Interactive effects of ocean acidification, temperature and seasonal timing in the marine benthos

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**Introduction**

**PHYSIOLOGICAL**
- metabolic rate
- calcification

**BEHAVIOURAL**
- bioturbation
- bioirrigation

**MECHANISTIC UNDERSTANDING**

1. Identify the physiological responses that underpin changes in organism performance and function
2. Effects of acclimatisation/adaptation

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**ORGANISM RESPONSES**

Experimental design

• **Time:** 3, 6, 12, 18 months

• **Temp. regime:** ambient, ambient + 4°C

• **CO₂ (ppm)** 380 750 1000 380 750

Response ~ f(CO₂ * Time * Temperature regime)
Response ~ f(CO₂ * Time) [Ambient temp regime only]
Responses

Growth
- mean biomass (g mesocosm⁻¹) at each timepoint

Sediment reworking (bioturbation)
- fluorescent pink luminophore tracers
- Imaging of the sediment profile (day 0 and day 6)
- quantification using image analysis (ImageJ) (f-SPI)

Burrow flushing (bioirrigation)
- Addition of NaBr⁻ to water column
- Incubate cores for 8 hours

Nutrient concentration
- NH₄-N, PO₄-P, NOₓ-N
Results - growth

Biomass ~ f(Timepoint + CO$_2$)

Ambient temperature regime:
- significant increase in biomass over time
- significant reduction in biomass with increasing CO$_2$
Results - growth

Biomass ~ f( Temperature regime + Timepoint + CO₂)

Greater increase in biomass under Amb+4°C temperature regime

Increase in biomass after 12 and 18 months exposure

Biomass of individuals exposed to 750 μAtm CO₂ reduced

Effects of temperature regime outweigh CO₂ effects
Results – bioturbation

Bioturbation~ f(Timepoint)

Ambient: seasonal response
→ shifted downwards after 18 mo.

Anova, $F = 8.842$, d.f. = 3, $p < 0.001$

Bioturbation~

f( Temperature regime x Timepoint)

Ambient: seasonal response
→ shifted downwards after 18 mo.
Amb+4°C: reduction over 12 months
→ 6 and 18 months depth similar

Anova, $F = 3.188$, d.f. = 3, $p < 0.05$
**Results – bioirrigation behaviour**

**Irrigation**\(\sim f(\text{Timepoint} \times \text{CO}_2)\)  

**Irrigation**\(\sim f(\text{Temperature regime} \times \text{CO}_2 + \text{Temperature regime} \times \text{Timepoint})\)

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**Reduced irrigation at high CO\(_2\)**  
**Increased irrigation over time under ambient CO\(_2\)**

**Reduction at higher CO\(_2\) and at Ambient temp. regime**  
**Stronger at Amb+4°C, BUT reduced at highest temperature**

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GLS, L.ratio = 21.208, d.f. = 6, \(p < 0.01\)  
Anova, \(F = 4.338\), d.f. = 3, \(p < 0.05\)  
Anova, \(F = 2.905\), d.f. = 3, \(p < 0.05\)
Results – ecosystem function

\[ \text{NH}_4 \sim f(\text{Timepoint } \times \text{CO}_2) \]

Seasonal fluctuations

\(\text{CO}_2\) treatment effects in winter temperatures reduced

\[ \text{NH}_4 \sim f(\text{Timepoint } \times \text{CO}_2) \]

Seasonal fluctuations

In winter higher \(\text{NH}_4\) concentrations @ high \(\text{CO}_2\)

In summer \(\text{CO}_2\) effect not consistent

GLS, L.ratio = 16.649, d.f. = 6, \(p < 0.05\)

GLS, L.ratio = 8.729, d.f. = 6, \(p < 0.05\)
Summary & Conclusions

• Behavioural and functional responses reflect seasonal timing, whilst physiological responses reflect the duration of exposure.

• The effects of ocean acidification are modified not just by absolute temperature, but also the seasonal timing and climate scenario.

• Despite complex interactions, effects of ocean acidification were generally weak relative to the effects of seasonal timing and/or climate scenario.

• Understanding the ecological consequences of future environmental change must simultaneously consider multiple aspects of change AND their seasonal timing.