Outputs and outcomes from the UKOA consortium on commercial species and socio-economic impacts

Kevin J Flynn et al.

Swansea University Prifysgol Abertawe

University of Exeter

University of Strathclyde Science

PML Plymouth Marine Laboratory

Natural Environment Research Council

Cefas

Seventh Framework Programme

Thanks for help with this talk to …

- **Swansea –** Ed Pope, Marie Scolamacchia, Jake Scolding, Andy King, Robin Shields
- **Exeter –** Rob Ellis, Rod Wilson, Ceri Lewis
- **Strathclyde -** David Morris, Douglas Speirs, Mike Heath
- **PML –** Nicola Beaumont, Jose A. Fernandes, Caroline Hattam

Project Aims

- Aim 4.1 Examine physiological and behavioural responses to OA
- Aim 4.2 Scale up laboratory studies to population/stock responses to OA including an analysis of possible socio-economic consequences.
- Aim 4.3 Examine how changes in planktonic and benthic food-webs, as a result of ocean acidification, impact upon the production and yields of commercial fish and shellfish stocks.
- Aim 4.4 Investigate possible socio-economic consequences of OA at an ecosystem level.

In essence … the impact of OA upon higher trophic levels

esp. commercial species

The Team

- **Swansea -** finfish & decapods; plankton mechanistic models
- **Exeter -** bivalves & respirometry
- **Strathclyde -** fisheries modelling
- **PML -** socio-economic modelling

Swansea University Prifysgol Abertawe

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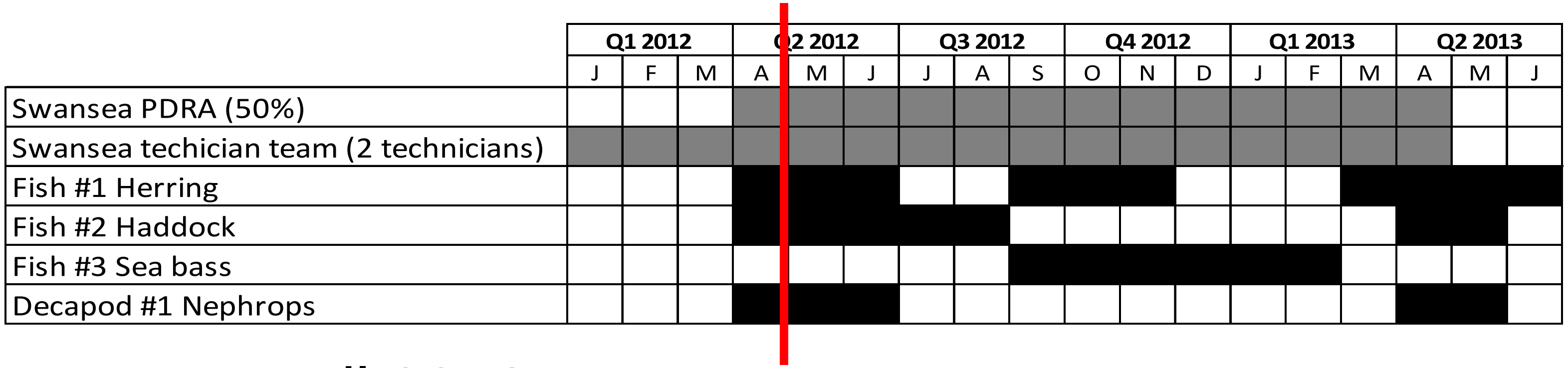
Swansea

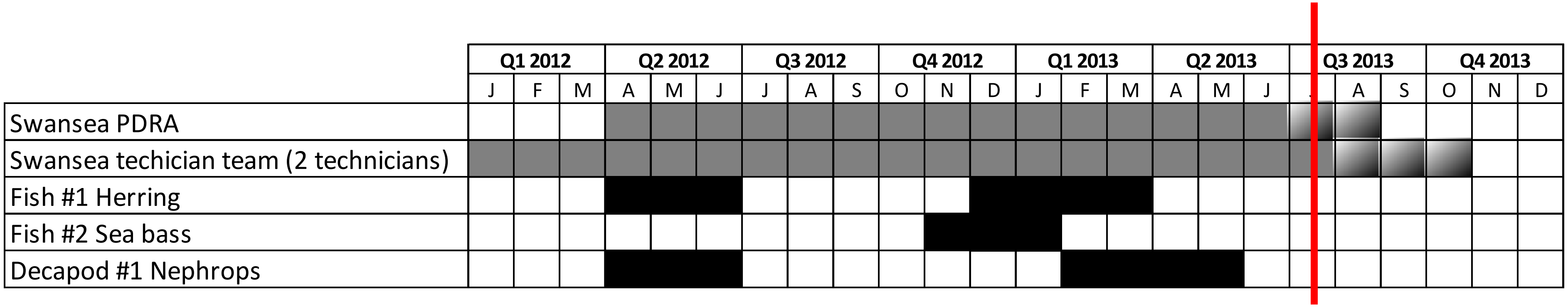
- finfish & decapods
- phytoplankton & copepods **(via other NERC funding)**
- mechanistic models of plankton **(in part via EuroBASIN)**

Effects of near-future oceanic conditions on **early life stages** of commercially important **finfish** and **decapods**



Exeter, April 2012

- 1st herring trial just started
- 1st *Nephrops* trial just started



July 2013

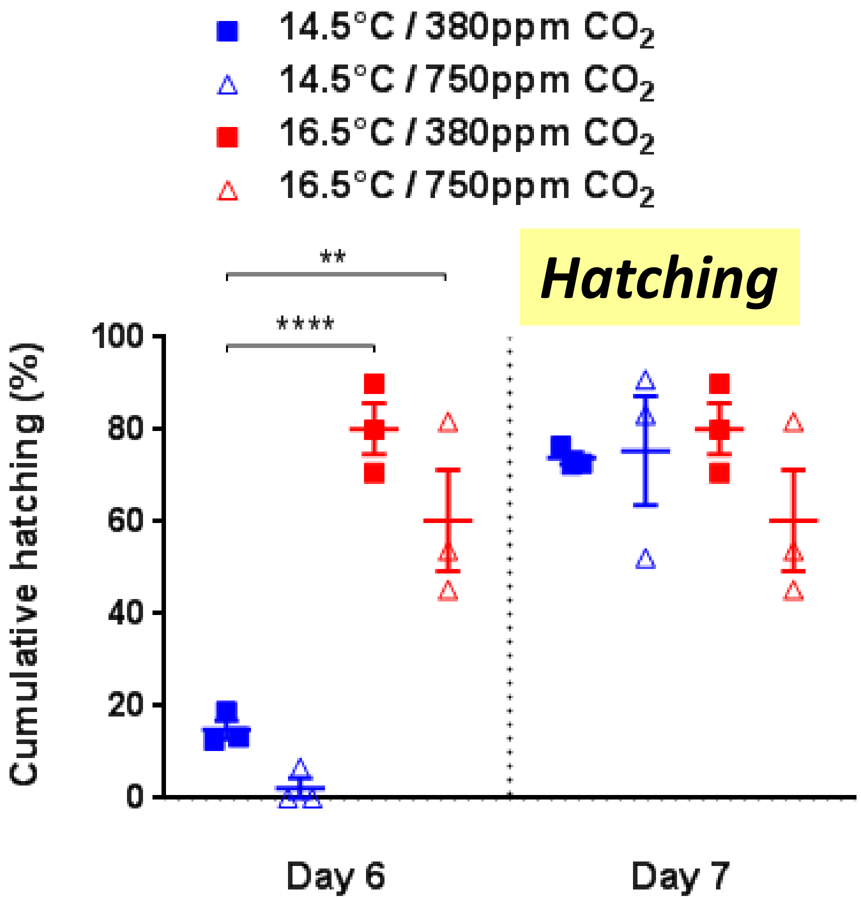
- Herring trial #1 completed **(until d_{26})**
- Herring trial #2 completed **(until d_{42})**
- Sea bass trial #1 completed

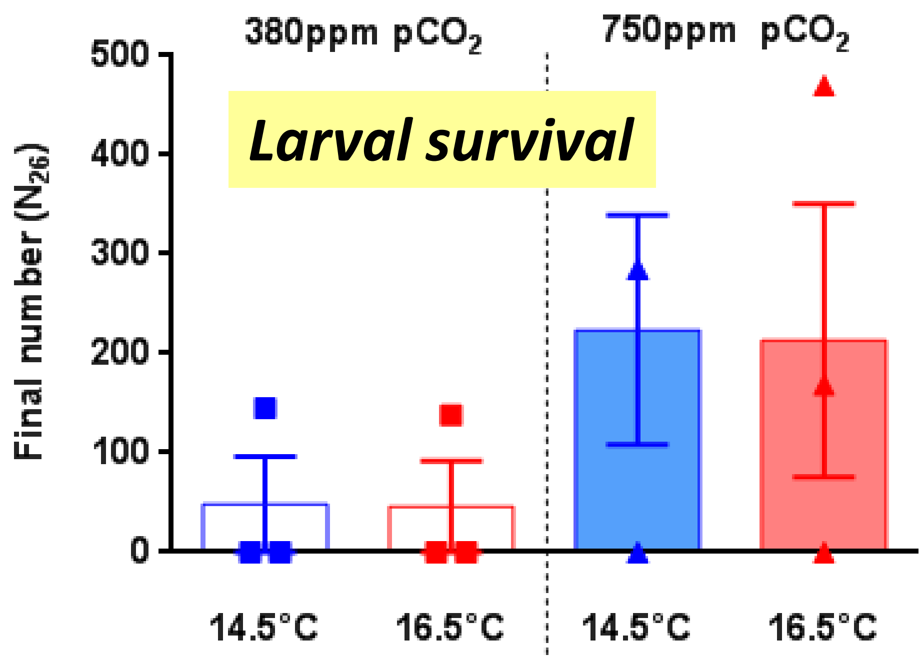
  (until metamorphosis to juveniles, at d_{42})
- *Nephrops* raised until metamorphosis to post-larvae **(larval stage IV, at ca. d_{30})**

Atlantic herring, *Clupea harengus* TRIAL #1, 2012

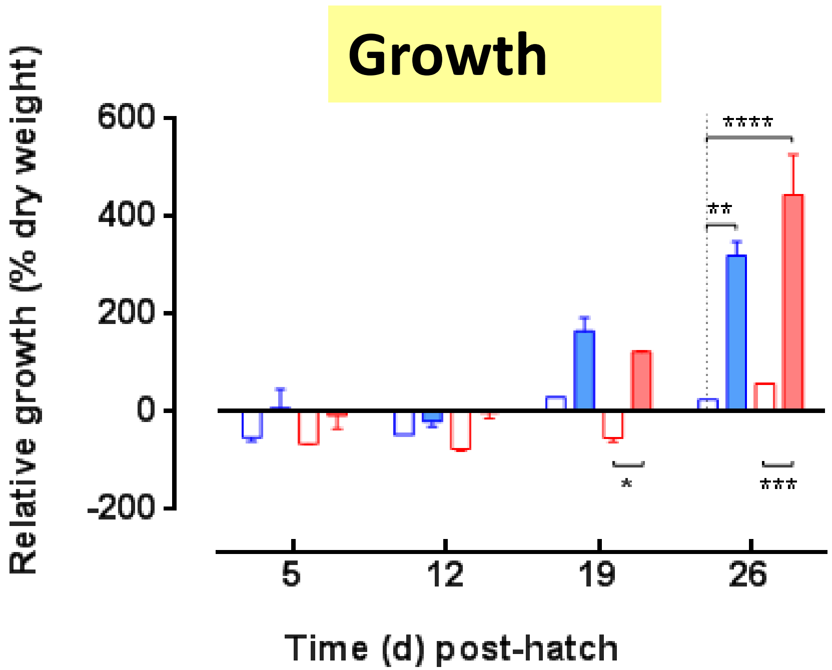
- Plates coated in fertilised eggs placed in experimental tanks
- Incubated until 26d post-hatch
- 3 tanks treatment^{-1}

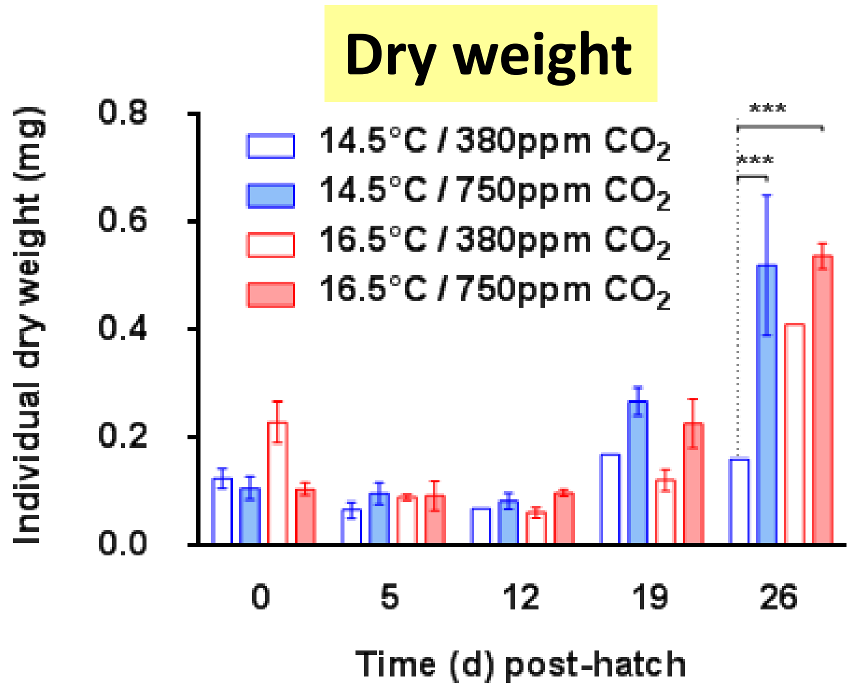
Method made equal distribution of larvae extremely problematic; though hatching occurred under treatment incubation conditions





Atlantic herring, *Clupea harengus* **TRIAL #1, 2012**





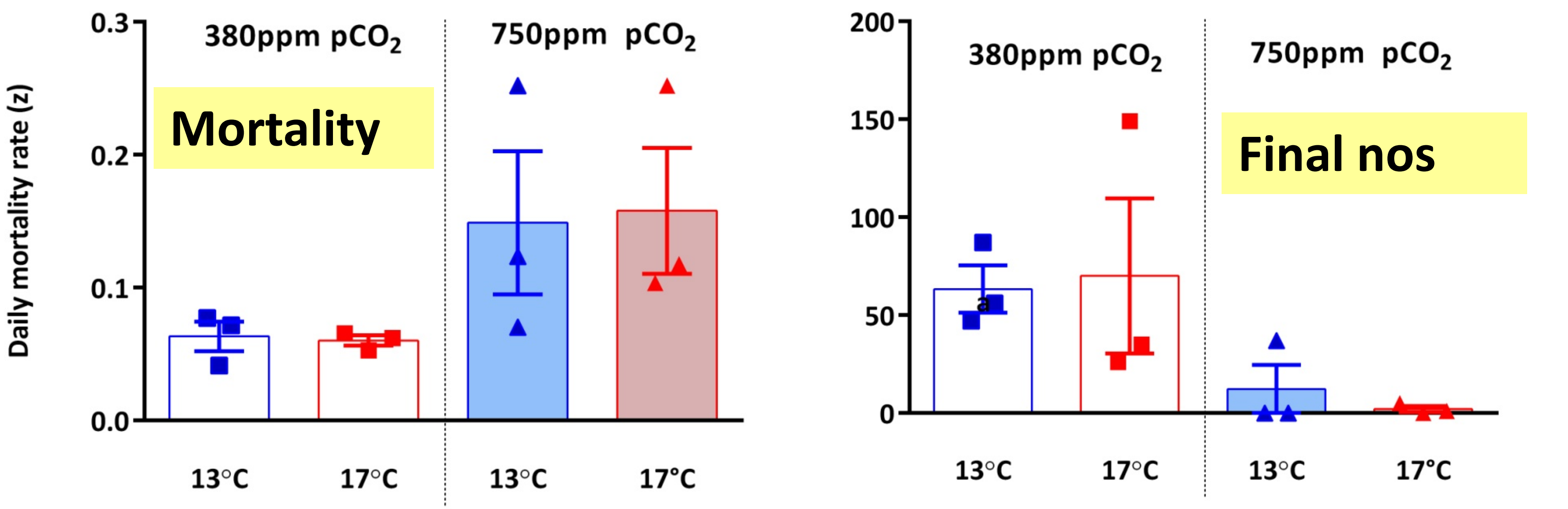
Atlantic herring, *Clupea harengus* ***TRIAL #1, 2012***

- Suggestion that 750ppm CO_2 was supportive of survival and growth
- However, concern was levelled at the poor survival of the control (extant T, extant pCO_2)
- Suspicion that something happened during the initial distribution of eggs resulting in marked differences in stocking density

Atlantic herring, *Clupea harengus* TRIAL #2, 2013

- <u>Eggs hatched under ambient conditions</u>
- 1,000 larvae counted into each experimental tank on hatch and raised until 42d post-hatch
- 3 tanks treatment^{-1}

Method made equal distribution of larvae easy BUT newly hatched larvae were now ramped to conditions over 24h

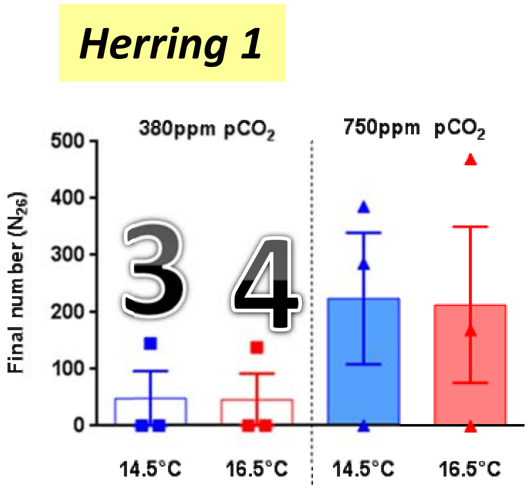


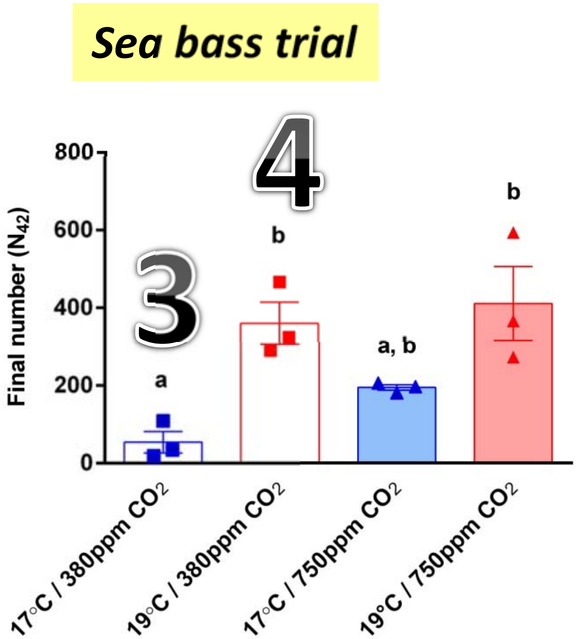
Atlantic herring, *Clupea harengus* ***TRIAL #2, 2013***

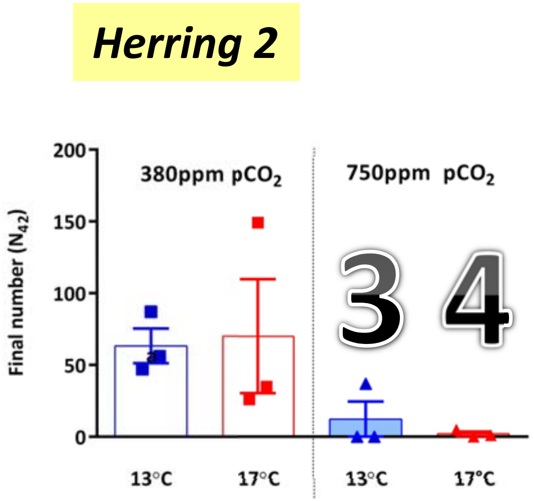
- Contrary result in comparison to trial #1 ..
- … now the 750ppm PCO_2 result appears worse
- WHY?

System	Tank	Trial 1 (2012)		Trial 2 (2013)	
		CO_2 (ppm)	Temperature	CO_2 (ppm)	Temperature
1	1	750	16.5°C	380	17°C
	2	750	16.5°C	380	17°C
	3	750	16.5°C	380	17°C
2	4	750	14.5°C	380	13°C
	5	750	14.5°C	380	13°C
	6	750	14.5°C	380	13°C
3	7	380	14.5°C	750	13°C
	8	380	14.5°C	750	13°C
	9	380	14.5°C	750	13°C
4	10	380	16.5°C	750	17°C
	11	380	16.5°C	750	17°C
	12	380	16.5°C	750	17°C

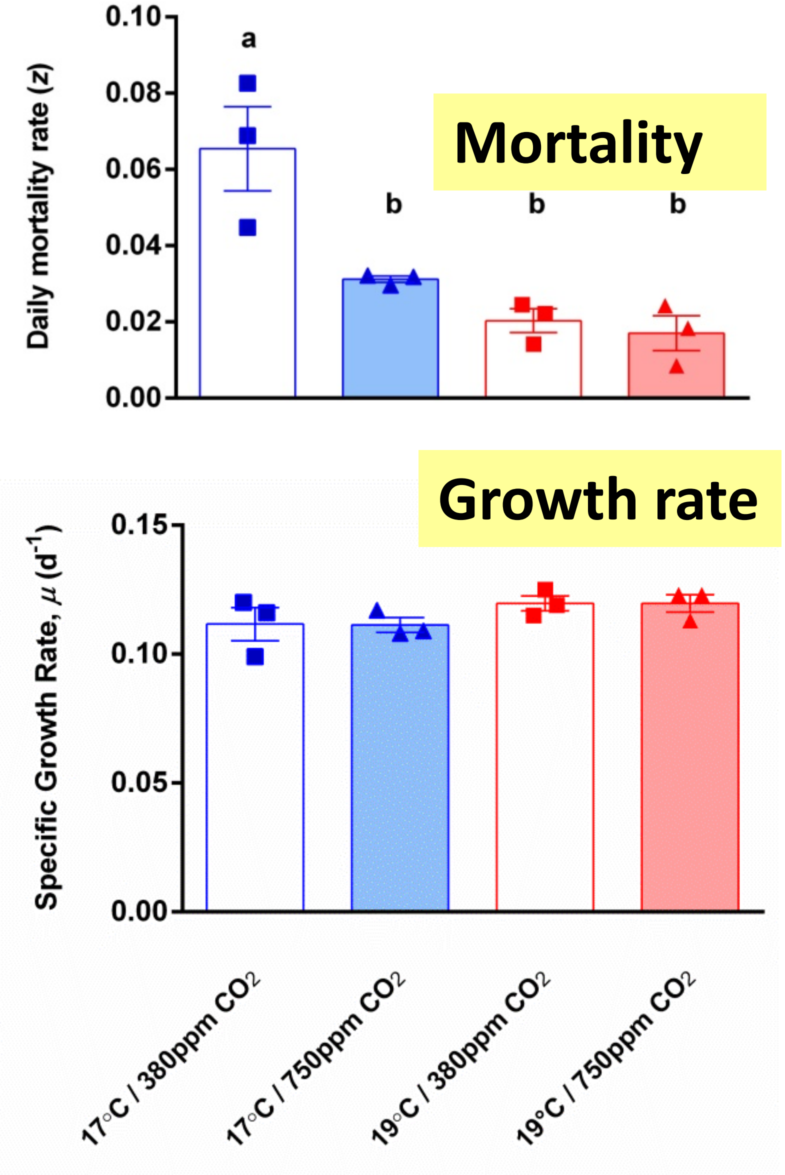
- ~~System (tank) effects?~~
- Pre-exposure of eggs enhanced survival?
- &/or prior nutritional history of wild-sourced eggs?

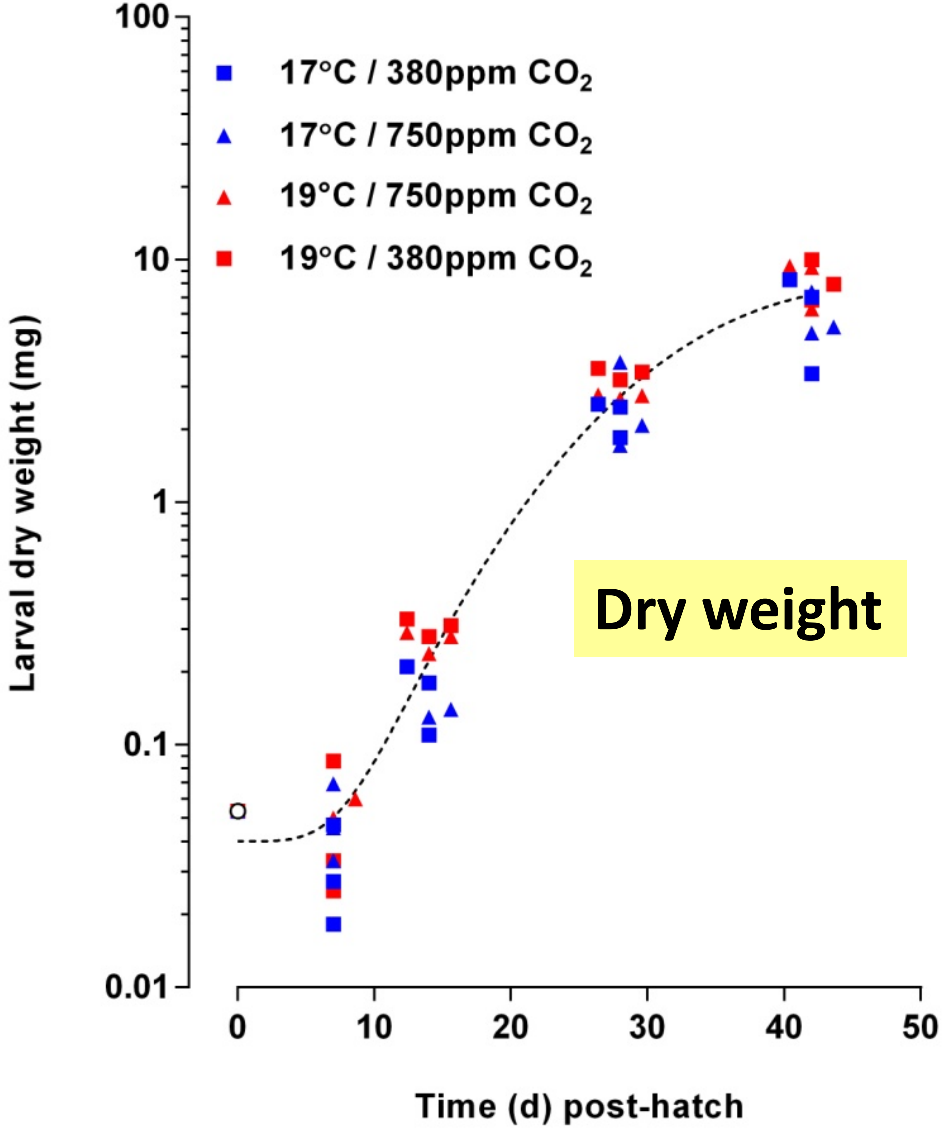






European seabass, *Dicentrarchus labrax*





Sea bass respirometry

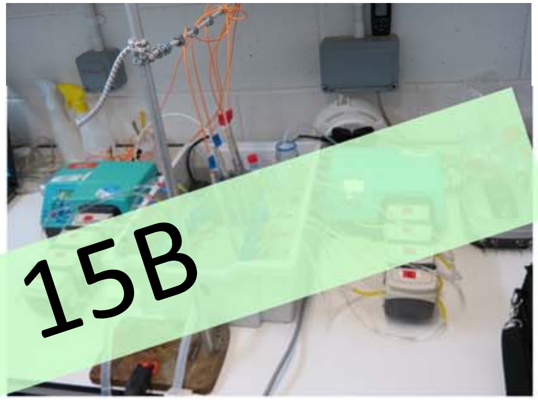
Objectives:

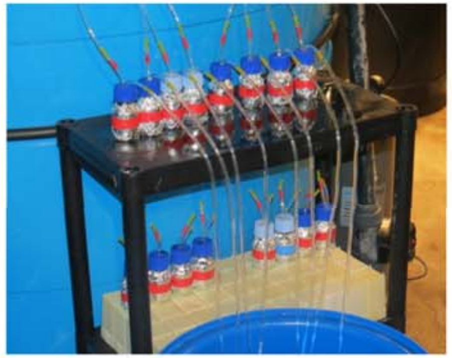
Investigate the impact of CO_2 concentration on routine and maximal O_2 uptake and aerobic scope

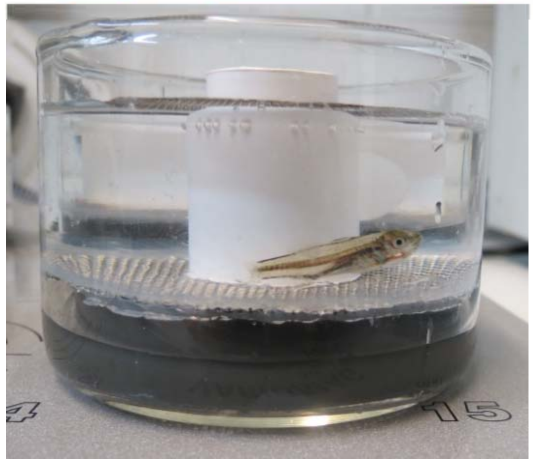
Larvae acclimated in respiration chambers 4 h prior to routine

For maximal O_2 uptake larvae swam at maximal speed for 10 min

POSTER – Pope et al. 15B







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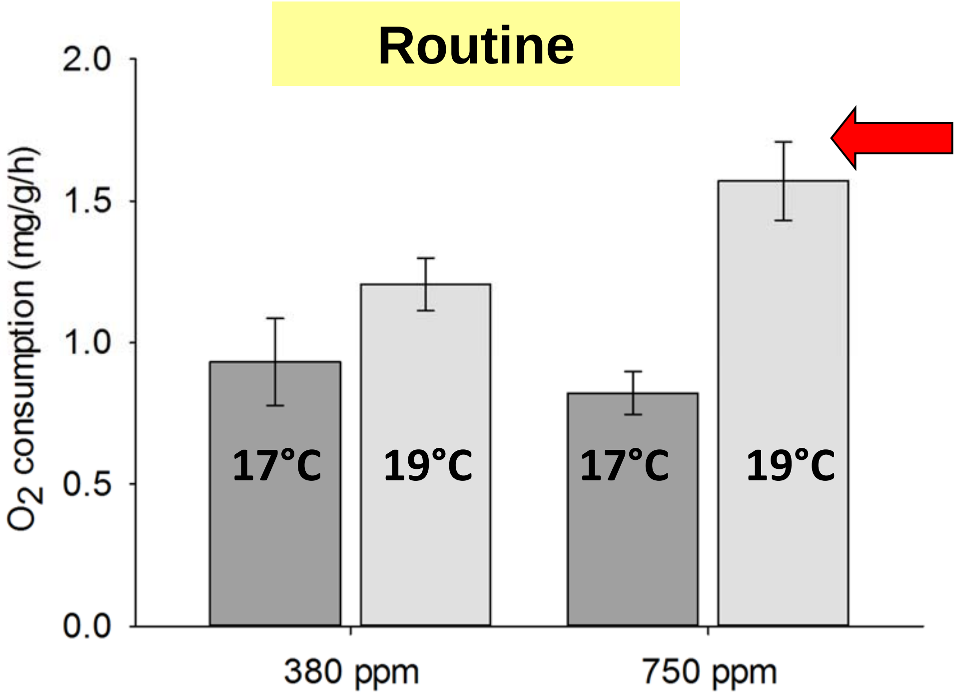
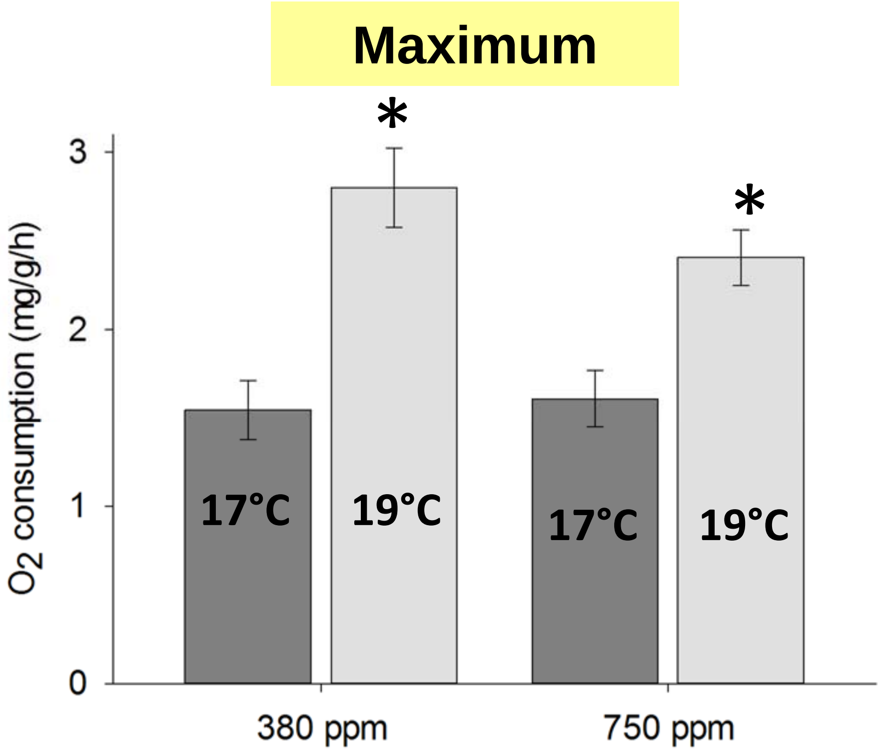
Sea bass respirometry



Significant *CO_2 concentration x Temp* interaction on routine O_2 consumption

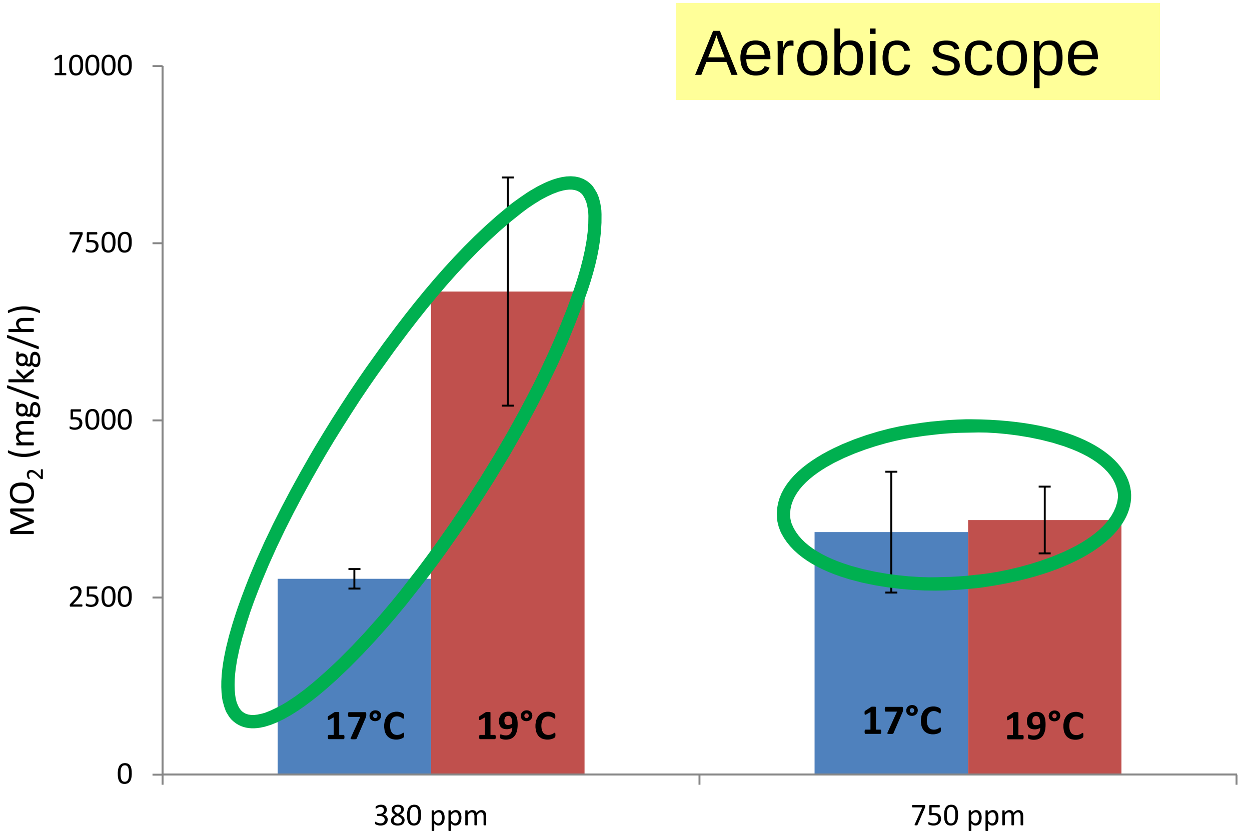
Sea bass respirometry



Significant effect of Temp on maximum O_2 consumption **(with interesting Q10)**

No effect of CO_2 concentration

Sea bass respirometry

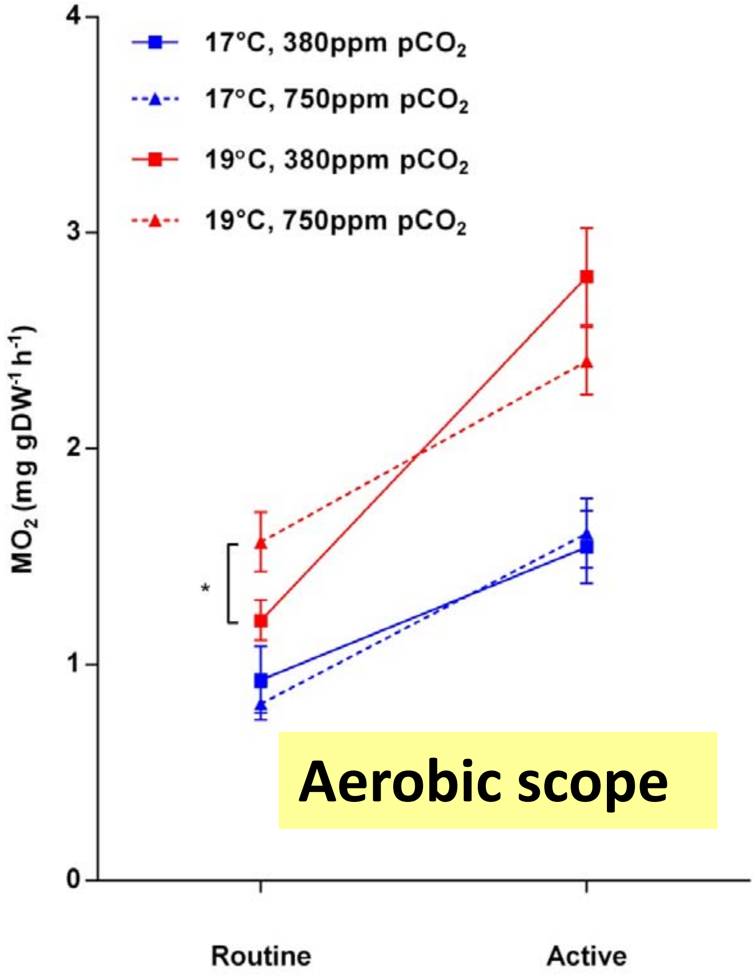


* Data pooled for treatment for aerobic scope

SO….

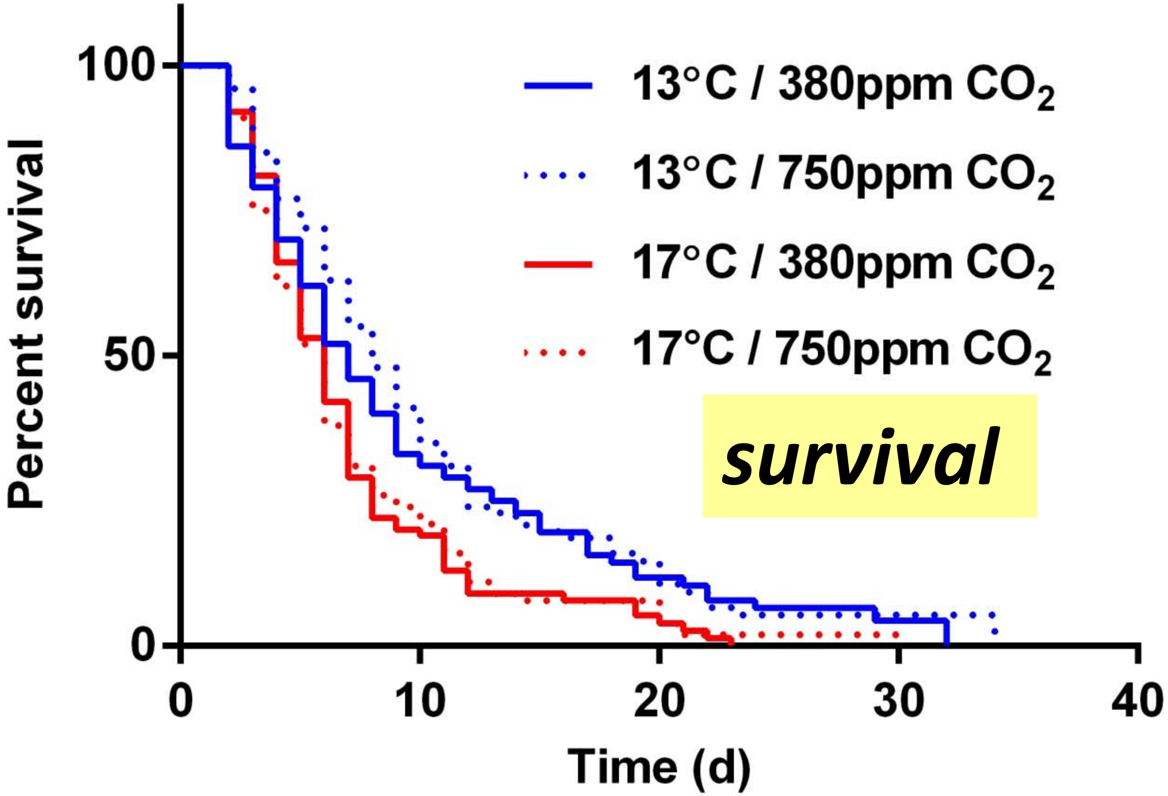
Early developmental stages of **European seabass** show resiliency to higher CO_2

but <u>decreased</u> aerobic scope
… perhaps linked to developmental state
… perhaps indicating additional stress at 750 ppm



Nephrops norvegicus

20 larvae per treatment, 5 replicates



survival

SEVENTH FRAMEWORK PROGRAMME

Elevated T is detrimental

750ppm pCO2 has little/no effect

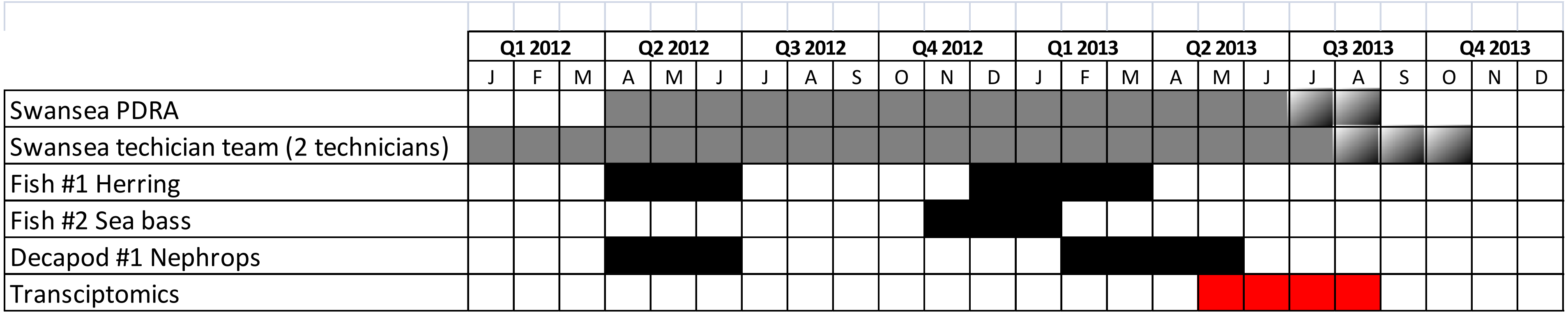
Conclusions for finfish & decapod larval stages

- Larval stages are critical in the life cycle, but are rarely studied over an substantive period
- Logistically very demanding experiments to initiate and then run (live feed etc.)
- Results give some cause for concern wrt OA, but also some cause for optimism
- T appears a greater issue.
- Equally problematic are synergistic effects with T, pH, prior nutritional history & food availability during and before larval stages

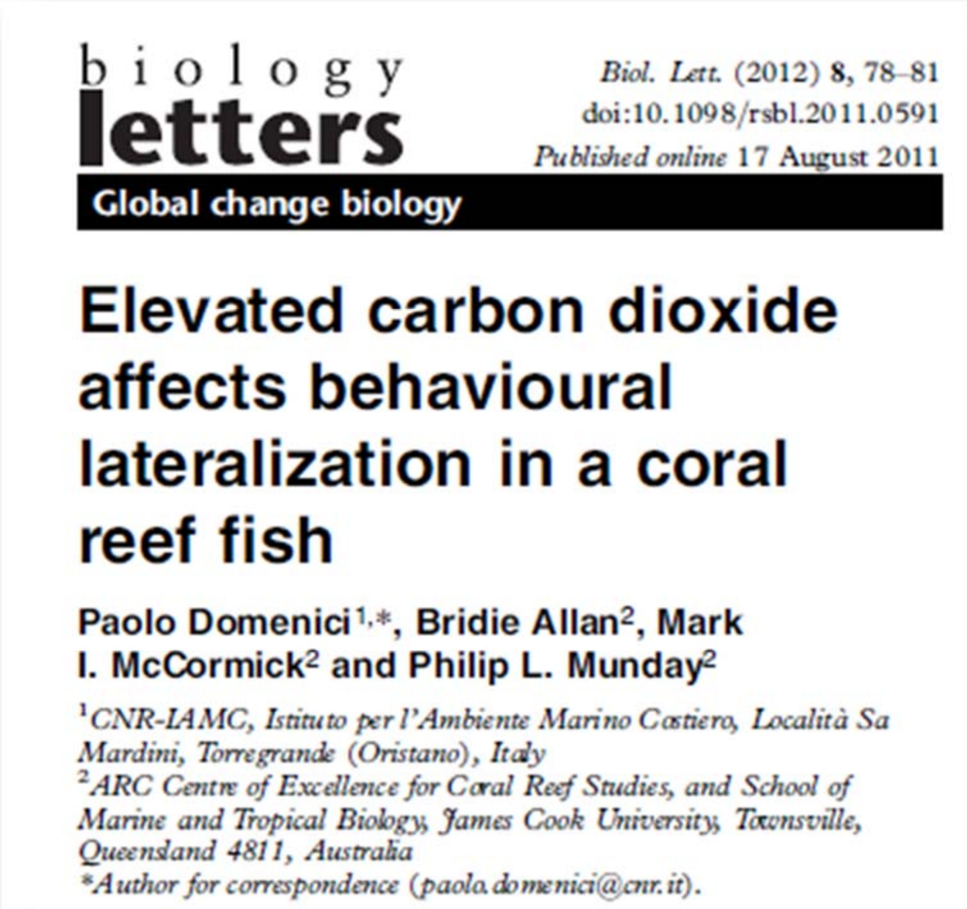
AVA - Detecting stress on larval marine fish under conditions of OA; a combined behavioural, biochemical and molecular approach

1. Further investigations on the effects of growing finfish larvae under near-future OA conditions, including an examination of the fatty acid profile
2. Use of transcriptomics to look for a molecular mechanism behind OA responses in finfish
3. Studying the potential effects of OA conditions on fish schooling

Detecting stress on larval marine fish under conditions of OA; a combined behavioural, biochemical and molecular approach



- Samples (herring and sea bass, d_0, d_7, d_{14}, d_{42}) stored (-20°C) for FTIR analysis of biochemical content ….
- …. sea bass data currently being analysed
- Samples (herring and sea bass, d_0, d_7, d_{14}, d_{42}) flash frozen (-80°C) for transcriptomics analysis. Herring will be dispatched to the Centre for Genomic Research, U Liverpool in August 2013.



biology letters

Global change biology

Biol. Lett. (2012) **8**, 78–81
doi:10.1098/rsbl.2011.0591
Published online 17 August 2011

Elevated carbon dioxide affects behavioural lateralization in a coral reef fish

Paolo Domenici[1,*], Bridie Allan[2], Mark I. McCormick[2] and Philip L. Munday[2]

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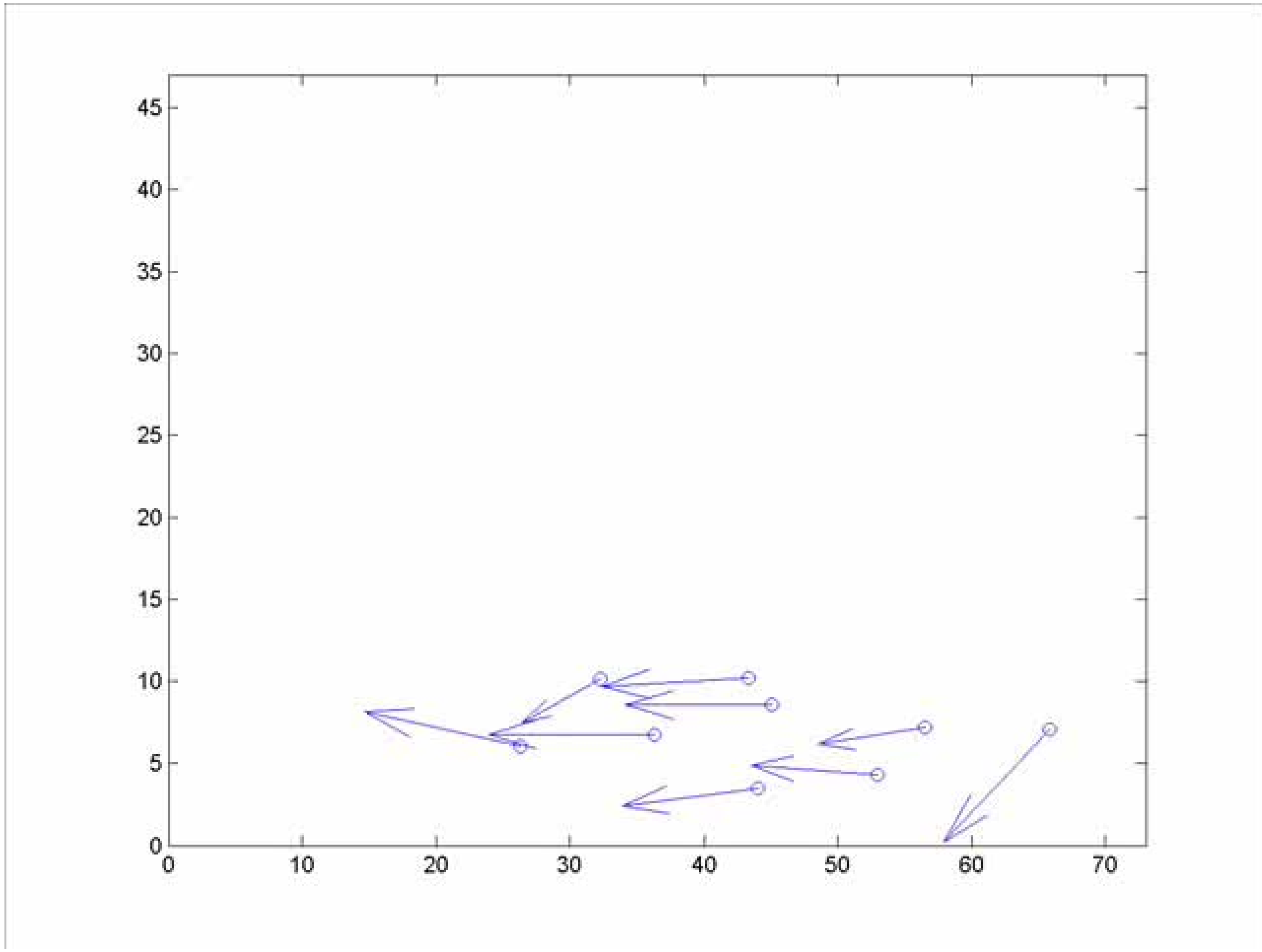
[2]*ARC Centre of Excellence for Coral Reef Studies, and School of Marine and Tropical Biology, James Cook University, Townsville, Queensland 4811, Australia*
**Author for correspondence* (paolo.domenici@cnr.it).

Impaired learning of predators and lower prey survival under elevated CO_2: a consequence of neurotransmitter interference

Douglas P. Chivers[1]*, Mark I. McCormick[2], Göran E. Nilsson[3], Philip L. Munday[2], Sue-Ann Watson[2], Mark G. Meekan[4], Matthew D. Mitchell[2], Katherine C. Corkill[2] and Maud C.O. Ferrari[5]

Studying the potential effects of OA conditions on fish schooling

Movie of fish tracking

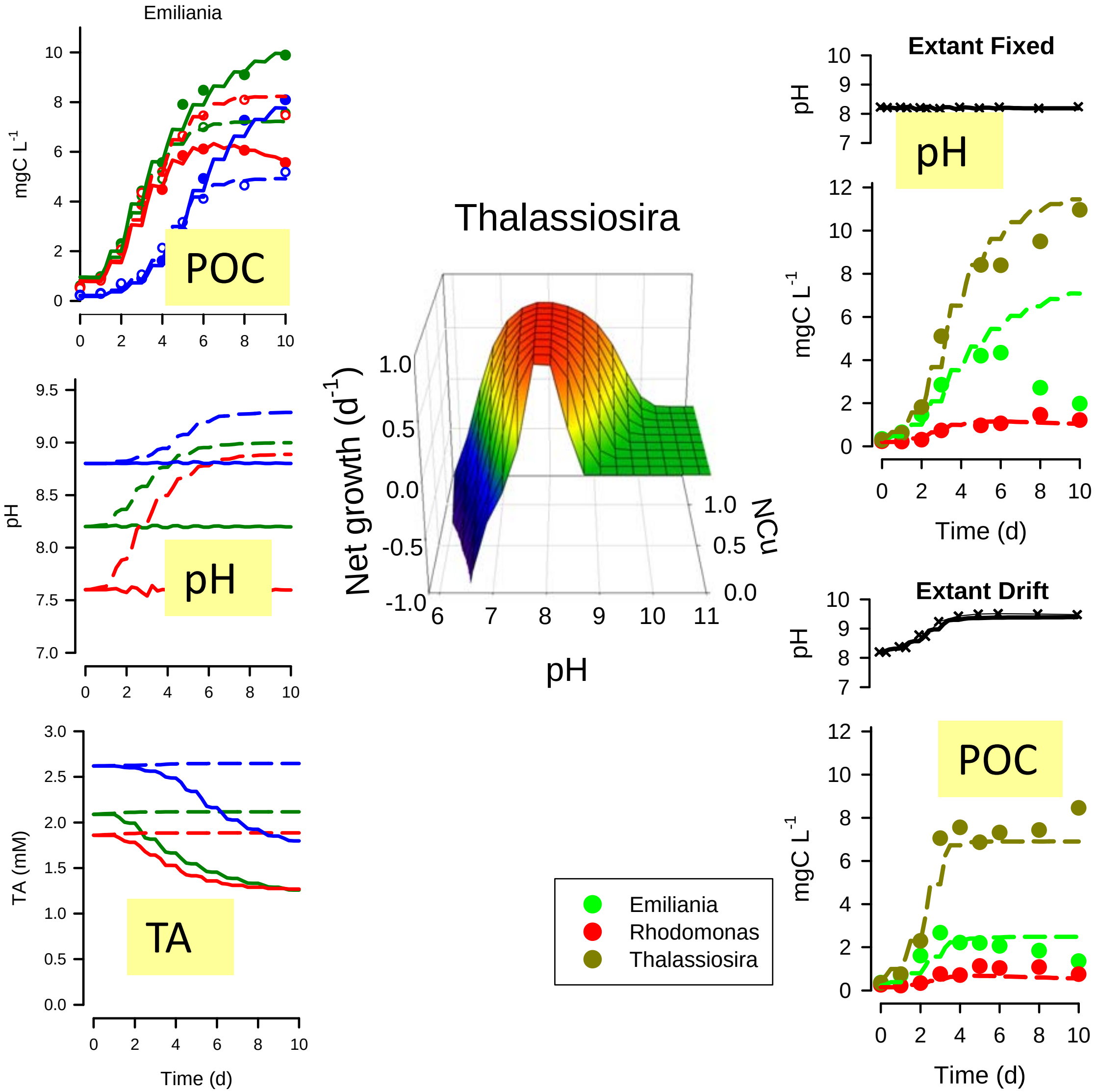


Swansea; other OA work

Partitioning of C, N and P between particulate and dissolved phases during growth of phytoplankton at different pH

Flynn, Clark, Blackford, Fabian (NERC funded, 2008-11)

- Unialgal cultures in fixed/drift pH used to parameterise CNPChl adaptive models
- Give response curves to pH and nutrient status
- Model vs mixed cultures indicate additional importance of allelopathic interactions changing with nutrient status



Could maternal influences be masking the negative reproductive effects of OA in copepods?

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Gemma Cripps et al.

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POSTER – Cripps et al. 5B

- Poster – go look at it ☺
- Like the finfish decapod results, this emphasizes cumulative importance of apparently subtle and synergistic impacts and criticality of exp design
- Data to be used to configure coupled phytoplankton-zooplankton models

EXETER

- Bivalves
- Respirometry **(fish work reported above)**
- AVA – OA and aquaculture

Recap from last meeting

- Exeter to investigate impact of OA and temp on bivalve species
- Undertake physiological, morphological and developmental measurements
- Investigate O_2 consumption in juvenile fish

- Initial set-up phase in April 2012

Mytilus edulis

Pecten maximus

Crassostrea gigas

Proposed experimental plan (Exeter meeting April 2012)

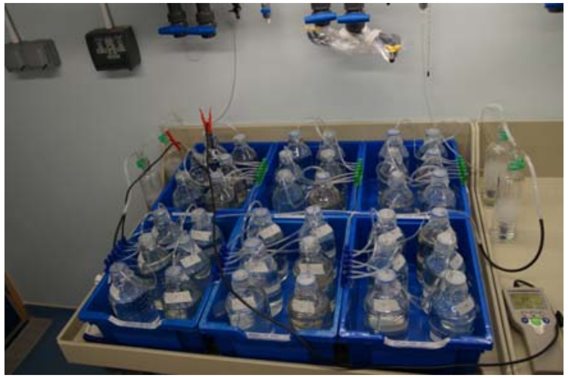
	2012																	
	April		May		June		July		Aug		Sept		Oct		Nov		Dec	
Finalise experimental Set up																		
Oyster availability																		
Scallop availability																		
1st Oyster Trial																		
1st Scallop Trial																		
2nd Scallop Trial																		
2nd Oyster Trial																		
Work up outstanding morphological data																		
Work up outstanding confocal microscopy																		

State of play for bivalve work

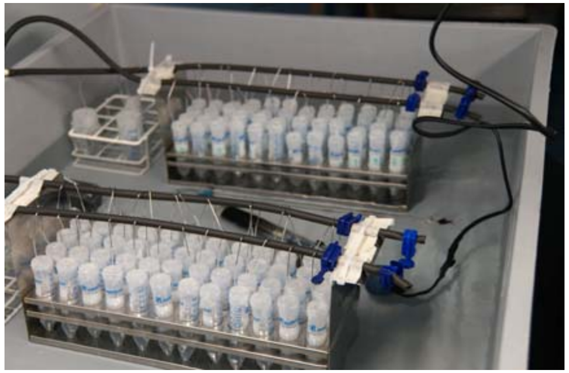
- Long term physiological studies are challenging
- 3 novel, purpose built, experimental setups
- 3 unsuccessful attempts to spawn scallops
- 7 Pacific oyster trials run 2012-13
- Success with sperm motility, fertilisation and 2 week feeding trial

System 1 (Developmental trial, flow through)

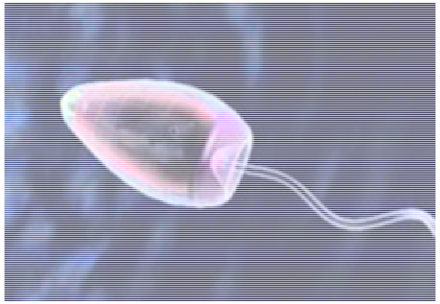
System 2 (feeding trial, static)



System 3 (fertilisation study, static)



*Oyster data – **Sperm motility***



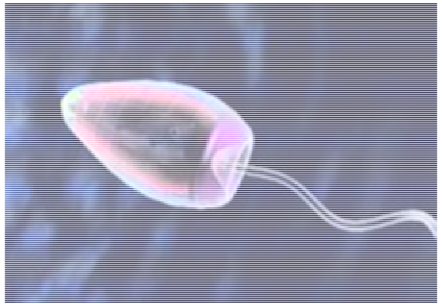
Objectives:

Impacts of OA on sperm motility and fertilisation show variable results in growing number of species

Such effects have implications for reproduction and thus population dynamics

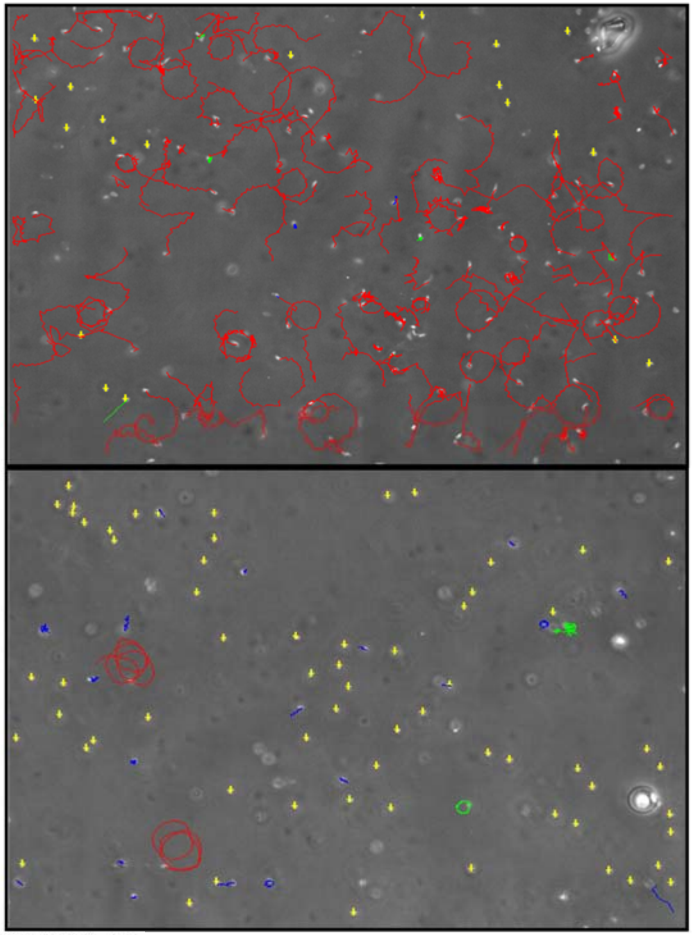
Study to investigate impact of OA, temp, on sperm motility and fertilisation in Pacific oyster

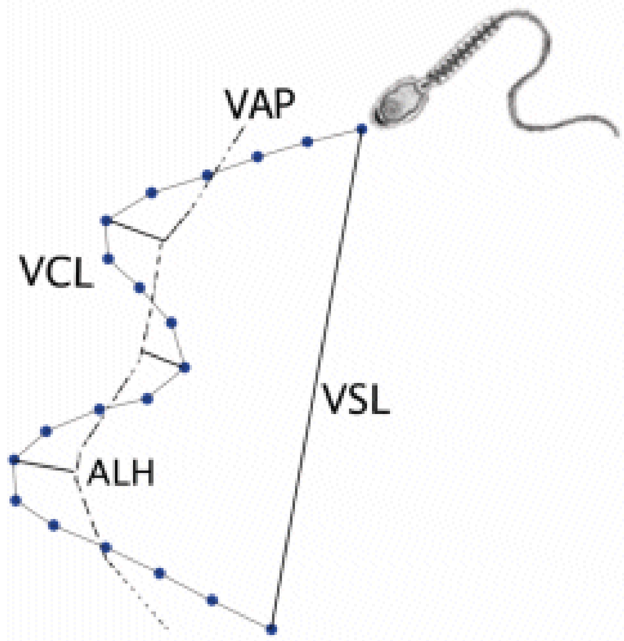
*Oyster data – **Sperm motility***



Measuring sperm motility

* Rapid progressive motility	* Medium progressive motility
* Slow progressive motility	* Immotile





Curvilinear velocity (VCL)
Straight line velocity (VSL)
Velocity average path (VAP)

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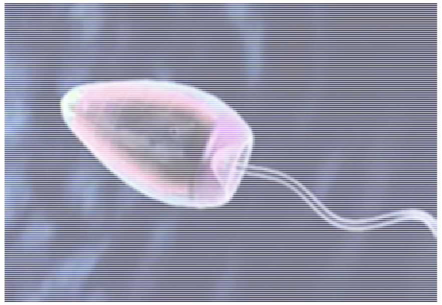
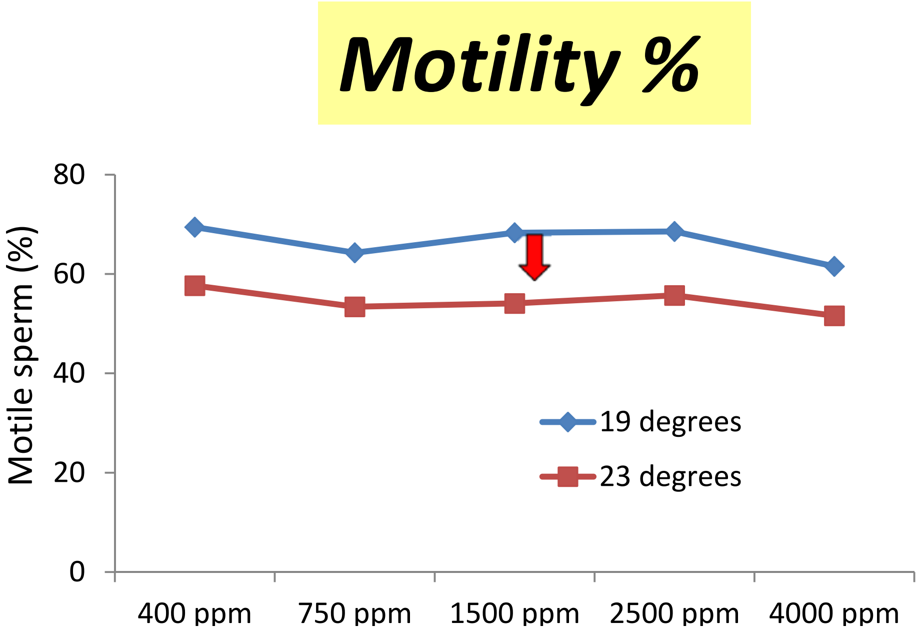
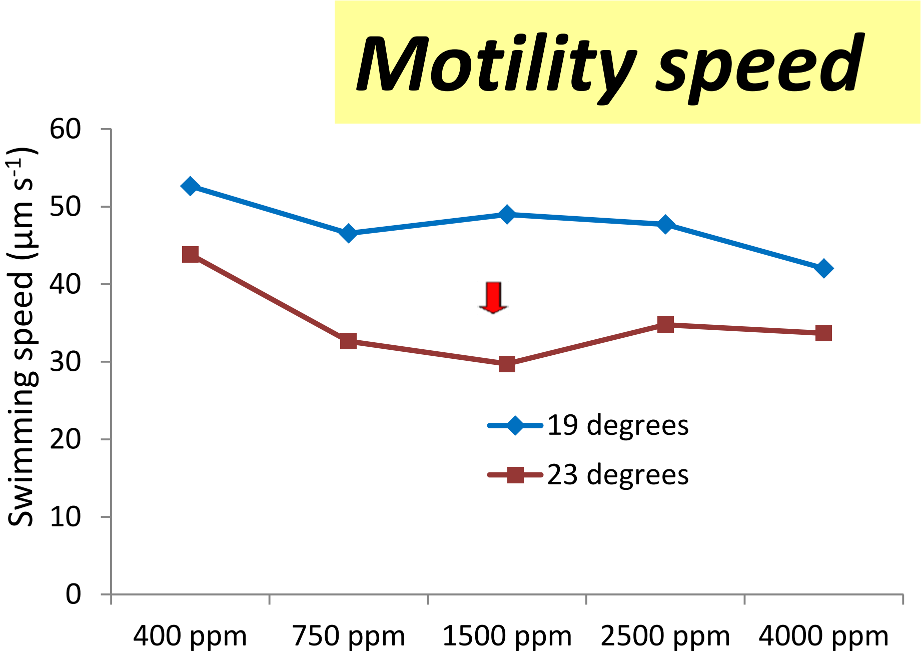
c.n.lewis@exeter.ac.uk; @CezzaLew

*Oyster data – **Sperm motility***



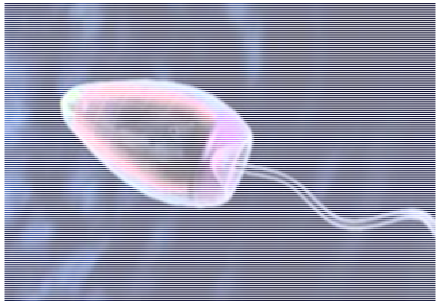


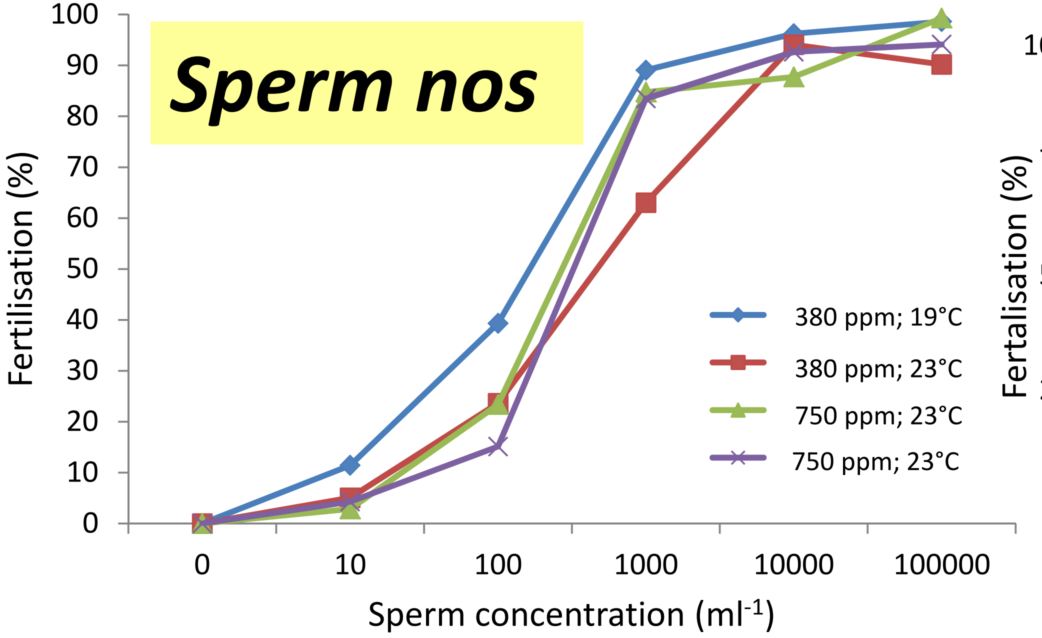


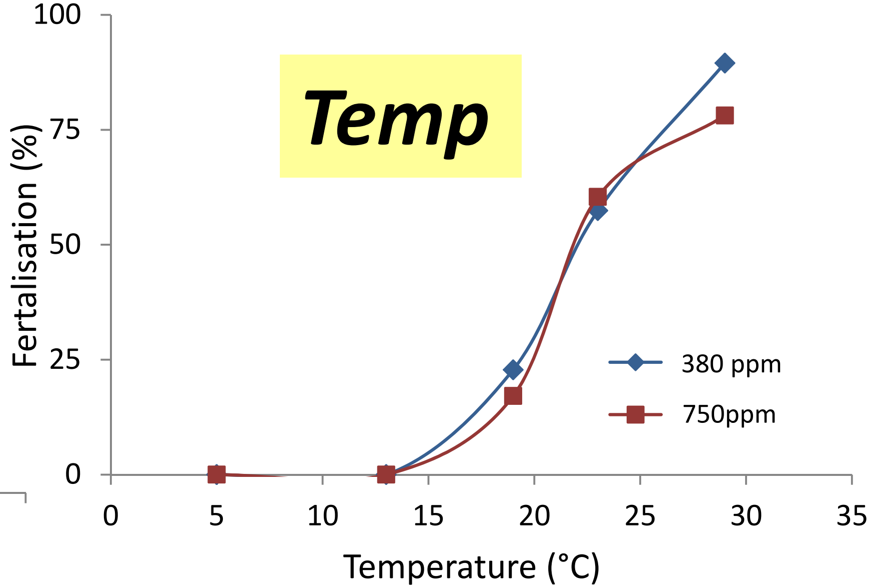
Increased temperature reduces the percentage of motile sperm and sperm swimming speed

No effect of CO_2 concentration on any measured sperm motility parameter

Oyster data – **Fertilization**



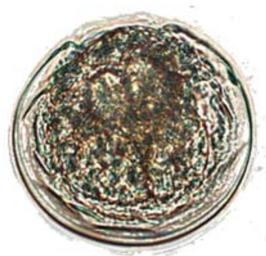




Both increased sperm concentration and increased T raise fertilisation, **BUT….**

… no interaction with CO_2 concentration

Oyster data – **Larval morphology**



Day 12 oyster larvae

Objectives:

2 week feeding trail

Measure larval morphology and survival

Investigate combined effect of CO_2 concentration and diet on development

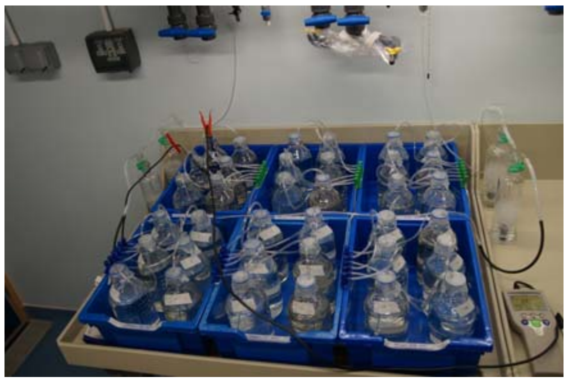
Investigate both single strain and mixed diets, as well as artificial and live diets

Hypothesis:

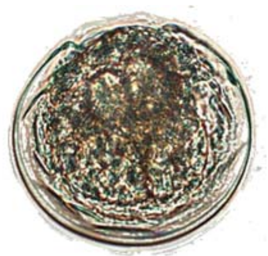
Larvae under increased CO_2 lower survival when food limited

Live mixed diet better than artificial
(implications for aquaculture and in nature)

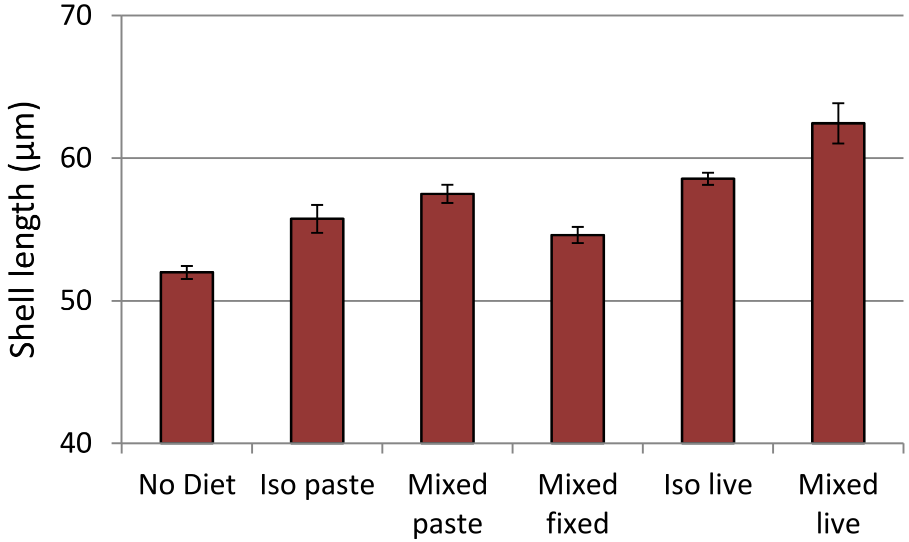
System 2 utilised

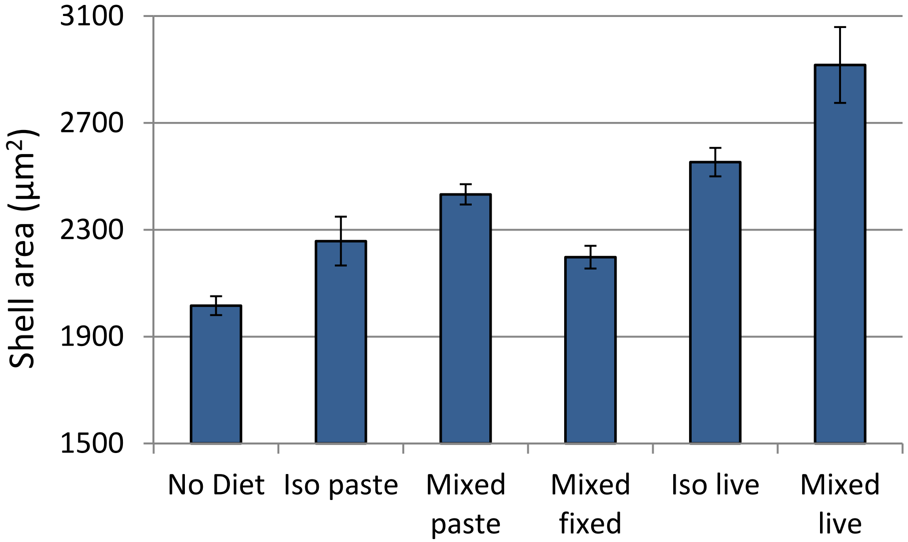


Oyster data – **Larval morphology**



Day 12 oyster larvae

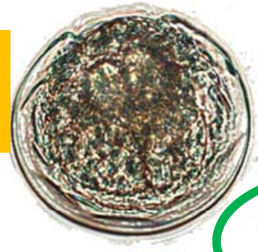




Diet significantly affects shell length and area

Largest larvae given under mixed live diet

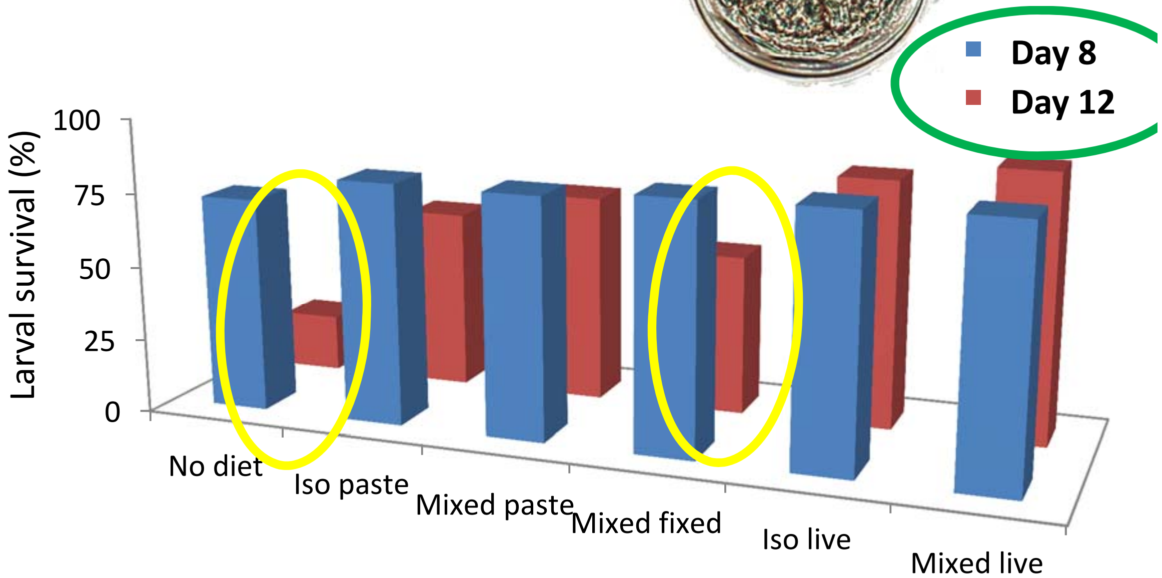
Oyster data – **Larval survival**

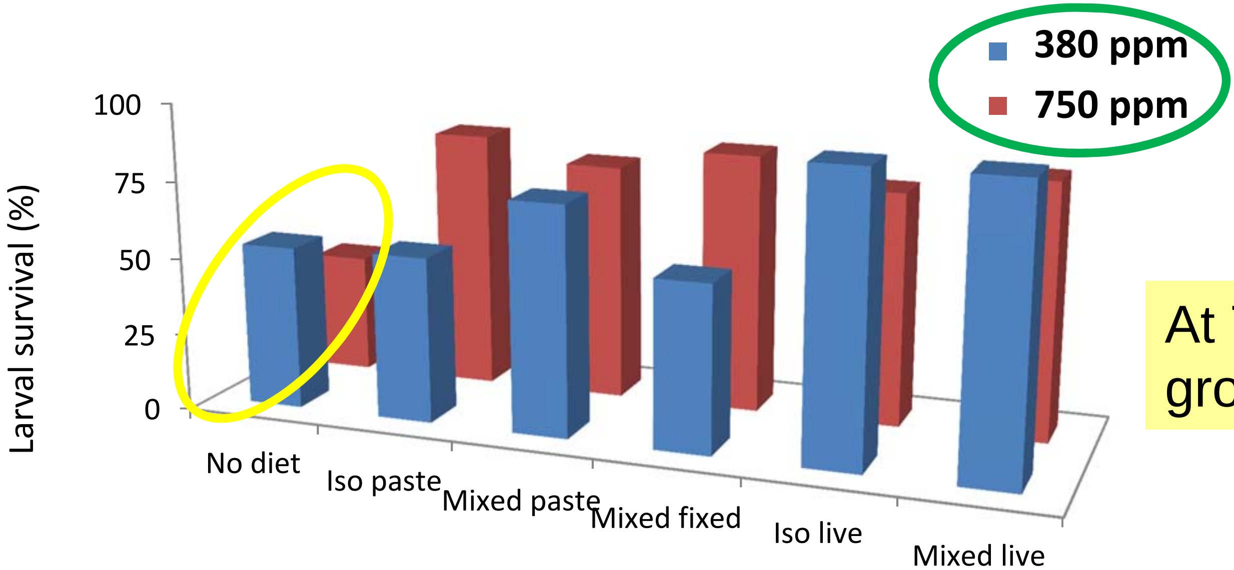


Pooled over both pCO2 …

After 8 days development no diet effect

After 12 days, less survival under artificial diet and no diet





At 750 ppm only the *no-diet* group had lower survival

Conclusions for bivalves (oyster)

- Sperm and fertilization data suggests no cause for concern for the very initial stages of oyster growth under OA
- Beyond fertilization, provided the diet is good, again no cause for concern with OA …
- … the problem is if the diet (phytoplankton) changes in chemical quality, taxonomic quality and/or quantity

AVA - Understanding future risks to the aquaculture and shellfish sectors from a high CO_2 world and its impacts on the marine environment

- Carbonate chemistry in open ocean systems is relatively well characterised

- In coastal regions carbonate system is rather less well understood

- Very little known about conditions that aquaculture sites experience

Objectives:

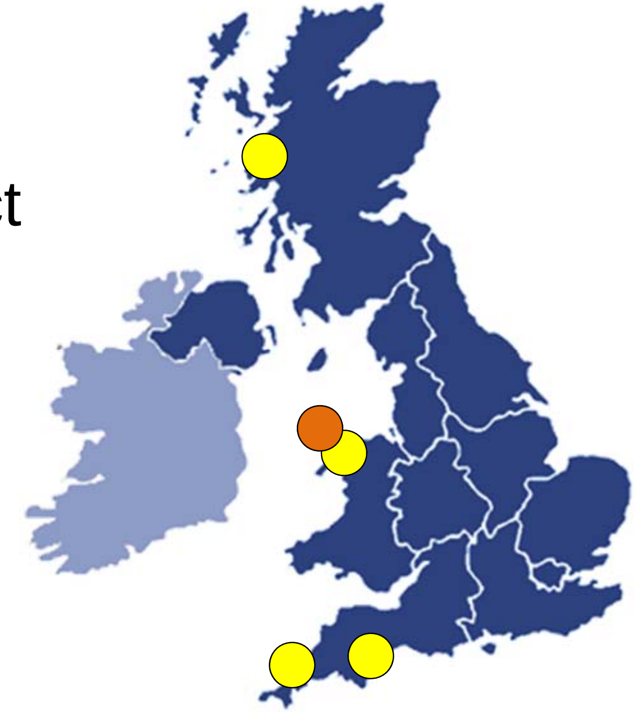
Work with industry partners, educating about OA, *via* workshops and training

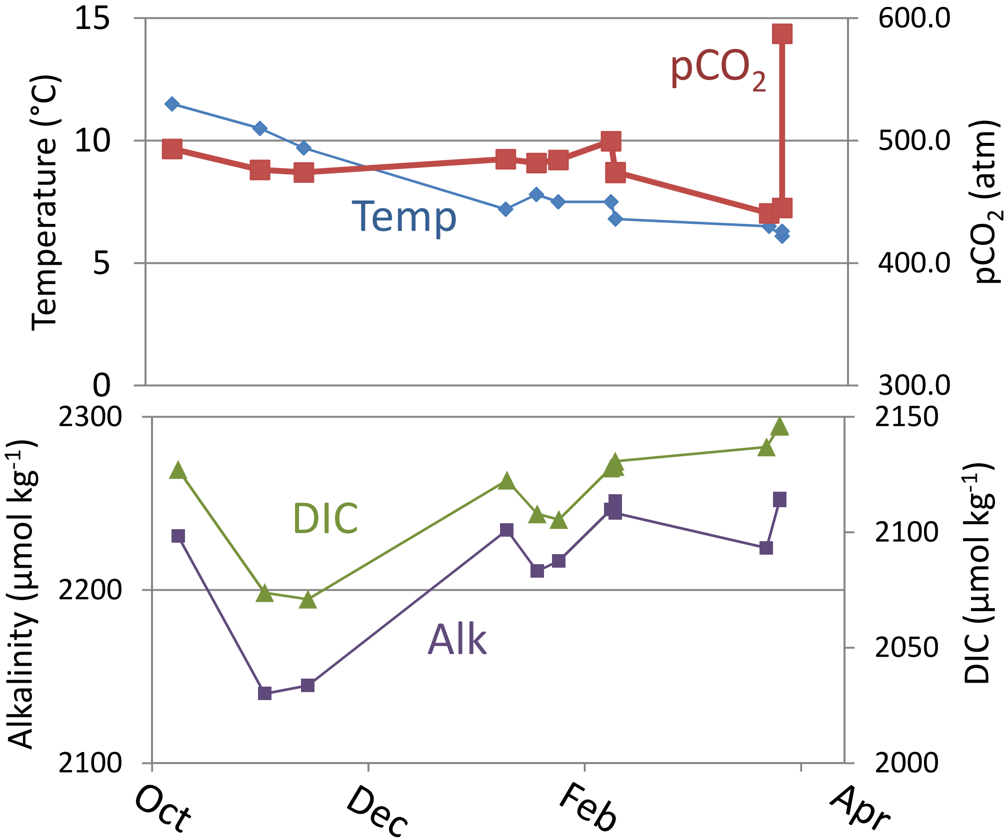
Undertake analysis of carbonate chemistry within aquaculture sites

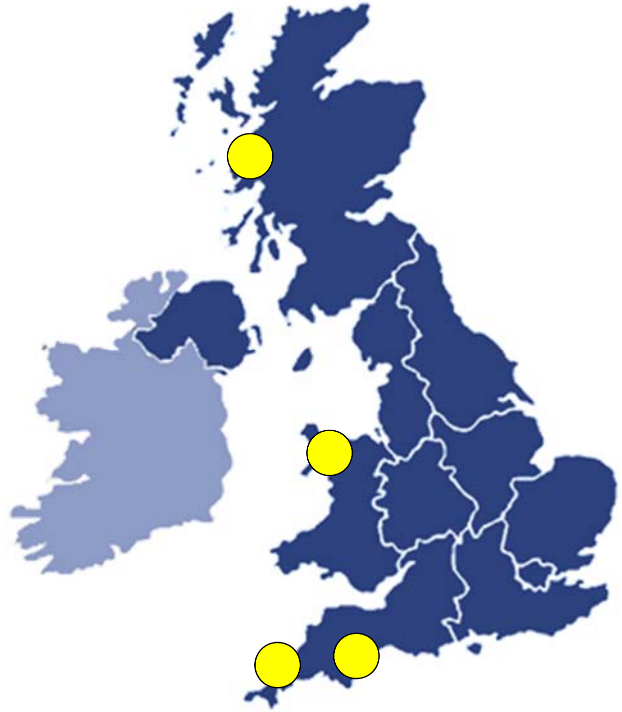
Does high density aquaculture lead to increased CO_2 concentration?

- 4 partners, UK wide, chemistry monitored 3x per month, over year
- Initiated Sept 2012, to be complete Oct 2013

- 5th partner – intense sampling 3x 24 h cycles, in re-circulating system

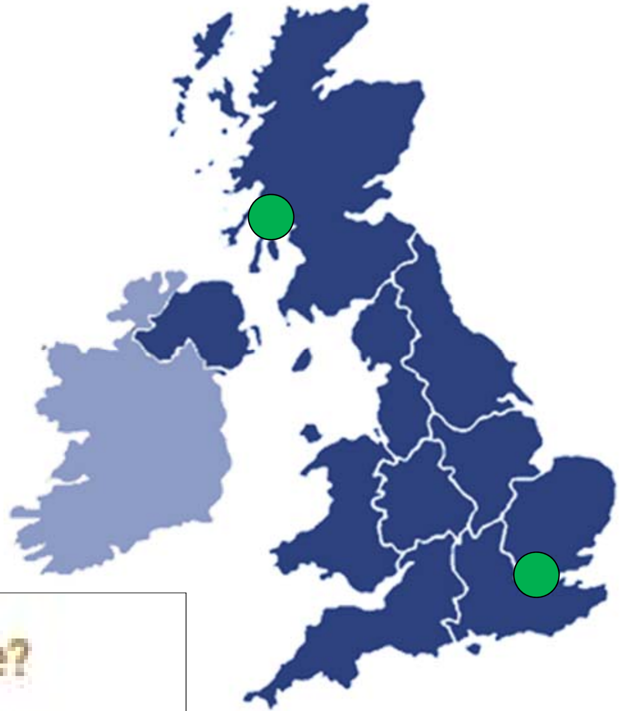



15
10
5
0
Temperature (°C)
600.0
500.0
400.0
300.0
pCO2 (atm)
pCO2
Temp
2300
2200
2100
Alkalinity (µmol kg-1)
2150
2100
2050
2000
DIC (µmol kg-1)
DIC
Alk
Oct
Dec
Feb
Apr



- 2 OA workshops , SAGB annual meeting, May 2013, and ASSG Conference, Oct 2012

- Workshops led to an article in Shellfish News



Shellfish News

Number 35, Spring / Summer 2013

Ocean acidification and shellfish: effects on UK aquaculture?

F. Hopkins[1], R. Ellis[2], E. Pope[3] and E. Papathanasopoulou[1]

[1]Plymouth Marine Laboratory, [2]University of Exeter, [3]Swansea University

CO_2 emissions and the oceans

Since the start of industrialisation some 200 years ago human activities have released a staggering 500 million metric tons of carbon dioxide (CO_2) into the atmosphere.

- …. and AVA collaboration between Exeter and Queens University, Belfast

AVA - To broadcast or brood; the impact of reproduction strategy on sensitivity to ocean acidification.

Liz Ashton (Queen's Univ., Belfast)

- Many studies investigated fertilisation impacts of OA
- Wide range of responses, yet most studies investigated broadcast spawning
- No study investigated brooding

Ostrea edulis

Queen's University Belfast

Ostrea edulis

Hypothesis:

Brooding larvae will offer protection from negative impact of OA

Aims:

First understanding of brooding protection

Knowledge exchange between partners

Develop collaboration

Queen's University Belfast

AVA - Will OA increase the toxicity of metal contaminants? C.Lewis NERC Fellowship & CEFAS collaboration

Gametes

??? No interaction observed on fertilisation… so far

Larvae

✓ Strong increase in toxicity of copper under OA observed in 2 species

Adults

Toxicity ↑ ↑ ↓

Possible relationship to acid-base regulation????

University of Exeter · Cefas

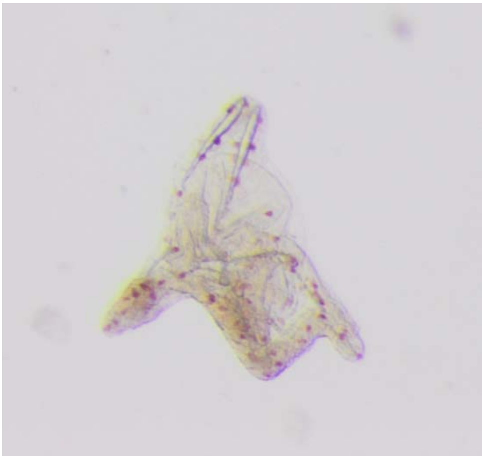
c.n.lewis@exeter.ac.uk; @CezzaLew

Larval development

380 ppm

380 ppm + Cu

750 ppm



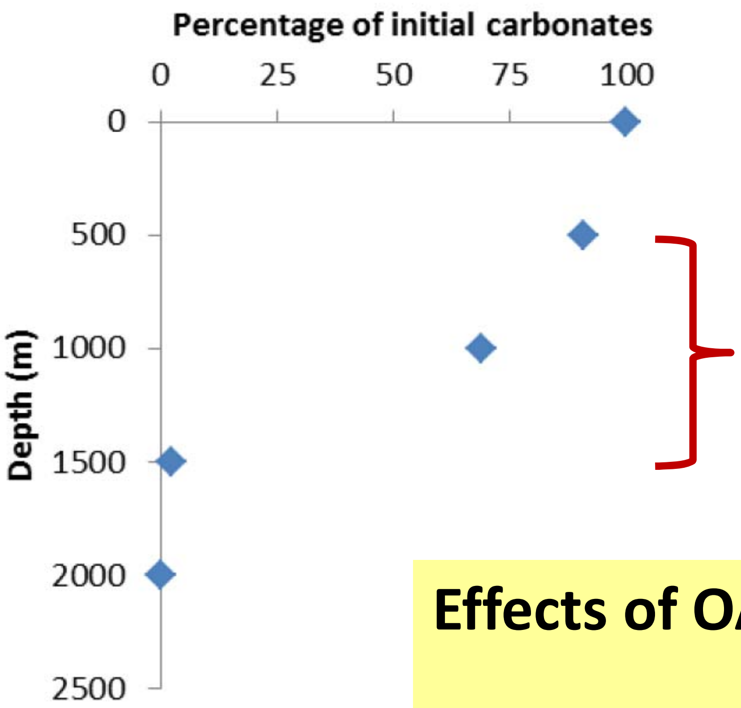
750 ppm + Cu

UNIVERSITY OF EXETER

c.n.lewis@exeter.ac.uk; @CezzaLew

AVA – Impacts of OA on vertical flux of fish-derived carbonates (with BIO-ACID Pedro de Jesus Mendes, Bremen, Germany)

Rapid dissolution of fish high-Mg calcite - may explain depth/pH profile?



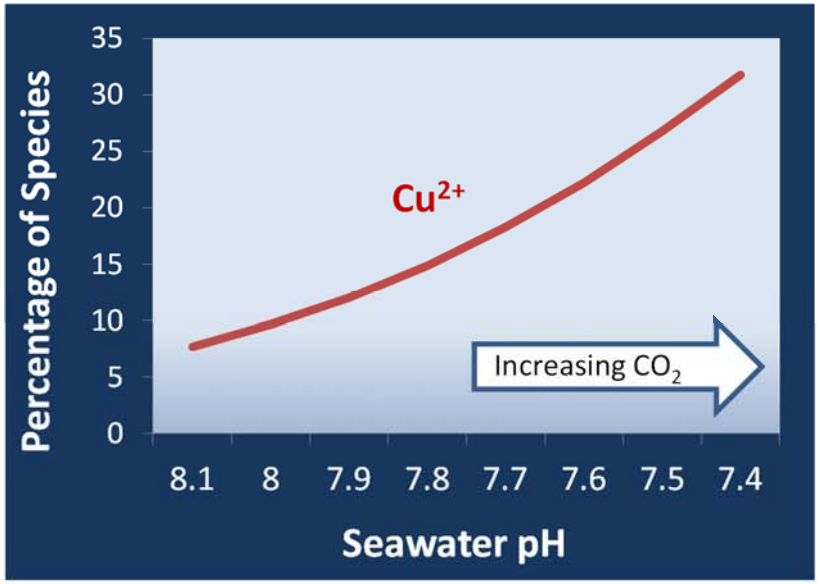
High Pressure Lab Conditions:

Flounder carbonates dissolve at pressures equivalent to 500 - 1500 m depth

Effects of OA? – Work in progress...

BUT mole% Mg of flounder carbonates is **not** affected by CO_2 exposures of 960 to 4500 ppm

Exeter; other OA work

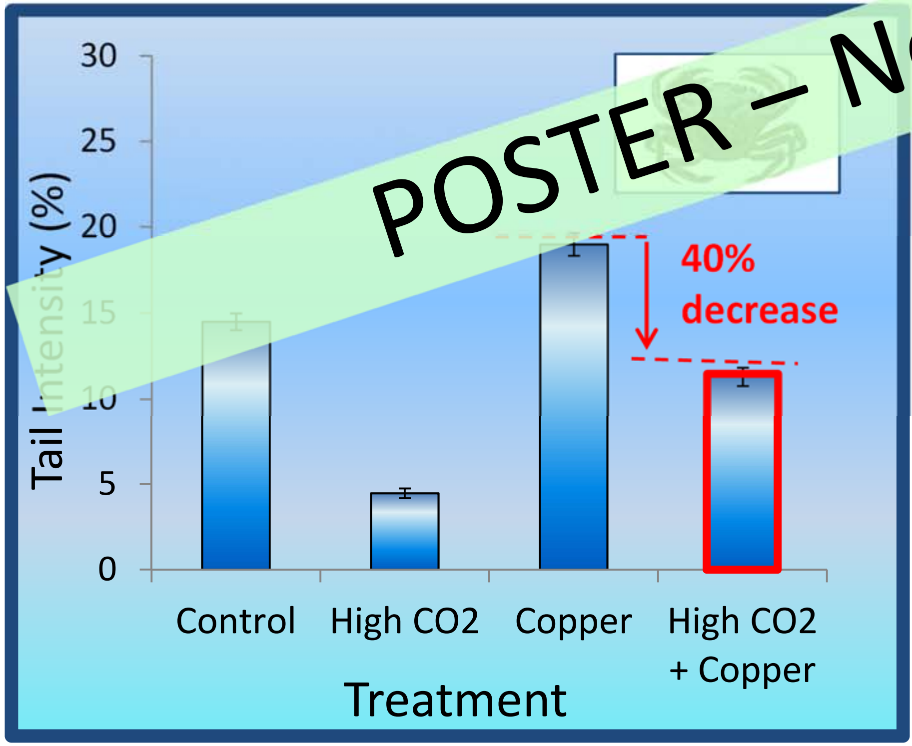


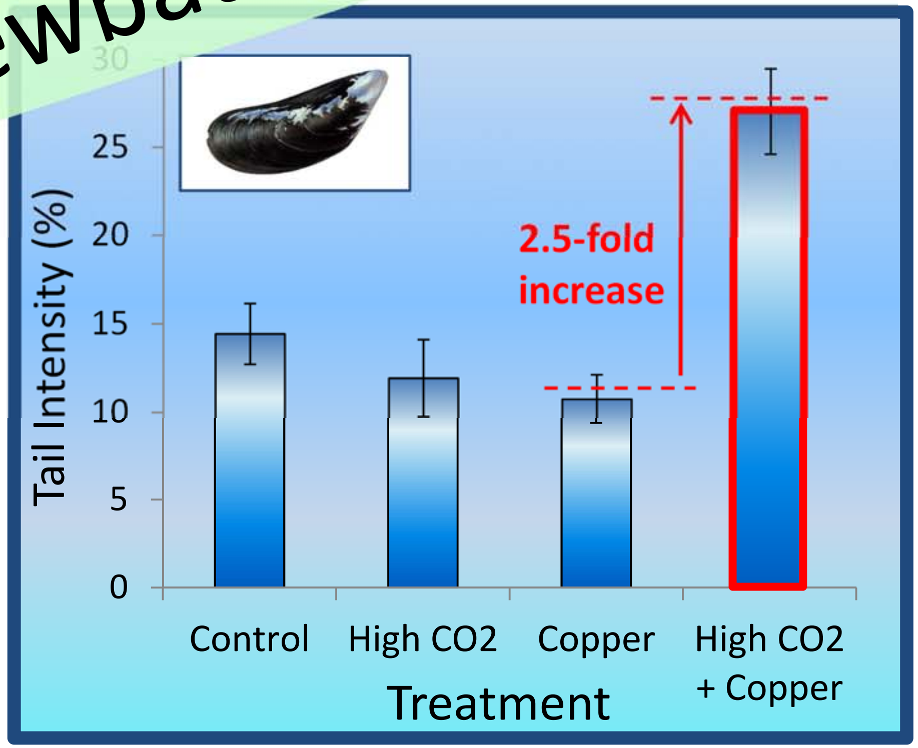
OA changes copper speciation to **more** bioavailable forms

But toxicity may be reduced or increased depending on whether the animal can regulate acid-base balance

POSTER – Newbatt et al.

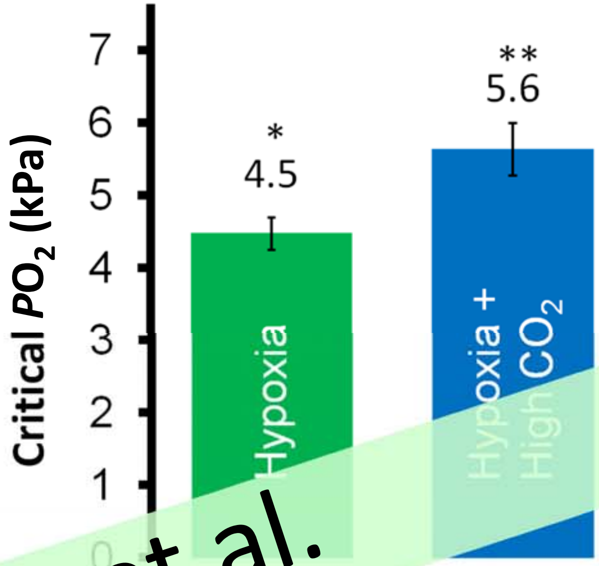
See Poster (Newbatt et al.)



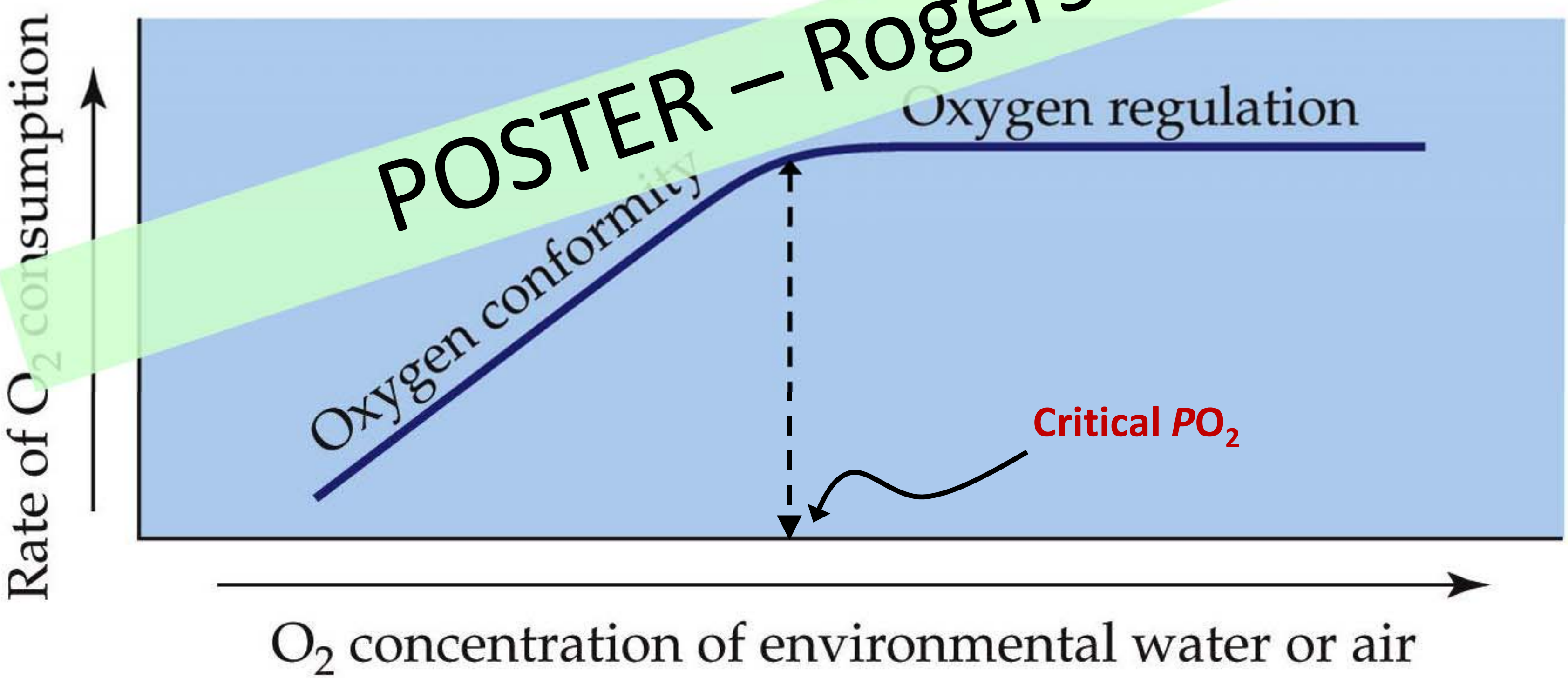


Flounder are more sensitive to low O_2 (hypoxia) when CO_2 is elevated

See Poster (Rogers et al.)



POSTER – Rogers et al.



STRATHCLYDE

- Fisheries modelling

Aim: To examine how changes in planktonic and benthic food webs, as a result of ocean acidification, impact upon the production and yields of commercial fish species.

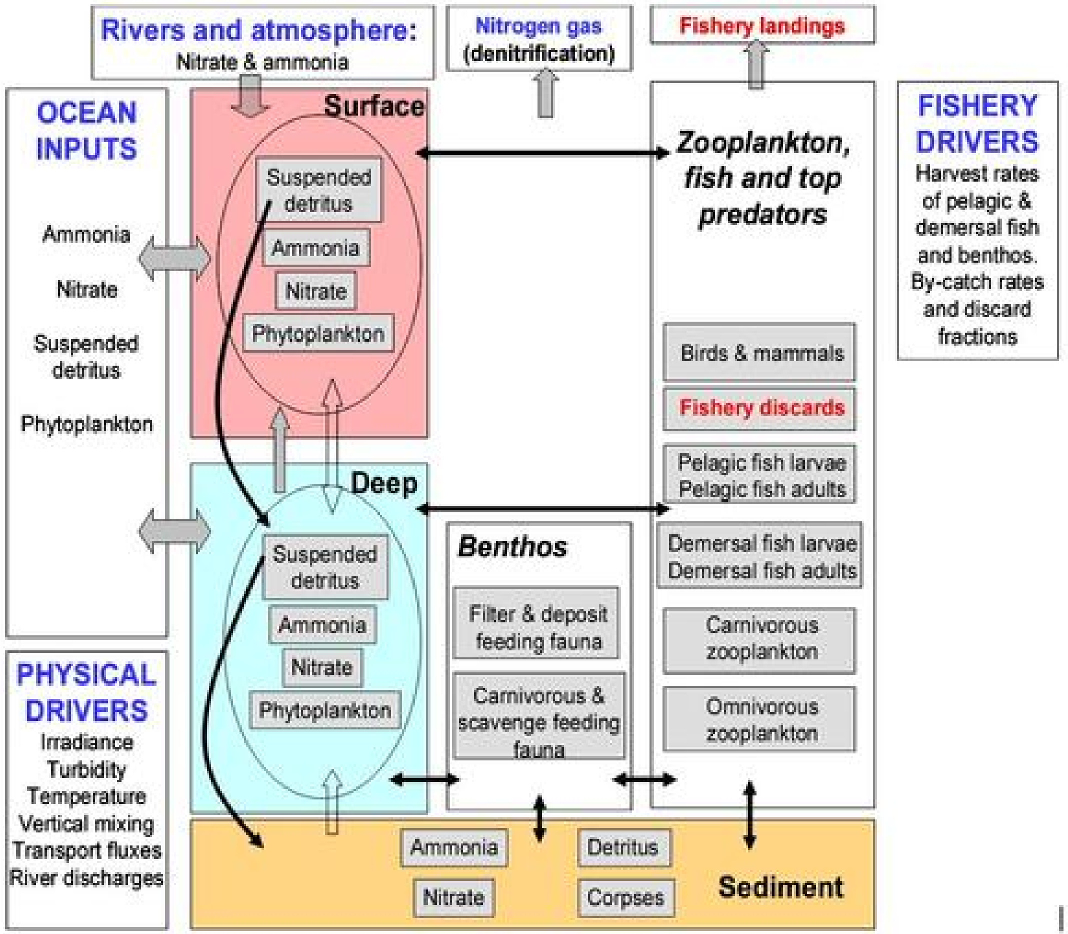
Timeline- Started July 2012 for 2.5 years

Progress in year 1

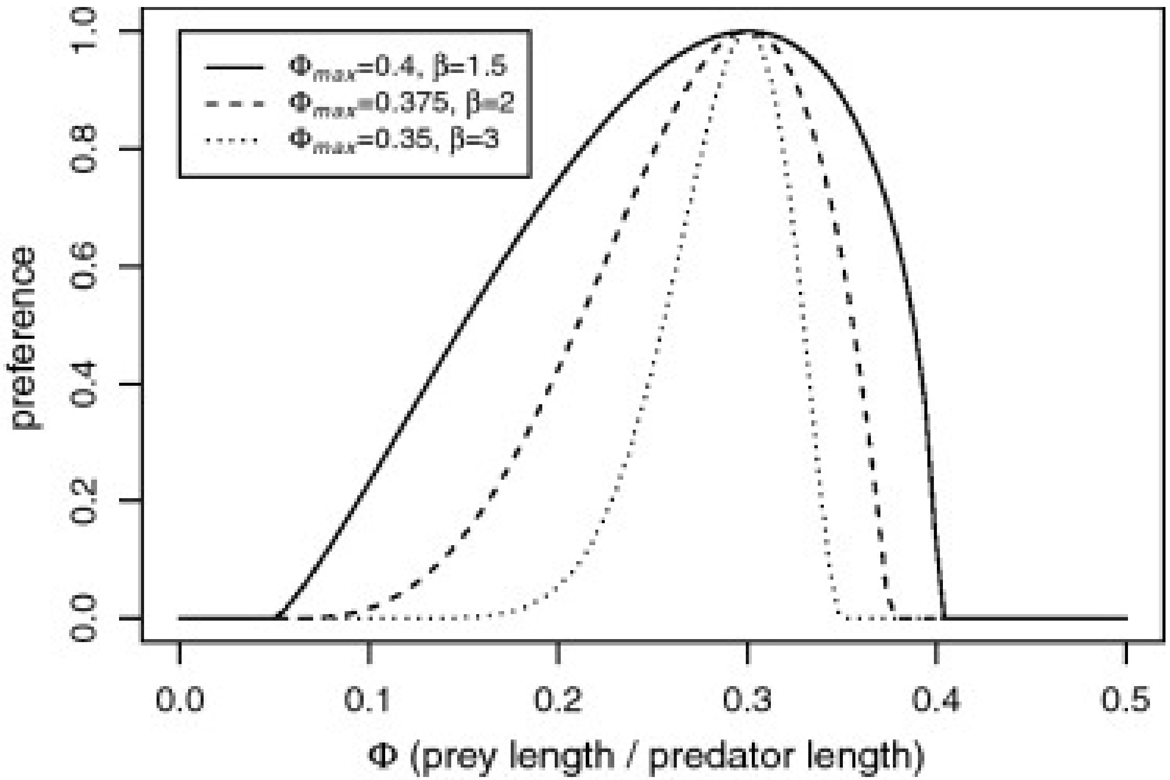
- selection of models,
- model validation,
- identification of key factors to include in models

Two models have been selected …

StrathE2E is an end-to-end ecosystem model that includes both bottom-up (resource limitation) and top-down (predation, fisheries) processes, to model the combined effects of environmental, fishing and nutrient inputs have on North Sea fisheries.



FishSUMS is a partial ecosystem model that simulates in detail 10-15 focal species divided into length classes representing the full life history from egg to adult.



Model Validation

Because pH will affect model parameters, it is important to identify which are influential in determining fishery biomasses.

Sensitivity analysis is used for this type of study….

Local methods

This is where one parameter is perturbed at a time, while all others are held constant. These techniques have significant limitations when examining models that are not additive and/or have non-linear responses.

Global sensitivity analysis **(is the preferred option)**.

Here all parameters are varied together across their input range. The techniques are model independent, BUT computationally expensive.

Strategy for global sensitivity analysis of **StrathE2E**

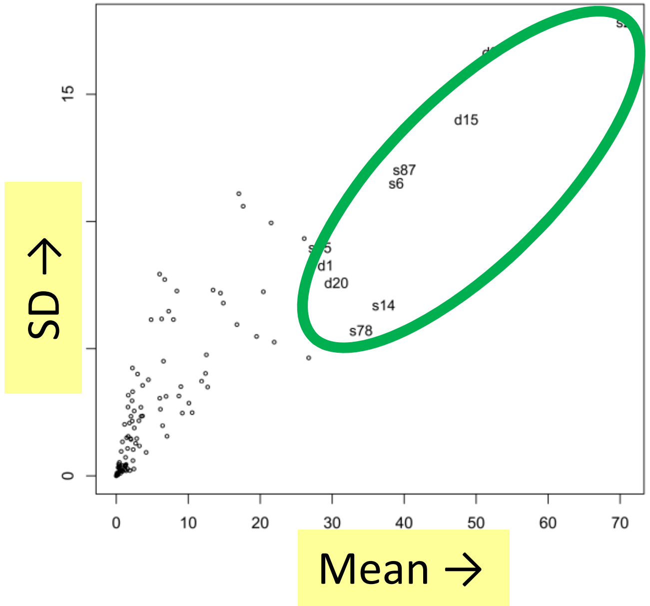
Convert R code of StrathE2E model into C

Implement a two-step analysis

Use of Morris method as a screening tool for influential parameters.

This method is relatively quick, but is qualitative.

Sus/Deposit feeding benthos



For StrathE2E, 155 parameters were examined using the Morris method…

34 were identified as influential.

Influential parameters then re-analysed using the Sobol method.

This method is slow but provides quantitative measures of parameter influence on output and interactions.

POSTER – Morris et al. 12A

Fishery outputs of StrathE2E affected by different parameter sets….

- Suspension/ detritus feeding benthos were influenced by an interplay of environmental factors.
- Carnivorous/ scavenging benthos appeared to be relatively robust to environmental parameters.
- Pelagic fish can be indirectly affected through impacts on the food chain.
- Demersal fish are not as dependant on changes to the food chain.

For all fishery outputs the metabolic parameter associated with the conversion of biomass from prey to predator was identified as influential.

Significant as growth rates have been affected in OA/T studies.

Prey quality & quantity also likely to be affected by OA/T etc.

OUTPUT

Paper submitted to Ecological Modelling
"Identifying key parameters affecting North Sea fisheries: Global sensitivity analysis of a marine end-to-end ecosystem model" by *Morris, Speirs, Cameron, Heath.*

ONGOING WORK

Global sensitivity analysis is currently being conducted for **FishSUMS**.

AVA - Representing ocean acidification effects in end-to-end ecosystem models working group meeting convening in September

Related projects at Strathclyde University

Euro-Basin EU FP7 - Modelling the effects of climate change on North Sea food webs

PML | Plymouth Marine Laboratory

PML

- Socio-economic modelling

Commercial and non-commercial impacts of OA using an Ecosystem Service Approach

- Provisioning (fish and shellfish)
- Regulation
- Bioremediation of waste
- Cultural impacts

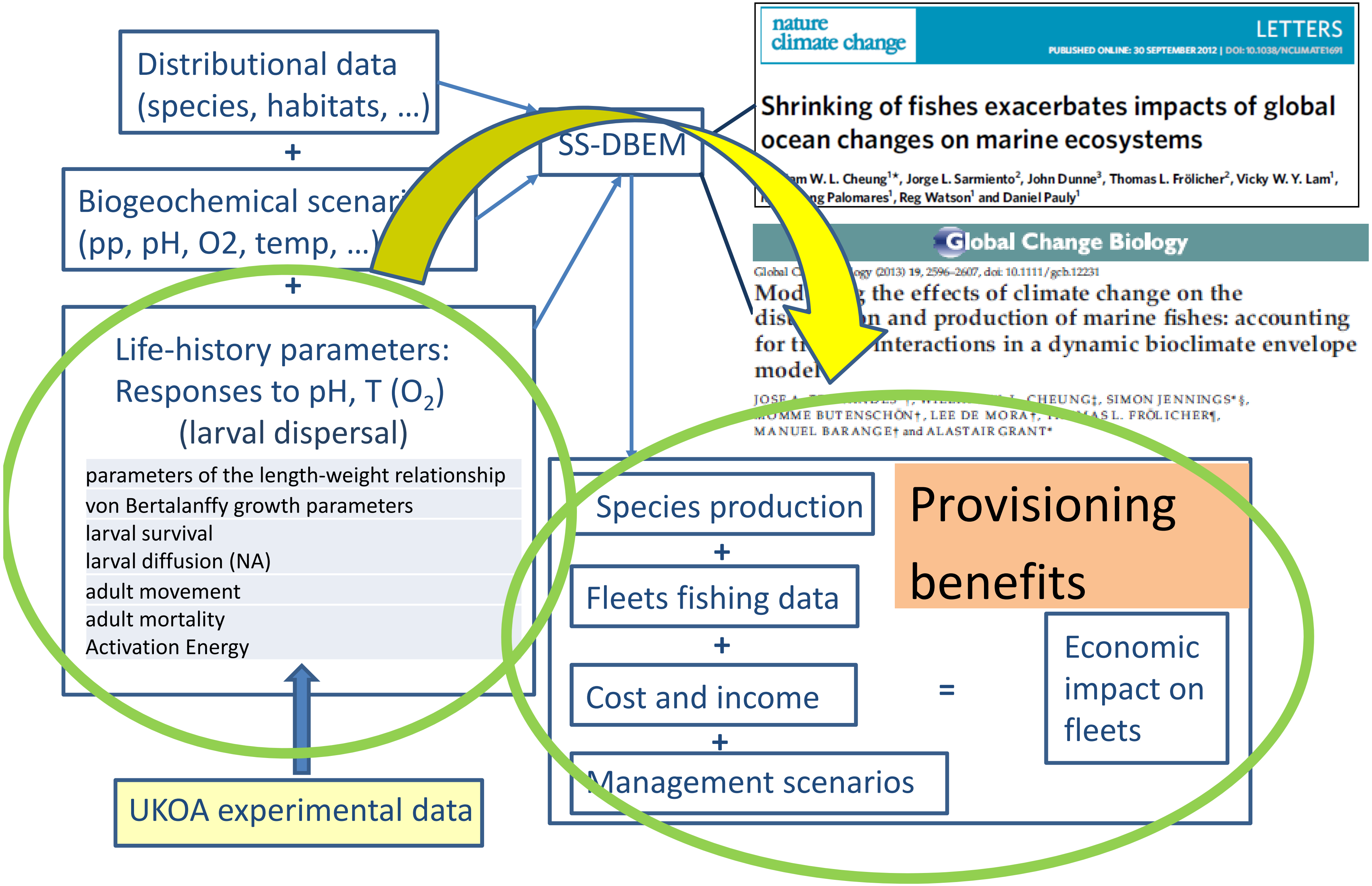
Deliverables due end of 2013, 9 months extension granted due to delays in data availability

Provisioning services (fish and shellfish)

Part model-driven

- Development of bio-economic framework to explore impacts of OA on supply for commercial species
- Explore implications for fishing industry (e.g. fleets) at regional, national and global level.

Link between experiments, models and socioeconomics



Species, parameters and data

- Species
  - 2/3 commercial fish species: ***herring, seabass & haddock***
  - 2/4 commercial shellfish: ***oysters, scallops, mussels & cockle***
  - 1 commercial (***Nephrops***) + 2 non-commercial invert. (***dog/peri –winkle***)

- Parameters
  - Length-weight relationship parameters, Von Bertalanffy growth equation parameters, larval survival rate & diffusion coefficients; adult movement rate, natural mortality & activation energy.

Species, parameters and data, cont.

- Other data
  - Biogeochemical scenarios: emissions as usual and high emissions scenarios from ERSEM and MEDUSA (**almost ready**).
  - Seaweed and seagrass habitat distribution (**ready**).
  - Cost and income data (**partially ready**).
  - Fleets catches and distribution (**partially ready**).
  - Management scenarios (**partially ready**)

Abstract accepted in ICES conference 2013.
Models almost ready to run, under testing and waiting for data contributions.

Regulating Ecosystem services

Using models, lit reviews, primary research, expert opinion

Gas and climate regulation (C sequestration)

- Current C sequestration, and associated value, by UK saltmarsh and seagrass documented (Beaumont *et al.* 2012, 2013 in press).
- Current UK offshore C seq documented (Beaumont *et al.* 2011) , links to ERSEM outputs under continued investigation.
- Review of impact of OA on these habitats and species underway (lit and model based) with a view to producing value change scenarios up to 2050.

Bio-remediation of waste

- Changes in waste processing and storage (organic and inorganic) in marine and coastal environments up until 2080-2099 is under assessment.
- Building on OA workshop methodology (Nov 2011), now refined with a paper in preparation….
- …. focus likely to be on bivalves, bacteria and saltmarsh.

Cultural impacts

- To start summer 2013 **(working with Bioacid and a SAG)**
- Leisure and recreation
  - Problematic as insufficient evidence for OA impacts at ecosystem level and timeframe of impact not relevant to present day recreation decisions
  - Alternatives
    - Survey of public with focus on awareness of OA
    - Focus on vulnerable habitats of social interest e.g. Lophelia reefs, cold water corals or mearl
    - Or changes in seagrass and seaweed distribution
    - **Any other suggestion?**
  - Survey to be conducted late 2013/early 2014

Cognitive benefits

- Impact of OA on research/education
- Qualitative assessment with focus on method development
- Case study of PML, with possible extension

AVA - Understanding future risks to the aquaculture and shellfish sectors from a high CO_2 world and its impacts on the marine environment

One workshop:

Association for Scottish Shellfish Growers Annual Conference. *Oban, Scotland, 23 – 25 October 2012.* Stakeholders workshop (organization and facilitation): Ocean acidification and shellfish.

One presentation:

Shellfish Association of Great Britain Annual Conference. *Fishmongers Hall, London, 21 – 22 May 2013.* Oral presentation: Ocean acidification and shellfish, FE Hopkins and EC Pope

Two publications:

FE Hopkins and E Papathansopoulou (2012). Ocean acidification and shellfish. *The Grower* (Newsletter for the Association of Scottish Shellfish Growers), October 2012.

FE Hopkins, R Ellis, E Pope, E Papathansopoulou (2013). Ocean acidification and shellfish: effects on UK aquaculture? *Shellfish News*, Centre for Environment, Fisheries and Aquaculture Science (Cefas) on behalf of the Department for Environment, Food and Rural Affairs (Defra), biannual newsletter, Spring/Summer 2013.

AVA - The Impact of Ocean Acidification on Marine Ecosystem Services

Nicola Beaumont, C. Hattam, A. Querios, G. Wheeler, S. Widdicombe, P. Calsoi, C.Widdicombe, K. Tait, M. Austen, N. Hardman-Mountford, J. Shaw, J. Blackford, Y. Artioli, A. Rees, M. Briffa, J. Hall Spencer, N. Stephens, C.Turley, F. Hopkins, H. Findlay.

Paper presented at Ecosystem Services Partnership Conference, Portland, Oregon

Acknowledgments to the SE work

- Ana Queiros (Plymouth Marine Laboratory)
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- Ceri Lewis (University of Exeter)
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- Duncan Hume (Marine Management Organization)
- Ed Pope (Swansea University)
- Garry Dando (Marine Management Organization)
- Gorka Merino (Azti-Tecnalia)
- Jason Hall-Spencer (University of Plymouth)
- Kevin Flynn (Swansea University)
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- Melanie Austen (Plymouth Marine Laboratory)
- Nova Mieszkowska (Marine Biological Association)
- Piero Calosi (University of Plymouth)
- Robert Ellis (University of Exeter)
- Stephen Widdicombe (Plymouth Marine Laboratory)
- Yuri Artoli (Plymouth Marine Laboratory)
- Vicky Lam (University of British Columbia)
- William Cheung (University of British Columbia)
- Others …

Project Conclusions So Far

- Long-duration experiments have proved challenging to conduct and interpret; results have generally been non-trivial to explain.
- Probably learnt as much about what not to do as anything else.
- Consistent theme has been the complexity of the autecology interactions, and thence that of the combined trophic interactions. **For sure a wider range of pH/T/nutrition status/etc is required to inform knowledge of the response envelope.**
- Modelling approaches are proving useful, not least as indicators of what we don't know and perhaps need to pay more attention to. **Models can be used to indicate response envelopes with complex data series through tuning/sensitivity approaches**
- Socio-economic work is progressing but, other than education, lags behind, dependent on the overall information base.
- AVAs have proven to be a most useful adjunct.