TRANSGENERATIONAL DELETERIOUS EFFECTS OF OCEAN ACIDIFICATION ON THE REPRODUCTIVE SUCCESS OF A GAMMARID AMPHIPOD SPECIES

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GLOBAL CLIMATE CHANGE IS UNEQUIVOCAL...

- Increase in global average atmospheric and ocean temperatures
- Rising global average sea level
- Melting of glaciers and polar land ice
- Extreme droughts
- Storminess
- Floods
Continued anthropogenic CO$_2$ emissions to the atmosphere

Increased oceanic CO$_2$ uptake (400 µatm $p$CO$_2$ -> 900 µatm $p$CO$_2$ by 2100)

Disruption of the ocean’s carbon chemistry
Oceanic uptake of atmospheric CO₂ has led to progressive acidification (IPCC, 2014)

- ↓0.1 pH units – since the Industrial Revolution;
- ↑26% in acidity [H⁺] over the past 150 years;
- ↓0.4 units in the year 2100.

Acidification could have major impacts on biogenic habitat (e.g., coral reefs, seagrass and oyster beds), food webs (e.g., calcifying organisms), and geochemical cycles.
**RESPONSES TO ENVIRONMENTAL STRESS**

- **ACCLIMATION**
  - Short-term physical and/or behavioural adaptations

  **Phenotypic plasticity**
  - Maintenance of individual fitness and ecological performance

- **LONG-TERM ADAPTATION**
  - Increase in abundance and reproductive success of resilient genotypes.

  **Selecting on genetic variability**
  - Maintaining favorable genotypes
  - Shifting the population structure towards a new optimal phenotype
• inherence of non-genetic traits from adults to offspring (i.e. carry-over effects), as a result of exposure to a particular stress factor

• can positively influence offspring performance when exposed to the same conditions as the parental generation

**EXAMPLES:**

Parental conditioning to global change drivers leads to largely positive effects in the offspring’s response to similar conditions (Donelson et al. 2012, Thor & Dupont 2015, Rodríguez-Romero et al. 2016, Gibbin et al. 2017)

carry-over effects can render offspring more sensitive to stressors (Byrne 2011, Schade et al. 2014), and thus parental exposure does not always ensure the resilience of subsequent generations (Griffith & Gobler 2017)

There is a gap of knowledge concerning trans/multigenerational effects of OA in crustacean species, the majority of which focused in copepods
To investigate the transgenerational effects of OA (pCO$_2$ ~ 900 µatm) on the survival and reproductive traits of *G. locusta* over two generations (F0 and F1).

Understanding how survival and reproductive traits may be affected by environmental change, and whether these effects are transmitted throughout subsequent generations, will allow:

- to infer possible changes in mating and recruitment stemming from CO$_2$-driven physiological changes;
- predict the sustainability of natural *G. locusta* populations in a future acidified ocean.
STUDY SPECIES: *Gammarus locust*.

**Gammarus locusta**
*Linnaeus, 1758*

- Sub-Order Gammaridae
- Marine euryhaline species
- Coastal and estuarine areas

- Wide geographical distribution from the North Sea up to the Southern Portuguese and Spanish coasts


STUDY SPECIES’ LIFE CYCLE

~ 40-50 days at 15°C
(Neuparth et al., 2002)
**Parental generation (F0)**
- 5 replicates (4-L tanks)
- 25 individuals per tank

**F1 generation**
- 5 replicates (4-L tanks)
- 25 individuals per tank

**Control**
- Ambient $pCO_2$ (C)
  - 400 μatm

**Acidification**
- High $pCO_2$ (A)
  - 900 μatm

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**Stock**
- 400 μatm
**Physico-Chemical Parameters Monitoring**

<table>
<thead>
<tr>
<th>Generation</th>
<th>Treatment</th>
<th>Temperature (°C)</th>
<th>Salinity</th>
<th>pH</th>
<th>TA (µmol/kgSW)</th>
<th>pCO₂ (µatm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>C</td>
<td>18.3 ± 1.3</td>
<td>35</td>
<td>8.1 ± 0.1</td>
<td>1932.2 ± 109.8</td>
<td>375.9 ± 67.7</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>18.4 ± 1.4</td>
<td>35</td>
<td>7.7 ± 0.1</td>
<td>1971.5 ± 64.3</td>
<td>827.5 ± 73.2</td>
</tr>
<tr>
<td>F1</td>
<td>CC</td>
<td>18.8 ± 0.8</td>
<td>35</td>
<td>8.0 ± 0.1</td>
<td>2126.5 ± 112.3</td>
<td>354.2 ± 28.7</td>
</tr>
<tr>
<td></td>
<td>AA</td>
<td>18.8 ± 0.6</td>
<td>35</td>
<td>7.7 ± 0.1</td>
<td>2044.1 ± 140.4</td>
<td>825.5 ± 71.5</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>18.7 ± 0.6</td>
<td>35</td>
<td>8.0 ± 0.1</td>
<td>2105.7 ± 108.9</td>
<td>366.8 ± 20.5</td>
</tr>
<tr>
<td></td>
<td>CA</td>
<td>18.8 ± 0.6</td>
<td>35</td>
<td>7.7 ± 0.1</td>
<td>1943.6 ± 88.4</td>
<td>803.2 ± 27.8</td>
</tr>
</tbody>
</table>
• **SURVIVAL AT ADULTHOOD (30 DAYS, %)**

Survival in F0 declined significantly in acidified conditions, which did not occur in F1.

Survival in cross treatments decreased significantly compared to the control.
• **MATE-GUARDING DURATION**

Exposure to high $p$CO₂ produced a significant reduction in mate guarding duration in F0. In the offspring generation no significant differences were found compared to the control.
**RESULTS**

- **REPRODUCTIVE INVESTMENT**
  - a) Mean number of eggs

Parental females under acidification produced significantly more eggs than controls.

In the second generation, production of eggs was reduced.
• REPRODUCTIVE INVESTMENT
  b) Duration of embryonic development

F0
• Embryonic development lasted 10-11 days
• No differences were found between treatments and within generations

F1
• **REPRODUCTIVE INVESTMENT**
  
  c) Fecundity / Number of juveniles

- Number of juveniles did not significantly differ in the first generation between treatments
- Significant decline in F1 fecundity under acidification compared to the control and progenitors
- Negative parental effects in AC (offspring raised in control and whose parents were reared under OA)
• **SURVIVAL**
  
  o First exposure (initial acclimation – F0) to acidified conditions systematically reduced survival in this amphipod species
  
  o **Previous studies:**
    Hauton et al., 2009; Cardoso et al., 2017 – *Gammarus locusta*: 25 and 21 days exposed to 7.8 pH and 7.6 pH, respectively: survival declined to 65%
  
  o Negative impacts in calcification and metabolism (Kroeker et al., 2010) could result in energy being re-allocated from fitness-enhancing processes to acid-base regulation machinery, as a compensatory response towards hypercapnia (Pörtner et al. 2004)

• **MATE-GUARDING**
  
  o High metabolic costs: males of *Gammarus* sp. have poor energetic conditions due to OA and may be less able to endure the costs associated with precopulatory MG (Plaistow et al. 2003)

• **FEMALE REPRODUCTIVE INVESTMENT**
  
  o Metabolic costs led to a temporary shift in the allocation of energy that would normally be used for reproduction - i.e. in the female investment on the number of mature oocytes that are deposited as eggs in the brood pouch and, possibly, egg quality (Neuparth et al. 2002)

<table>
<thead>
<tr>
<th>Survival</th>
<th>F0</th>
<th>F1</th>
<th>Parental Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mate-guarding duration</td>
<td>![Red Down Arrow]</td>
<td>![Red Down Arrow]</td>
<td><strong>Negative</strong></td>
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<tr>
<td>Female investment</td>
<td>![Blue Up Arrow]</td>
<td>![Red Down Arrow]</td>
<td><strong>Negative</strong></td>
</tr>
<tr>
<td>Fecundity</td>
<td>![Green Equal]</td>
<td>![Red Down Arrow]</td>
<td><strong>Negative</strong></td>
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ACKNOWLEDGMENTS

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