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Acidification and the Marine Ecosystem:

observations

Synthesising experiments and models.

Jerry Blackford

Plymouth Marine Laboratory

Contents & acknowledgements

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- **Brief Overview**

- **Modelling Acidification and Ecosystem Effects on the NW European Shelf**
Jerry Blackford & Nancy Jones

- **Responses to Acidification in Shelf Sea Benthic Systems**
Steve Widdicombe, Dave Lowe, Andy Rees, Amanda Beesley, Helen Findlay, Louise McNeill, Christine Pascoe, Hannah Wood

- **Pulling together Models, Experiments and Observations**
Icarus Allen, Jerry Blackford & AMEMR workshops

- **Moving towards Policy Needs**
Mel Austin, Jerry Blackford, Carol Turley, Steve Widdicombe

- **Conclusion**

Overview

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- Within a similar time frame to ocean acidification, the marine ecosystem will be affected by global warming adding to the complexity of the response.

- The scientific community is challenged to address this intricate issue on a relatively short timescale and produce robust and relevant science that underpins international policy development.

The geochemistry is based on very well defined knowledge and with some provisos the translation between atmospheric CO2 and ocean pH is uncontroversial.

For both climate change and acidification, predicting the response of ecosystems and resources is far more problematic and is at a very early stage.This is due to:

- Complexity of whole systems
- Range of potential effects
- Sparse and sometimes conflicting experimental results
- Unknown potential for acclimation or adaptation to changes in pH.

Overview

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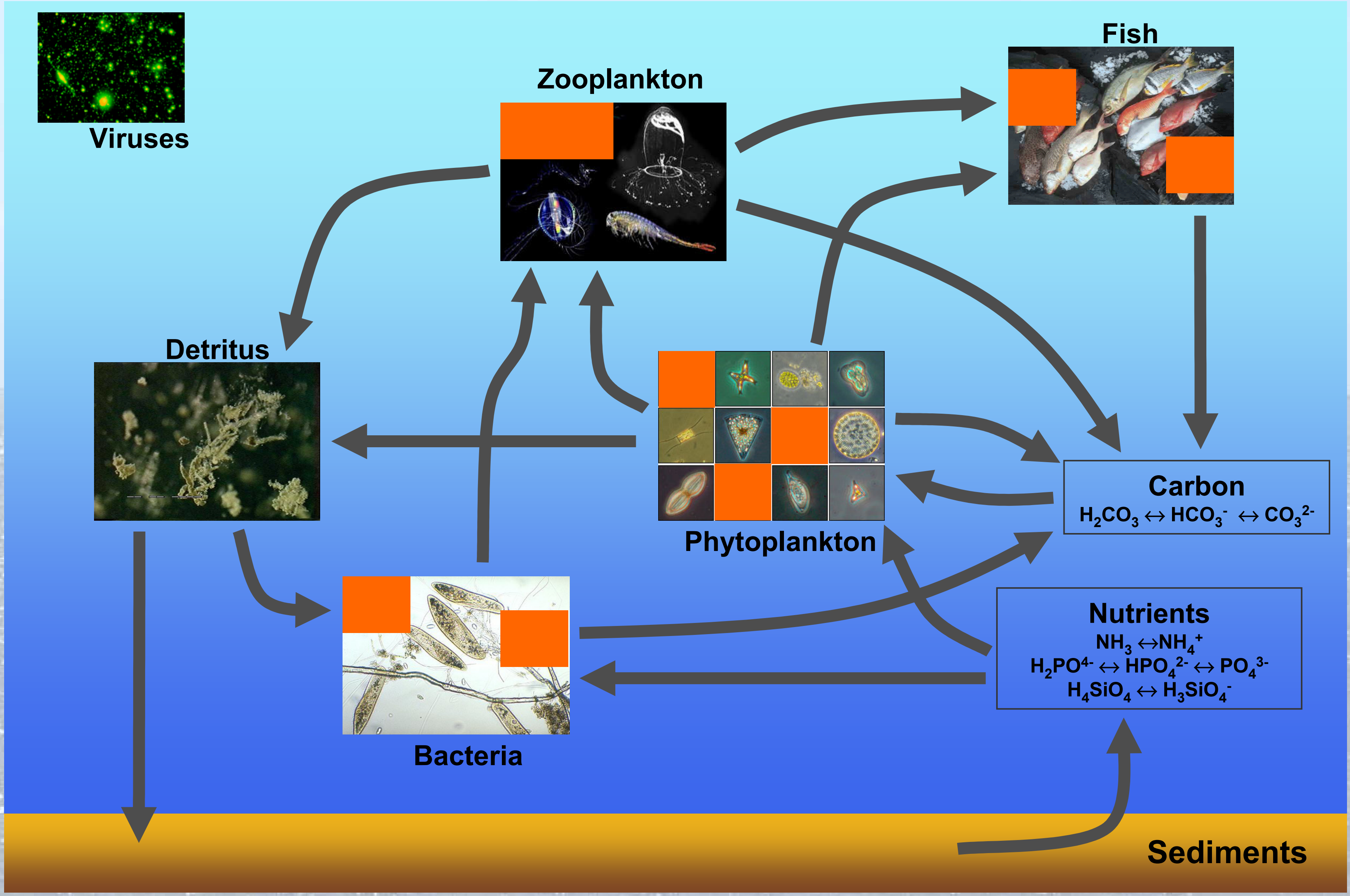
- **Acclimation and adaptation pose a huge challenge to this research area.**

- **Bacterial tolerance to antibiotics has emerged over decadal timescales.**

- **Evidence from mesocosm experiments indicates that some processes are optimal at current CO_2 levels and decline at low or high CO_2.**

- **There is not enough information to treat acclimation and adaptation in model systems.**

Overview



Key element cycles, biodiversity and resources are at risk.

Overview

- Many biogeochemical and ecosystem processes may be vulnerable
- Regulatory biogeochemical feedbacks and ecosystem properties are at risk

Global carbon cycle: Carbon fixation and sequestration.

Global sulphur cycle: DMS.

Nutrient cycles: Speciation and benthic nutrient cycling in shelf systems.

Biodiversity: Differential response of species threatens to change community structure and possibly the trophic transfer of energy into commercially important species.

Modelling Research Agenda

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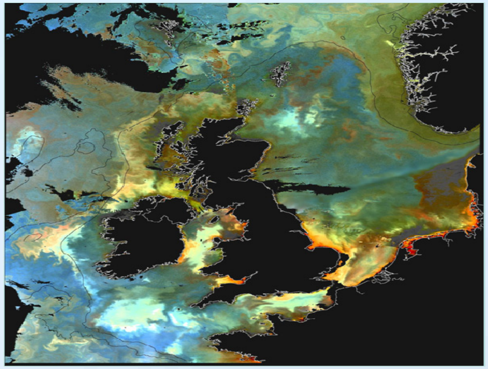
Ecological, human resource importance of shelf seas



- **Given the high seasonal pH variability in coastal and productive regions, how does the predicted change in pH compare with the seasonal signal?**

- **What are the likely ecosystem effects on shelf sea scales?**

- **What are the likely interactions with other drivers such as climate change, eutrophication and fishing?**

- **What are the likely impacts of leakage from carbon capture and storage systems?**

Closely driven by requirements of policy makers

Shelf Modelling

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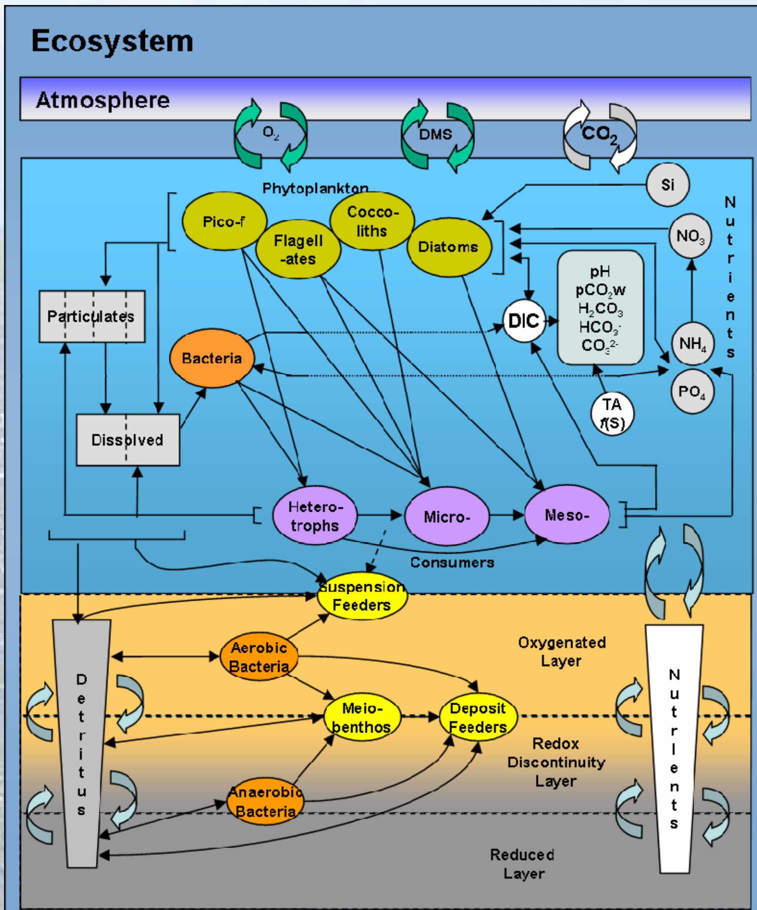
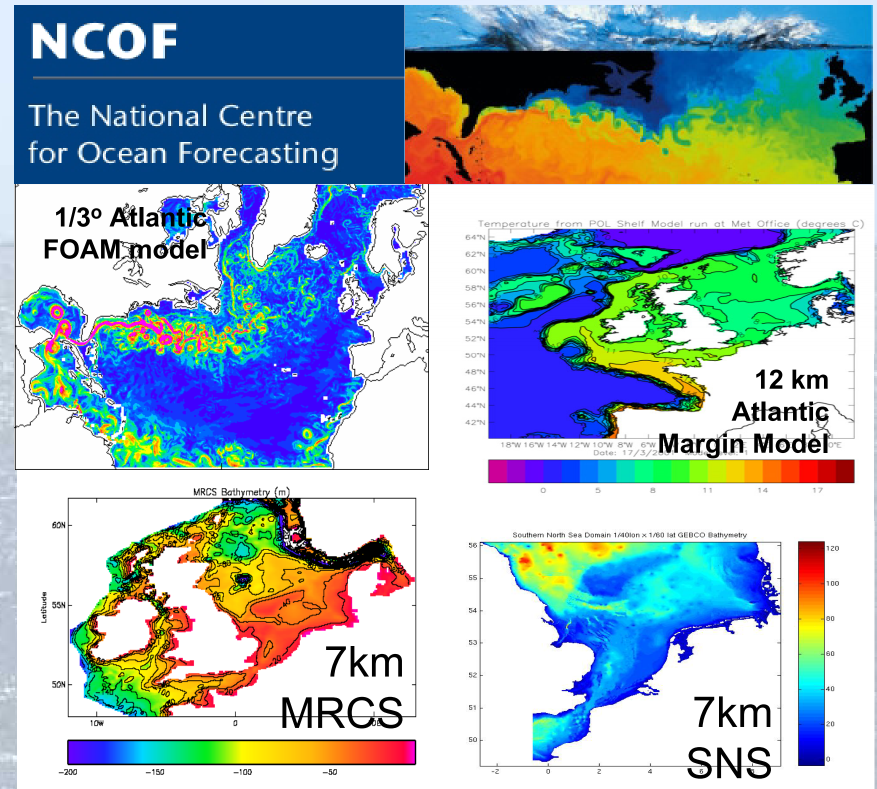
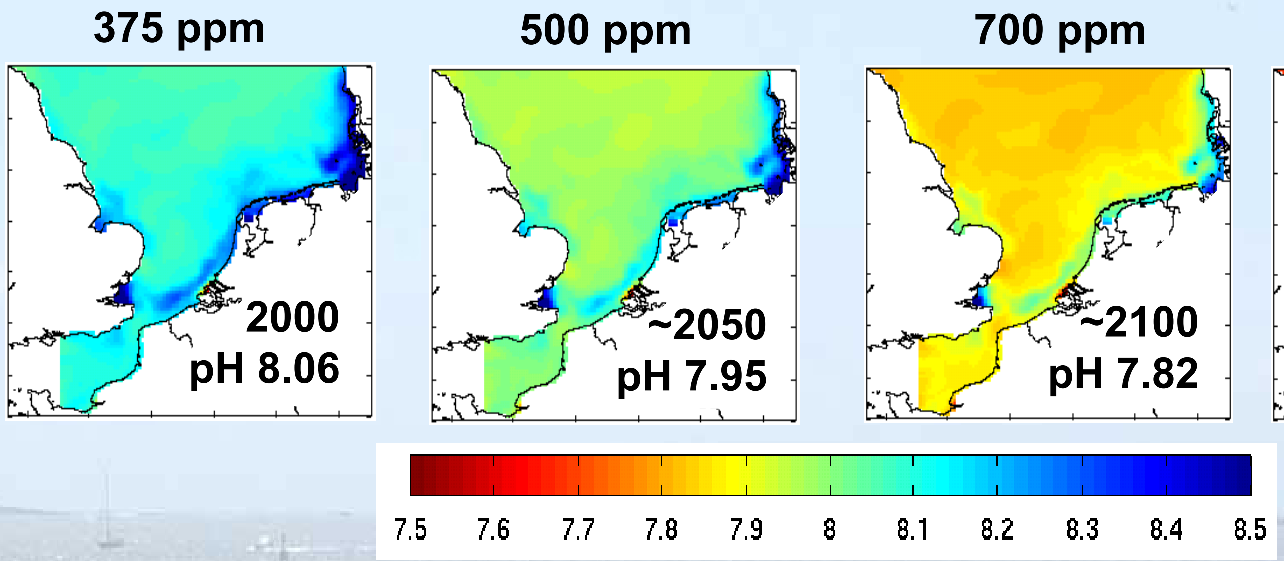
We have developed a coupled hydrodynamic – ecosystem – carbonate (pH) system model that allows us to investigate and predict ecological responses to low pH





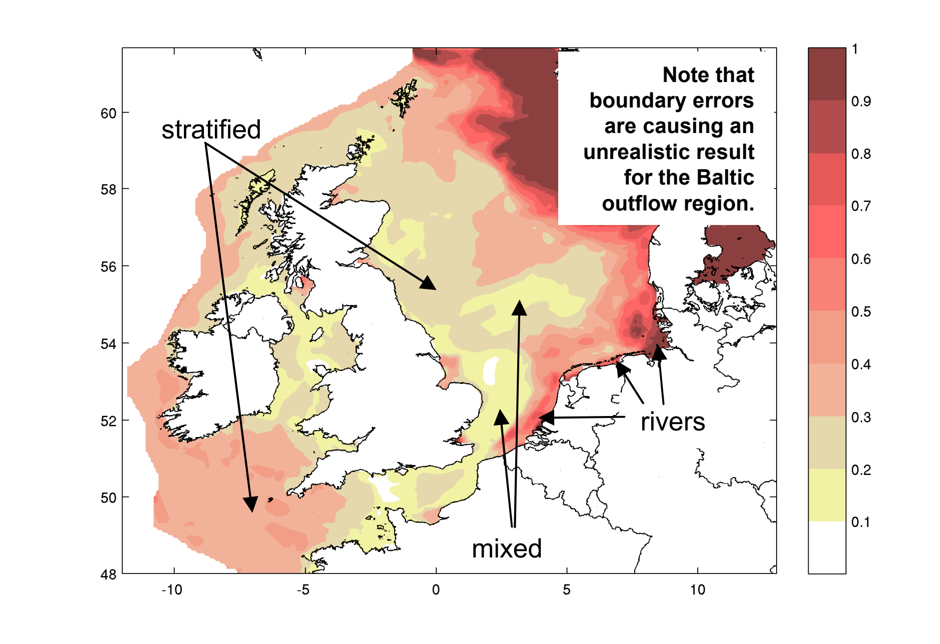
Nested in wider area models and used for operational research

Shelf Modelling



The rate of acidification of UK shelf seas is consistent with rates predicted for ocean systems.

But there is a background of heterogeneity and sometimes large variability, unique to shelf systems



Shelf Modelling

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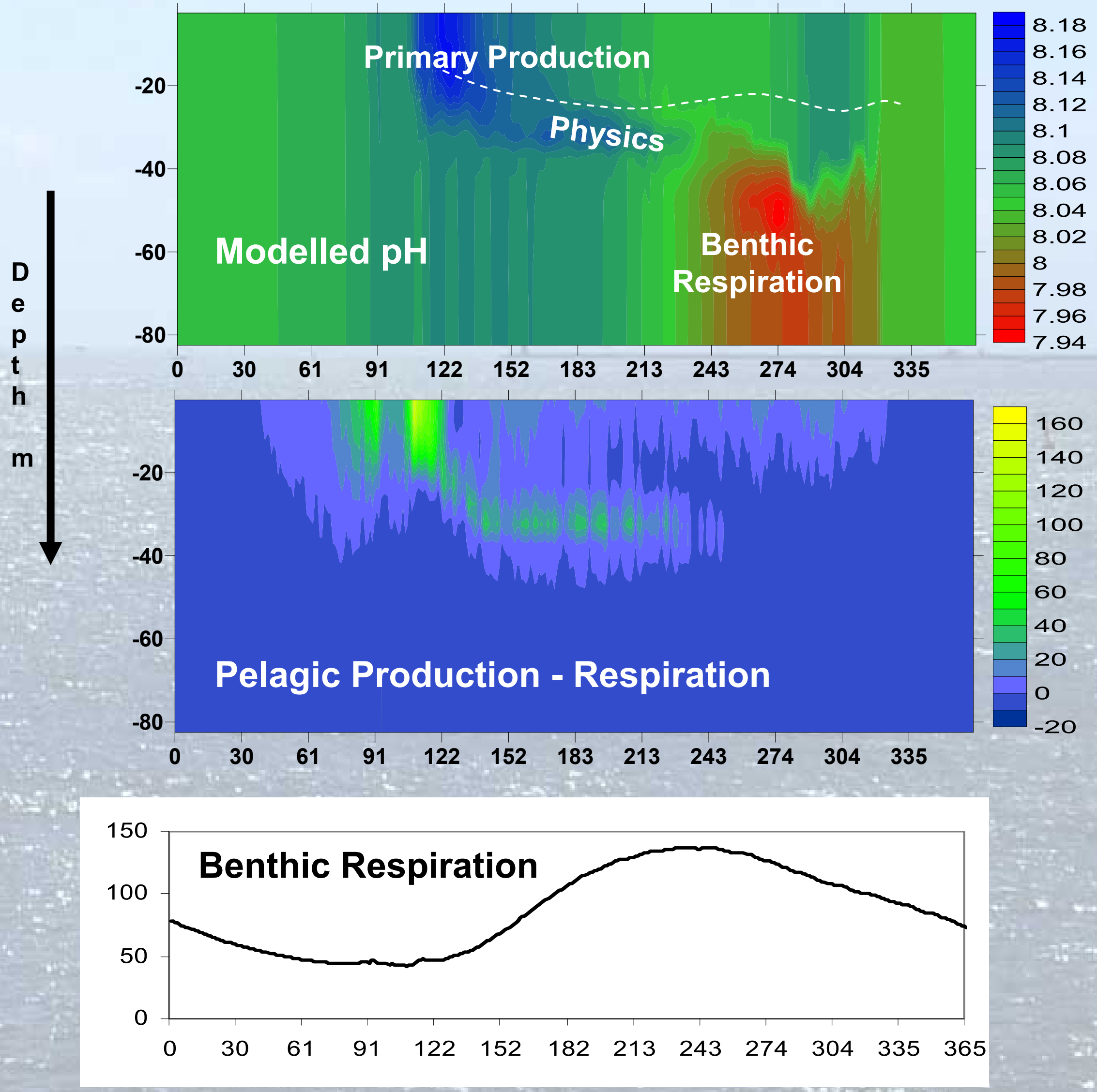
Depth – time plot from central North Sea illustrating the interaction of biology and physics in determining in-situ pH.



Shelf Modelling

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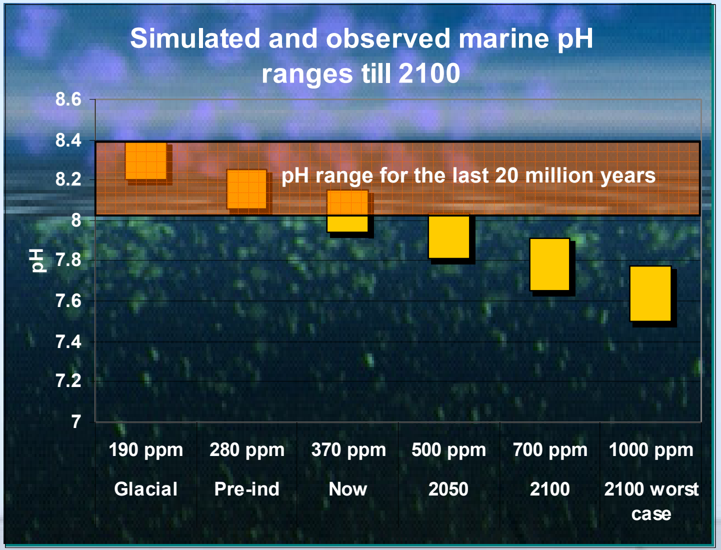
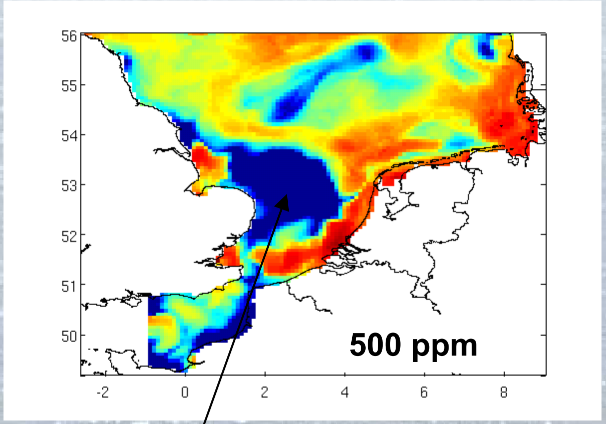
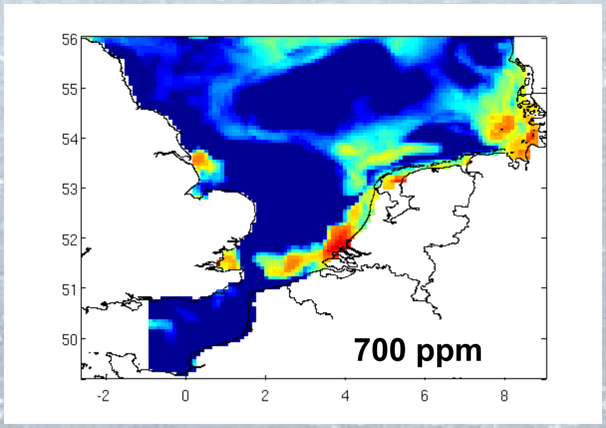
Disconnection of in-situ pH ranges – how long until pH range is completely distinct from pre-industrial?

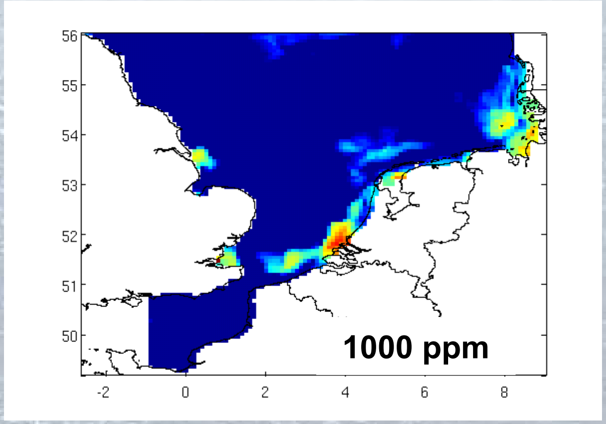
Stylised Oceanic assuming 0.2 pH annual variability



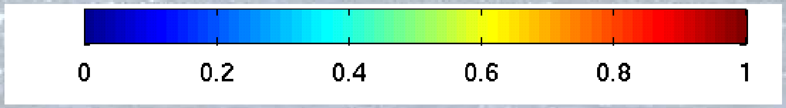
Shelf







limited disconnection



overlap

~ completely distinct

Shelf Modelling

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Nitrification / Denitrification

Oxidation of ammonia to nitrate / nitrite

$$NH_4^+ \Leftrightarrow NH_3 \rightarrow N_2O \rightarrow NO_2^- \Leftrightarrow NO_3^-$$

$$\downarrow$$

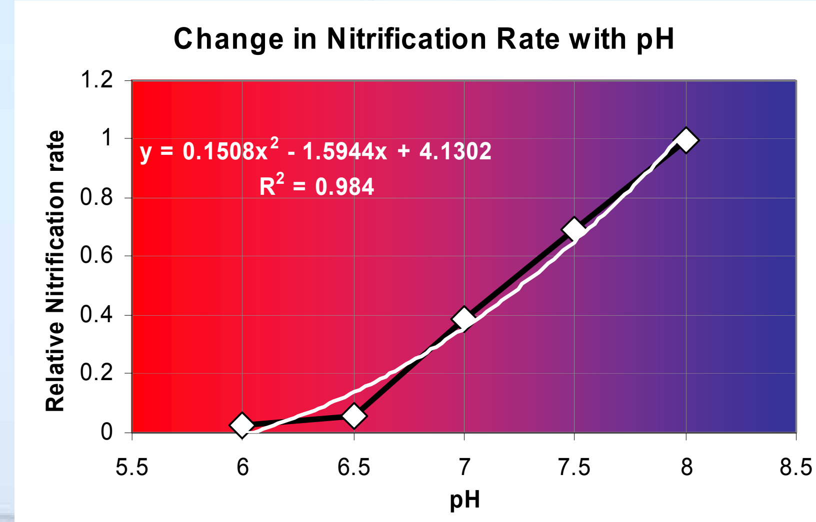
$$N_2$$

Low pH ←

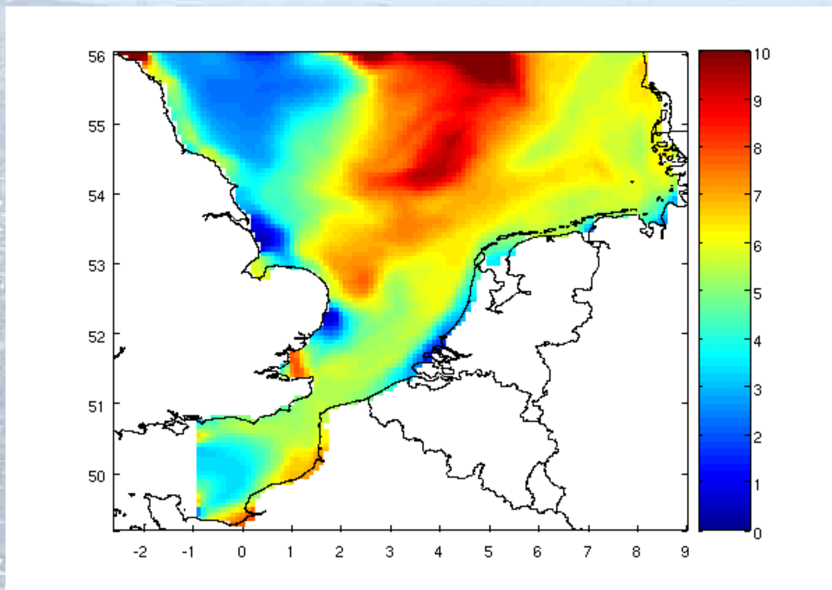
nitrification

Denitrification to atmosphere

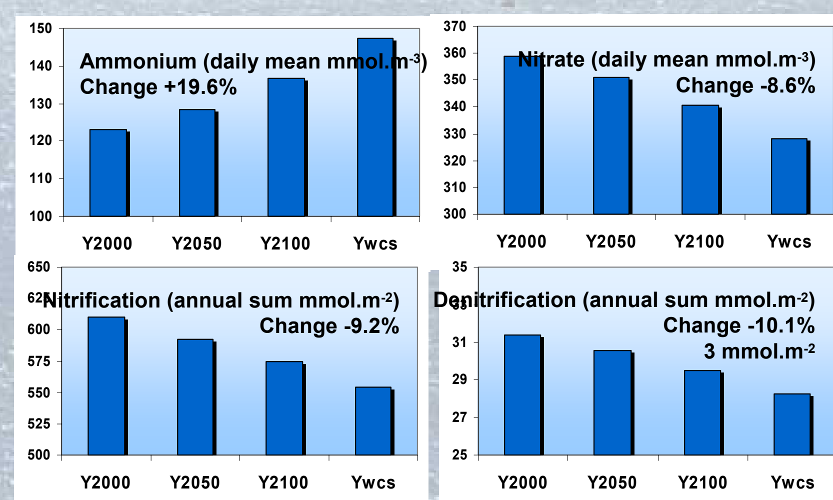
The shift away from NH_3 will inhibit nitrification, which in turn may inhibit denitrification.



Experimentally derived response curve (Huesemann et al, 2002)



% change in the ratio of nitrate to total nitrogen between the 375 ppm and 1000 ppm simulations.



the model predicts measurable changes to NH_3:NO_3 ratio.

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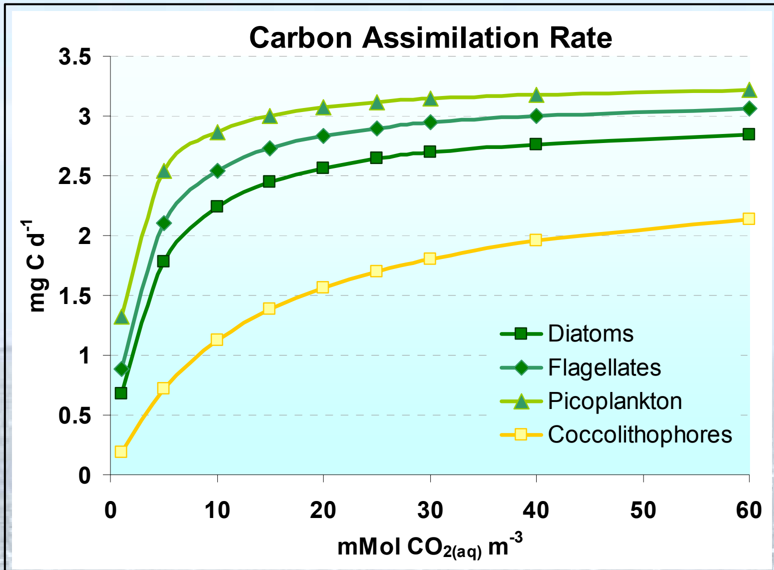
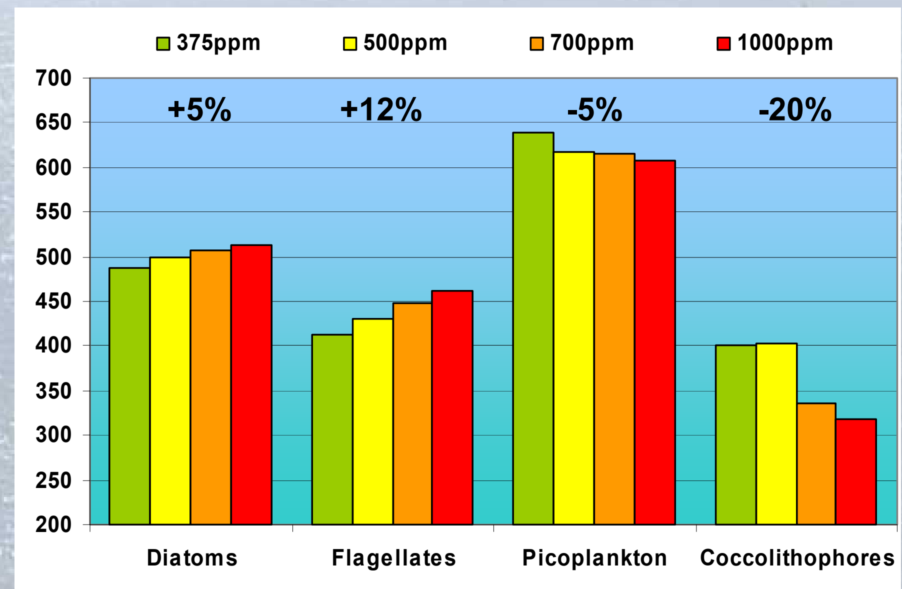
Sensitivity of carbon acquisition in relation to CO_2 supply



Species specific rates

Burkhardt et al. 2001, Limnol. Oceanogr., 46(6), 1378–1391
Rost et al. 2003, Limnol. Oceanogr., 48(1), 55–67
Sultëmeyer et al. 1998, Plant Physiol. 116: 183–192
Riebesell et al. 1993, Nature 361(6409): 249-251.

Phytoplankton daily mean biomass

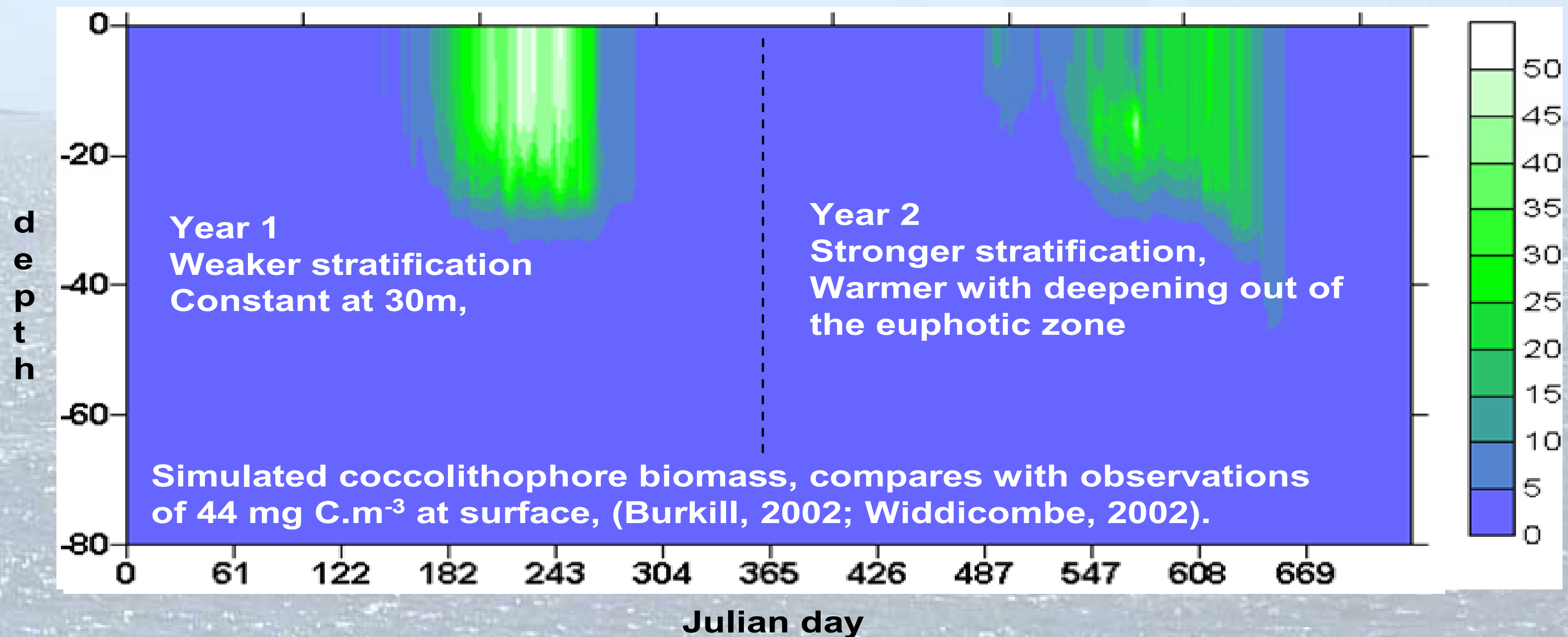


Although total biomass & production is not much altered, there are indications that community composition could change.

Shelf Modelling

A potential effect of integrating high pCO2w and climate change: Coccolithophores and the weather

- Simulated for different weather patterns



- Inhibition of Calcification parameterised from Riebesell et al (2000)
- Assumed extra mortality and grazing at low calcification.

So applying future high CO2 scenarios & IF this model is realistic………

Shelf Modelling

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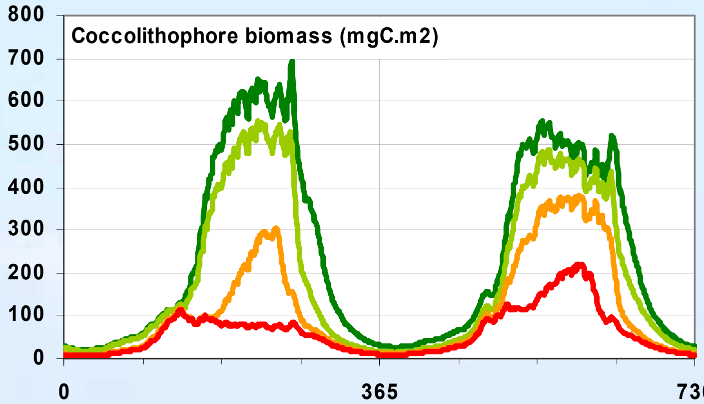
ppm CO_2

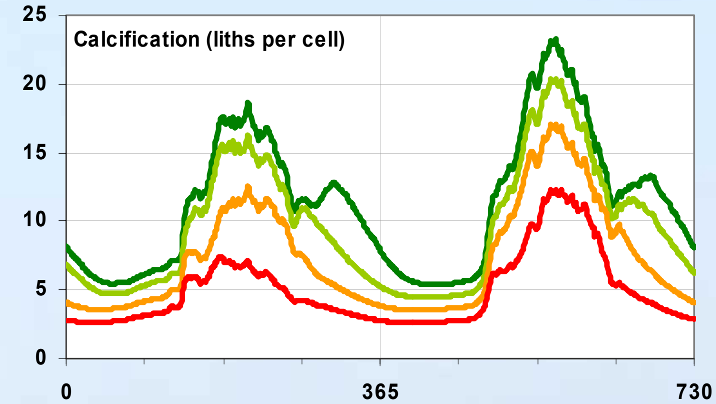
375

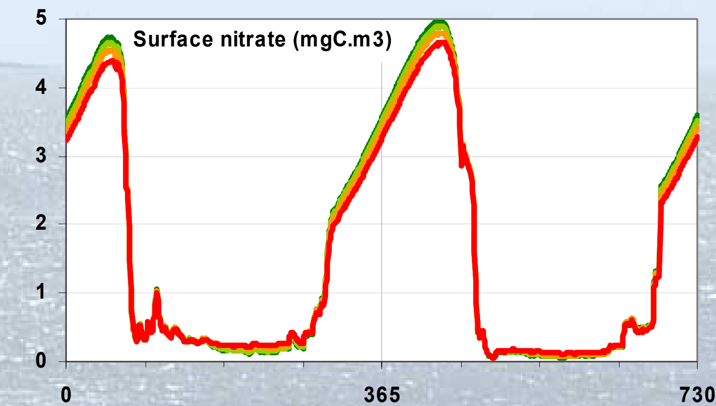
500

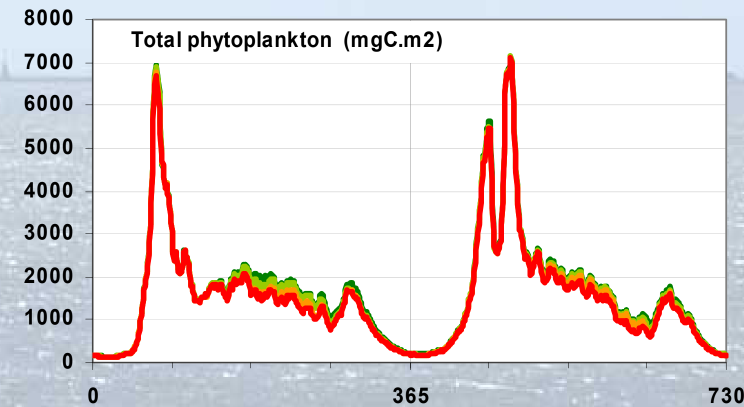
700

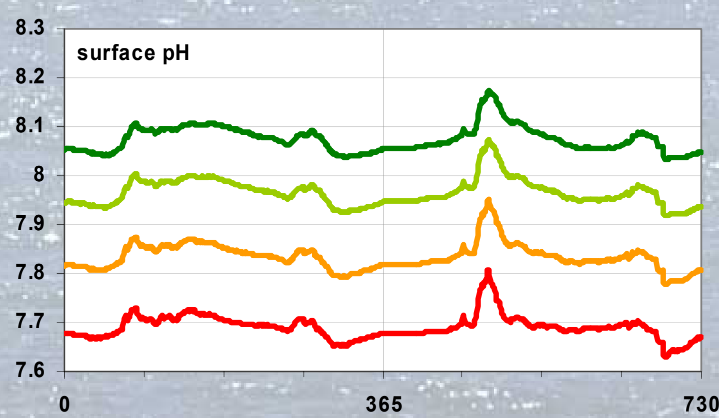
1000











Environmental drivers in spring (strength of spring bloom) and summer (mixing) key to modifying early calcification and nutrient supply.

Suggests that the weather / climate may have a significant influence on ecosystem response to acidification.

Diversity and nutrient flux experiment

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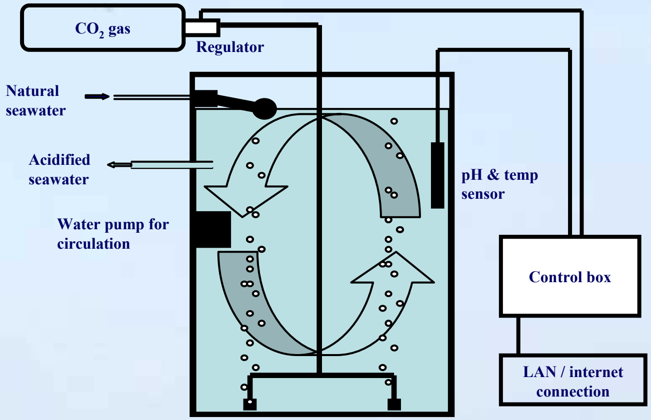
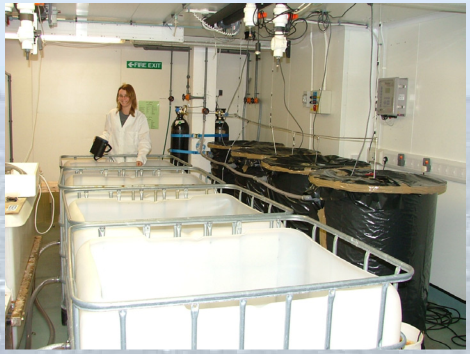
Impact of pH :

Benthic diversity
Nutrient flux
Predator / prey interactions



Impact of pH on a range of species:

Psammechinus miliaris (Sea urchin, hard bottom)
Strongylocentrotus droebachiensis (Sea urchin, hard bottom)
Brissopsis lyrifera (Sea urchin, burrows in muddy sediment)
Echinocardium cordatum (Sea urchin, burrows in sandy sediment)
Ophiura ophiura (Brittlestar, sediment surface)
Amphiura filiformis (Brittlestar, burrows in sediment)
Nereis virens (Polychaete worm, burrows in sediment)
Mytilus edulis *(Bivalve)*
Callianassa subteranea (Burrowing shrimp)
Upogebia deltuara (Burrowing shrimp)



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Norwegian Institute for Water Research

4 pH treatments: 8.0, 7.3, 6.5 and 5.6

2 sediment types: Muddy silt and fine sand

pH and macrofaunal diversity

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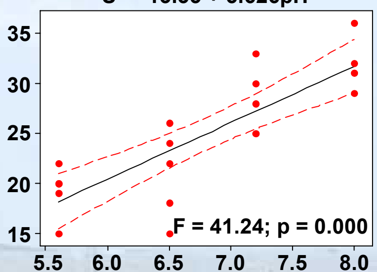
Sand | Mud

number of species

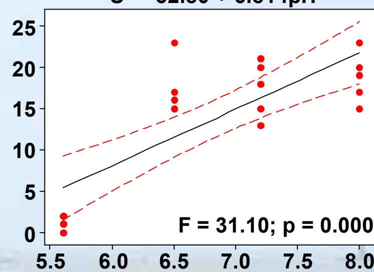
Sand – 2 weeks

S = -13.35 + 5.626pH



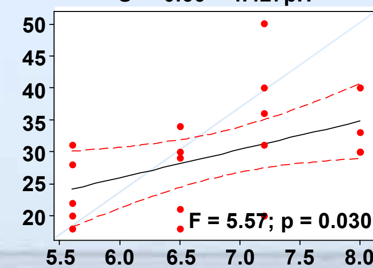
Sand – 20 weeks

S = -32.80 + 6.814pH



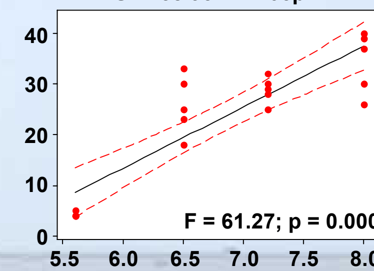
Mud – 2 weeks

S = -0.66 + 4.427pH



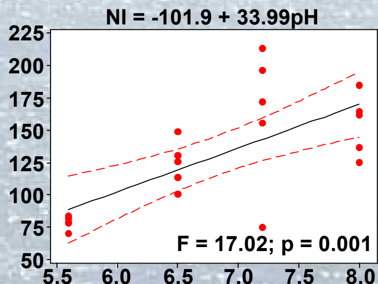
Mud – 20 weeks

S = -58.95 + 12.05pH

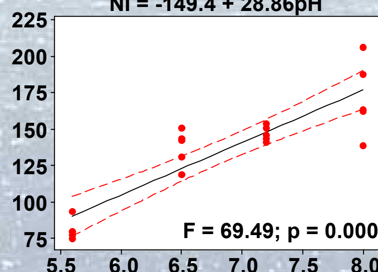


number of indvs

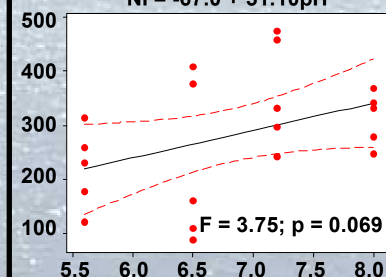
NI = -101.9 + 33.99pH



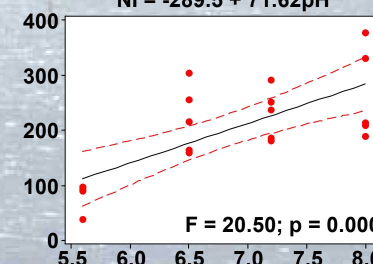
NI = -149.4 + 28.86pH



NI = -67.0 + 51.10pH



NI = -289.5 + 71.62pH



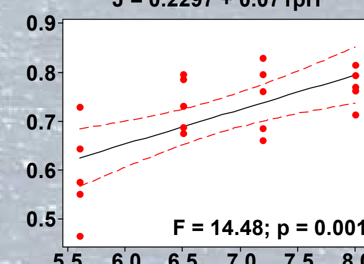
evenness

n.s.

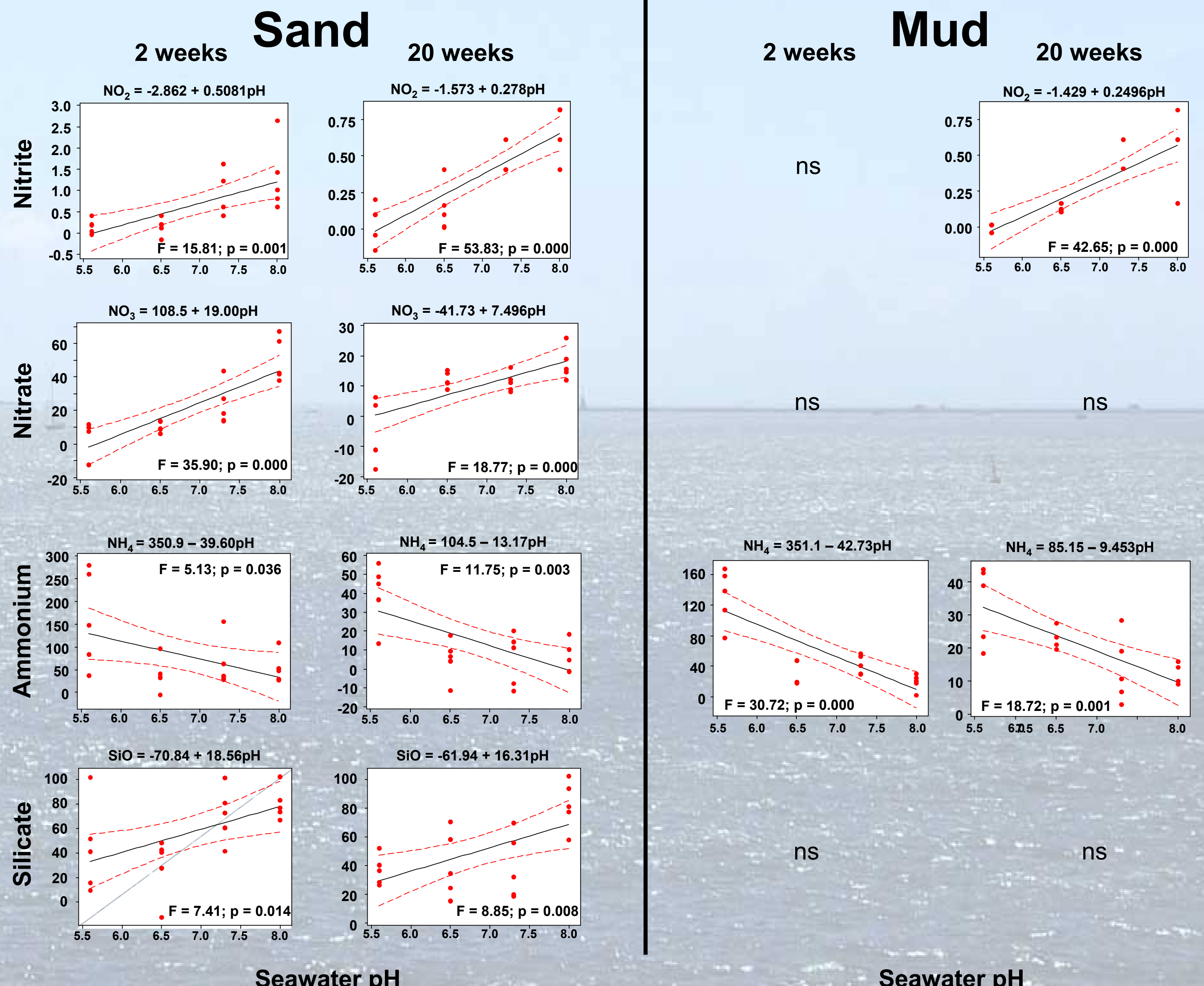
n.s.

n.s.

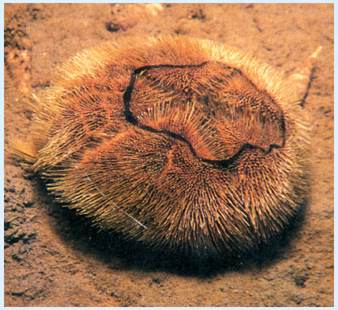
J = 0.2297 + 0.071pH



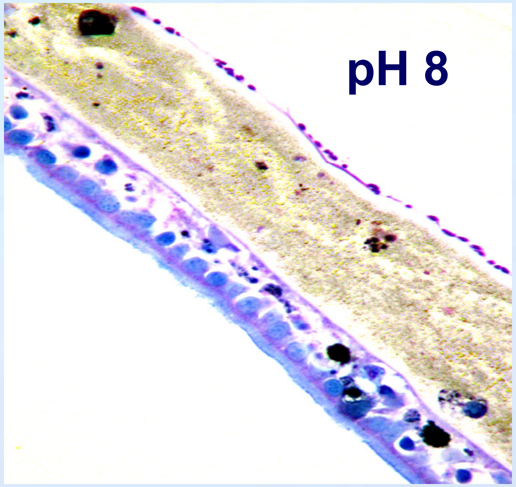
pH and nutrient flux

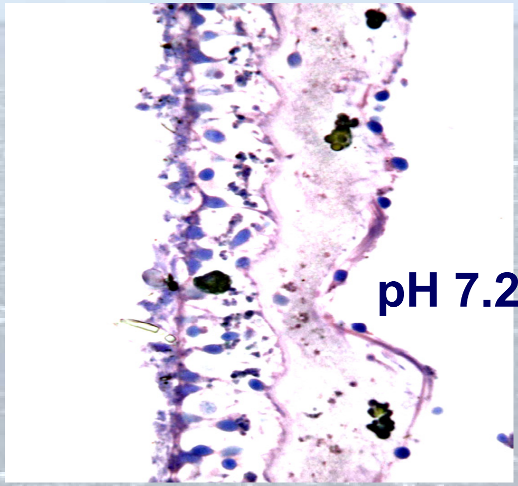


Impact on *Brissopsis lyrifera*



- Calcareous skeleton.
- No impermeable barrier between ambient seawater and their internal body cavity.
- Little ability to buffer changes in the acid-base balance of their body fluids.
- Rely a large perivisceral fluid reservoir and the passive dissolution of the test (skeleton) to buffer extracellular acidosis.
- Have a significant impact on nutrient flux however this impact is different to that of *Nereis*.



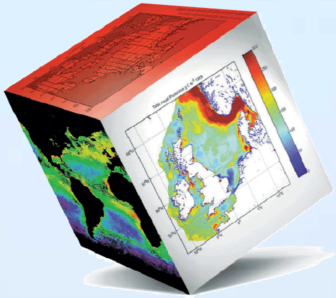


We have also observed impacts on:

- Acid-base balance
- Reproductive tissues
- Impact on meiofaunal communities

www.amemr.info

advances in marine ecosystem modelling research



Model validation, analysis and quantification of error. February 5-7 2007

The response of marine ecosystems to increasing CO2. February 12-14 2007

Operational biophysical oceanography. Nov/Dec 2007

Bridging the gap between lower and higher trophic levels. 2008

DMS production in the upper ocean. 2008

AMEMR Symposium 2008. *June 23-26, Plymouth, UK*

AMEMR seeks to promote the advancement of marine ecosystem modelling science by facilitating discussion and debate about all aspects of model based research thorough symposia and workshops.

Model Evaluation

A systematic analysis of the performance of 153 biological models concluded that: (Arhonditsis and Brett 2004).

o**Only 47% of the models assessed had any validation**

o**Only 30% determined some measure of goodness of fit.**

It would seem to be a basic requirement that before any model can be used for either scientific or policy application with any confidence an assessment of their accuracy and predictive capability is required.

Model Evaluation

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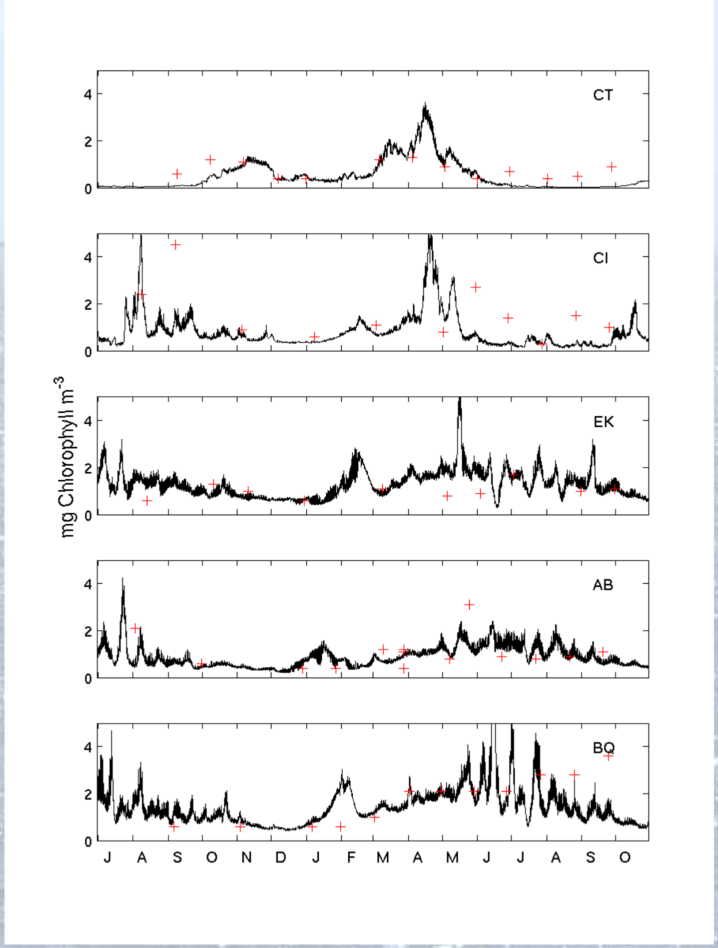
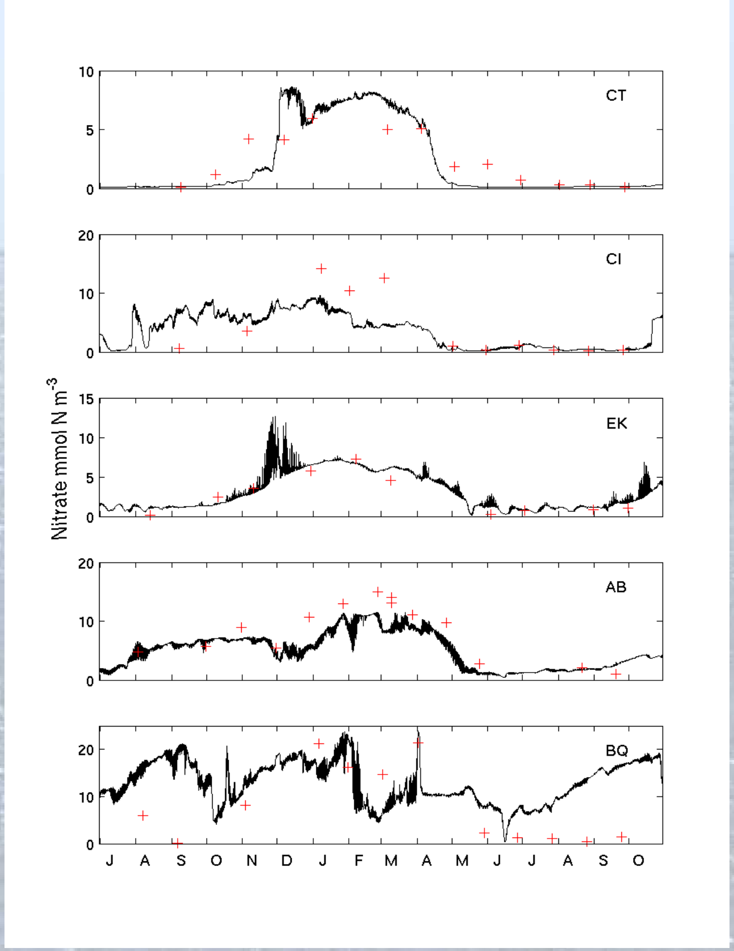
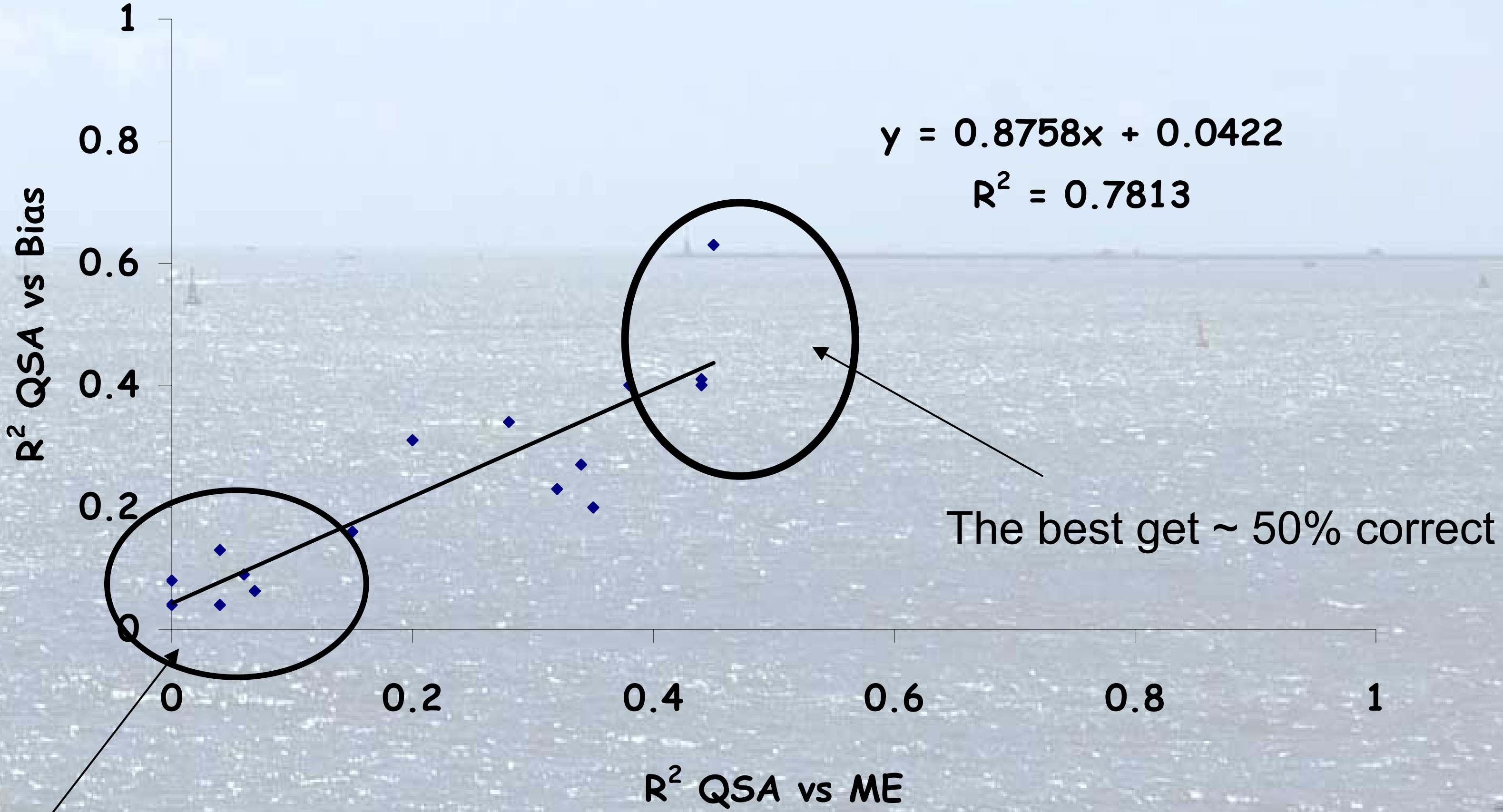
Many scientists base at least an initial, and sometimes their complete analyses of model outputs on a subjective visual comparison.





Model Evaluation

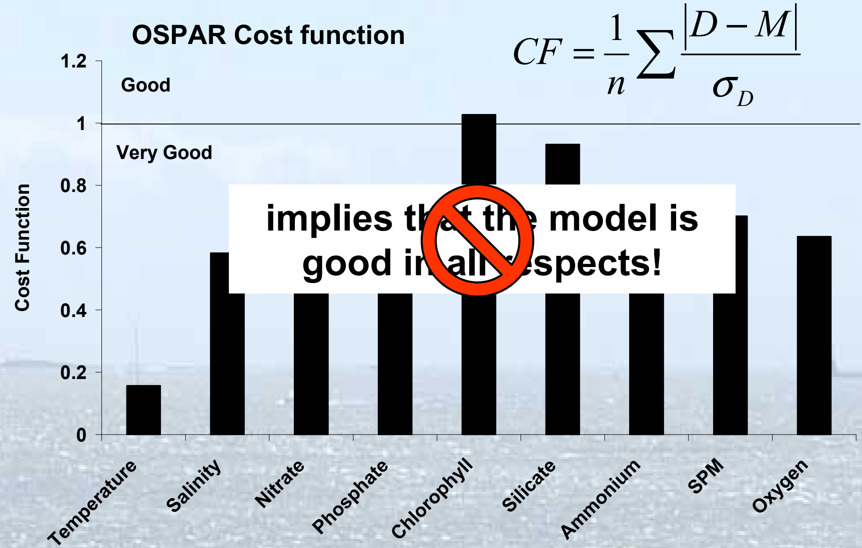
Quantitative Subjective Analysis



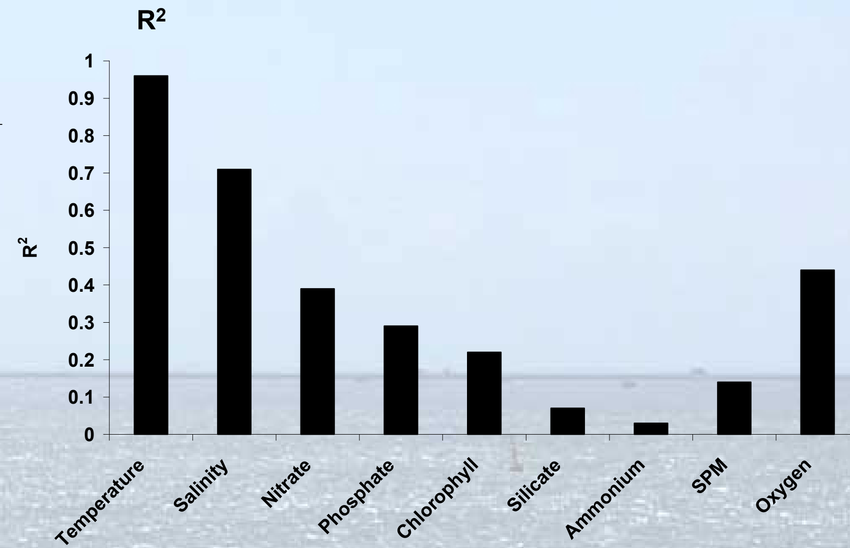
Some researchers have no ability to visually discriminate goodness of fit

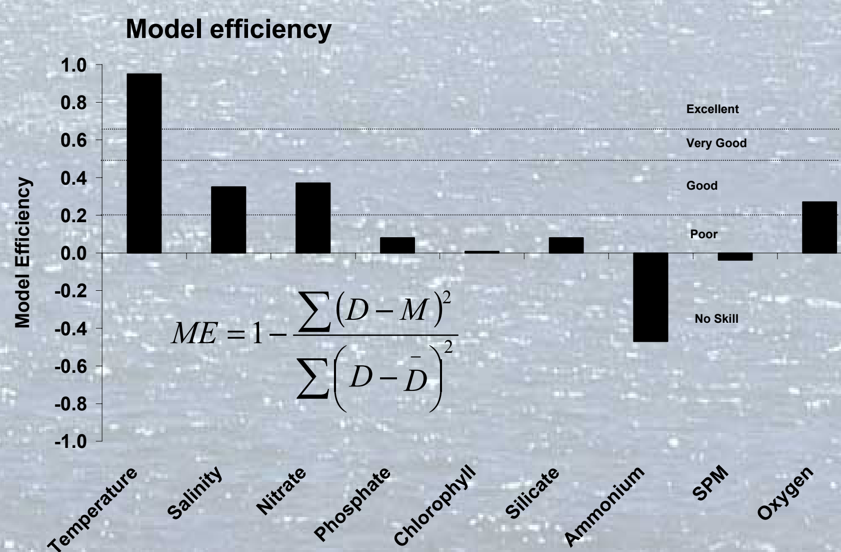
Model Evaluation

Cost Functions and other metrics

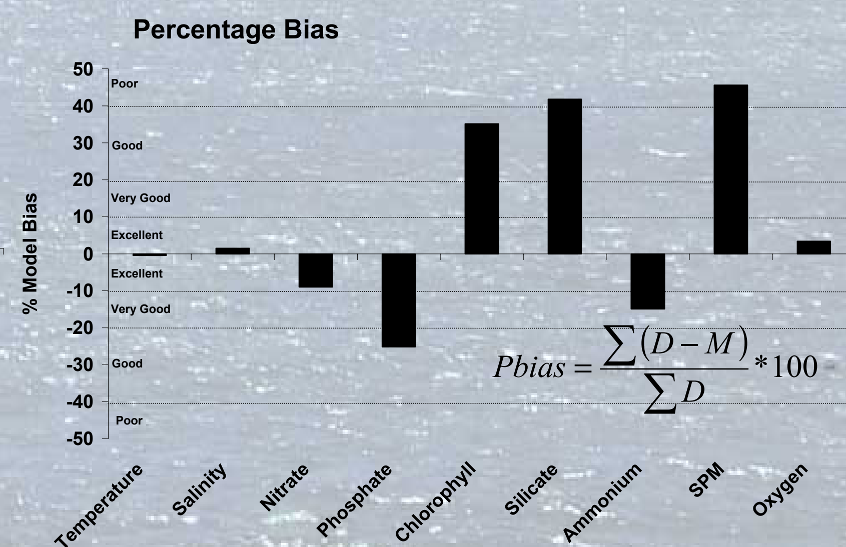


$$CF = \frac{1}{n}\sum\frac{|D-M|}{\sigma_D}$$





$$ME = 1 - \frac{\sum(D-M)^2}{\sum\left(D-\bar{D}\right)^2}$$



$$Pbias = \frac{\sum(D-M)}{\sum D} * 100$$

Modelling pre-requisites

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- **Evaluation should be mandatory**
- **Evaluation should be rigorous**
- **Need for error estimates on model outputs…**

how do these compare with those of the validation information.

- **Meta analysis very important – often the crucial link between data and models**
- **Need easy access to data.**

Shelf Model Validation

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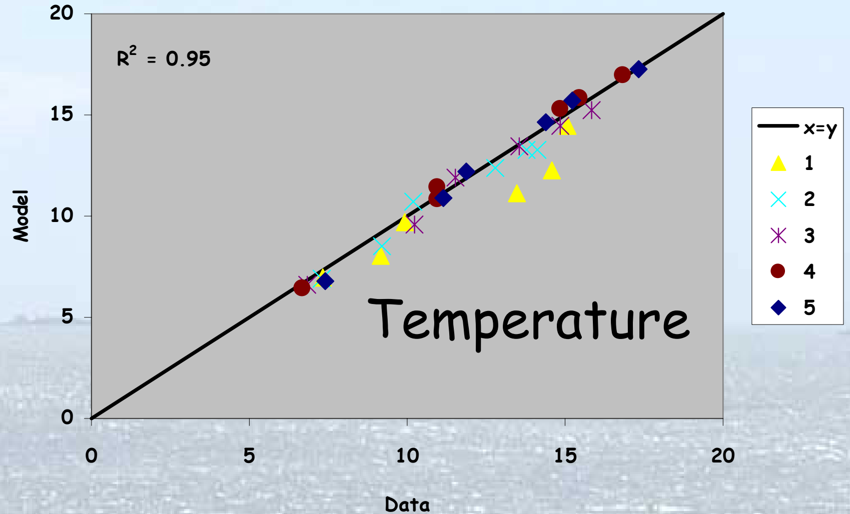
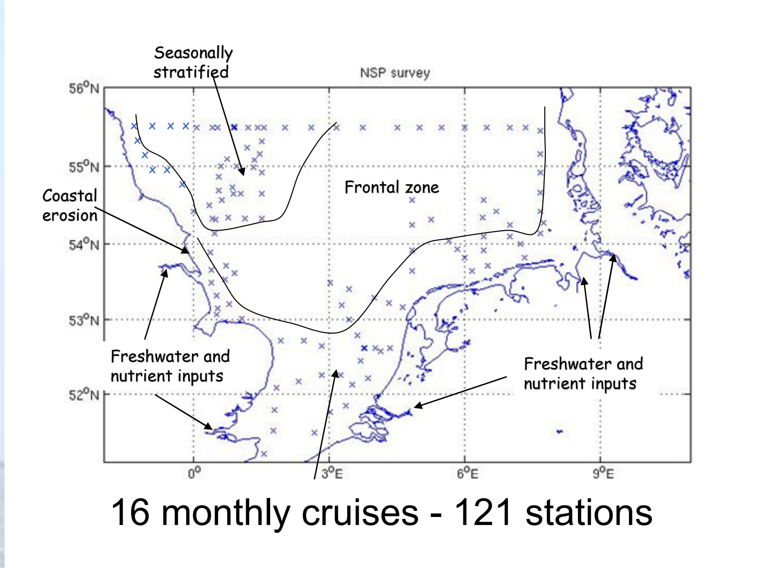
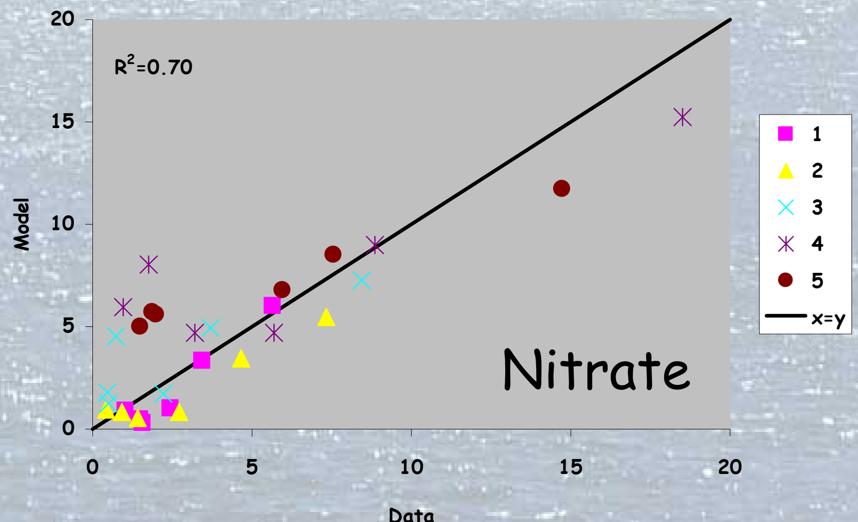
Seasonally binned
Regions identified by neural network analysis

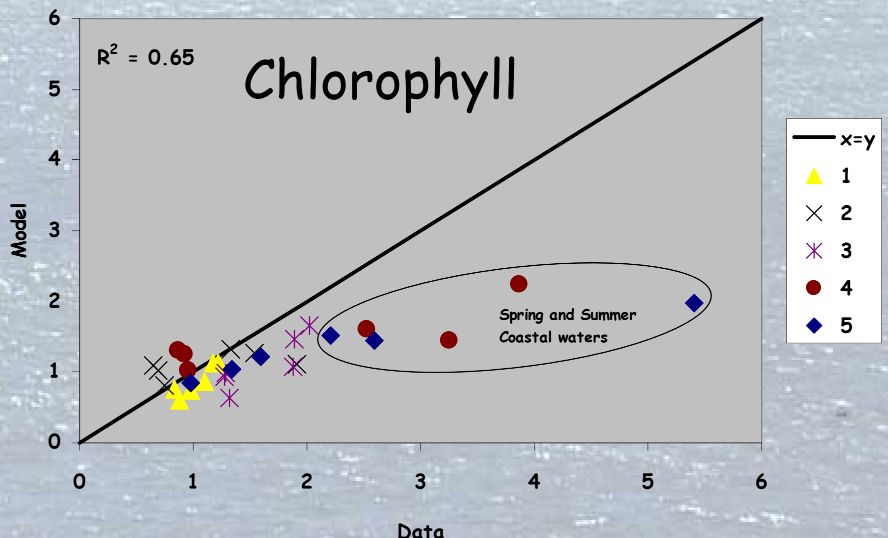


North Sea Project 1988-1989



16 monthly cruises - 121 stations





Now 3 papers in Journal of Marine Systems on evaluation of the model system

Shelf Model Valuation

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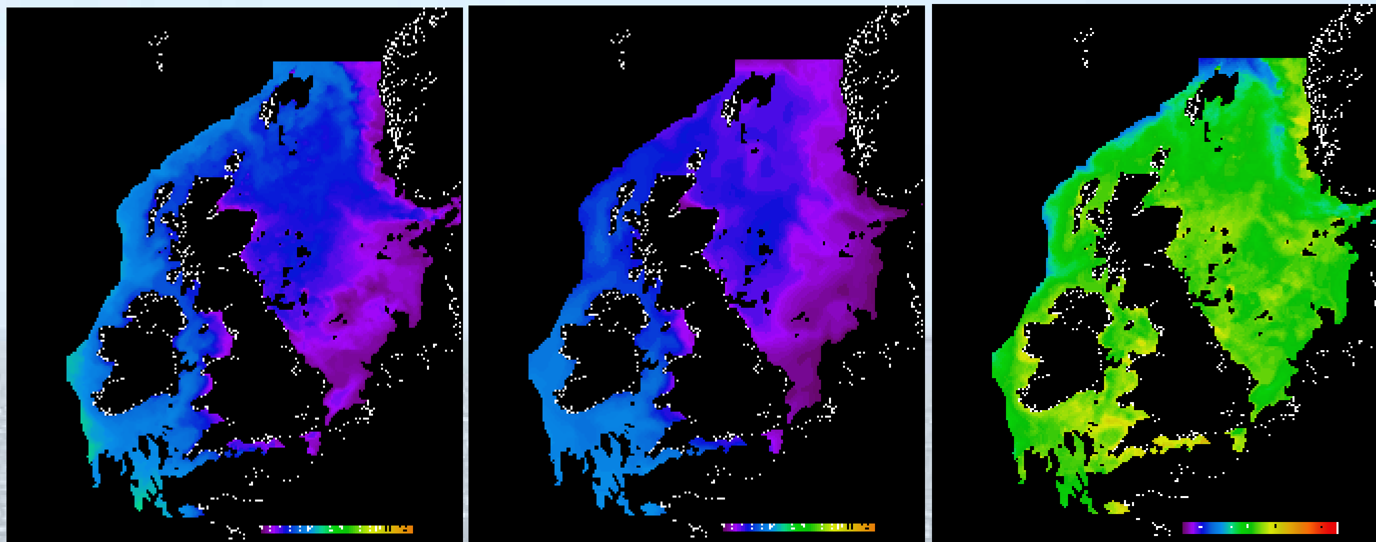
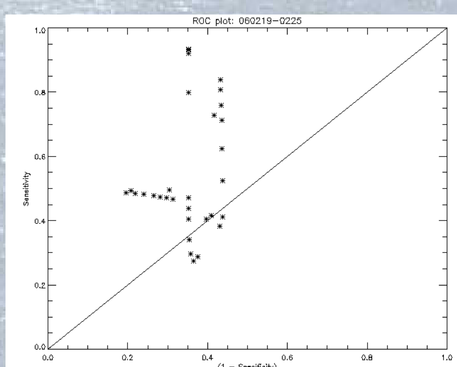
Near Real Time Model Validation - Sea Surface Temperature

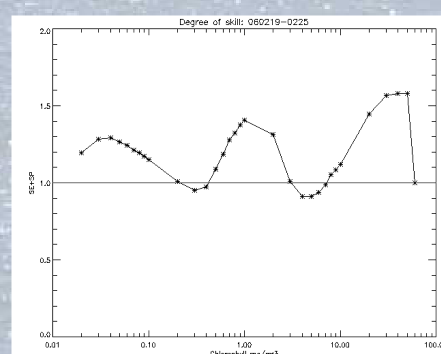
Satellite | Model | Difference



Comparisons for the week ending 25th Feb 2006

Regions in green are good, blue model under predicts, red model over predicts





Receiver Operator Characteristic (ROC)

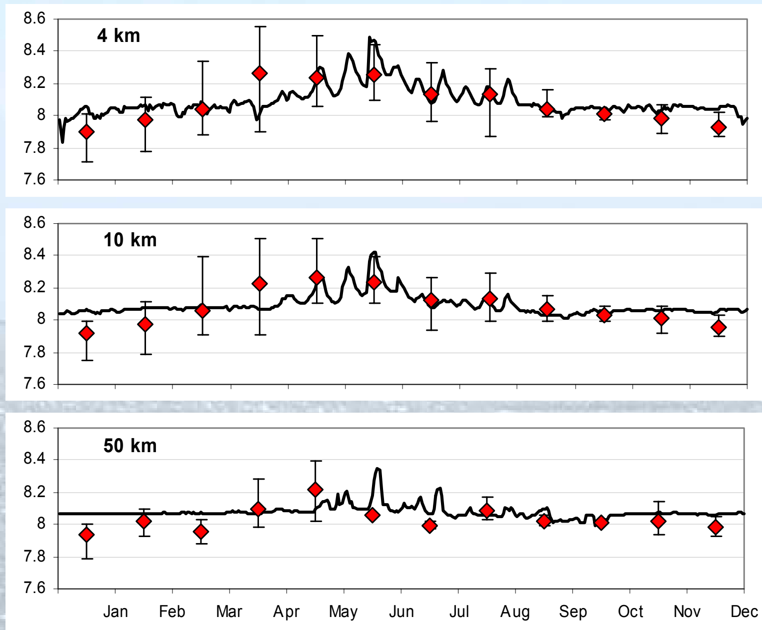
Skill analysis at given threshold

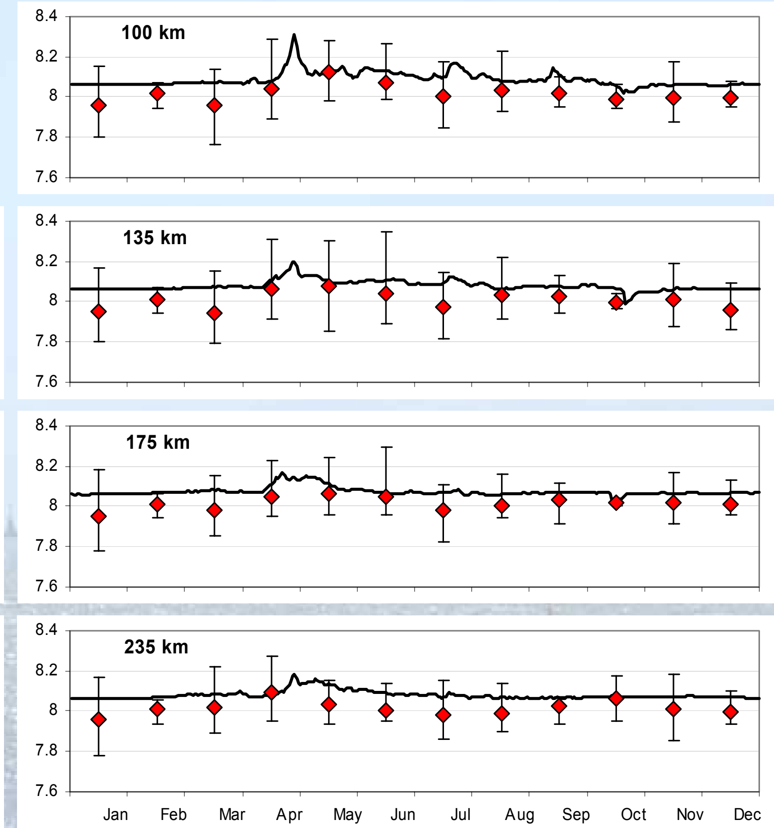
Data comparison updated weekly http://www.npm.ac.uk/rsg/projects/mceis/

Shelf Carbonate Model Validation

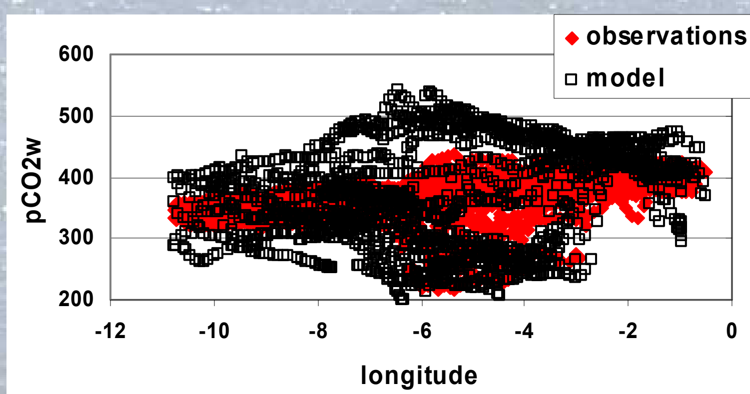
Plymouth Marine Laboratory

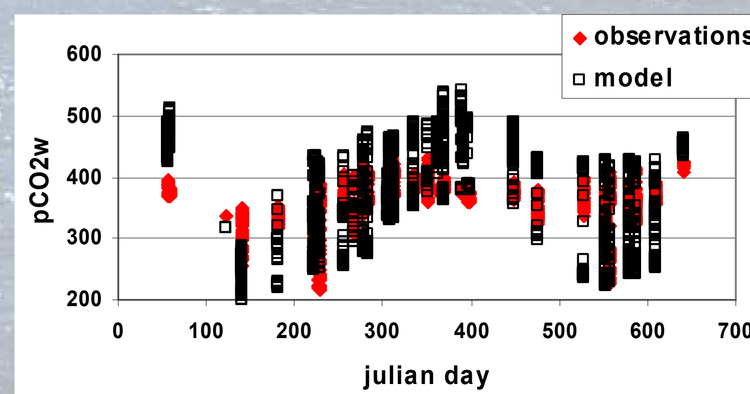
Comparison with 'Waterbase' data





Comparisons with underway pCO_2





Recommendations: Modelling

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- Models need to deliver probabilistic information by exploring the range of parameter, process and scenario uncertainties and reporting results with uncertainty estimates. This requires very significant computational resource.

- No single model system will be able to address all the questions posed. It is therefore pragmatic to develop specialised classes of model, basic geochemistry should be correct, and outputs comparable.

- Models that fail are valuable results, potentially exposing where assumptions break down or what process descriptions require development.

Observations

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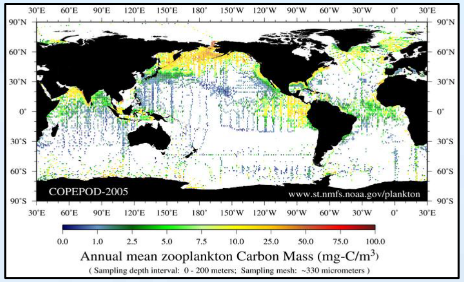
Given the scale, heterogeneity and dynamisms of the world's oceans, it is not surprising that observational data is inadequate for models.



- Data should be quality-assured, include meta data and error estimates

- Observed variables should include information that can constrain the physics (light, salinity, temperature, mixing), the carbonate system (two from DIC, TA, pCO2, pH) and the biochemistry (nutrients, biomass, production).

- A multi-disciplinary approach broadening the scope of existing / planned observations should ensure that appropriate parameters are collected. Carbonate monitoring systems should be standard.

- Long term time series datasets are vital - the maintenance of these programmes requires a commitment to long-term funding.

Experiments: Issues

- Increasing the [CO_2] in experiments (bubbling) is problematic.

- Natural dynamics can cause unrealistically large fluctuations in DIC, returning future scenario treatments to levels typical of current conditions.

- Experimental approaches are short term (< several weeks).

Experiments: example

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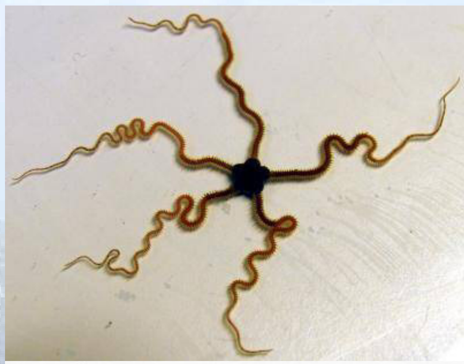
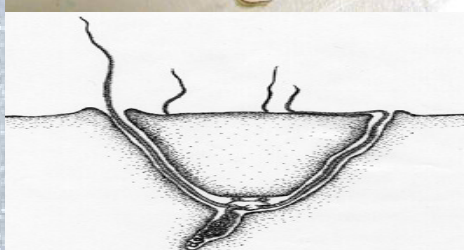
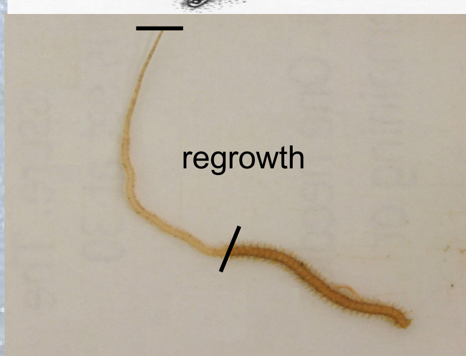
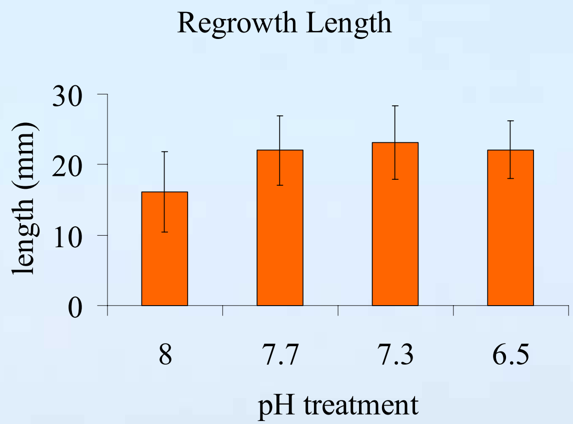
Arm regeneration in *Amphiura filiformis* at low pH

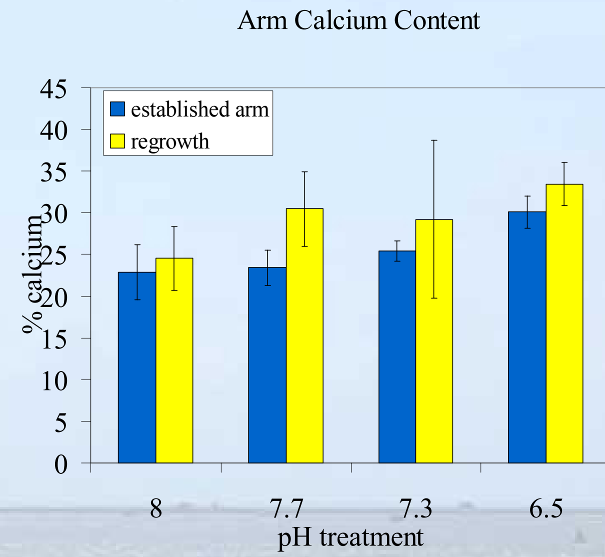
Hannah Wood

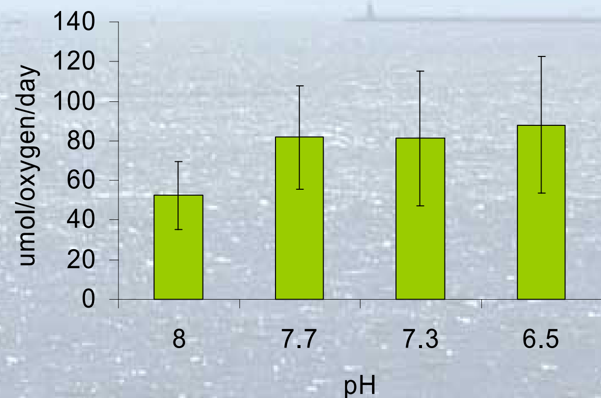












- 35 day exposure
- stress response

- Nutritional quality of regenerated arms ?
- Long term, slow onset exposures

Experiments: recommendations

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Specific recommendations: experimental approaches
Prioritisation of research topics is not desirable as this invokes a-priori an assessment of relative vulnerabilities – which are as yet unknown.

Key knowledge gaps:

- Acclimation and adaptation, requires long-term, patient funding.

- Rigorous dose-response investigations for a wide range of species at *realistic* CO_2 perturbations identifying the sub-lethal effects and also the mechanism(s) through which the CO_2 response is mediated.

- The maximum possible variables should be measured within each experiment, with consideration going to variables that are not identified a-priori by hypothesis or questions. Meta-data, are essential.

Making it policy relevant

- Ensembles exploring different scenarios and model uncertainties. Probabilistic rather than deterministic results.
- Consensus and consistency of message.
- Recasting results in a value system that policy makers and economists can relate to.
- Communication and access.

Making it policy relevant

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Recasting results in a value system that policy makers and economists can relate to: ***Goods and Services*** *are indirect or direct benefits to human society which arise from the marine system……..*

- **Production services**: *products obtained from ecosystem*
  Food production:◄ *energy transfer from lower to higher trophic levels*

- **Regulating services**: *benefits obtained from the regulation of ecosystem processes*
  Gas & climate regulation: ◄ *carbon cycling and production of climate changing gases*
  Nutrient cycling: ◄ *nutrient incorporation and stoichiometry*
  Bioremediation of pollution: ◄ *CCS contaminants and pH induced contaminant remobilization*

- **Cultural services**: *nonmaterial benefits people obtain from ecosystems*
  "Its nice to be beside the seaside" ◄ *HAB prediction, erosion, sea level rise*

Information flow to policy makers

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Misconstrued

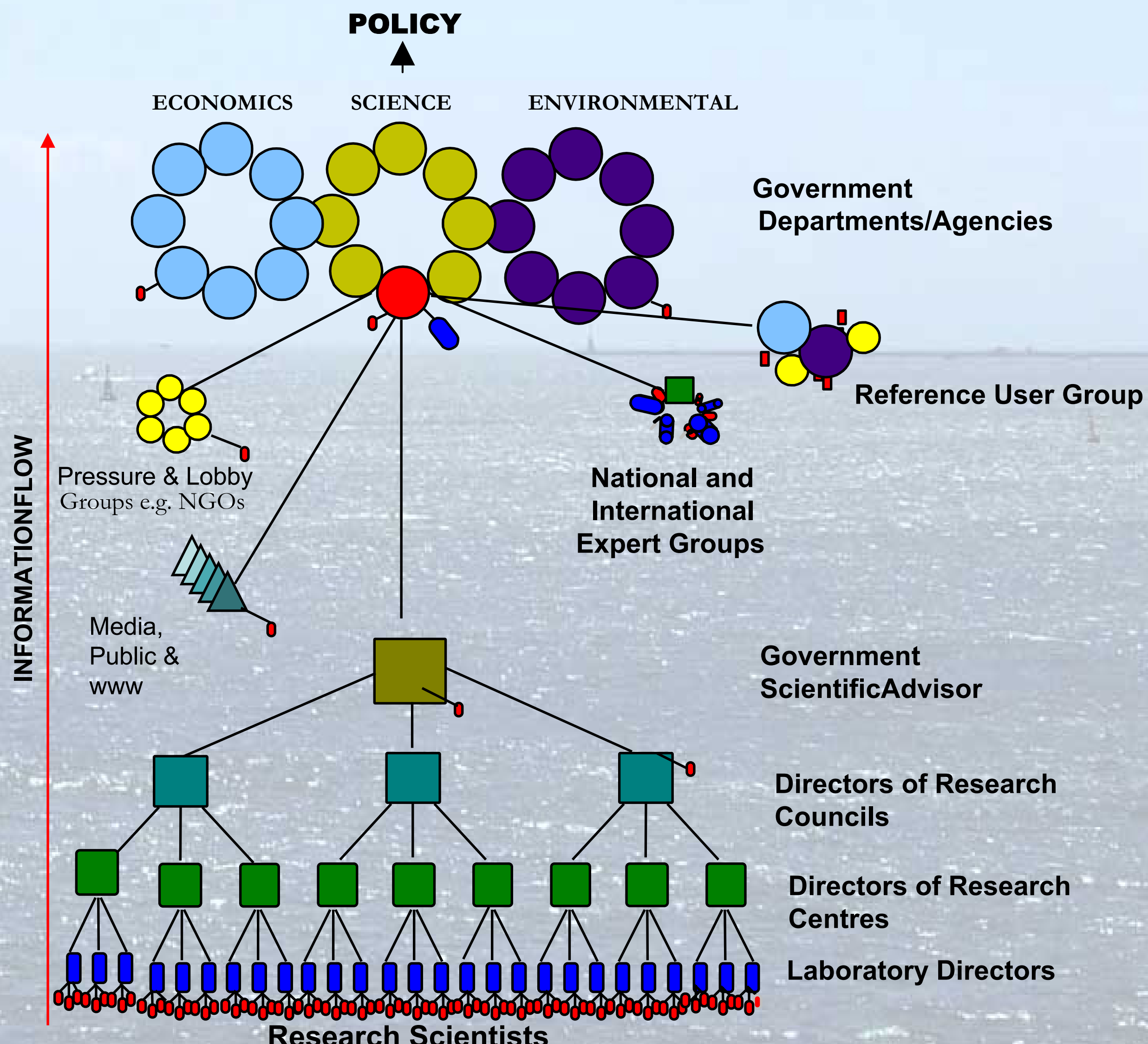
Misinterpreted

Generalization

Quality loss

Loss of context

Probabilities became facts



Communication & access

Involve the User Community in the Science

The PML Reference User Group (RUG) for High CO_2:

Government Depts: DEFRA, DTI, SE

NGOs: EN/NE, EA, UKCIP, SNH

Industry: BP

Pressure groups: WWF, Greenpeace, E3G

Europe: EEA

Independents: BGS, The Royal Society

Chair: Dan Laffoley - Natural England & IUCN WCPA

Conclusions

There is clearly a need for stronger interactions with models, observations, experiments and statisticians

- That funding schemes that couple modelling and observational / experimental research are prioritised. The design of new observational and experimental programmes should be driven by model requirements and statistical rigour.

- It is important for modellers and experimentalists to speak a common language for mutual understanding – often problems arise from the use of jargon. Funding provision for regular workshops that bring modellers and experimentalists together would improve communication and language issues and facilitate a synergistic approach.

thank you