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

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Washington, DC, USA
5th June 2018

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EXPLORING THE OCEANS OF TOMORROW

Ciências ULisboa

The Effects of Climate Change on the World's Oceans

GLOBAL CLIMATE CHANGE IS UNEQUIVOCAL…

INCREASE IN GLOBAL AVERAGE ATMOSPHERIC AND OCEAN TEMPERATURES

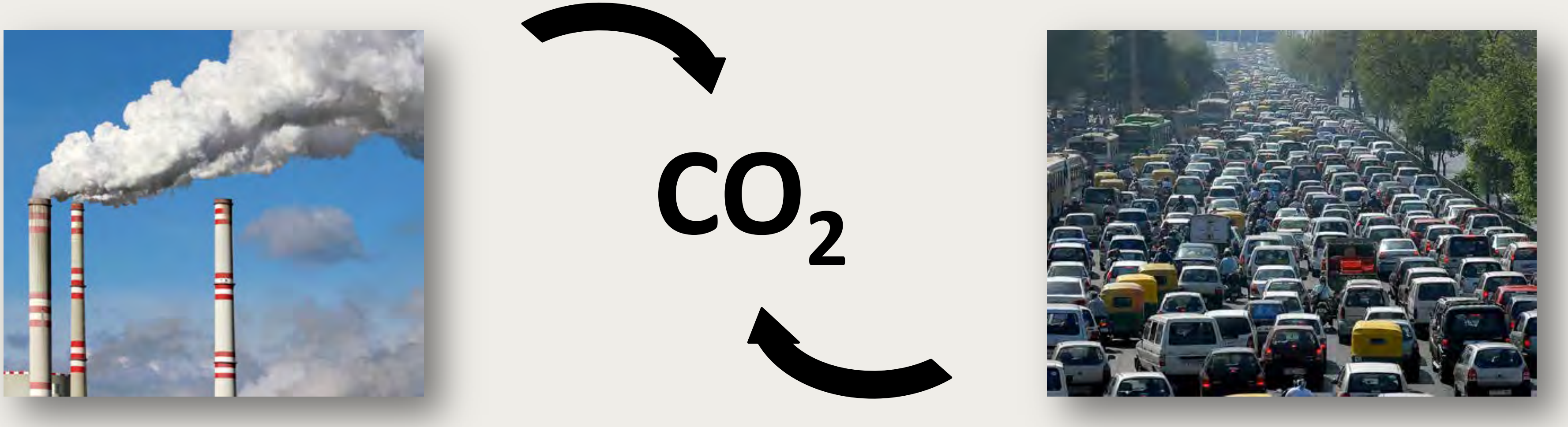
RISING GLOBAL AVERAGE SEA LEVEL

STORMINESS

MELTING OF GLACIERS AND POLAR LAND ICE

EXTREME DROUGHTS

FLOODS



CO_2

Continued anthropogenic CO_2 emissions to the atmosphere

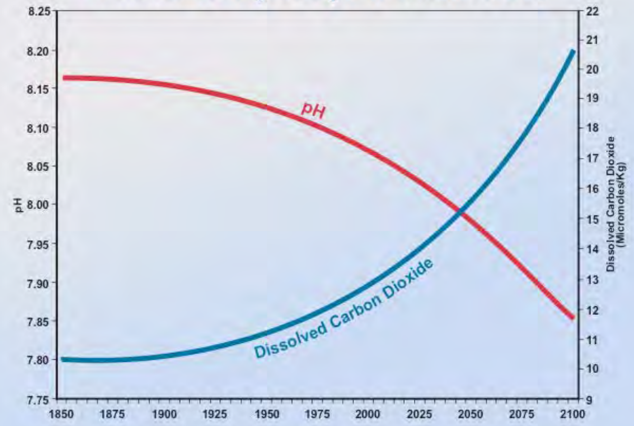
Increased oceanic CO_2 uptake (400 µatm pCO_2 -> 900 µatm pCO_2 by 2100)

Disruption of the ocean's carbon chemistry

OCEAN ACIDIFICATION

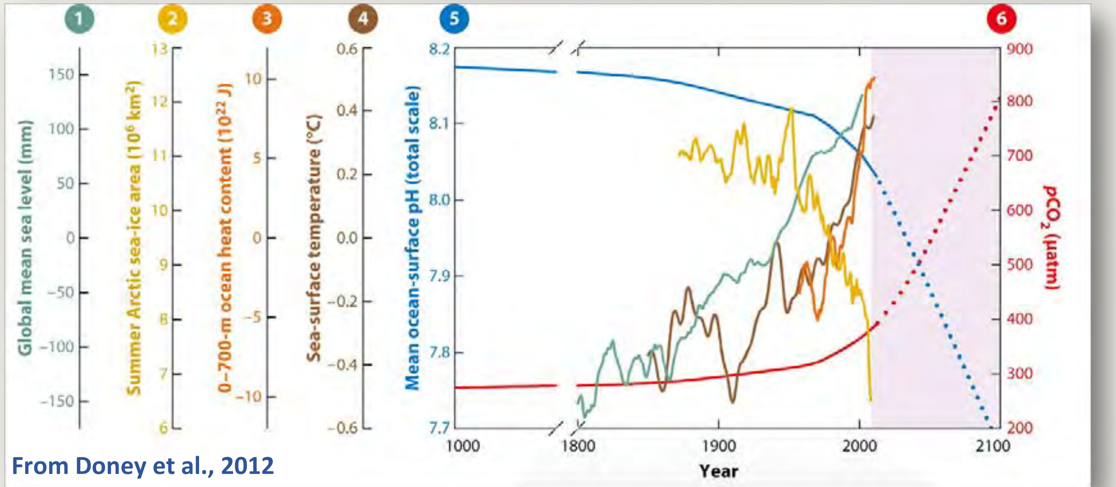
- Oceanic uptake of atmospheric CO_2 has led to progressive acidification **(IPCC, 2014)**
- ↓0.1 pH units – since the Industrial Revolution;
- ↑ 26% in acidity $[H^+]$ over the past 150 years;
- ↓ 0.4 units in the year 2100.
- Acidification could have major impacts on biogenic habitat (e.g., coral reefs, seagrass and oyster beds), food webs (e.g., calcifying organisms), and geochemical cycles

Historical & Projected pH & Dissolved CO_2



As the ocean concentration of carbon dioxide increases, so does acidity (causing pH to decline).

Source: Feely, Richard A., et al. (2006) Carbon Dioxide and Our Ocean Legacy. Pew Trust



From Doney et al., 2012

RESPONSES TO ENVIRONMENTAL STRESS

- **<u>ACCLIMATION</u>**
  - Short-term physical and/or behavioural adaptations

Phenotypic plasticity

- Maintenance of individual fitness and ecological performance

- **<u>LONG-TERM ADAPTATION</u>**
  - 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

TRANSGENERATIONAL APPROACH

- 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

MAJOR AIMS

- 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)

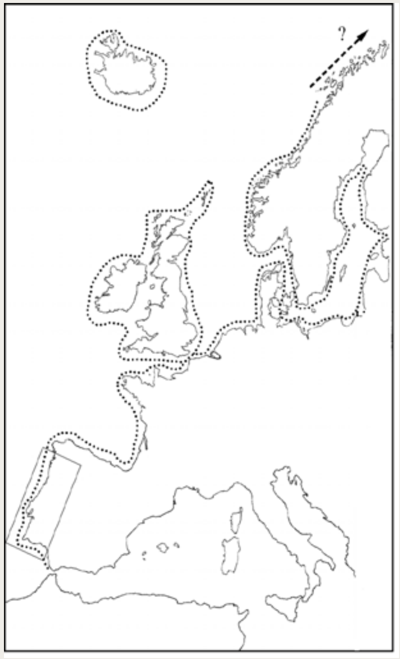
- Understanding how survival and reproductive traits may be affected by environmental change, and whether these effects are transmitted throughout subsequent generations, will allow:
  - to infer possible changes in mating and recruitment stemming from CO_2-driven physiological changes;
  - predict the sustainability of natural *G. locusta* populations in a future acidified ocean.

STUDY SPECIES: *Gammarus locusta*

Gammarus locusta

Linnaeus, 1758

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



Adapted from Costa et al., 2004

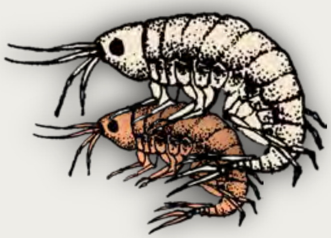
- Wide geographical distribution from the North Sea up to the Southern Portuguese and Spanish coasts

STUDY SPECIES' LIFE CYCLE

~ 40-50 days at 15ºC

(Neuparth et al., 2002)

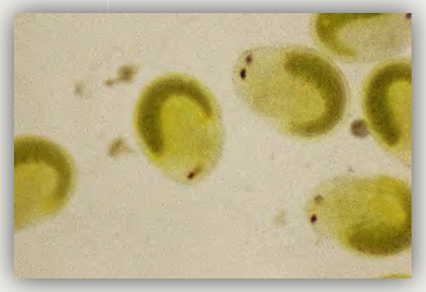
Mature adults



Pre-copulatory Mate guarding

Fertilization

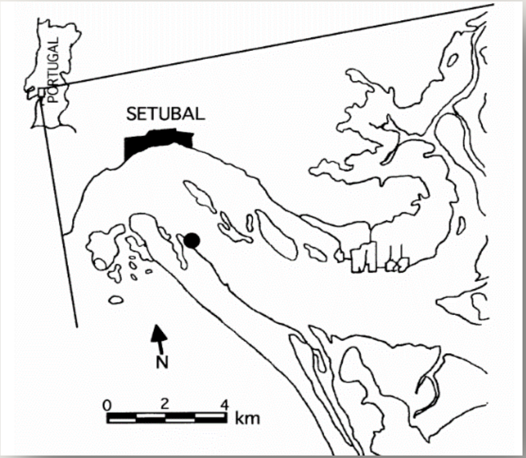
Embryonic development
(inside the brood pouch)



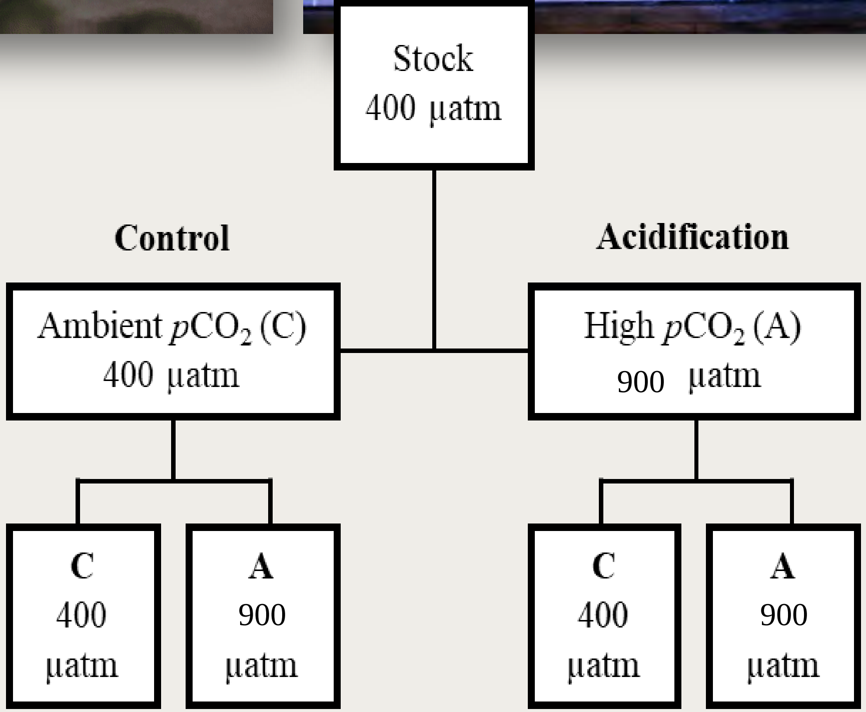
Juveniles

Sub-adults

SAMPLING AND EXPERIMENTAL DESIGN



Original sampling location



Stock
400 µatm

Control

Acidification

Ambient pCO_2 (C)
400 µatm

High pCO_2 (A)
900 µatm

Parental generation (F0)
5 replicates (4-L tanks)
25 individuals per tank

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

C
400
µatm

A
900
µatm

C
400
µatm

A
900
µatm

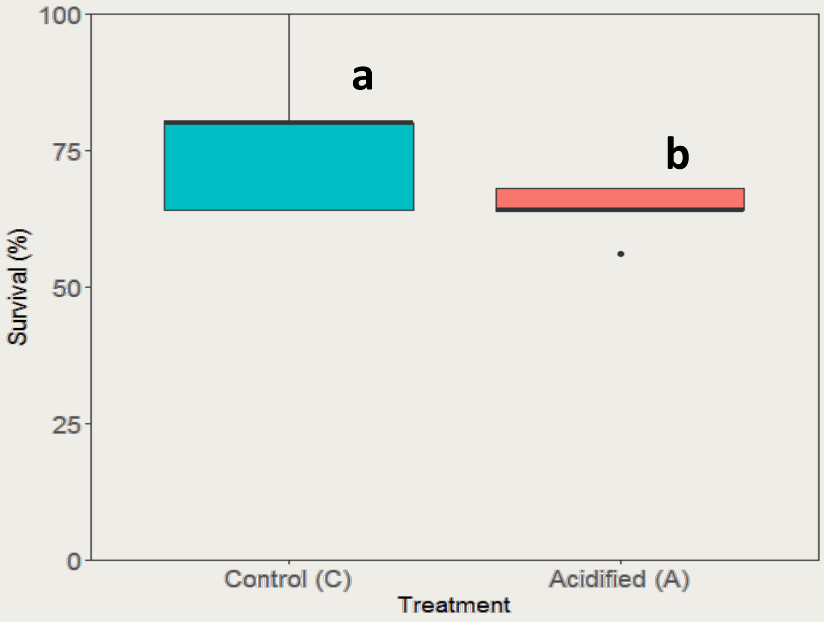
RESULTS

PHYSICO-CHEMICAL PARAMETERS MONITORING

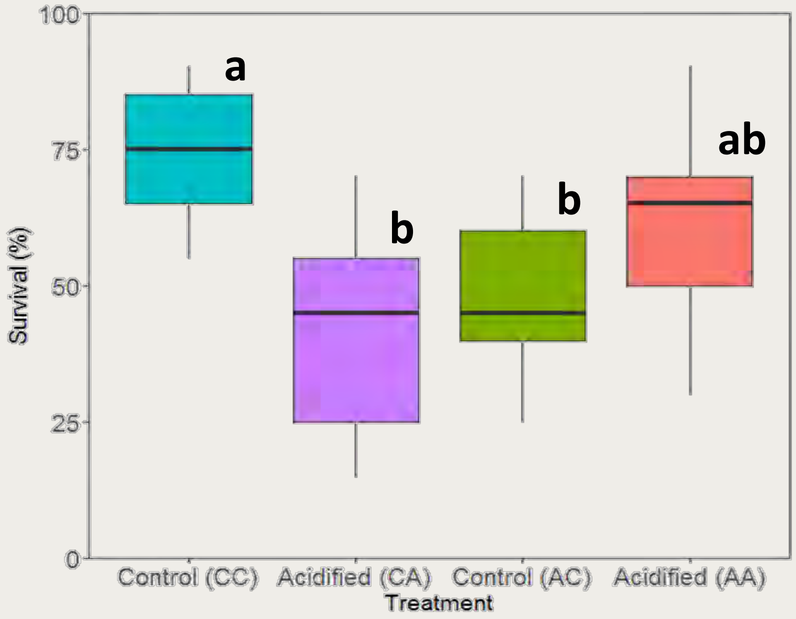
Generation	Treatment	Temperature (º C)	Salinity	pH	TA (µmol/kgSW)	pCO_2 (µatm)
F0	C	18.3 ± 1.3	35	8.1 ± 0.1	1932.2 ± 109.8	375.9 ± 67.7
	A	18.4 ± 1.4	35	7.7 ± 0.1	1971.5 ± 64.3	827.5 ± 73.2
F1	CC	18.8 ± 0.8	35	8.0 ± 0.1	2126.5 ± 112.3	354.2 ± 28.7
	AA	18.8 ± 0.6	35	7.7 ± 0.1	2044.1 ± 140.4	825.5 ± 71.5
	AC	18.7 ± 0.6	35	8.0 ± 0.1	2105.7 ± 108.9	366.8 ± 20.5
	CA	18.8 ± 0.6	35	7.7 ± 0.1	1943.6 ± 88.4	803.2 ± 27.8

RESULTS

- SURVIVAL AT ADULTHOOD (30 DAYS, %)



F0

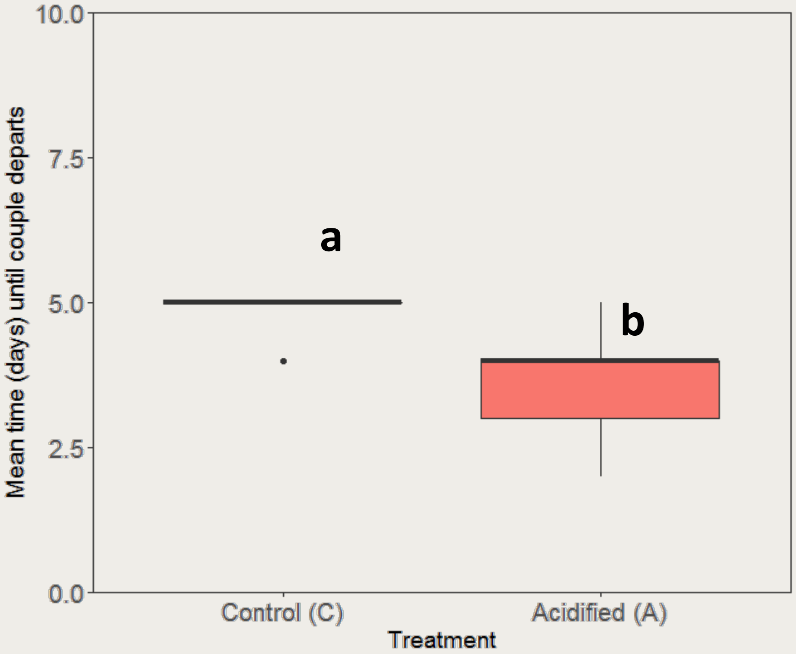


F1

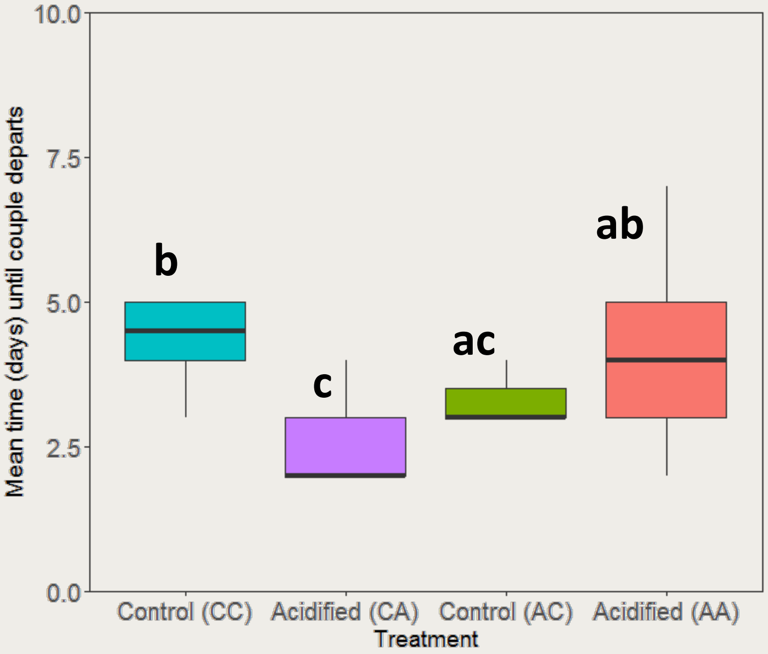
- Survival in F0 declined significantly in acidified conditions, which not occurred in F1
- Survival in cross treatments decreased significantly compared to the control

RESULTS

- **MATE-GUARDING DURATION**



F0

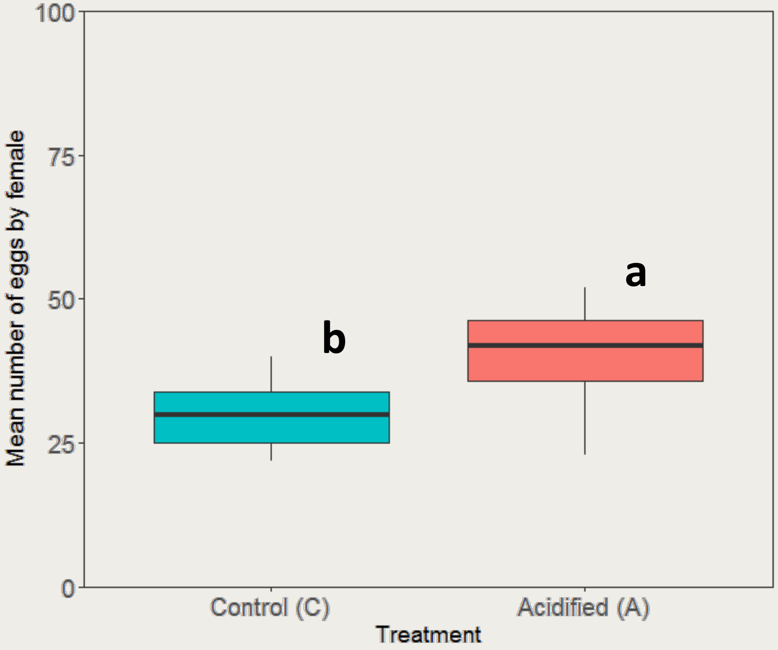


F1

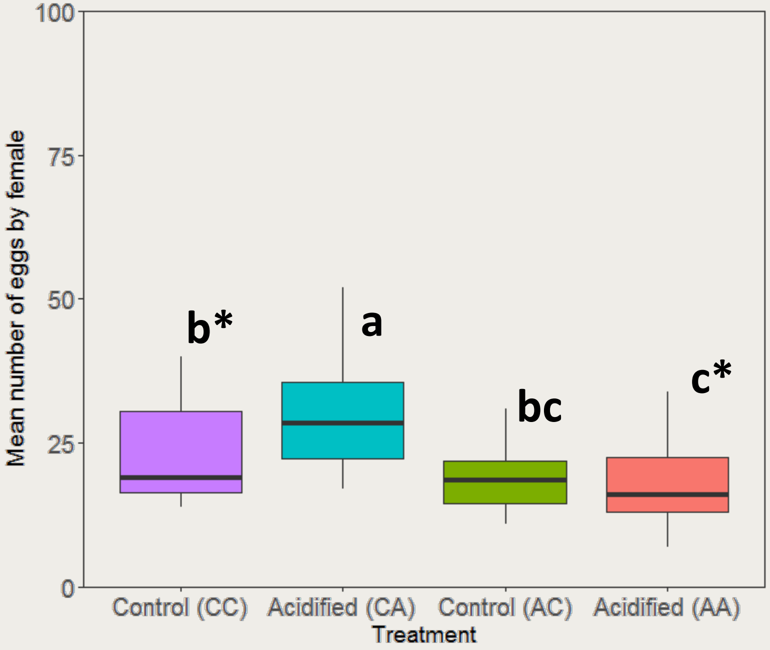
- Exposure to high *p*CO2 produced a significant reduction in mate guarding duration in F0
- In the offspring generation no significant differences were found compared to the control

RESULTS

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



F0

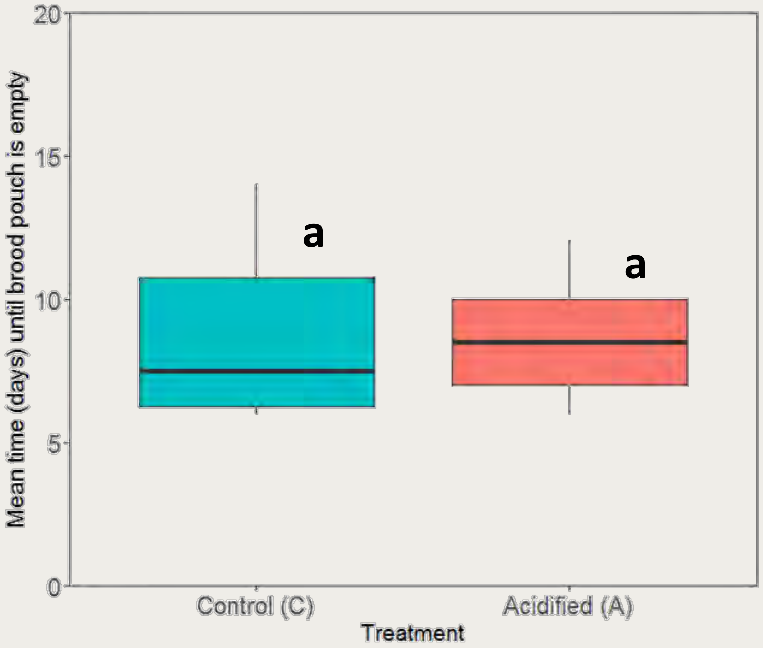


F1

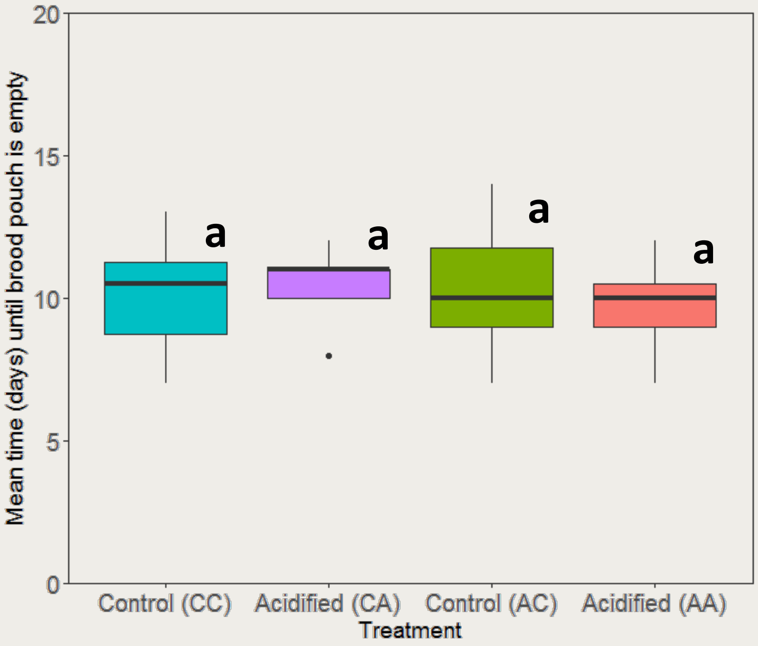
- Parental females under acidification produced significantly more eggs than controls
- In the second generation, production of eggs was reduced

RESULTS

- **REPRODUCTIVE INVESTMENT**
  - b) Duration of embryonic development



F0



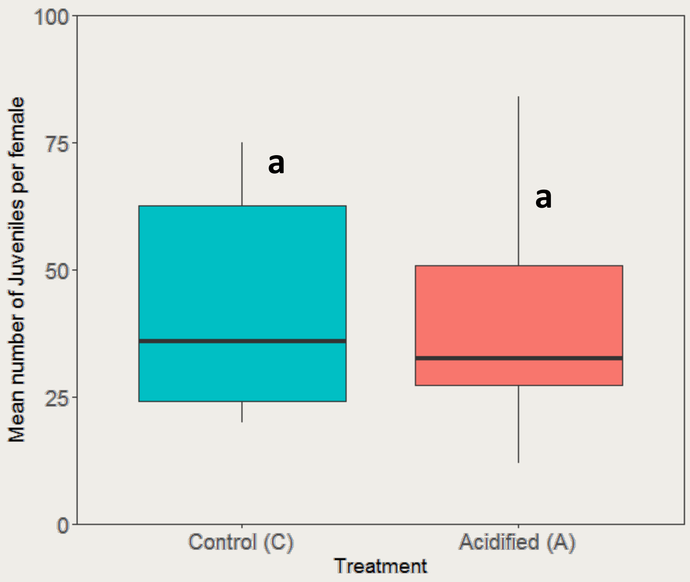
F1

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

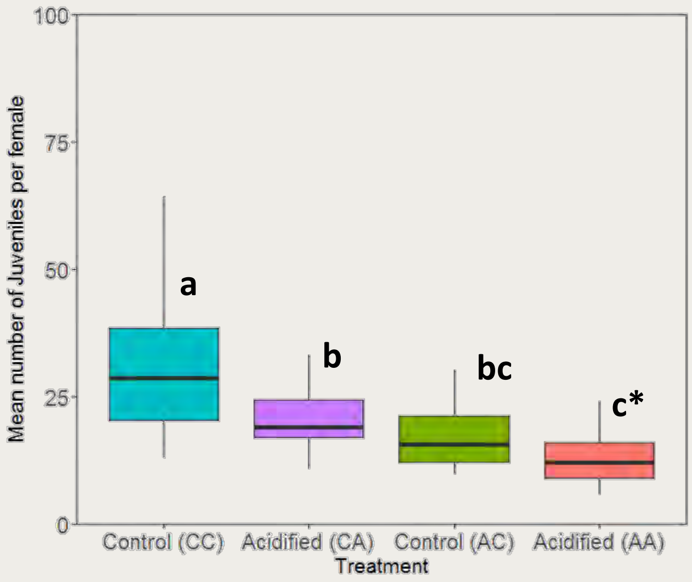
RESULTS

- **REPRODUCTIVE INVESTMENT**

  c) Fecundity / Number of juveniles



F0



F1

- 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)

DISCUSSION

- **SURVIVAL**
    - First exposure (initial acclimation – F0) to acidified conditions systematically reduced survival in this amphipod species
    - **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%
    - 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**
    - 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**
    - 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)**

IN SUMMARY...

	F0	F1	Parental Effects
Survival	↓	=	Negative
Mate-guarding duration	↓	↓	Negative
Female investment	↑	↓	Negative
Fecundity	=	↓	Negative

For further information please see: Borges, F.O., Figueiredo, C., Sampaio, E., Rosa, R., Grilo, T.F. (2018). Transgenerational deleterious effects of ocean acidification on the reproductive success of a keystone crustacean (*Gammarus locusta*). Marine Environmental Research. doi: 10.1016/j.marenvres.2018.04.006

Accepted Manuscript

Transgenerational deleterious effects of ocean acidification on the reproductive success of a keystone crustacean (Gammarus locusta)

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PII: S0141-1136(18)30108-9
DOI: 10.1016/j.marenvres.2018.04.006

ACKNOWLEDGMENTS

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A special acknowledgment for the collaboration and advices provided by **Marta Pimentel** and **José Paula**

THANK YOU FOR YOUR ATTENTION!

This work was supported by the MARE strategic project (UID/MAR/04292/2013) and Fundação para a Ciência e Tecnologia (FCT) through a post-doctoral grant attributed to Tiago Grilo (SFRH/BPD/ 98590/2013), PhD grants attributed to Cátia Figueiredo and Eduardo Sampaio (SFRH/BD/130023/2017 and SFRH/BD/131771/2017, respectively), Programa Investigador FCT 2013 – Development grant to Rui Rosa and and the FCT Project CLIMATOXEEL (PTDC/AAG-GLO/3795/2014) awarded to Tiago Grilo