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# Effects of $CO_2$-driven ocean acidification and warming on early development of fish

Atsushi Ishimatsu
Atsuko Fukuda
Seiya Ueoka
Institute for East China Sea Research,
Nagasaki University

Haruko Kurihara
**Transdisciplinary Research Organization for Subtropical Island Studies**
The University of Ryukyus

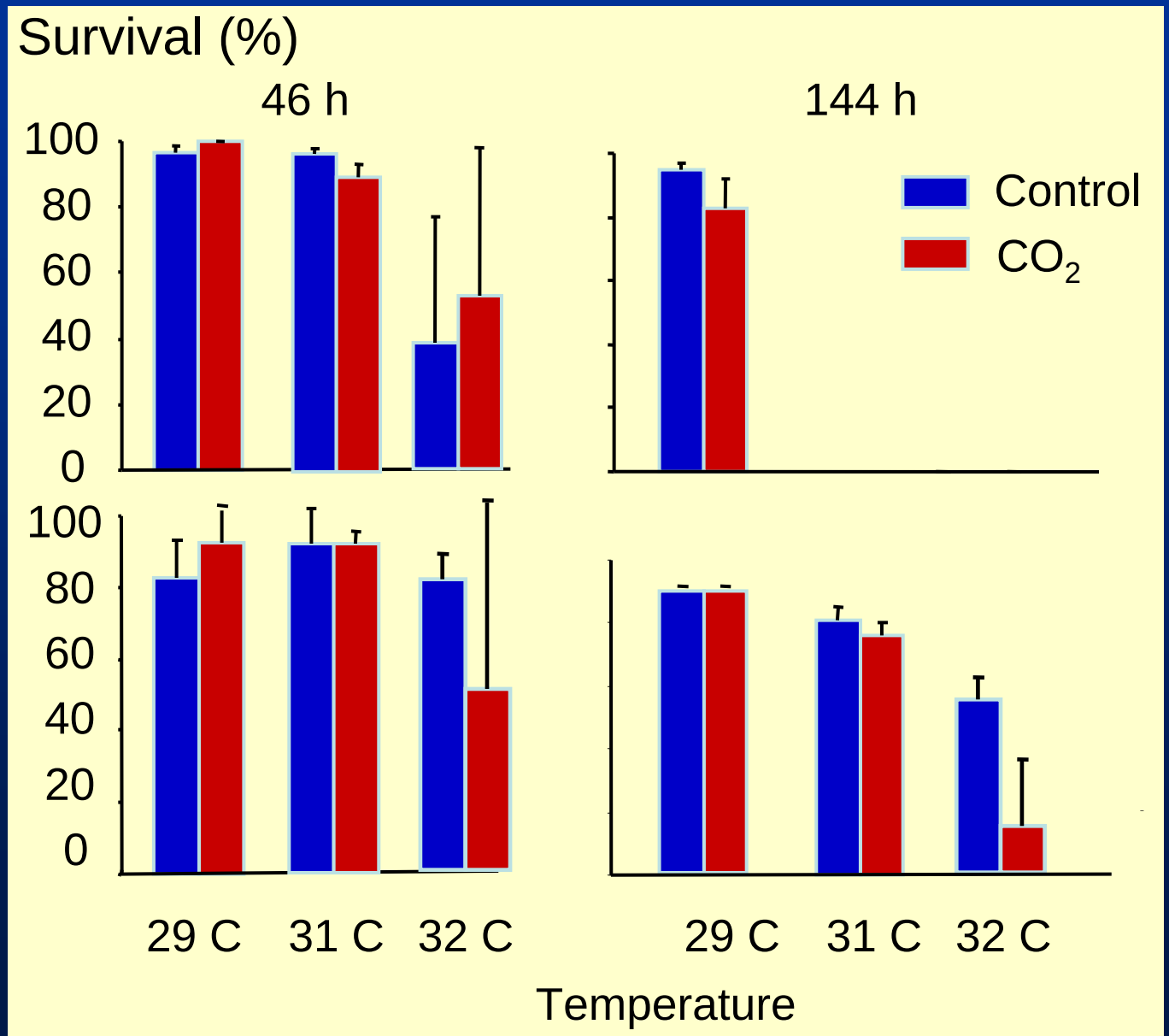
# Outlines of Our Fish Experiments

- Clown fish experiment (*Amphiprion clarkii and A. ocellaris*)
  Eggs obtained from spawning one pair
  $PCO_2$ 1000 μatm, Exposure period 6 days
  Embryonic and larval survival, larval morphology, heart rate etc.

- Javanese estuarine medaka experiment (*Oryzias javanicus*)
  Seven pairs reared separately
  $PCO_2$ 1000 μatm, Exoposure period 125 days
  Adult and larval survival, spawning, fertilization, larval morphology etc.

- Japanese sillago experiment (*Sillago japonica*)
  $PCO_2$ 4000-12000 μatm, Exoposure period 154 days
  Growth, gonad development, chloride cell morphology etc.

# Combined Effect of Temperature and $CO_2$ (1000 μatm) on Embryonic Survival of Two Clown Fish

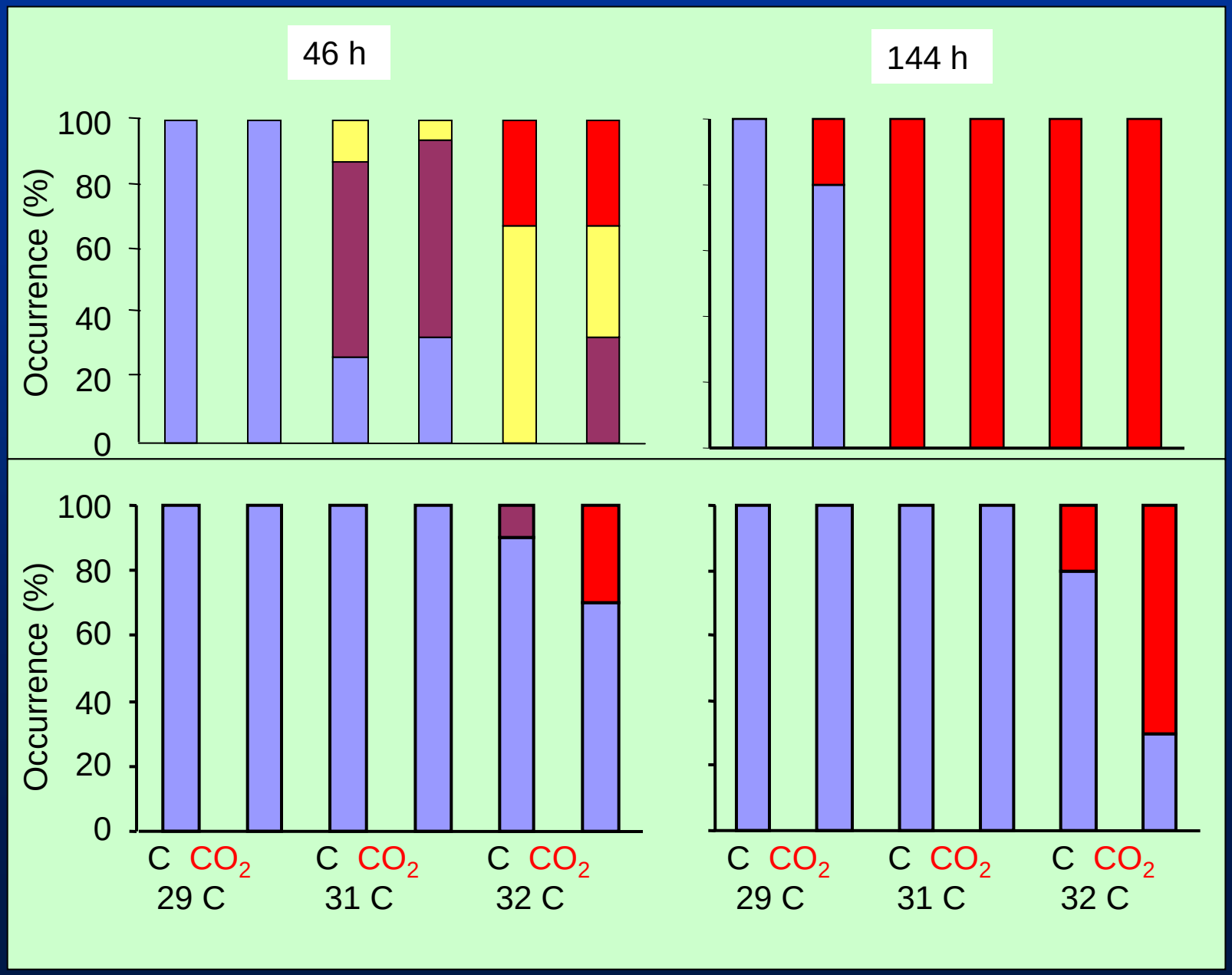


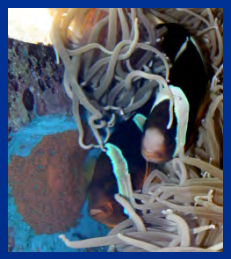

***Amphiprion clarkii***

***Amphiprion ocellaris***

Fukuda et al
unpublished

# Combined Effect of Temperature and $CO_2$ (1000 μatm) on Embryonic Development of Two Clown Fish

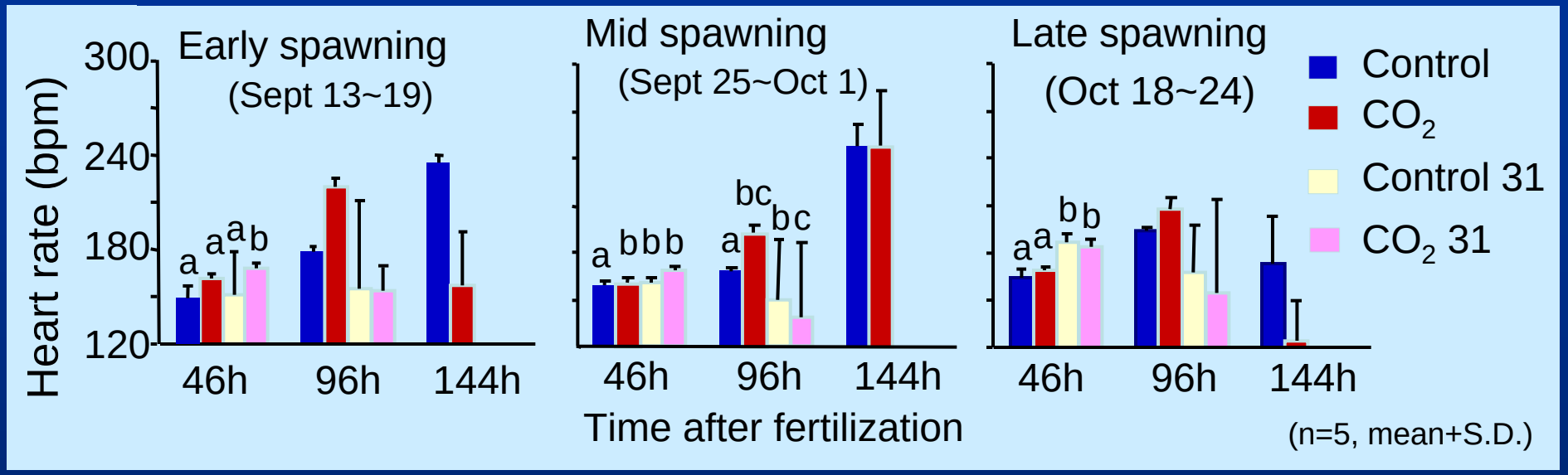


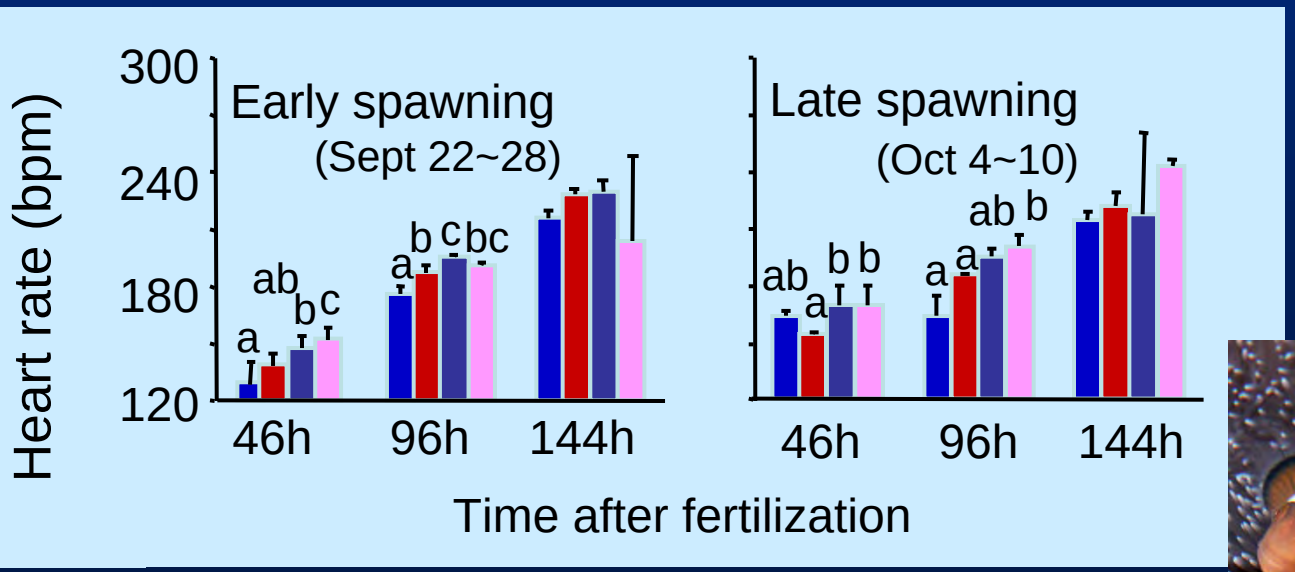



*Amphiprion clarkii*

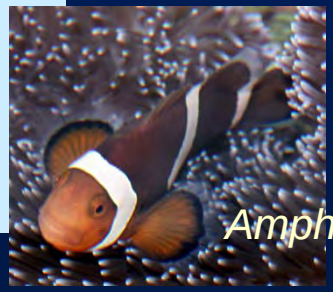
*Amphiprion ocellaris*

# Combined Effect of Temperature and $CO_2$ (1000 μatm) on Embryonic Heart Rate of Two Clown Fish



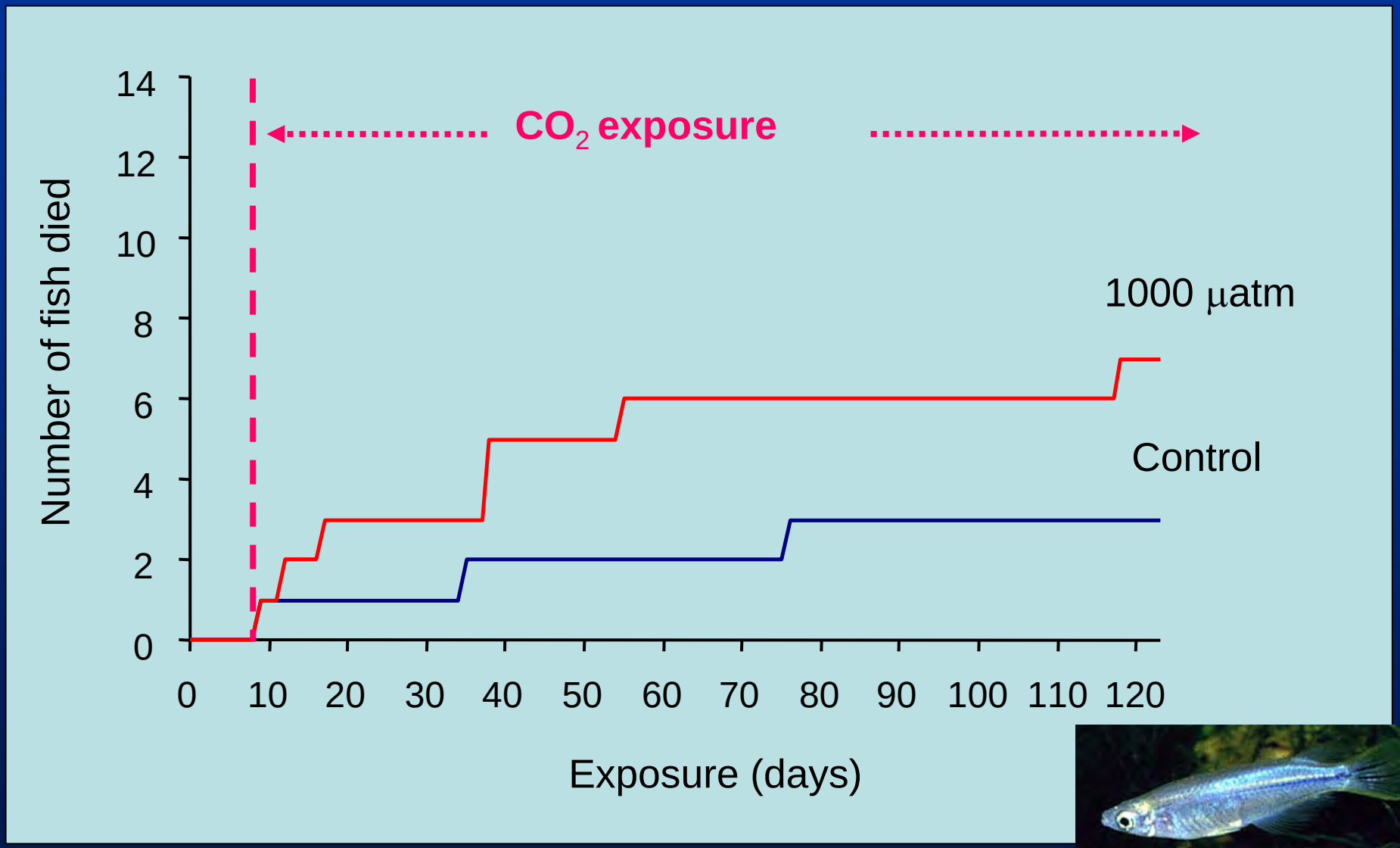




*Amphiprion clarkii*



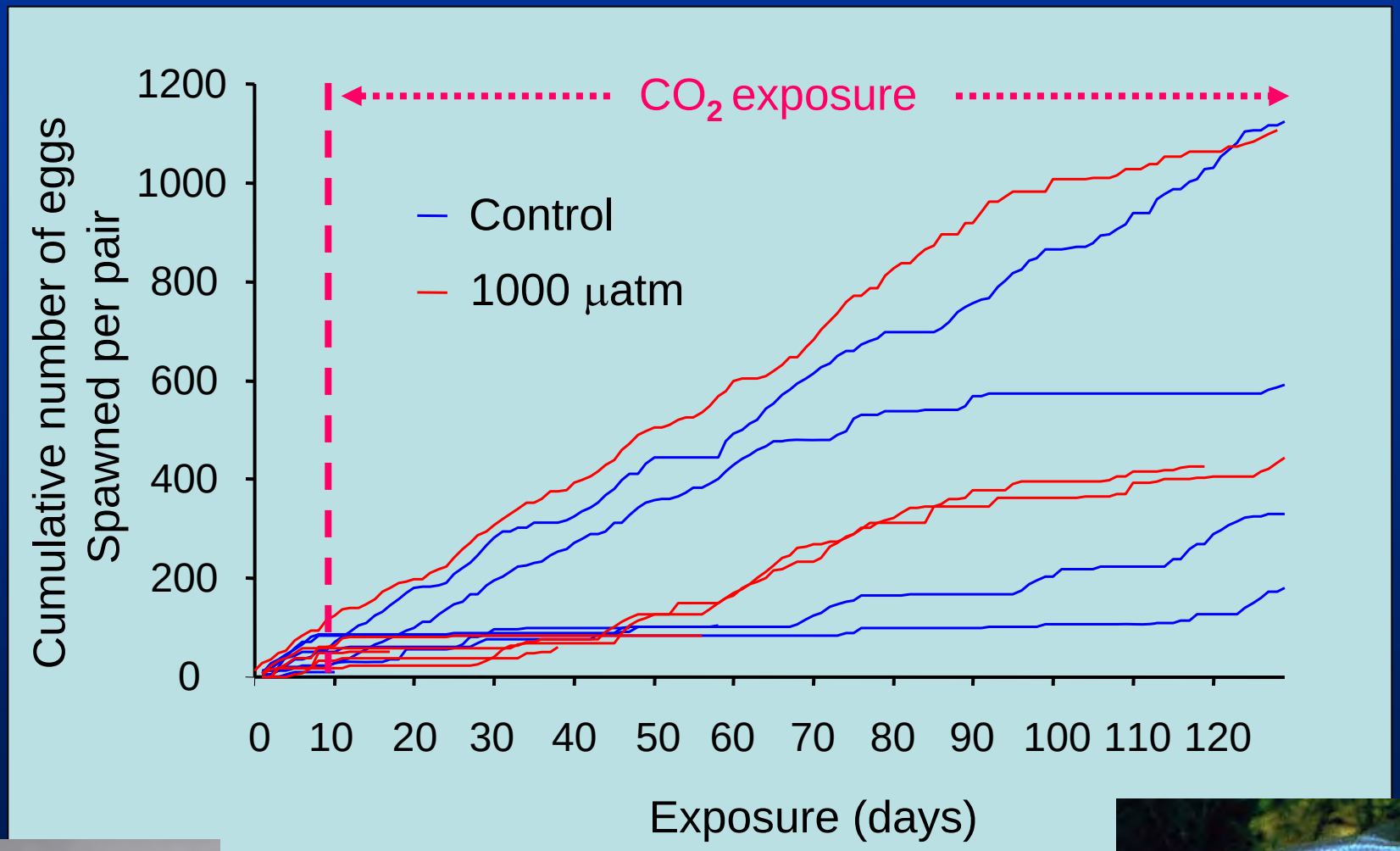
*Amphiprion ocellaris*

# Effect of 125-day $CO_2$ Exposure on Survival of *Oryzias javanicus*



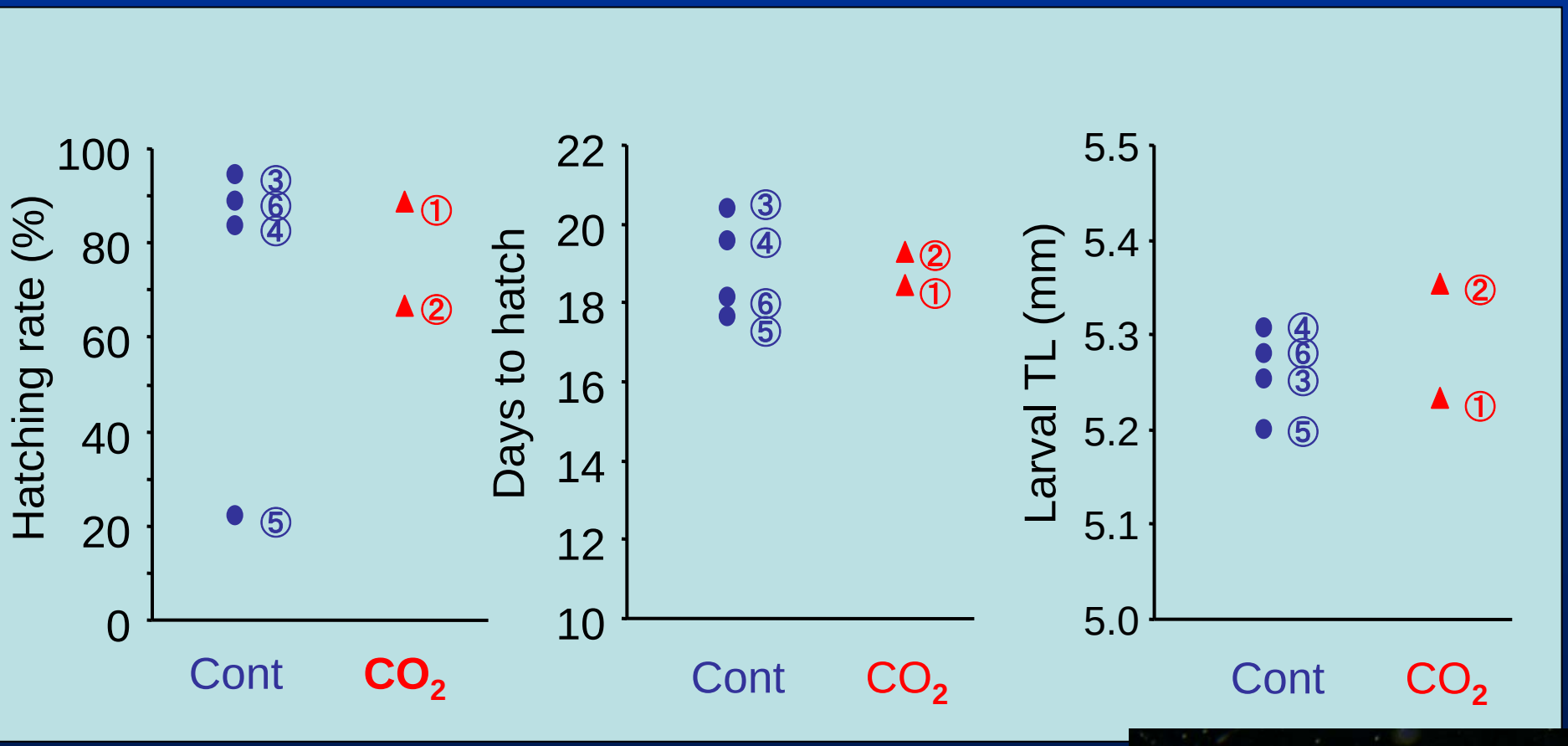

Ueoka et al. unpublished

# Effect of 125-day $CO_2$ Exposure on Survival of *Oryzias javanicus*

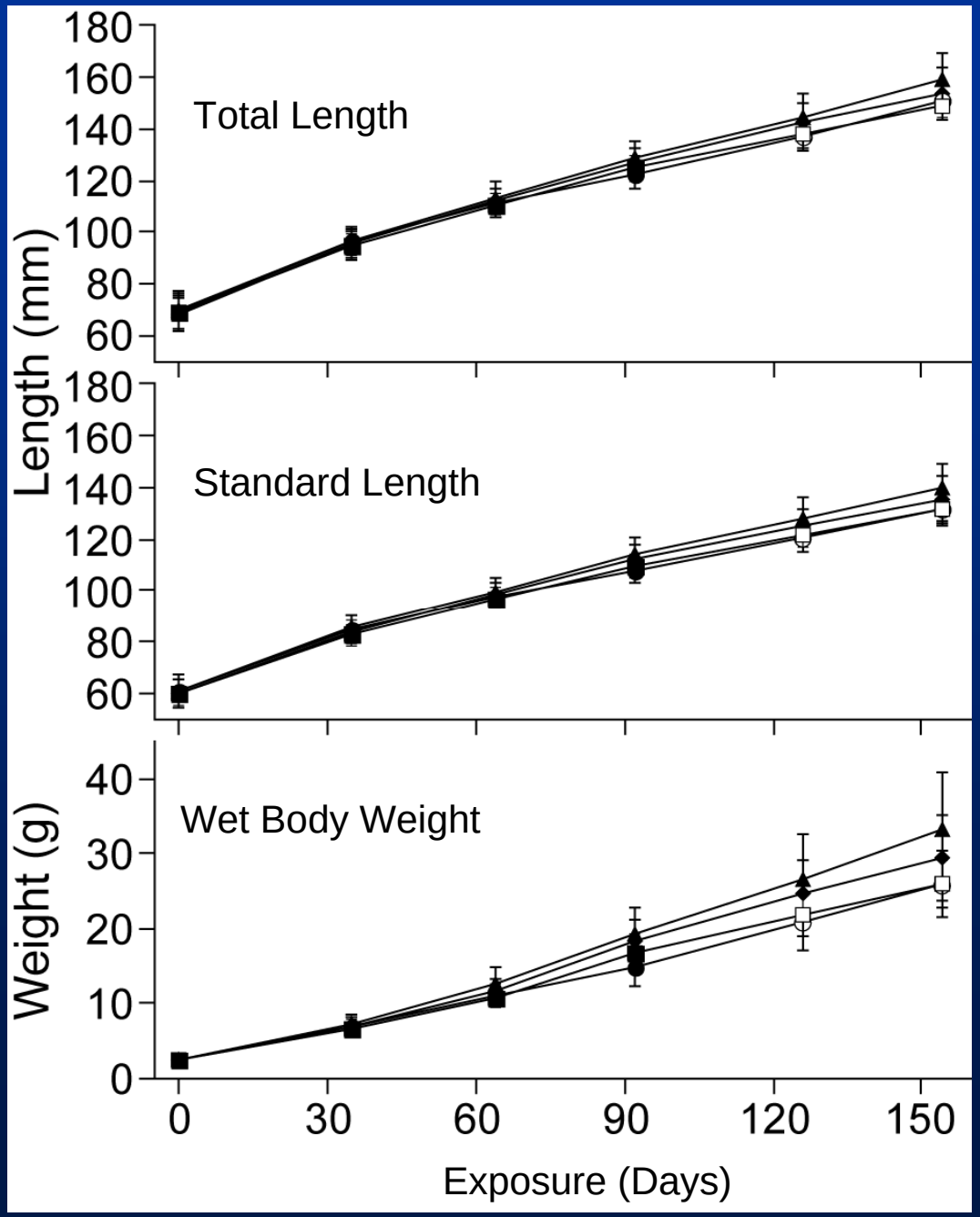




# Hatching rate, Days to Hatch, and Total Length of Just Hatched Larvae of Control and $CO_2$-exposed *Oryzias javanicus*




# Effect of 154-day $CO_2$ Exposure on Growth of *Sillago japonica*

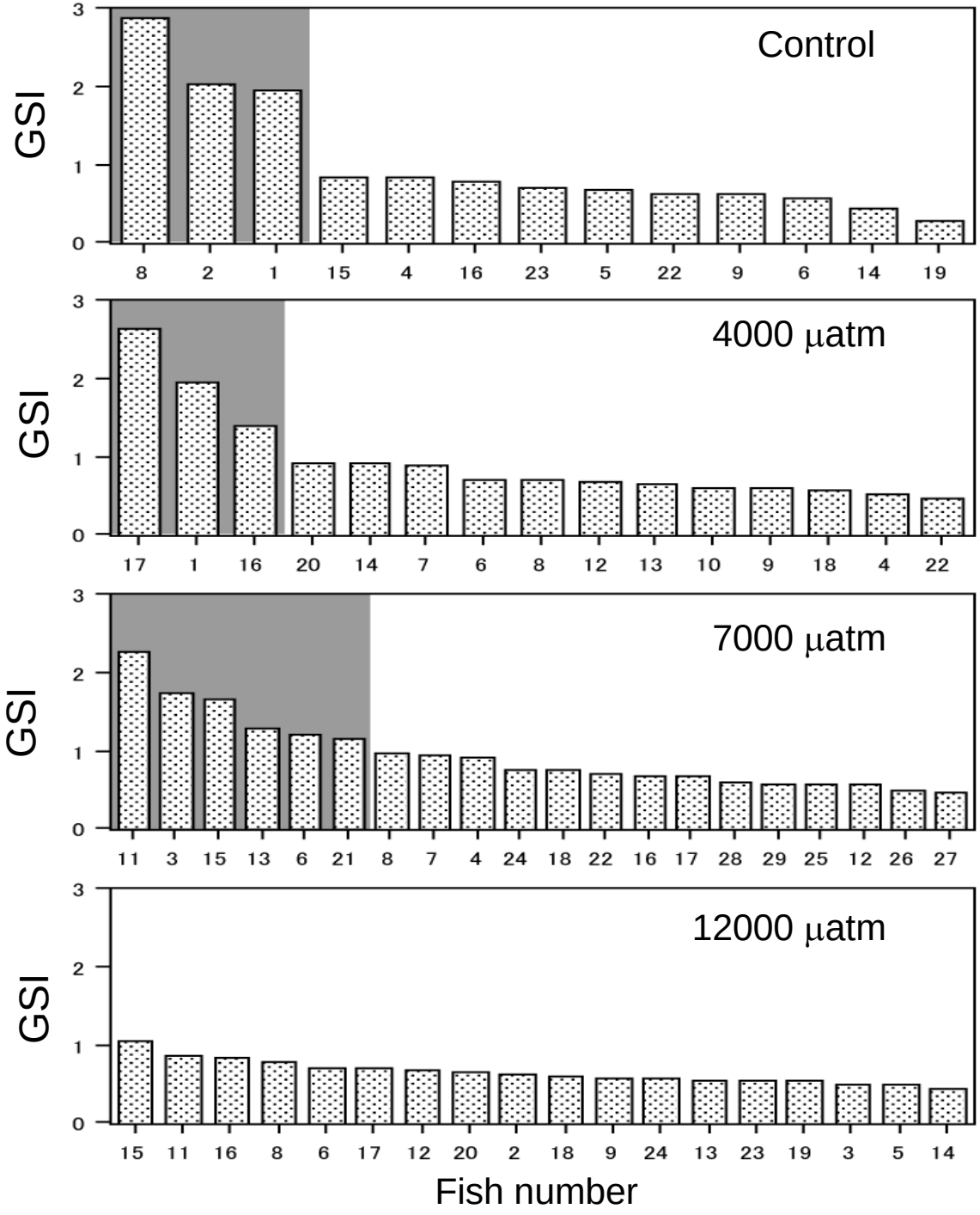



*Sillago japonica*

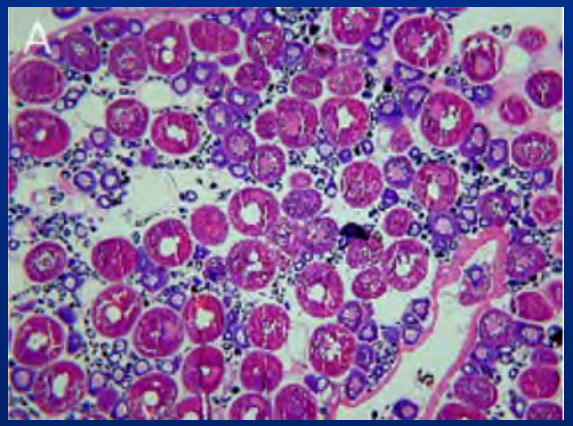
▲ Control
■ 4000 μatm
◆ 7000 μatm
● 12000 μatm

Kikkawa et al (unpublished)

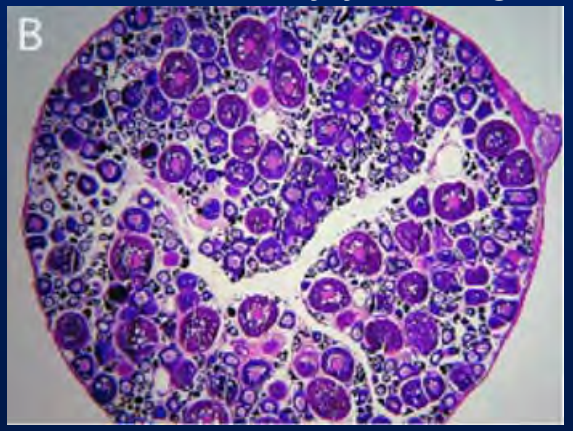
# Effect of 154-day $CO_2$ Exposure on Ovarian Development of *Sillago japonica*



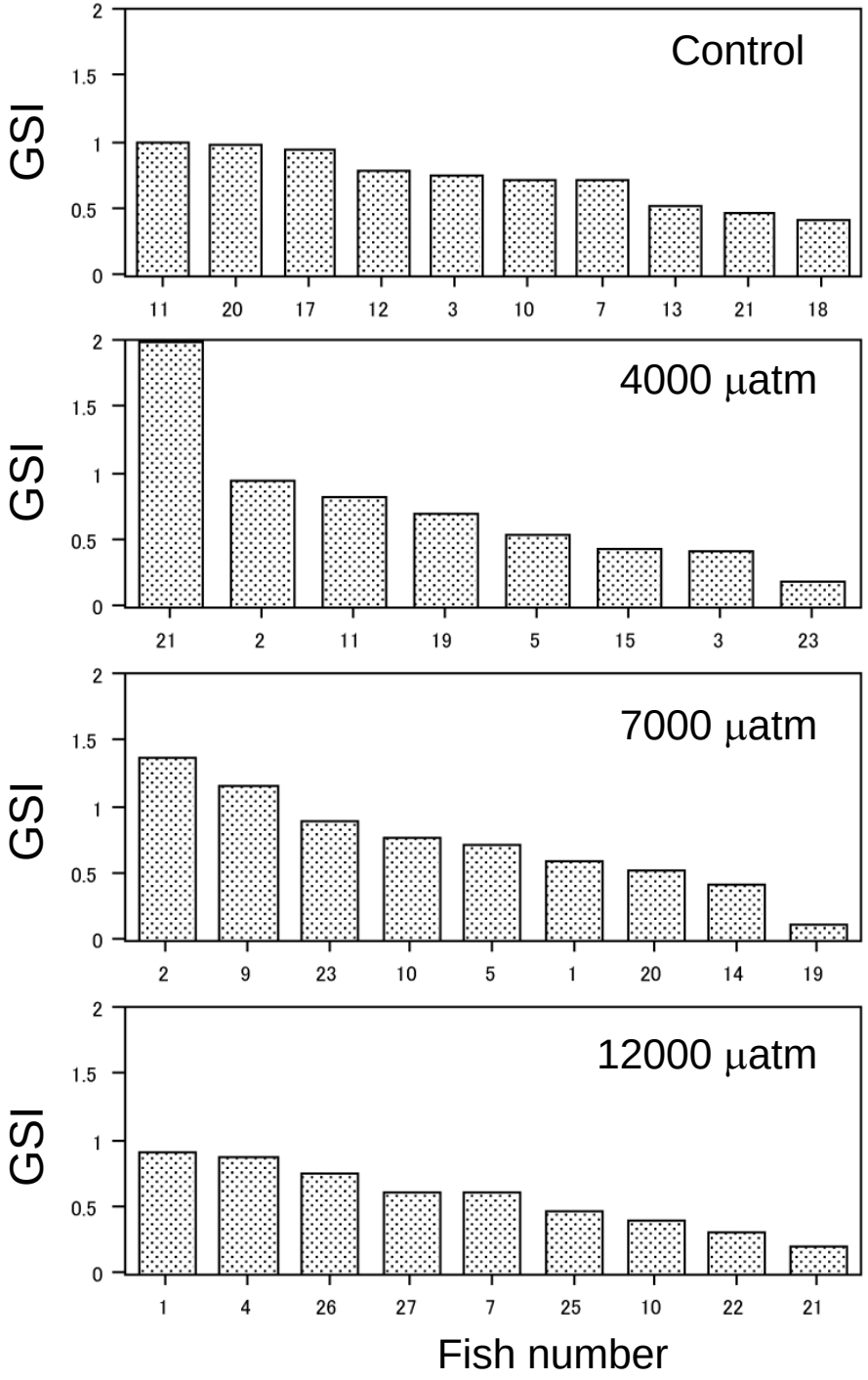

**Bars in gray area are in**




Secondary yolk stage

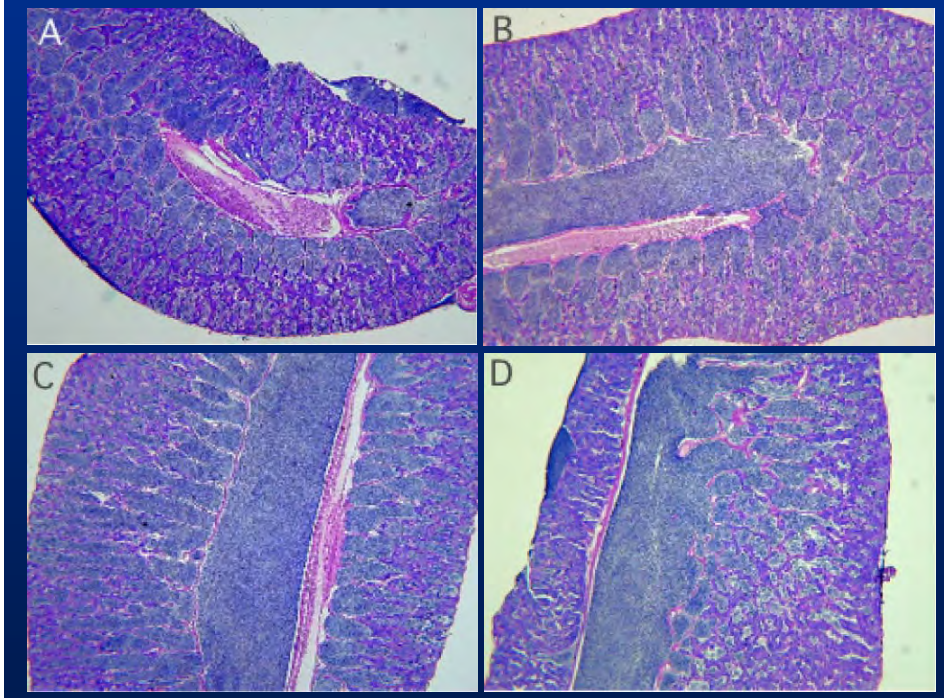



Primary yolk stage



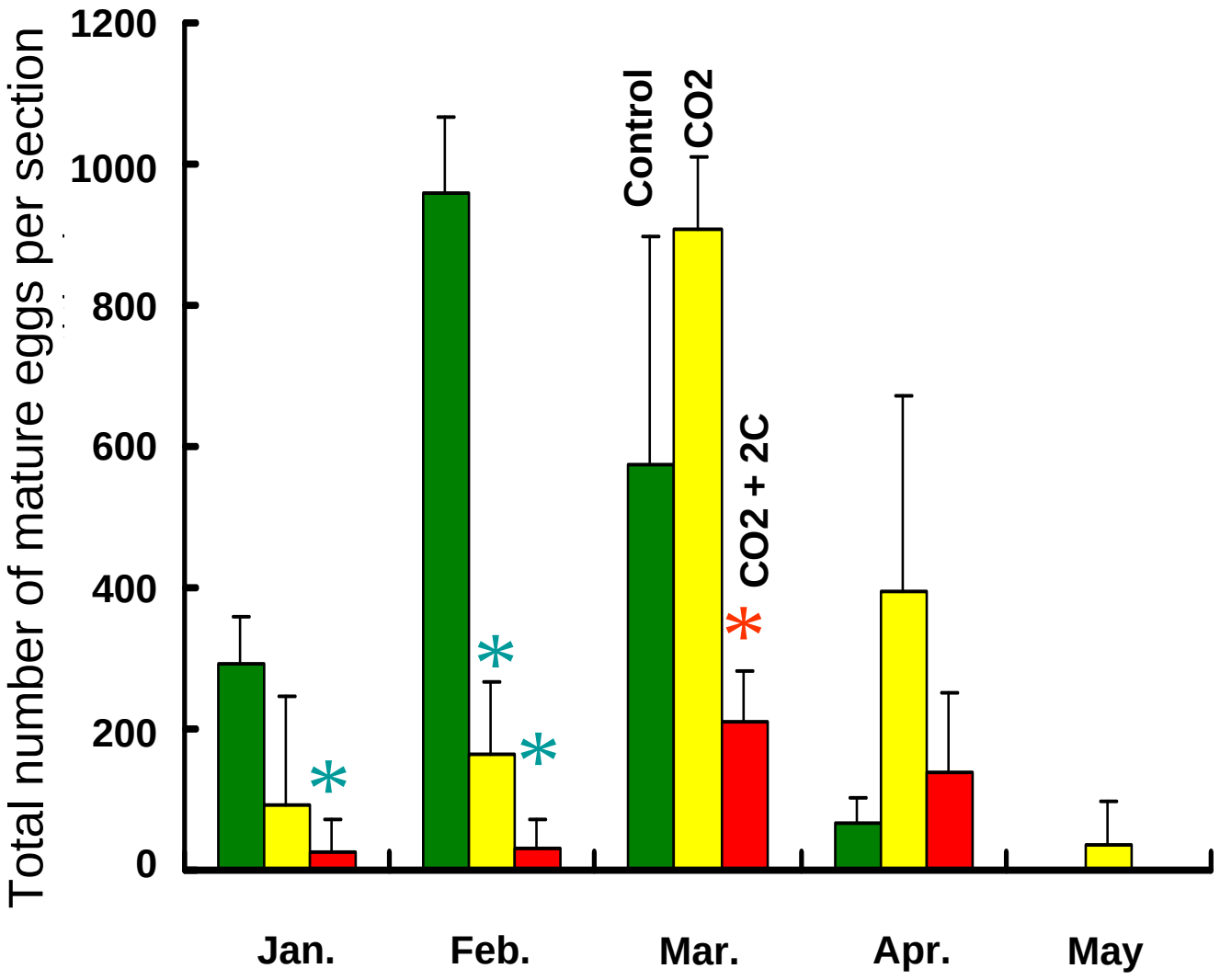

# Effect of 154-day $CO_2$ Exposure on Testis Development of *Sillago japonica*

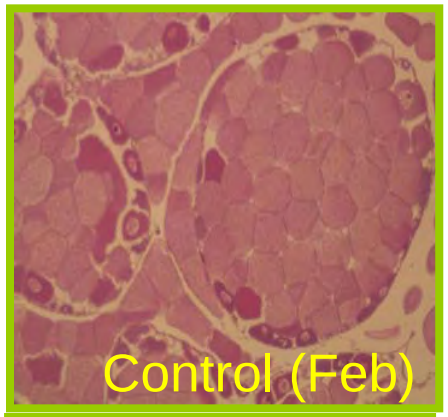
**Control** **4000 μatm**

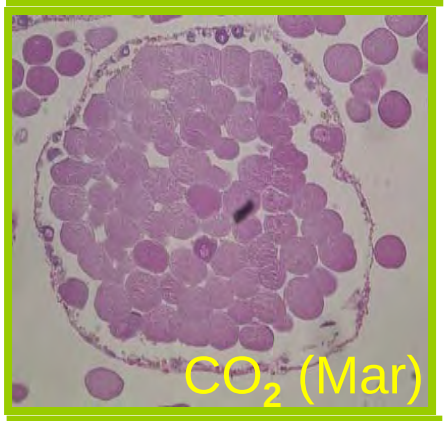


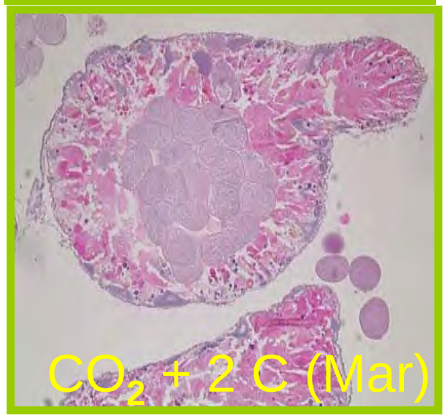

**7000 μatm** **12000 μatm**

# Effect of $CO_2$ and Temperature on Ovarian Development of the Sea Urchin *Hemicentrotus pulcherrimus*



## Summary

- Early development of clown fish was disrupted by temperature but not by $CO_2$. ··· Not enough data, continuing
- Survival of *O. javanicus* might be affected by $CO_2$.

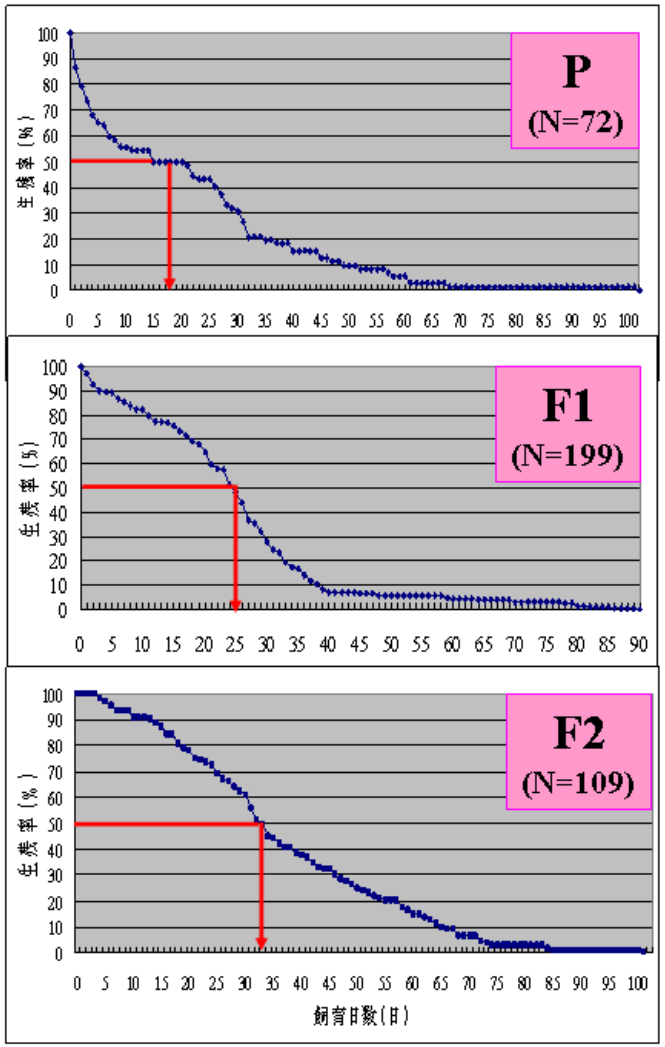
  ··· Not enough data, continuing
- Growth and ovary maturation of *S. japonica* were reduced by $CO_2$ only at > 10,000 μatm.

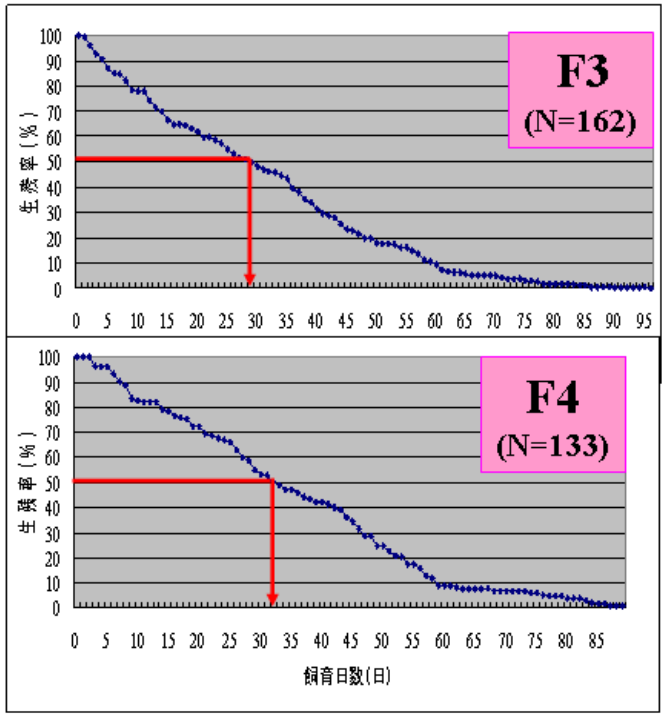
## Further studies

- Combined effects of $CO_2$ and temperature on growth, sexual maturation, reproduction, and early development of temporal and boreal species.
- Effects of $CO_2$ and temperature on fish through food organisms.

We are rearing the mysid *Nipponomysis fusca* over generations to study effects of $CO_2$ on survival, reproduction, mysid-fish interactions, and their nutritional value as fish food.


*Nipponomysis fusca*




**50% lethal time (days)**

| | |
|---|---|
| P | 18 |
| F1 | 25 |
| F2 | 33 |
| F3 | 29 |
| F4 | 33 |

# Our literature survey on "$CO_2$ effect on fish" papers revealed:

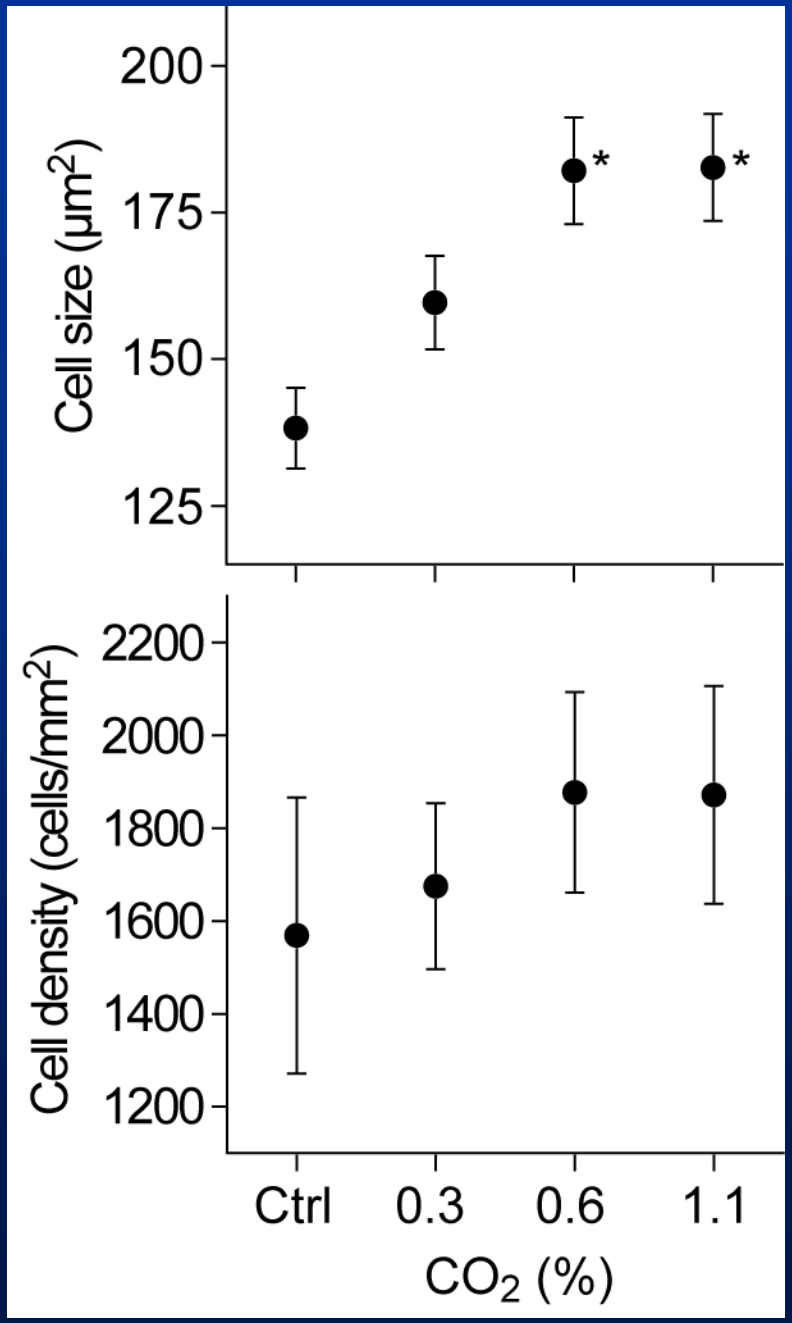
1. Effects of $CO_2$ on fish have been intensively investigated in comparative physiology but used relatively high $CO_2$ levels.

Total number of papers (1969-2008): 116 papers
Freshwater fish: 88 Seawater fish: 28

$CO_2$ levels used: > 5000 μatm in 97%

Exposure duration: < 2 days in 65%

Stage of the fish: adults in nearly all papers


200
175
150
125
Cell size (μm²)
*
*
2200
2000
1800
1600
1400
1200
Cell density (cells/mm²)
Ctrl
0.3
0.6
1.1
CO₂ (%)

# Our previous invertebrate studies

Kurihara et al. (

Control $CO_2$