MarClim Module 6

Prediction and modelling of climate change impact scenarios

Objectives:

i. Update rule-based qualitative models of distributions of rocky shore species for the British and Irish coasts
ii. Develop interactive models of population and community responses to climate change and produce long-term predictions (2020, 2050 and 2080)
iii. Optimise design of sampling programmes
iv. Produce multi-species models of response to climate for north-south species pairs

i. UK and Irish coastline models

Rule-based models for predicting species distribution with sea surface temperature (SST) were produced by K. Hiscock (MBA). This approach was updated using SST isotherms, wave exposure and latest survey data collated by MarClim on species distributions. A 0.5 km grid was laid over the coastline using GIS mapping techniques, this forms the basic framework for distribution mapping. Two environmental parameters have been considered, SST and wave exposure, as these are considered to have the strongest influences on intertidal community dynamics. SST and wave exposure for each grid cell was calculated. This was originally done for the Scottish west coast (Figure 1) but has now been extended to the entire UK coast.

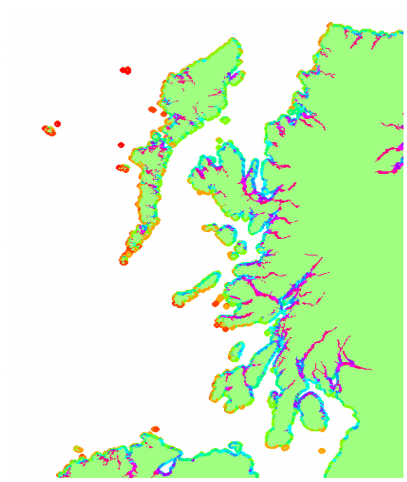

Figure 1. Wave exposure map for the west Scotland coastline. Red/yellow = high exposure, blue/purple = low exposure

A statistical modelling technique has been identified to combine the presence/absence of species with environmental parameters using logistic regression (Figure 2). This technique can be applied to actual count data (numbers per unit area, or per timed count) or to more interpretative data such as SACFOR or ACFOR scales where species are recorded objectively in a scale rated from super-abundant or abundant to rare. Species are mapped using abundance data collected by MarClim but it is also the intention to employ "interpreted" data sets such as rough distribution maps produced in many field guides.

<u>Summary</u>
Data integration into GIS is almost complete.
Modelling approach is fully developed.

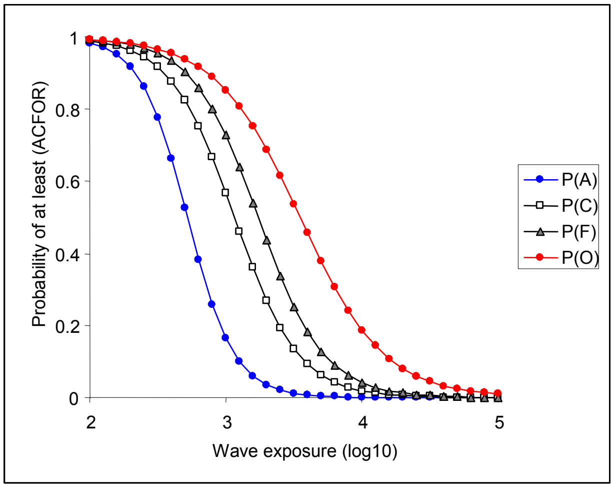

Figure 2. Prediction of four abundances of *Ascophyllum nodosum* against wave exposure.

ii. Interactive population models and long-term predictions

After consultation with UKCIP, it is intended to produce predictive models of species distributions with forecast climate change scenarios. The UKCIP workshop for marine decision makers, March 2004, allowed dialogue as to climate data requirements for the models. The data will be used to update statistical models to produce predictions of species distributions as climate changes.

An interactive model will be produced using Visual Basic with accompanying documentation. It is envisaged this will take the form of a map of the UK and Ireland. Users will select species from a drop down menu and SST on a moveable scale. Special consideration will be given to the climate scenarios for 2020, 2050 and 2080. A more detailed examination of predicted distributions for these times will be undertaken.

<u>Summary</u>
UKCIP scenario data required for forecasting.
Interactive model still to be produced

iii. Optimise sampling programme design

Surveys can be costly in terms of manpower and time and require certain expertise. For long-term monitoring the question arises of how many sites should be sampled to detect change. Using the historical MarClim mid-shore barnacle data set for south-west England, bootstrap analysis (Efron & Gong 1983) was applied to investigate how many sites should be sampled to detect differences between years. Further, bootstrap analysis was used to ascertain if the same sites should be sampled each year or if random sites may be used.

For the unpaired data set (random sites), pairs of years were selected were there were 2-fold, 6-fold and 10-fold differences in mean population numbers, across all sites. A 2-tail, equal variance t-test was used to verify that years were significantly different at P=0.05. 1000 bootstrap simulations were carried out for each test. The number of sites used was sequentially increased from 2 to 20. Analysis was repeated using paired sites between years.

Analysis indicated that a significant difference was more likely to be detected if sites were paired between years than if randomised. For *Chthamalus* data years tested, a 6-fold increase in numbers was 50% likely to be detected by sampling between 5-10 sites and 90% likelihood by sampling between 8-19 sites if sites are paired but 6-12 and 13 to 20+ sites are required respectively for random sites (Figure 3). A 10-fold increase was detected with 50% likelihood using 6 paired sites and the likelihood rose to 90% if 10 paired sites were used. A 2-fold increase was more difficult to detect given the underlying variability in population dynamics between quadrats (within sites), between sites and between years. The number if sites required was slightly higher for paired *S. balanoides* data. The number of sites to be sampled will depend on the level of difference to be detected but the same sites should be visited each year.

<u>Summary</u>
Analysis completed for SW England barnacle data.

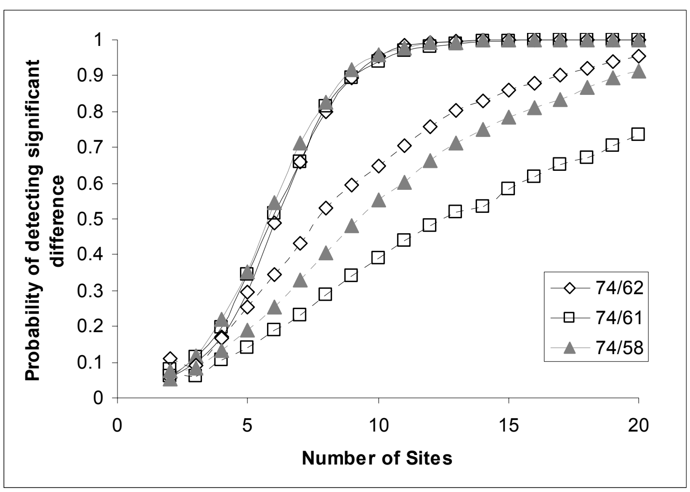

Figure 3. Probability of detecting a significant difference in mid-shore *Chthamalus* abundance between years for sites around south-west England, results of bootstrap analysis. Solid line: sites paired between years, dotted line: random sites selected.

iv. North-south species pairs modelling

Mechanisms underlying change in the abundance and distribution of intertidal barnacles in relation to climate change were the subject of a NERC small grant

"Climate change and competitive interactions: models built on evidence of 40 years of change in intertidal barnacle populations" (Dr M T Burrows, Prof. S J Hawkins and Dr E S Poloczanska). During a period of marked cooling of SST, abundance of temperate barnacle *Semibalanus balanoides* around south-west England increased while the warm-water *Chthamalus* species decreased (Southward 1967, 1991; Southward & Crisp 1954; Southward *et al.* 1995). Statistical path analysis suggested a competitive interaction was apparent in fluctuations of both species with temperature, with the effect of temperature on *Chthamalus* being mediated by the presence of *S. balanoides*. *S. balanoides* is considered the the dominant competitor (Connell 1961a,b).

This evidence guided the implementation of first 1- then 2-species population models, based on the age-class model with space-limited recruitment developed by Roughgarden *et al.* (1985). An extensive historical dataset of barnacle abundance was used both as a source of data to detect effects of environment on barnacle populations and as a test dataset to judge model performance. With competition embodied as space pre-emption only and temperature-dependant early survival of *S. balanoides*, the resulting simulations showed very little sensitivity to temperature in *Chthamalus* fluctuations. However, when recruitment of *S. balanoides* was expressed as a function of adult numbers, as well as temperature, the models reproduced the observed historical dynamics of *S. balanoides* but *Chthamalus* remained insensitive. Only when early survival of recruited *Chthamalus* was made negatively dependant on the abundance of *S. balanoides* recruits (using data from Connell's original experiment) were changes in both species successfully reproduced. The effects of temperature alone were not enough to predict changes in these species. This work demonstrates that evidence from long-term monitoring combined with experimental studies lead to much more robust predictive models of change.

Summary

Data analysis and modelling complete.
Oral paper presented at European Marine Science Symposium.
Paper in preparation for peer-reviewed science journal.

References

Connell J.H. (1961a) Effect on competition, predation by Thais lapillus, and other factors on natural populations of the barnacle *Balanus balanoides*. Ecological Monographs 31: 61-104.

Connell J.H. (1961b) The influence of interspecific competition and other factors on the distribution of the barnacle *Chthamalus* . Ecology 42: 710-723.

Efron B. & Gong G. (1983) A leisurely look at the bootstrap, the jackknife and cross-validation. The American Statistician 37: 36-48.

Roughgarden J., Iwasa Y. & Baxter C. (1985) Demographic-theory for an open marine population with space-limited recruitment. Ecology 66: 54-67.

Southward A.J. (1967) Recent changes in the abundance of intertidal barnacles in south-west England: a possible effect of climatic deterioration. Journal of the Marine Biological Association of the UK 47: 81-95.

Southward A.J. (1991) 40 years of changes in species composition and population-density of barnacles on a rocky shore near Plymouth. Journal of the Marine Biological Association of the UK 71: 495-513.

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., Hawkins S.J. & Burrows M.T. (1995) 70 years of 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.