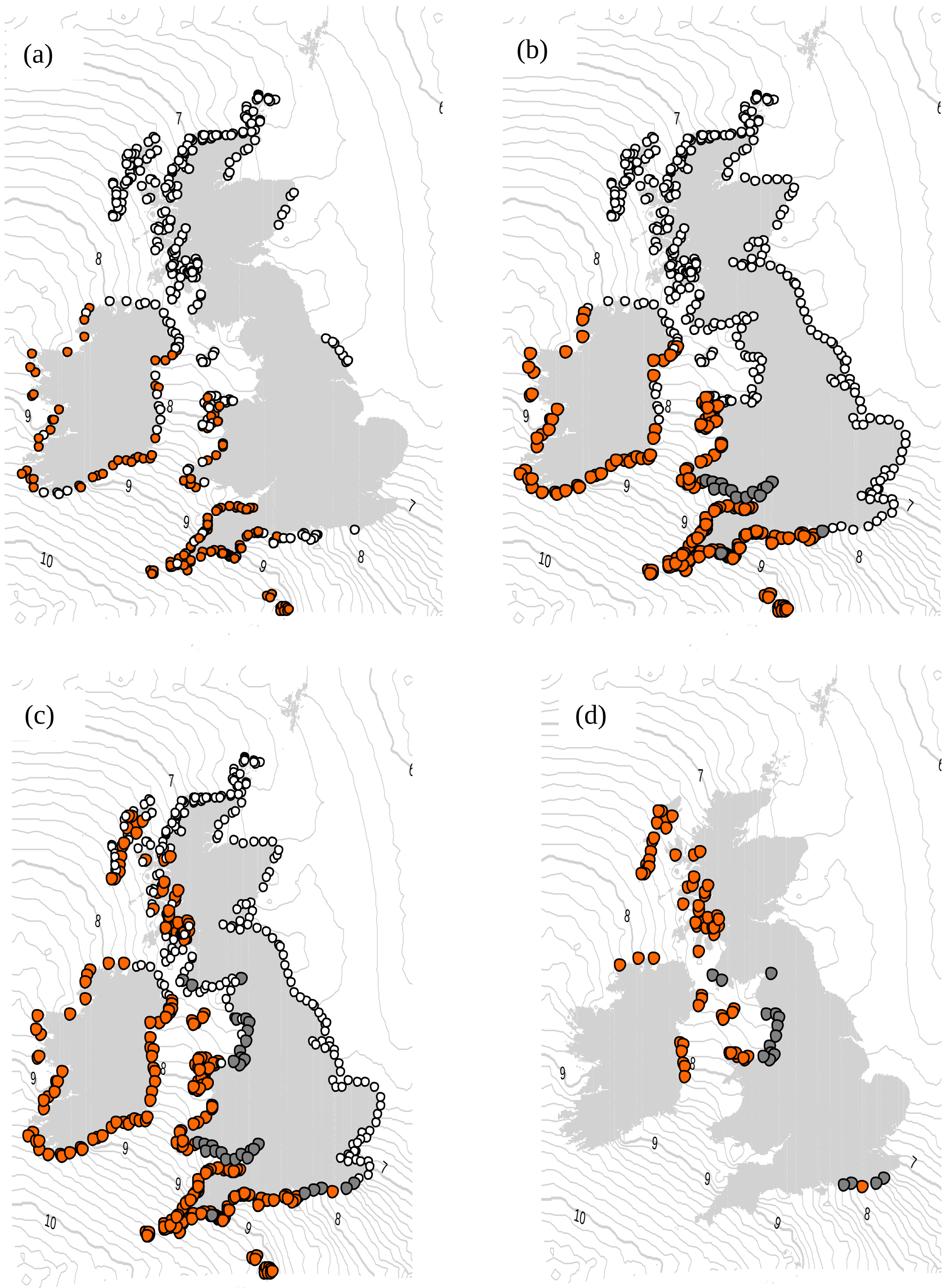

Figure 2. Predicted change in species range for the topshell, *Osilinus lineatus*, under the UKCIP02 High 2020s scenario (Feb SST increase 0.4°C to 0.8°C, PO model). From top left to bottom right, plots show (a) recorded range 2002-04, (b) range as predicted by PO model using present day Feb. SST and wave fetch and P(R)>0.3 as the criterion, (c) range predicted for the UKCIP02 High 2020s scenario, and (d) range extensions. For plots (a) to (c) filled symbols denote presence (orange for sites visited during the MarClim project), open symbols absence. For plot (d) filled symbols show sites where the species is likely to appear.

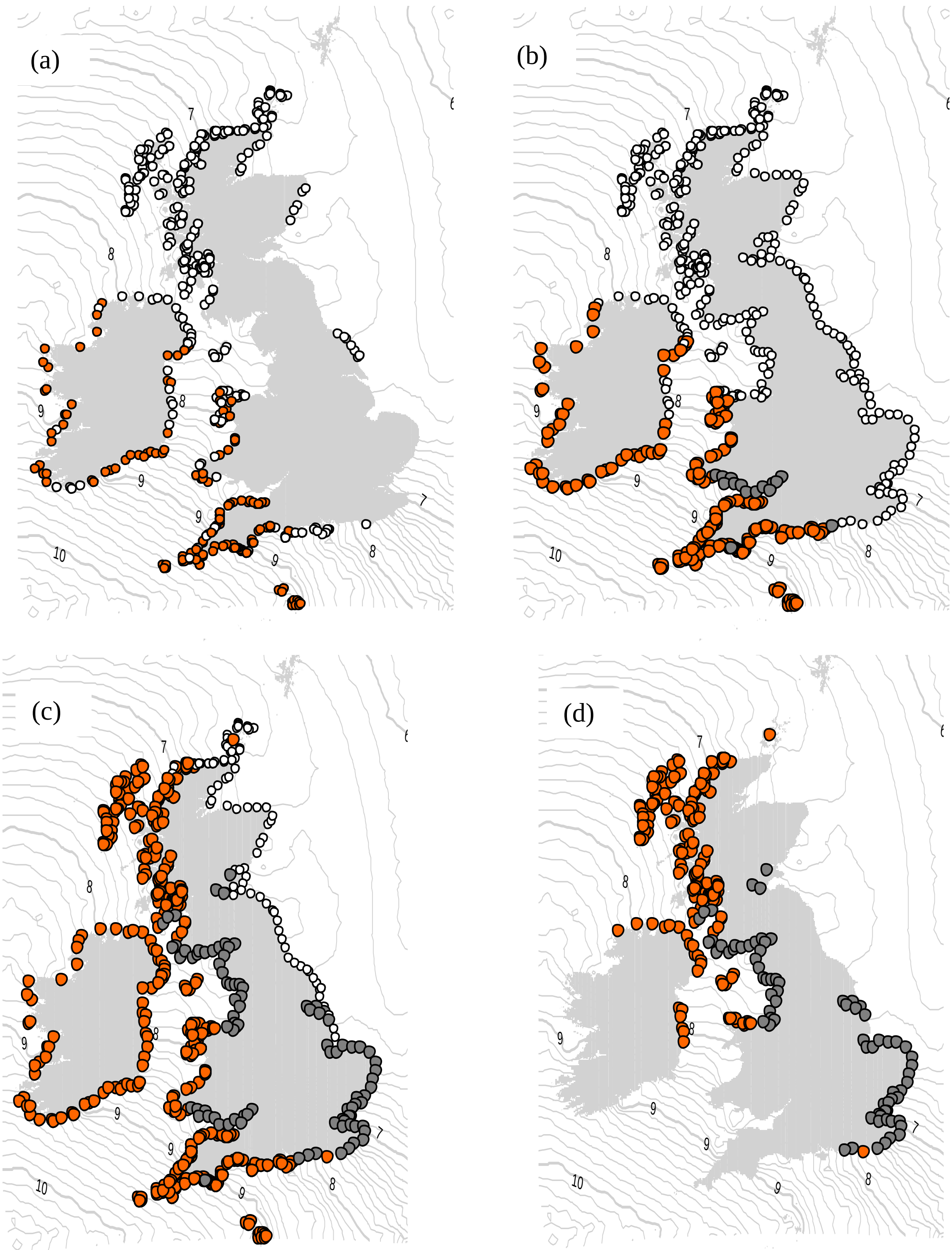

Figure 3. Predicted change in species range for the topshell, *Osilinus lineatus*, under the UKCIP02 Medium-Low 2080s scenario (Feb SST increase 1.0°C to 2.0°C, PO model). From left to right, plots show (a) recorded range 2002-04, (b) range as predicted by PO model using present day Feb. SST and wave fetch and P(R)>0.3 as the criterion, (c) range predicted for the UKCIP02 Medium-Low 2080s scenario, and (d) range extensions. Symbols as Fig. 2.

Maps of forecast ranges and range changes are given in Appendix A2 for all the climate indicator species predicted to show a change in range in the UK. Table 2 summarises these forecasts and gives the numbers to the Figures in the Appendix. Species are shown as indicators of two EUNIS Level 3 Biotope Complexes: Moderately-Exposed Littoral Rock, and Exposed Littoral Rock, and in addition, two further distinct biotopes: Rockpools as Features of Littoral Rock and Moderately- exposed littoral rock with *Sabellaria* reefs (both EUNIS Level 4). While rockpools are found on moderately exposed and exposed littoral rock, this biotope does have a different flora and fauna with potentially different sensitivities to environmental pressures. *Sabellaria* reefs form very untypical assemblages.

Table 2. Rocky intertidal indicator species as characterising species of key intertidal biotopes. Completely ubiquitous species (e.g. *Corallina officinalis*) were omitted from the analysis of dependence of species distributions on temperature, as were those found at only a handful of sites during the MarClim surveys (e.g. *Calliostoma zizyphinum*, *Crassostrea gigas*). Temperature dependence is shown by the value of the logistic regression parameter, *b*, where logit(P)= *a* + *b*.February SST in degrees.

Biotope indicator species (1 Moderately-exposed littoral rock (LR); 2 Exposed LR; 3 LR (rockpools); 4 Moderately-exposed LR with *Sabellaria* reefs)		Dependence on Feb SST	P Incidence	Figure A2	Forecast Change in range
Algae					
Alaria esculenta	*2	0.498	0.243	1	-
Ascophyllum nodosum	*1	0.752	0.559	2	-
Bifurcaria bifurcata	*3	6.880	0.265	3	+
Chondrus crispus	*1, 2, 3	2.227	0.530	4	+
Codium spp.	*3	1.660	0.312	5	+
Corallina officinalis	*1, 2, 3				
Cystoseira spp.	*3	3.093	0.156	6	+
Fucus distichus	*2	0.744	0.004		R
Fucus serratus	*1, 2, 3, 4	1.052	0.846		nc
Fucus spiralis	*1, 2	0.996	0.696		nc
Fucus vesiculosus	*1, 2	0.848	0.647		nc
Halidrys siliquosa	*3	0.714	0.355	7	-
Himanthalia elongata	*1, 2, 3	1.741	0.364	8	+
Laminaria digitata	*1, 2, 3	0.972	0.718		nc
Laminaria hyperborea		1.299	0.133	9	+
Laminaria ochroleuca		3.712	0.008		R
Laminaria saccharina	*3	1.429	0.248	10	+
Lichina pygmaea	*1, 2	1.833	0.545	11	+
Lithophyllum & Lithamnion crusts	*				
Mastocarpus stellatus	*1, 2, 3	1.801	0.701		nc
Palmaria palmata	*2, 3				
Pelvetia canaliculata	*1	0.715	0.727		nc
Porphyra spp.	*2				nc
Sargassum muticum	*3	4.607	0.330	12	+
Porifera and Cnideria					
Actinia equina	*1, 2, 3	1.617	0.873		nc
Actinia fragacea		1.684	0.169	13	+
Anemonia viridis	*3	3.362	0.309	14	+
Aulactinia verrucosa		1.894	0.125	15	+
Halichondria panicea	*1, 3	1.387	0.449		nc

Biotope indicator species (1 Moderately-exposed littoral rock (LR); 2 Exposed LR; 3 LR (rockpools); 4 Moderately-exposed LR with *Sabellaria* reefs)		Dependence on Feb SST	P Incidence	Figure A2	Forecast Change in range
Annelids					
Sabellaria alveolata	*4	1.401	0.121	16	+
Sabellaria spinulosa	*4	0.727	0.012		
Crustaceans					
Balanus crenatus	*4	0.599	0.096	17	-
Balanus perforatus		4.366	0.312	18	+
Chthamalus montagui	*1, 2	3.372	0.840	19	+
Chthamalus stellatus	*1, 2	3.586	0.586	20	+
Elminius modestus		1.504	0.459	21	+
Semibalanus balanoides	*1, 2, 3	0.426	0.965		nc
Molluscs					
Calliostoma zizyphinum					
Crassostrea gigas					
Crepidula fornicata					
Gibbula cineraria	*1, 3	1.164	0.451		nc
Gibbula umbilicalis	*3	3.250	0.776	22	+
Littorina littorea	*1, 3, 4	0.707	0.829		nc
Littorina neglecta	*1, 2	1.602	0.122	23	+
Littorina saxatilis agg.	*2	0.718	0.857		nc
Melarhaphe neritoides	*1	1.513	0.633	24	+
Mytilus spp.	*1, 2, 3	0.993	0.695		nc
Nucella lapillus	*1, 2, 3, 4	0.743	0.928		nc
Onchidella celtica		2.004	0.024		R
Osilinus lineatus		5.484	0.624	25	+
Patella depressa	*1	3.739	0.473	26	+
Patella ulyssiponensis	*3	2.102	0.658	27	+
Patella vulgata	*1, 2, 3, 4	1.532	0.982		nc
Tectura testudinalis		0.417	0.031		R
Echinoderms					
Asterias rubens		1.154	0.162		NFR
Leptasterias muelleri		43.535	0.004		+
Paracentrotus lividus	*3	2.251	0.051	28	(+)

Expected changes in species ranges are: - (minus), contraction; +, expansion; nc, no change in the UK; R, species too rare to build a reliable model; NFR, species not fully recorded around the UK in the MarClim project.

4. Predicted distributions of dominant intertidal biotopes

Intertidal biotopes under the EUNIS classification are recognised by the association of habitats and species they comprise. Here we examine the species predicted to change in range as characteristic of particular biotopes.

From Table 3 it can be seen that biotope indicator species tend to be less likely to be affected by a changing marine climate around the UK than those not characteristic of a particular biotope. Out of the 18 species identified as characteristic of Moderately Exposed Littoral Rock, only 4 are expected to show any change in range (22%). In contrast, of the 26 other species modelled, 24 out of 26 (92%) are expected to show large changes in range. A similar pattern exists for Exposed Littoral Rock species – only 3 out of 15 are likely to show changes in distribution (20%). Rockpool species are much more likely to show significant changes in range than exposed rock surface species (52% of characteristic species forecast to change). This difference in climate sensitivity between biotope indicator species and non-indicator species is not surprising. Biotope indicator species have generally been chosen for their ubiquity in the UK to add to their usefulness in diagnosing particular biotopes. Climatically sensitive species on the other hand are inferred as such by their absence from critical parts of the UK coastline, usually the east and north in the case of southern or warm-water species and, rarely, from the south and west for northern or cold-water species.

Table 3. Forecast changes in species ranges by status of species as indicators of intertidal biotopes. The Table shows the numbers of species ranges likely to expand (+), contract (-) and to show no change (nc).

Moderately Exposed Littoral Rock	Forecast Change			
	-	nc	+	Total
Indicator species	0	14	4	18
Other species	4	2	20	26
Total	4	16	24	44

Indicator species set to increase:
Chondrus crispus
Himanthalia elongata
Melarhaphe neritoides
Patella depressa

Indicator species set to decrease:
None

Exposed Littoral Rock	Forecast Change			
ELR	-	nc	+	Total
Indicator species	1	12	2	15
Other species	3	4	22	29
Total	4	16	24	44

Indicator species set to increase:
Chondrus crispus
Himanthalia elongata

Indicator species set to decrease:
Alaria esculenta

Littoral Rock (Rockpools)	Forecast Change			
LR(R)	-	nc	+	Total
Indicator species	1	11	11	23
Other species	3	5	14	22
Total	4	16	25	45

Indicator species set to increase:	Indicator species set to decrease:
Bifurcaria bifurcata	*Halidrys siliquosa*
Chondrus crispus	
Codium spp.	
Cystoseira spp.	
Himanthalia elongata	
Laminaria saccharina	
Sargassum muticum	
Anemonia viridis	
Gibbula umbilicalis	
Patella ulyssiponensis	
Paracentrotus lividus	

Moderately exposed Littoral Rock with *Sabellaria* Reefs	Forecast Change			
MLR(S)	-	nc	+	Total
Indicator species	1	4	1	6
Other species	3	12	24	39
Total	4	16	25	45

Indicator species set to increase:	Indicator species set to decrease:
Sabellaria alveolata	*Balanus crenatus*

All the species listed in Table 3 are characteristic of the EUNIS Level 3 classification of intertidal biotopes, the coarsest level of biotope classification. The Level 5 classification, does incorporate species identity as the defining criterion for classification. Species-specific changes, such as a change from a *Chthamalus*-dominated mussel-barnacle biotope to a *Semibalanus balanoides*-dominated mussel-barnacle biotope (LR.HLR.MusB.Sem.Sem to LR.HLR.MusB.Cht.Cht), will be expected to reflect changes at species level (see Table 3).

Despite this lack of sensitivity to climate of the species range of the major biotope-characterising species, the models do predict changes in abundance of some of these species in response to changing temperatures. Biotopes are more likely to be defined not by the presence and absence of particular species but rather by these species achieving near dominance of the biological communities at these localities. Here we have defined the level of abundance at which we might expect species to define a biotope as being at least Abundant. For the MarClim survey data, this simply allows the definition of those sites likely to have biotopes associated with particular species. If we set the likelihood that a species is at least Abundant at 30% (P(>=A)>0.3) as the criterion for a site likely to have enough of the species to form a biotope, then we can identify those sites where particular biotopes may occur from model forecasts of species abundance.

Appendix A3 gives the present day distributions of sites where biotope characterising species are abundant and forecasts under the same three UKCIP02 scenarios as used for species range changes (Table 1). Bioclimate envelope models have been used instead of proportional occupancy models for forecasts because of the ubiquity of the species involved: there are no biogeographical barriers to spread in these particular species.

For *Ascophyllum* biotopes (LR.HLR.FT.AscT, LR.LLR.F.Asc, LR.LLR.FVS.AscVS, LR.LLR.FVS.Ascmac, IR.LIR.Lag.AscSpAs, Grosholz *et al.* 2000) survey results and model predictions show these are likely to occur only in sites with Low energy littoral rock (Figure A3.1). With increased temperatures in the higher emissions scenarios, the models forecast that *Ascophyllum* biotopes will retreat further into wave sheltered areas and be lost from the more wave-exposed areas. The biotopes may eventually be restricted to Scottish sea lochs.

Pelvetia canaliculata biotopes (LR.MLR.BF.PelB, LR.LLR.F.Pel, LR.LLR.FVS.PelVS) are currently likely to occur almost anywhere around the UK (Figure A3.2). Warmer temperatures may result in the loss of these biotopes around southern Britain. For the High 2020s scenario, models predict losses of this biotope from wave exposed sites along the Channel, in north Cornwall and Devon and in Wales. For the High 2080s scenario, the model predicts the loss of *Pelvetia* biotopes from all around English and Irish coasts, as well as Scottish coasts, with the effect most pronounced in wave exposure.

Changes in fucoid dominated biotopes are less simple to predict, since at least five species are involved. *Fucus distichus* (LR.HLR.FR.Fdis) was never recorded on MarClim surveys and only found in Caithness on other surveys in the last five years. Warming is likely to see the disappearance of this boreal species from the UK mainland. *Fucus vesiculosus* was more likely to be abundant in shelter and at lower average February SST. Models thus predict a decline of *Fucus vesiculosus* in moderately wave exposed sites in the west and south with increasing temperatures (Fig. A3.3). The most likely affected biotope would therefore be '*Fucus vesiculosus* and barnacle mosaics on moderately exposed mid eulittoral rock' (LR.MLR.BF.FvesB). This mirrors changes that occur with latitude and are largely mediated by limpet grazing (Coleman *et al.* 2006, Hawkins & Southward 1992, Jenkins 2005). *F. vesiculosus*-related biotopes in more wave sheltered areas would be less affected (LR.LLR.F.Fves, LR.LLR.FVS.FvesVS, LR.LLR.FVS.AscVS).

Fucus serratus was found throughout the UK and Ireland from the far south to the far north, as likely as in wave shelter as wave exposure (Fig. A3.4). No changes are expected in biotopes associated with this species (LR.HLR.FT.FserT, LR.HLR.FT.FserTX, LR.MLR.MusF.MytFR, LR.MLR.BF.Fser, LR.LLR.F.Fserr, LR.LLR.FVS.FserVS). *Fucus spiralis* is similarly ubiquitous (Fig. A3.5), with no changes forecast for these biotopes (LR.MLR.BF.FspiB, LR.LLR.F.Fspi, LR.LLR.FVS.FspiVS). This is the hardiest *Fucus* spp. and is found as far south as North Africa, the Azores and Canaries. *Fucus ceranoides* was never recorded in MarClim surveys since sites were deliberately chosen to be fully marine wherever possible.

Of the biotopes associated with limpets, *Patella vulgata* (LR.HLR.MusB.Sem.Sem) and *Patella ulyssiponensis* (LR.HLR.FR.Coff.Puly), only the latter may be expected to show any change with climate warming (Fig. A3.7) since the former shows little by way of spatial trends in the UK (Fig. A3.6). *P. ulyssiponensis* is forecast to become more abundant in the north and east.

Finally, there may be considerable changes in biotopes dominated by the barnacles *Semibalanus balanoides* (LR.HLR.MusB.Sem) and *Chthamalus montagui* and *Chthamalus* *stellatus* (LR.HLR.MusB.Cht). *S. balanoides* is a northern species, absent only locally from some parts of the coasts of Devon and Cornwall but otherwise found all around the UK. Models and past trends predict that this species will become less abundant on south-western coasts (Fig. A3.8) with increasing warming (Hawkins & Southward 1992, Jenkins 2005, Southward & Crisp 1954, Southward 1967, Southward 1991, Southward *et al.* 1995). Similarly *Chthamalus montagui* and *C. stellatus* (Figs. A3.9 & A3.10) are predicted to become abundant in the north and east. Here, the forecasts from the bioclimate envelope models must be interpreted with caution since they take no account of potential interactions among species. The distributions of *C. montagui* and *C. stellatus* are limited by the presence of *S. balanoides*, the superior competitor for space in barnacle-dominated intertidal rock communities. *S. balanoides* is faster growing and tends to undercut, overgrow and crush the slower growing *Chthamalus* species (Connell 1961). Changes in *Chthamalus* species are unlikely to be fully realised without a concomitant decline in *S. balanoides*.

5. Suitable temporal and spatial scales for surveillance of key assemblages

One important way in which the extent and spatial and temporal frequency of surveys can be objectively established is through the consideration of the number of sites needed to detect a statistically significant change. Methods for doing this, generally known as ‘power analysis’, are well established in the statistical literature and examples of their application are readily available (Keough & Mapstone 1997, Osenberg *et al.* 1996).

Change in this context can be expressed as a ‘null hypothesis’, often referred to by the abbreviation H_0, that states ‘there is no change in the response variable’ between, for example, comparison periods or survey sites. In statistical terms, it is concluded that change has occurred or a difference exists if the Null Hypothesis is rejected. Power analysis seeks to establish the likelihood of making mistakes in accepting or rejecting null hypotheses, and through this, establish either the minimum change that can be detected for a survey of a given design or the size that a survey must be to detect a change of a set magnitude.

Table 4. The two types of error in hypothesis testing (after Zar 1984)

	If H_0 is true	If H_0 is false
If H_0 is rejected	Type I error (α)	No error ($1-\beta$)
If H_0 is accepted	No error ($1-\alpha$)	Type II error (β)

Statistical power analysis deals with the likelihood of making the two types of errors, Type I – mistakenly rejecting a true null hypothesis (α) and Type II – failing to reject a false null hypothesis (β). Power itself is measured by the quantity ($1-\beta$), the likelihood that a real change is correctly detected. Values of the likelihood of Types I and II error are generally set at $\alpha = 0.05$ and $\beta = 0.20$, the latter equivalent to a statistical power of a test of 80%. Thus, a well-designed survey should detect a predetermined change by correctly rejecting the null hypothesis of ‘no change’ 80% of the time.

For numerical estimates of population abundance, such as numbers per m^2 or percentage cover, establishment of the within-population variance in the abundance estimate allows determination of the number of samples needed to detect a significant change. Many statistical texts give this methodology in full, and we will not repeat this here.

We use this criterion here to investigate the consequences of different sampling frequencies for the ability of a MarClim-type broadscale survey to detect change in rocky intertidal communities, when the surveys use the SACFOR scales to record abundance. Further funding would enable this approach to be extended to quantitative time series on barnacles, limpets and trochids.

5.1 Best and worse case scenarios

The first step is to define the magnitude of the change that the survey is designed to detect. The change may be considered as either relatively small or relatively large according to 'best' and 'worse' case scenarios for survey designs – defined thus:

i.. Best case: over and above U.K. and international obligations: ecosystem approach and statistically rigorous.

ii. Worst case: only to meet U.K. obligations to undertake surveillance under the Habitats directive; resource restricted.

Translation of these two scenarios into an expected magnitude of change is a non-trivial matter. The Gothenburg Summit in June 2001 (Commission 2001), relating to 2010 target states: Biodiversity decline should be halted with the aim of reaching this objective by 2010 as set out in the 6th Environmental Action Programme (page 9, 3rd bullet from top). However, a decrease in abundance for a single species may well be within expected natural bounds for that species and not in any way cause for concern. Marine intertidal species, especially those relying on settlement of larvae from the plankton, often show large variation in abundance from year to year.

In this context, therefore, and in order to make some projections about the level of survey effort required to detect a change (a decline in the strict terms of the 6th EAP), we have considered changes in abundance of two levels, corresponding to changes in average abundance of one or two categories as measured on the SACFOR scale.

This scale measures abundance on a semilogarithmic scale, with two categories separating values of abundance approximately an order of magnitude apart. For example, in algae the upper limit of the Occasional category is equivalent to 1% cover, Frequent 5%, and Common 30%. For argument's sake, here we consider:

i. **that 'best case' monitoring strategy should be able to detect at least a UK-wide increase or decrease of one abundance category** in a biotope-characterising species, corresponding to either a five-fold increase (500%) or a decline to 20% of the former value;

ii. **for a 'worst case' survey scenario, this requirement could be relaxed to the detection of a decrease or increase of two categories on the SACFOR scale** . This approximates to a 2500% increase or a decline to 4% of the original value.

To illustrate the relative size of these 'best case' and 'worst case' changes, consider the macroalga *Ascophyllum nodosum* – the egg wrack. A decline of two abundance categories from Abundant to Frequent would involve the percentage cover of the weed changing from over 30% of the rock surface to less than 5% cover, a dramatic change that would be equivalent to the loss of the biotope characterised by that species. A change of one abundance category ('best case') would be less striking but could have profound ecological consequences.

5.2 Simulations of surveys of different spatial frequencies using the MarClim data set

As stated earlier, data collected during the MarClim project mostly followed the JNCC-accepted SACFOR scale (MarClim 2002). However, to enable comparisons with surveys made in the 1950s for detection of broadscale change, this data was downgraded to the truncated ACFOR scale by reclassifying Super Abundant records to Abundant. For Bioclimate Envelope modelling, this change will have no effect on the predicted outcomes for either species ranges (Section 3) or the predicted extent of dominant intertidal biotopes (Section 4). Inclusion of the Super Abundant point on the abundance scale simply adds another intercept term to the ordinal logistic regression models linking species abundance to wave fetch and sea temperature.

In this section also, the addition of an extra abundance category would have only an insignificant effect on the outcome of the following analyses. Here we consider changes across a number of sites either within regions or spanning a broad geographical area. Such changes need not be caused only by a climatic change, but could result from a change in any one of the potential environmental factors involved in selecting 'exposure pressure' species (Hiscock *et al.* 2005) (substratum loss, smothering, suspended sediment, increased turbidity, physical disturbance, priority substances, nitrate/phosphate, salinity, oxygen concentration, thermal range/heat, industrial effluents). The MarClim dataset contains much information on the natural variability in species assemblages among sites. It is this variability that allows an assessment of the power of a survey to detect change whatever the cause. Adoption of ACFOR or SACFOR scales makes no difference to the ability of a survey to detect a change, except at the upper range of abundance values.

The effect of changing the size of the survey on the ability to detect change can be determined by using the UK-wide frequency distribution of abundance categories to establish a null hypothesis. Abundance data from the 617 sites in the MarClim dataset allows the present-day 'likelihood of each category' for each species to be determined. The effect of an increase or decrease of an average of one or two categories on the frequency of sites in each category can be predicted with the ordinal logistic regression models used to forecast changes in species ranges (section 3). Using this approach, a new frequency distribution that produces the change in average category can be produced (Figure 4 left).

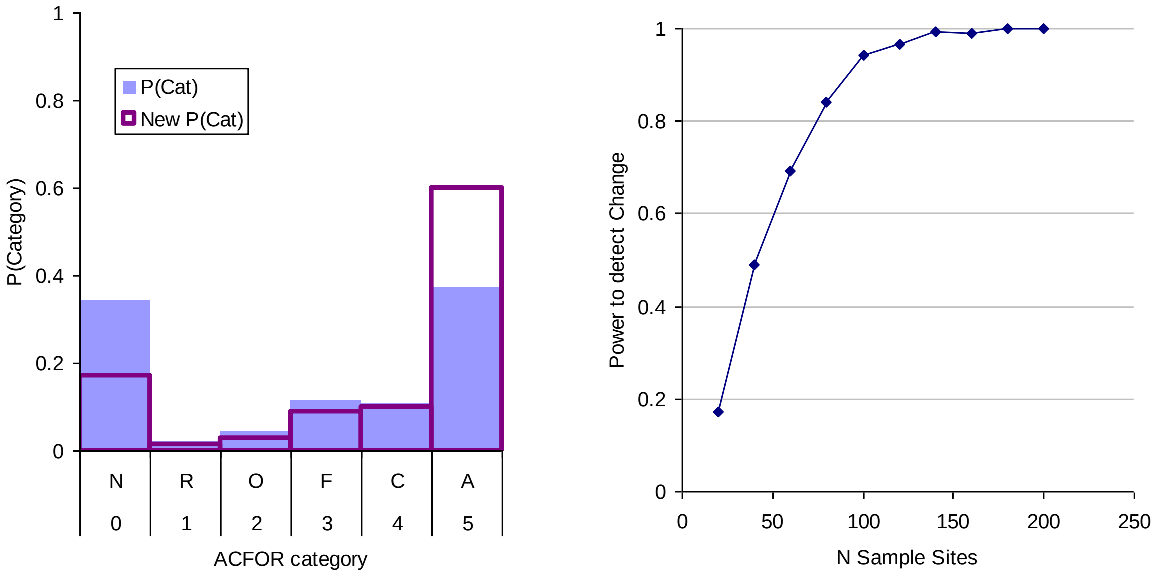

Figure 4. (left) Change in proportional incidence of abundance categories of *Patella ulyssiponensis* equivalent to an average increase of 1 abundance category. (right) Power (1- β) of increasing numbers of sample sites to detect this change as statistically significant (α = 0.05).

In our simulations we generated samples of abundance category data for a set number of sites from the projected new distribution of categories. A chi-squared test was used to determine whether the frequency of each category differed from the present-day distribution of frequencies. If the chi-squared statistic was significant (α = 0.05) then the null hypothesis of no change was rejected, if not, the null hypothesis was accepted. By generating many samples (1000 replicates were used) of the same set number of sites, the probability of correctly rejecting the false null hypothesis, the power, of the sample size could be determined. Thus, 75 sample sites would be needed for a survey designed to detect an average increase of one category for *Patella ulyssiponensis* (Figure 4 right) with a statistical power of 80%.

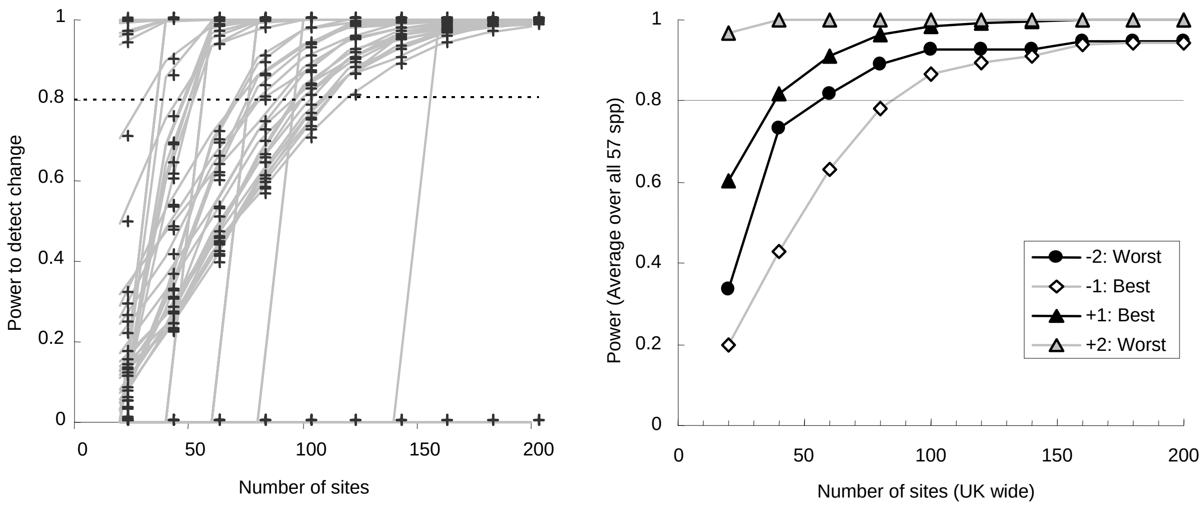

Figure 5. Determination of number of sites needed to detect change. (left) Power to detect a decrease of one category for all MarClim species. (right) Average power over all species for changes of -2, -1, +1 and +2 abundance categories.

This process has been applied for changes in all (57) MarClim species (Figure 5). On average, a survey of 50 sites around the UK would be needed to detect a decrease of 2 categories with a power of 80%. 85 sites on average would be needed to detect a decrease of one category, while 39 and less than 20 sites would be needed to detect increases of 1 and 2 categories respectively.

Variability between species in the number of sample sites needed to detect changes with 80% power is largely associated with the prevalence of the species (Figure 6). Rare or ubiquitous species need surveys of fewer sampling sites to detect change.

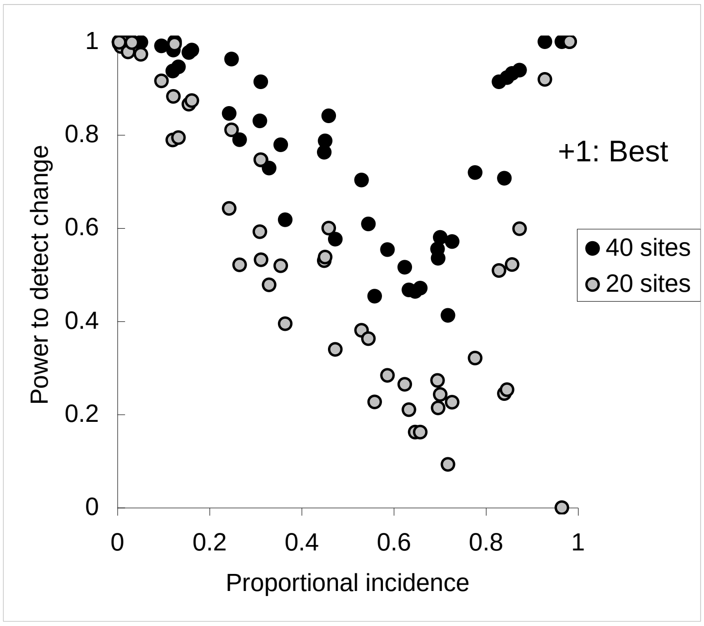

Figure 6. Power to detect an increase of 1 abundance category for two sample sizes (n=20, n=40) for each of 57 MarClim species as a function of the proportional incidence of each species (Table 2).

5.3 Surveys designed to detect changes forecast under UKCIP02 scenarios

Power analysis can be used to determine the number of sites in a survey that would be necessary to detect changes as forecast by bioclimate envelope models. Here we demonstrate the number of sites needed for 80% power in detecting change as forecast for the High 2020s emissions scenario.

A similar approach was adopted. For a sample size of 20 sites for example, 20 MarClim sites were selected at random from the total dataset. Predicted likelihoods of each abundance category at each of these sites using a present-day bioclimate envelope model were summed to give the expected frequencies of each category under a null hypothesis of no change. Projected ‘observed’ data was then simulated for each site using the likelihoods of abundance categories from the scenario model. The significance of the difference in expected and projected ‘observed’ frequencies of abundance categories was determined using a chi-squared test. Many simulations were repeated for each sample size to give power / sample size curves similar to those in Figure 6.

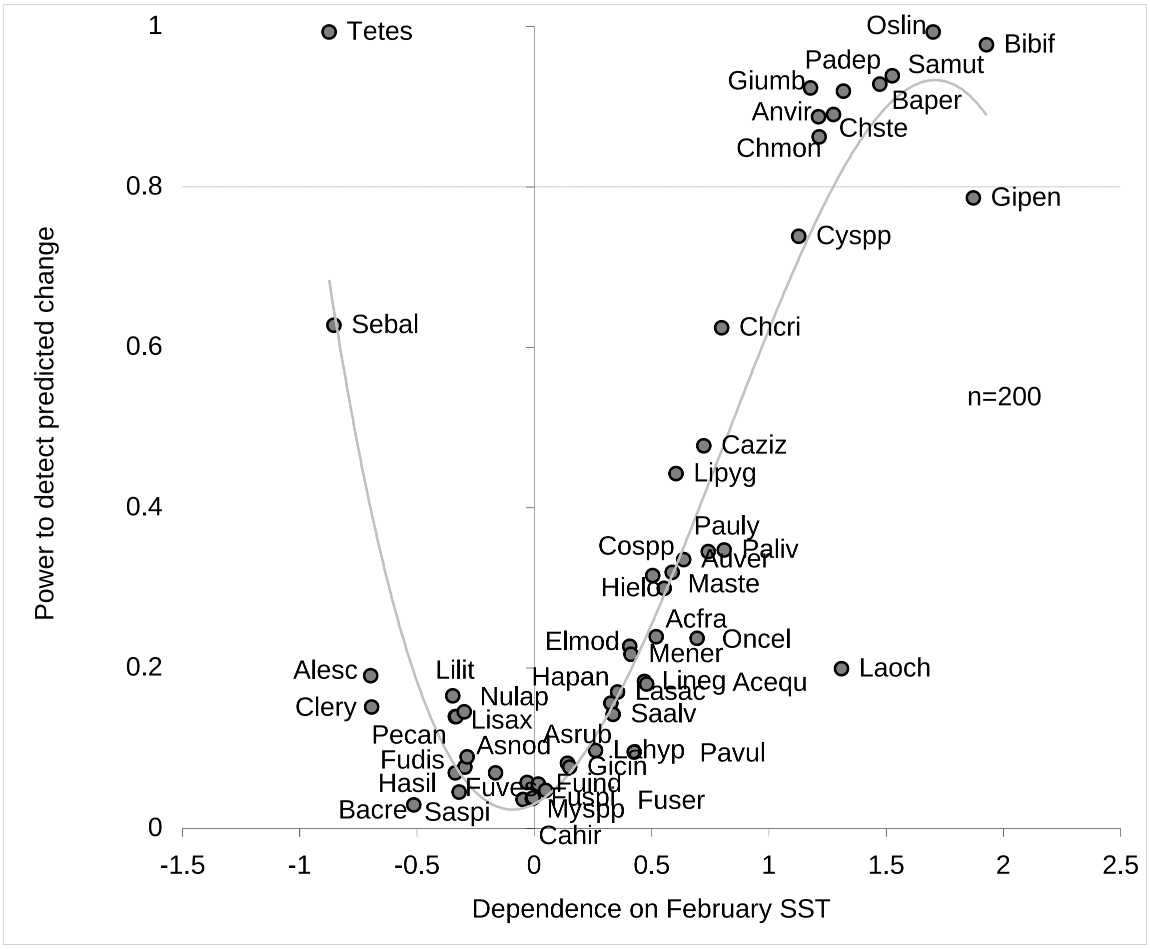

Figure 7. Power of a sample size of 200 sites to detect the changes forecast for each of the MarClim species under the High 2020s emissions scenario, as a function of the sensitivity of each species to February sea surface temperatures.

For changes in distribution in relation to climate as predicted for the High 2020s emissions scenario (0.4 to 0.8°C), it can be seen that far more sites will be needed to detect the relatively smaller changes than even the ‘best case’ scenario. A relatively large sample size of 200 sites will only successfully discriminate the projected changes (with a power of 80%) for those species for which large changes are predicted (Figure 7). This means that, while the climate sensitive species are expected to show appreciable changes in geographical ranges (Section 3) and overall abundance (this Section), for the size of change forecast under the High 2020s scenario a relatively large survey (200 sites) will be needed to detect the expected changes as statistically significant with an acceptable level of confidence in the findings.

Intertidal systems remain our most accessible marine habitat, both to scientists and the general public, and changes in the species on rocky shores are likely to be indicative of changes happening in coastal seas. The public perception of the state of the seas often hinges on events on the shoreline. Strandings and spread of unusual species, native and non-natives, oil washed ashore and affected seabirds all shape public opinion and prompt a thirst for answers. The approach presented here offers one objective way to address the issue as to whether change has occurred or is occurring on coastal scales, whatever the cause, over and above obvious local impacts. Thus, the importance of establishing large-scale responses of intertidal biota to environmental change, climate-related or otherwise, would more than justify the cost of such a large survey, only necessary every 10 years or more. In addition, targeted surveys annually at range edges (e.g. Scotland, Wales, Northern Ireland, north-east England and south-west England) could provide the 100 or so sites needed to track changes and separate noise from signal. Two people can work two shores per tide. Therefore between April and October inclusive there are 7 months × 2 spring tide periods per month × 5 suitable tides in each spring tide period in which fieldwork can be undertaken; which with working two tides per day in some locations (e.g. Irish Sea, Eastern English Channel, Scotland) gives over 100 locations.

6. Location of surveillance sites under different scenarios

ESRI Shape files provided for 20, 30, 50, 100, 200 and 400km spaced survey schemes for intertidal areas. These files show idealised locations, without regard to access or substratum constraints (the availability of intertidal hard substrata), with the nearest MarClim sampling location for reference and survey use. We recommend that MarClim sites be used wherever possible to enhance the power of the survey to detect change.

The location of the MarClim sites and their recommendations for inclusion or otherwise in surveys of different spatial frequencies are given in Appendix 5.

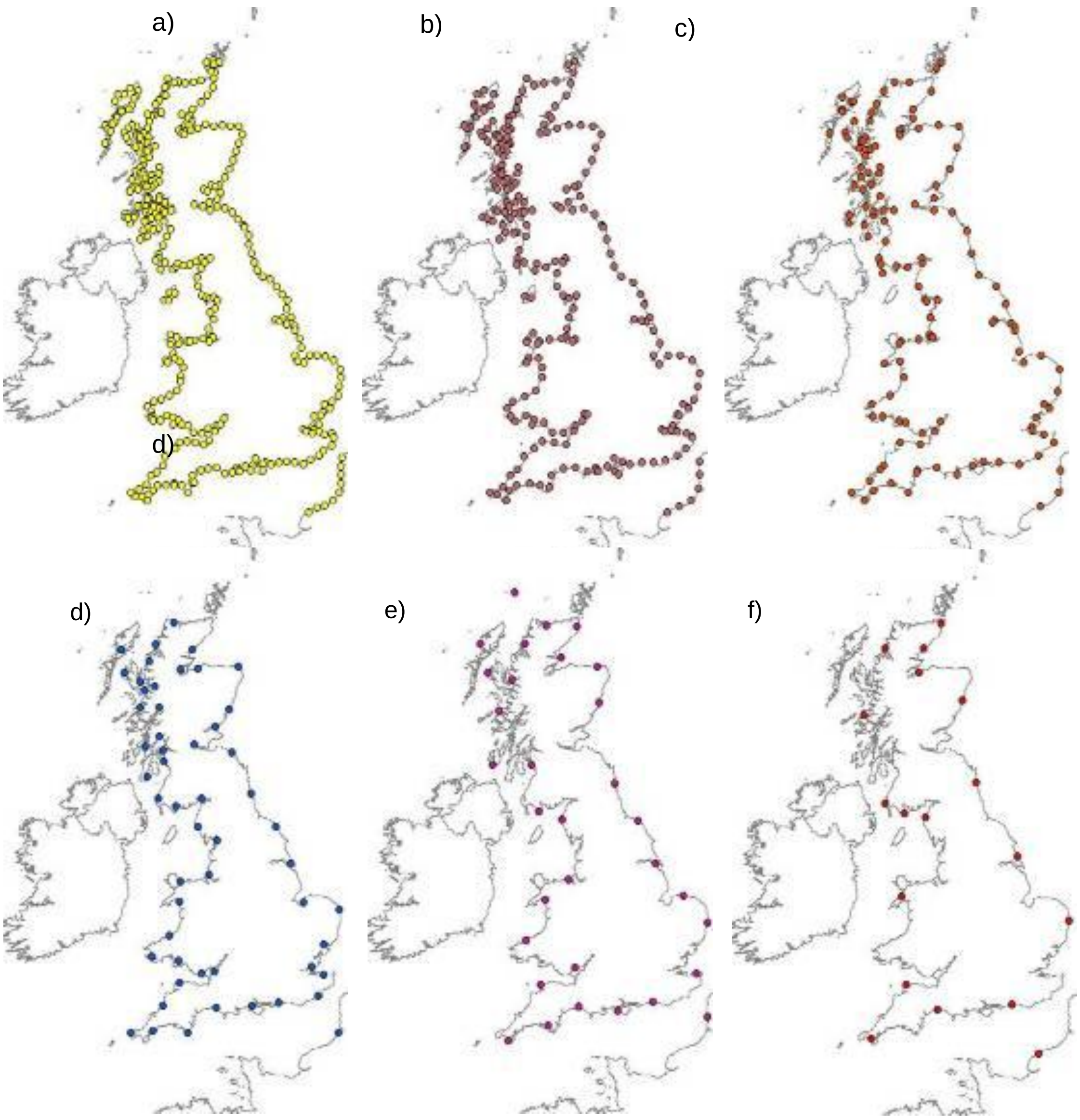

Figure 8. GIS shape files showing the location of surveillance sites at different spatial scales a) 20km (n=359) b) 30km (n=238) c) 50km (n=135) d) 100km (n=54) e) 200km (n=32) f) 400km (n=18) around the UK. Distances along complex coastlines are not equivalent to straight-line distances between sites.

The final choice of sites for surveys with different spatial frequencies should always be guided by issues such as ease of access and availability of rocky shores. Large stretches of coastline may lack suitable bedrock outcrops in the intertidal zone, for example, and the selection of sites in these areas may well be limited to groynes, breakwaters, pier pilings and other artificial hard structures. Such artificial structures may have quite different species compositions from nearby hard natural substrata so may not always be very representative of the regional species pool.

7. Conclusions

The main conclusions to be drawn from the analyses using data from the broadscale MarClim surveys are:

1. Rapid semi-quantitative assessments of rocky shores using multiple species at multiple sites, provides suitable data to report on the diversity and health of marine systems (Section 2). Choice of species is guided by their ease of identification, status as 'exposure pressure' species, climate sensitivity and being key non-natives. A full list is given in Appendix 1.

2. Changes in species abundances and ranges are better indicators of species responses to anthropogenic impacts than whole biotope responses. Statistical models fitted to present day abundance distributions allow us to forecast changes likely under new climatic temperature regimes, taken from UKCIP models run under different emissions scenarios (Section 3).

3. Representative species within biotopes, which are sensitive to a number of anthropogenic impacts, are proposed as the best focus for surveillance programmes designed to detect changes in biotopes (Section 4).

4. Examination of the statistical power of surveillance schemes to detect change allows the evaluation of the worth of different levels of survey efforts (Section 5):

   i. **For a worst case scenario**, where surveillance programmes perhaps only just meet U.K. obligations under the Habitats Directive, **50 sites and 20 sites would need to be surveyed to detect an order of magnitude increase and decrease, respectively, in species abundance.**

   ii. **For a best case scenario**, meeting targets over and above U.K and international obligations, **85 and 40 sites would need to be surveyed to detect a change of a single category species abundance.**

5. However, to detect the change predicted for most temperature sensitive intertidal indicator species for the High 2020s emission scenarios (0.4 to 0.8ºC) over 200 sites would need to be surveyed.

7.1 Further work

Five areas are highlighted by this pilot project for further work:

1. Follow up this specific project by extending the power analysis to MarClim quantitative datasets (barnacles, limpet and trochids) and other available intertidal time-series data as well as extending the analysis to subtidal regions.

2. This project indicates that relatively large sample sizes (n = 200 sites) will be needed to detect the relatively small changes in species abundances expected under High 2020s emissions scenarios. Therefore the more general issue of work started as part of the

MarClim project, to provide a monitoring network need to be addressed (see Appendix 3 for the MarClim proposed monitoring strategy).

3. To update species distribution maps using data collected during the MarClim project and MNCR data already in existence.

4. Undertake surveys where gaps in species distribution data still exist for areas such as east, north-east and north-west England where surveys were not undertaken during the MarClim project. Undertaking surveys at locations along theses sections of U.K. coastline are important for validating and creating predictive models.

5. Develop better models of distributions of intertidal species, including other environmental pressures (as listed in Appendix Table 1, and including potential anthropogenic impacts other than climate and better descriptors of the physical environment) emerge as strong predictors from further analysis of the MarClim intertidal dataset. Future models should be extended to whole coastlines and linked to predictive habitat mapping projects such as the MESH programme.

8. References

COLEMAN, R.A., UNDERWOOD, A.J., BENEDETTI-CECCHI, L., ABERG, P., ARENAS, F., ARRONTES, J., CASTRO, J., HARTNOLL, R.G., JENKINS, S.R., PAULA, J., DELLA SANTINA, P. & HAWKINS, S.J. 2006. A continental scale evaluation of the role of limpet grazing on rocky shores. *Oecologia*, **147**, 556-564.

EUROPEAN COMMISSION. 2001. *Environment 2010: Our future, our choice. 6th EU environment action programme 2001-2010*. European Commission. Available from: http://ue.eu.int/ueDocs/cms_Data/docs/pressData/en/ec/00200-r1.en1.pdf

CONNELL, J.H. 1961. The influence of interspecific competition and other factors on the distribution of the barnacle *Chthamalus stellatus*. *Ecology*, **42**, 710-723.

CRISP, D.J. & SOUTHWARD, A.J. 1958. The distribution of intertidal organisms along the coasts of the English Channel. *Journal of the Marine Biological Association, UK*, **37**, 157-208.

DAVIS, A.J., JENKINSON, L.S., LAWTON, J.H., SHORROCKS, B. & WOOD, S. 1998. Making mistakes when predicting shifts in species range in response to global warming. *Nature*, **391**, 783-786.

GROSHOLZ, E., RUIZ, G., DEAN, C., SHIRLEY, K., MARON, J. & CONNORS, P. 2000. The impacts of a non-indigenous marine predator in a California bay. *Ecology*, **81** 1206-1224.

HAWKINS, S.J. & SOUTHWARD, A.J. 1992. In *Restoring the Nations Marine Environment*, (ed. G.W. Thorpe), Chapter 13, pp. 583-631. Maryland, USA: Maryland Sea Grant College.

HISCOCK, K., LANGMEAD, O., WARWICK, R., & SMITH, A. 2005. *Identification of seabed indicator species to support implementation of the EU Habitats and Water Framework Directives.* Second edition. Marine Biological Association, Plymouth

HULME, M., JENKINS, N., LU, X., TURNPENNY, J., MITCHEL, L.C., JONES, R., LOWE, J., MURPHY, J.M., HASSELL, D. & BOORMAN, P. 2002. *Climate Change Scenarios for the United Kingdom:* The UKCIP02 Scientific Report. 120p.

JENKINS, S.R. 2005. Larval habitat selection, not larval supply, determines settlement patterns and adult distribution in two *chthamalid* barnacles. *Journal of Animal Ecology*, **74**, 893-904.

KEOUGH, M.J. & MAPSTONE, B.D. 1997. Designing environmental monitoring for pulp mills in Australia. *Water Science and Technology*, **35**, 397-404.

LAFFOLEY, D.d'A., *et al*. 2005. The MarClim Project. Key messages for decision makers and policy advisors, and recommendations for future administrative arrangements and management measures. *English Nature Research Report*, No. 671.

MARCLIM. 2001. *MarClim - Marine Biodiversity and Climate Change*. Marine Biological Association, UK. Available from: http://www.mba.ac.uk/marclim/

MARCLIM. 2002. *MarClim Sampling Protocols*. Marine Biological Association of the United Kingdom. Available from: http://www.mba.ac.uk/marclim/pdf/Sampling_protocols.pdf

SIMKANIN, C., POWER, A.M., MYERS, A., MCGRATH, D., SOUTHWARD, A., MIESZKOWSKA, N., LEAPER, R. & O'RIORDAN, R. 2005. Using historical data to detect temporal change in the abundances of intertidal species on Irish shores. *Journal of the Marine Biological Association, UK*, **85**, 1329-1340.

SOUTHWARD, A.J. & CRISP, D.J. 1954. Recent changes in the distribution of the intertidal barnacles *Chthamalus stellatus* Poli and *Balanus balanoides* L. in the British Isles. *Journal of Animal Ecology*, **23**, 163-177.

SOUTHWARD, A.J. 1967. Recent changes in abundance of intertidal barnacles in sout-west England: a possible effect of climatic deterioration. *Journal of the Marine Biological Association, UK*, **47**, 81-95.

SOUTHWARD, A.J. 1991. Forty years of changes in species composition and population density of barnacles on a rocky shore near Plymouth. *Journal of the Marine Biological Association, UK*, **71**, 495-513.

SOUTHWARD, A.J., HAWKINS, S.J. & BURROWS, M.T. 1995. Seventy years' observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. *Journal of Thermal Biology*, **20**, 127-155.

ZAR, J.H. 1984. Biostatistical Analysis. 2nd edition. Prentice-hall Inc., Englewood Cliffs, New Jersey, USA