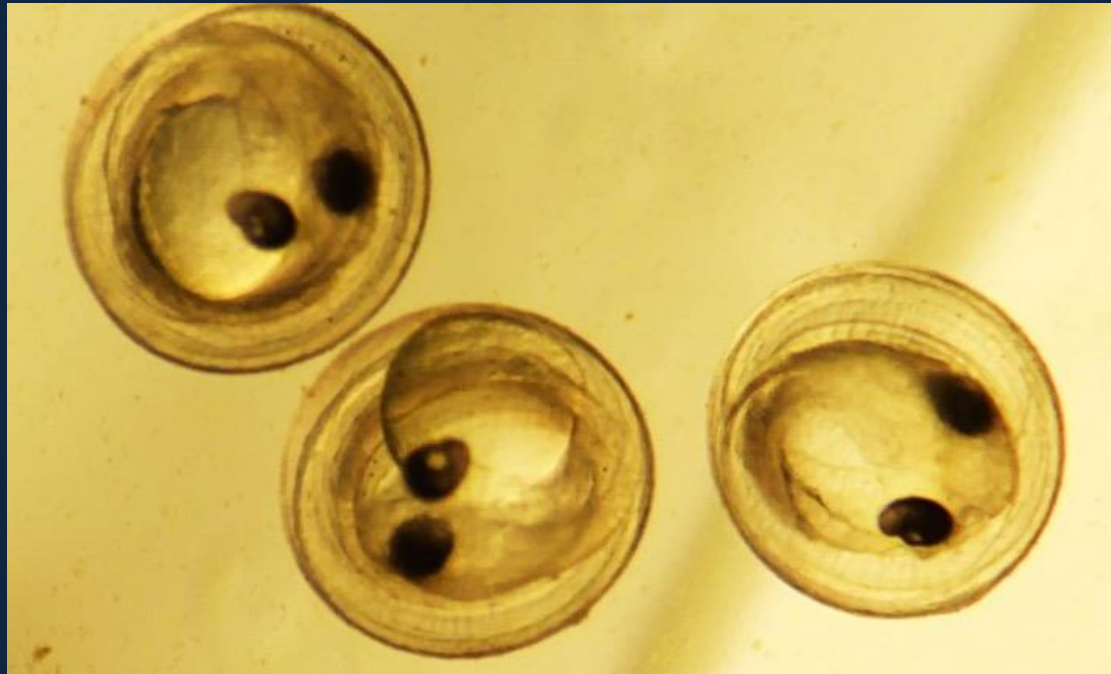


# Interactive effects of ocean acidification and ocean warming on Pacific herring (*Clupea pallasii*) early life stages

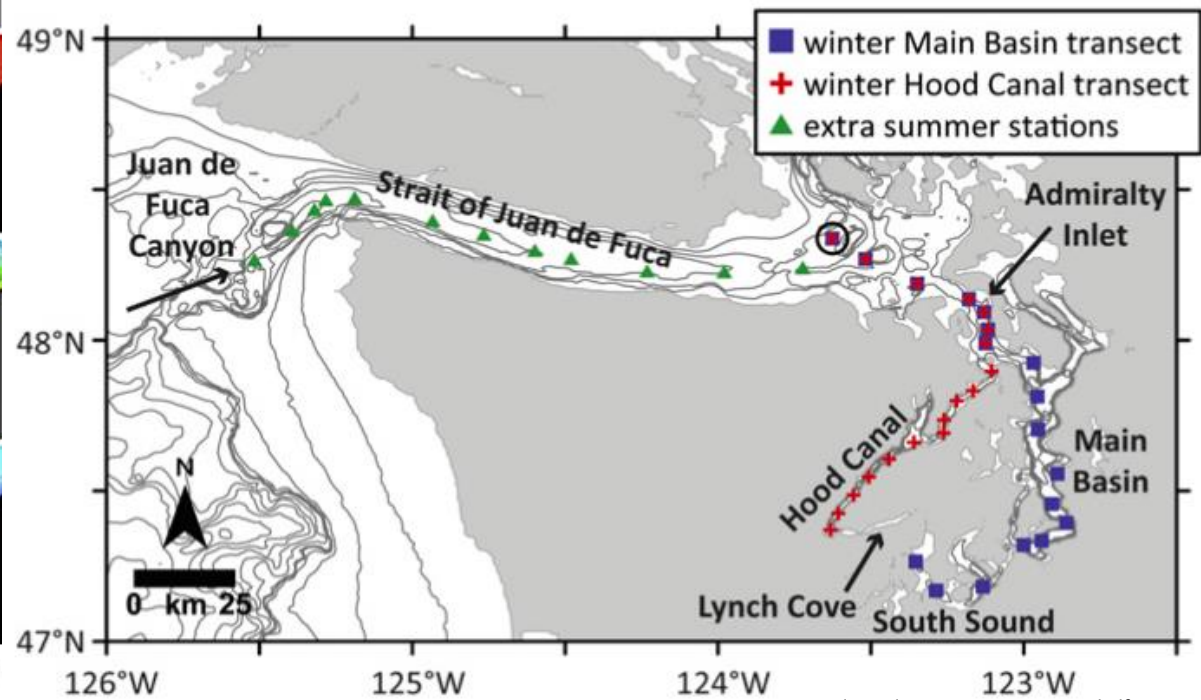
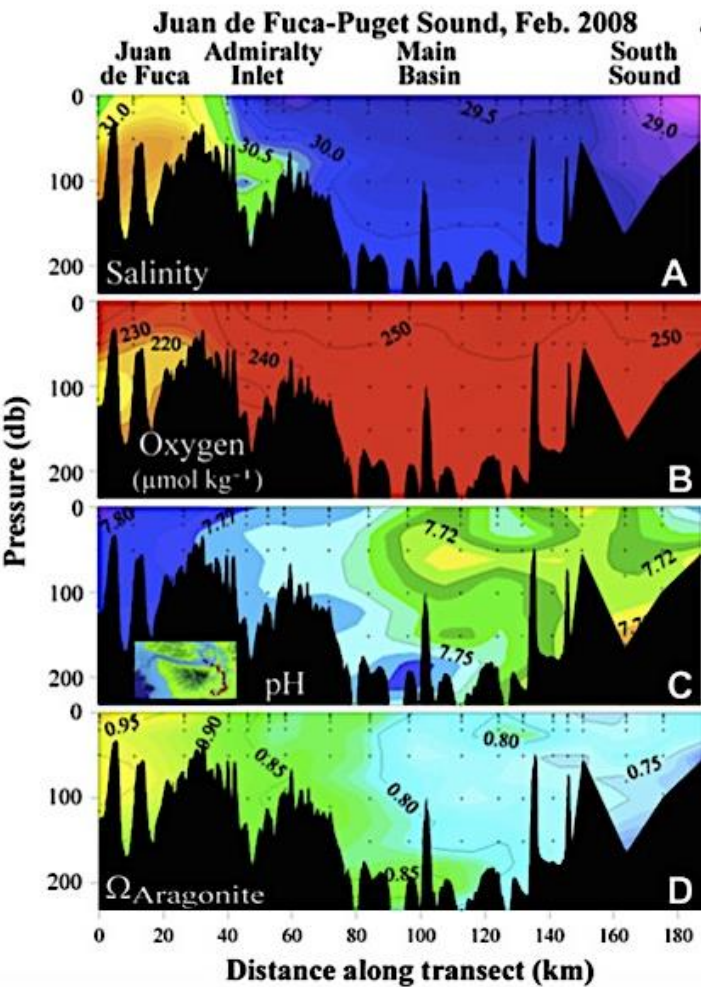
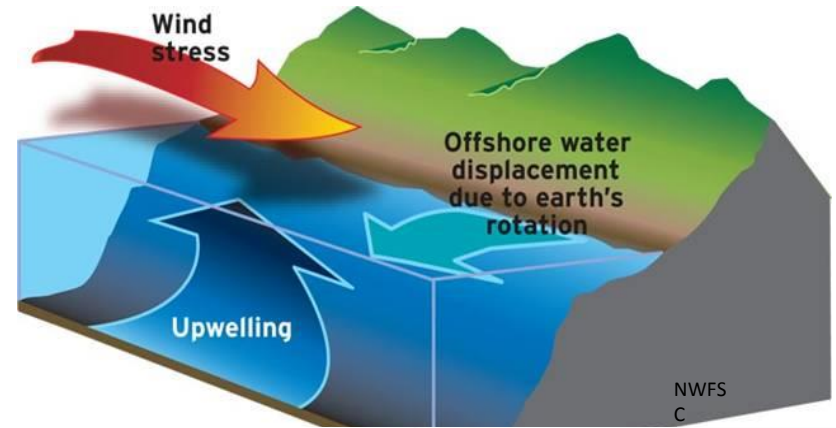


Cristina Villalobos<sup>1</sup>, Brooke Love<sup>1</sup>, M. Brady Olson<sup>2</sup>, and Leo Bodensteiner<sup>1</sup>

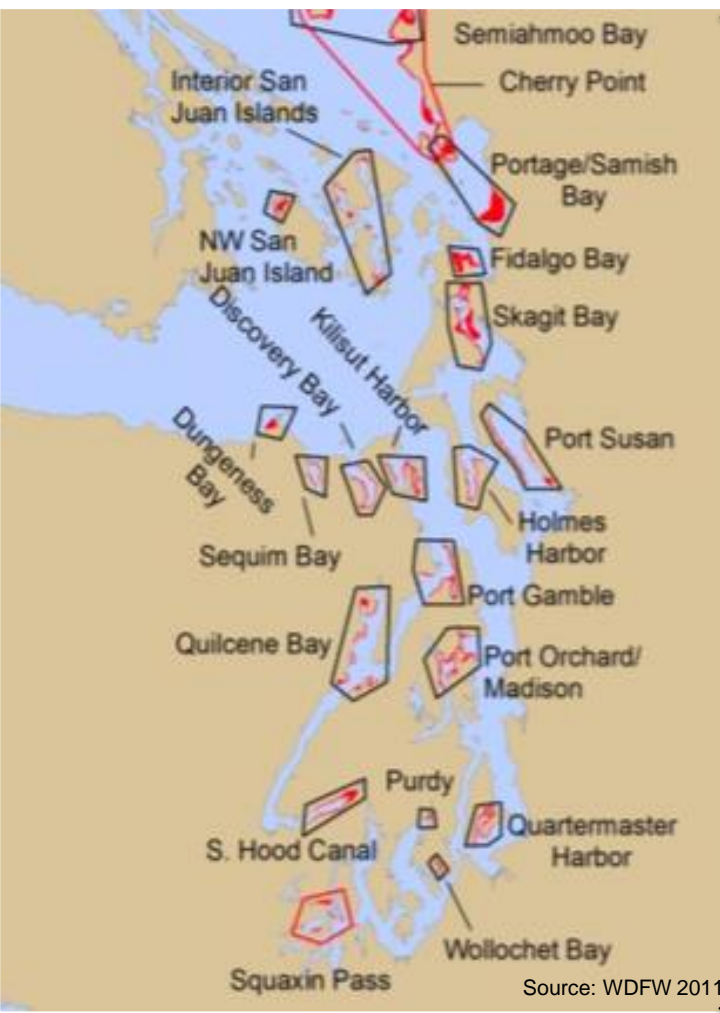
<sup>1</sup>Huxley College of the Environment, Western Washington University, Bellingham, WA

<sup>2</sup>Shannon Point Marine Center, Western Washington University, Anacortes, WA

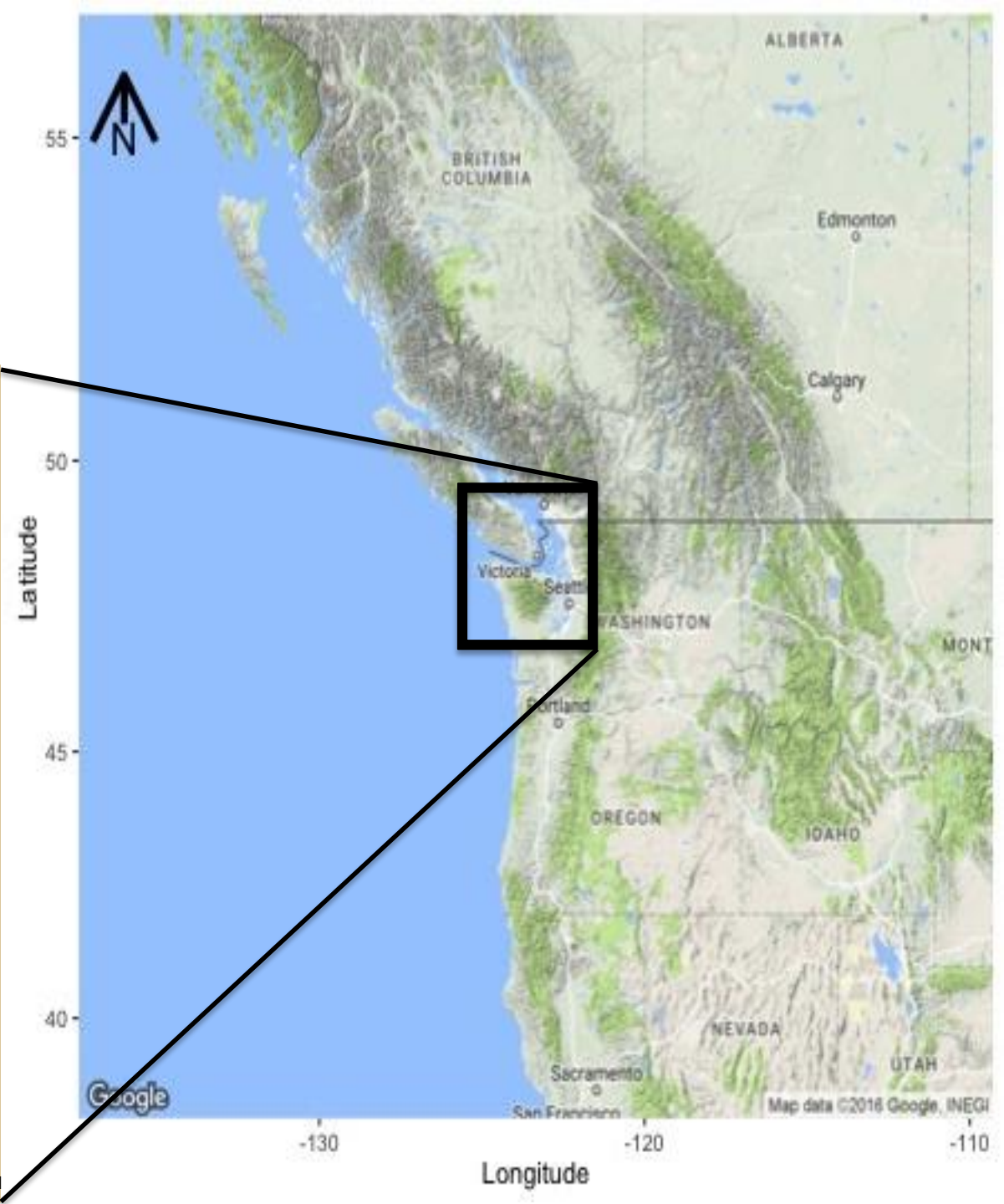
# Seasonal upwelling gives us a glimpse of future ocean acidity



Pacific herring spawning stocks in Puget Sound are predisposed to low ocean acidity levels



Source: WDFW 2011





# Responses to acidification are species-specific

Impairs olfactory senses



Orange Clownfish (Munday et al. 2008. *PNAS*)

Reduces growth and survival



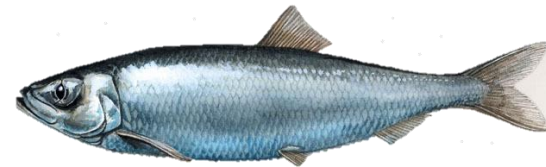
Inland Silverside (Baumann et al. 2012. *Nat. Clim. Chang.*)

No sperm motility effects



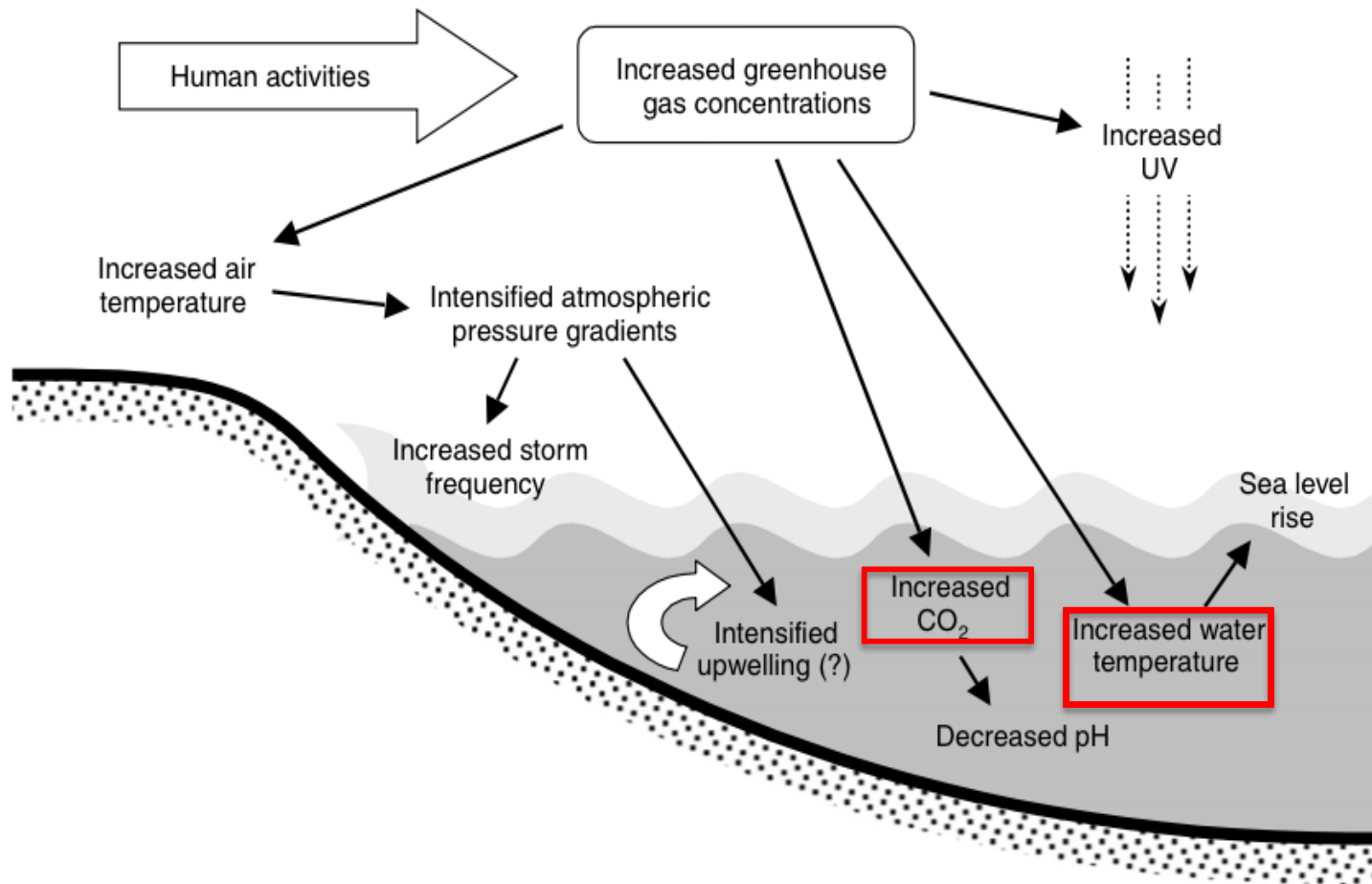
Baltic Cod (Frommel et al. 2012. *Mar. Biol.*)

No embryonic or hatch rate effects



Atlantic Herring (Franke & Clemmesen 2011. *Biogeosci.*)

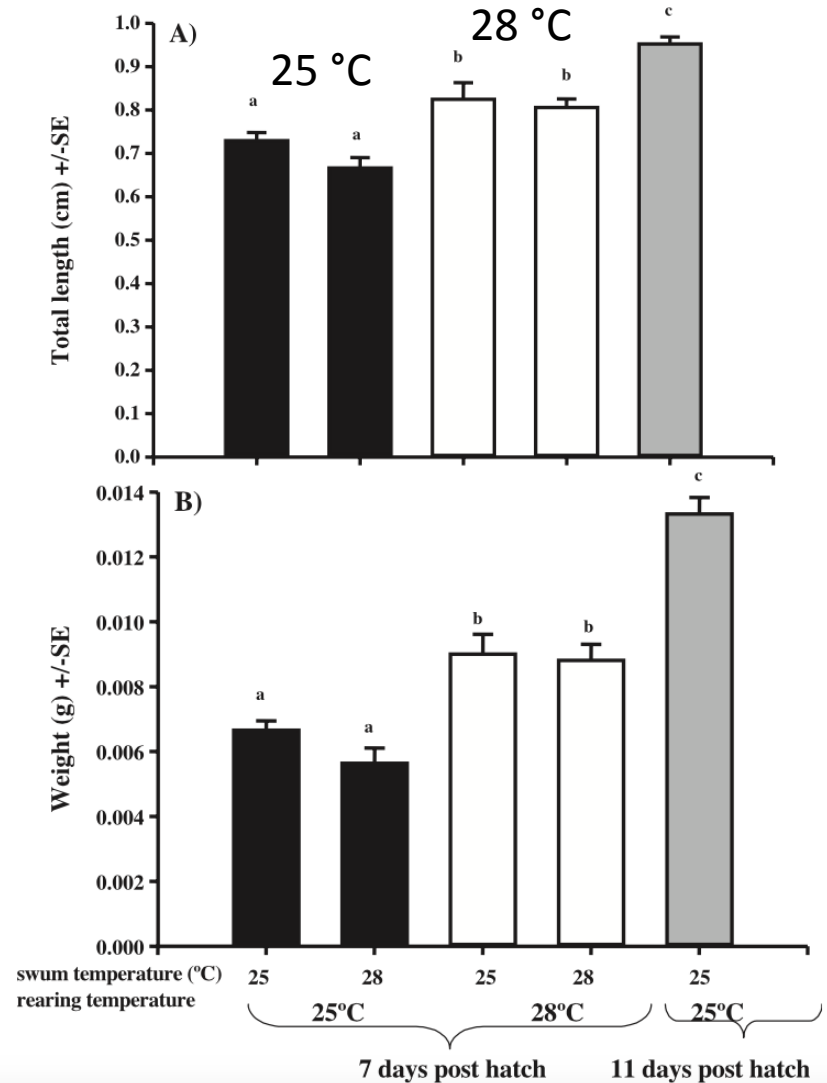
# Organisms are bombarded by multiple environmental stressors



# “Bigger may not be Better”

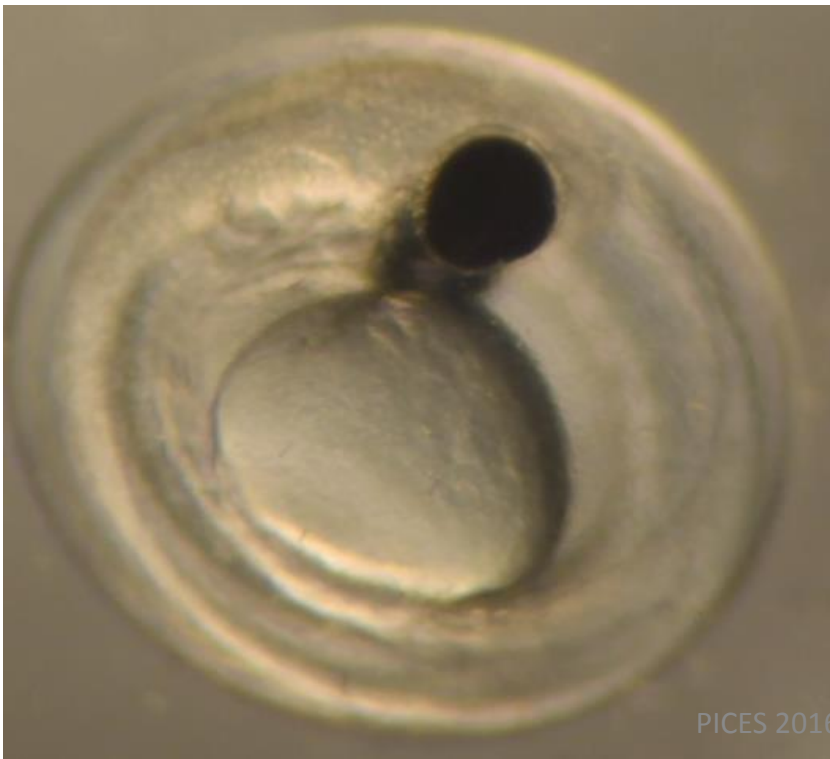


- Warmer temperatures accelerate growth
- Gill and muscle deformities
- Increases energetic needs for survival – reduced aerobic scopes and swimming performances





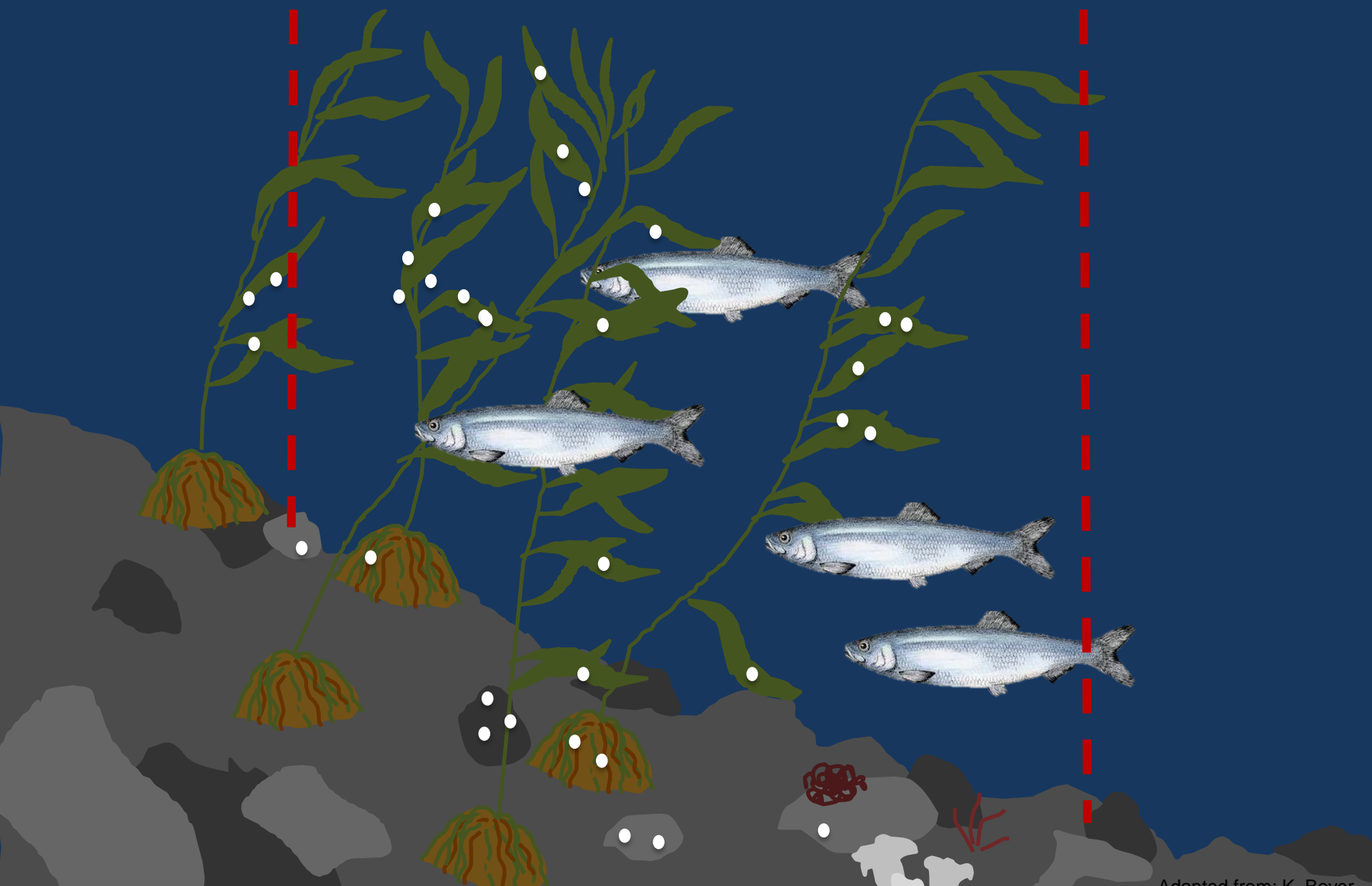
How are Pacific herring embryos affected by  $p\text{CO}_2$  and temperature changes?



Intertidal

Shallow Subtidal

Slope



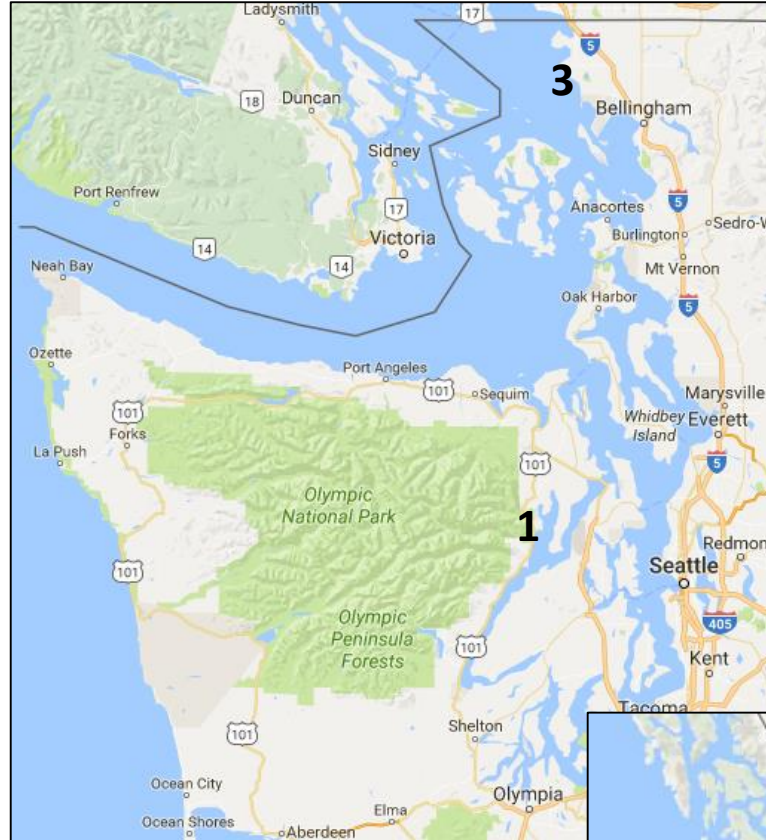


# Herring Collections

1. Quilcene, WA
  - March 2016

1. Craig, AK
  - March 2016

2. Cherry Point, WA
  - May 2016





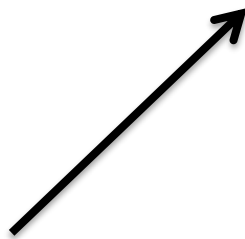
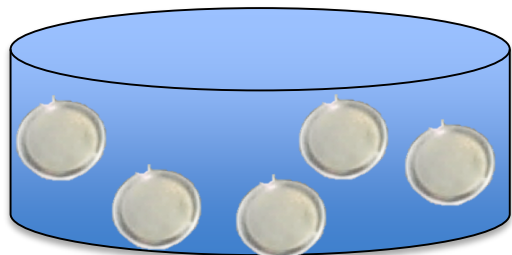
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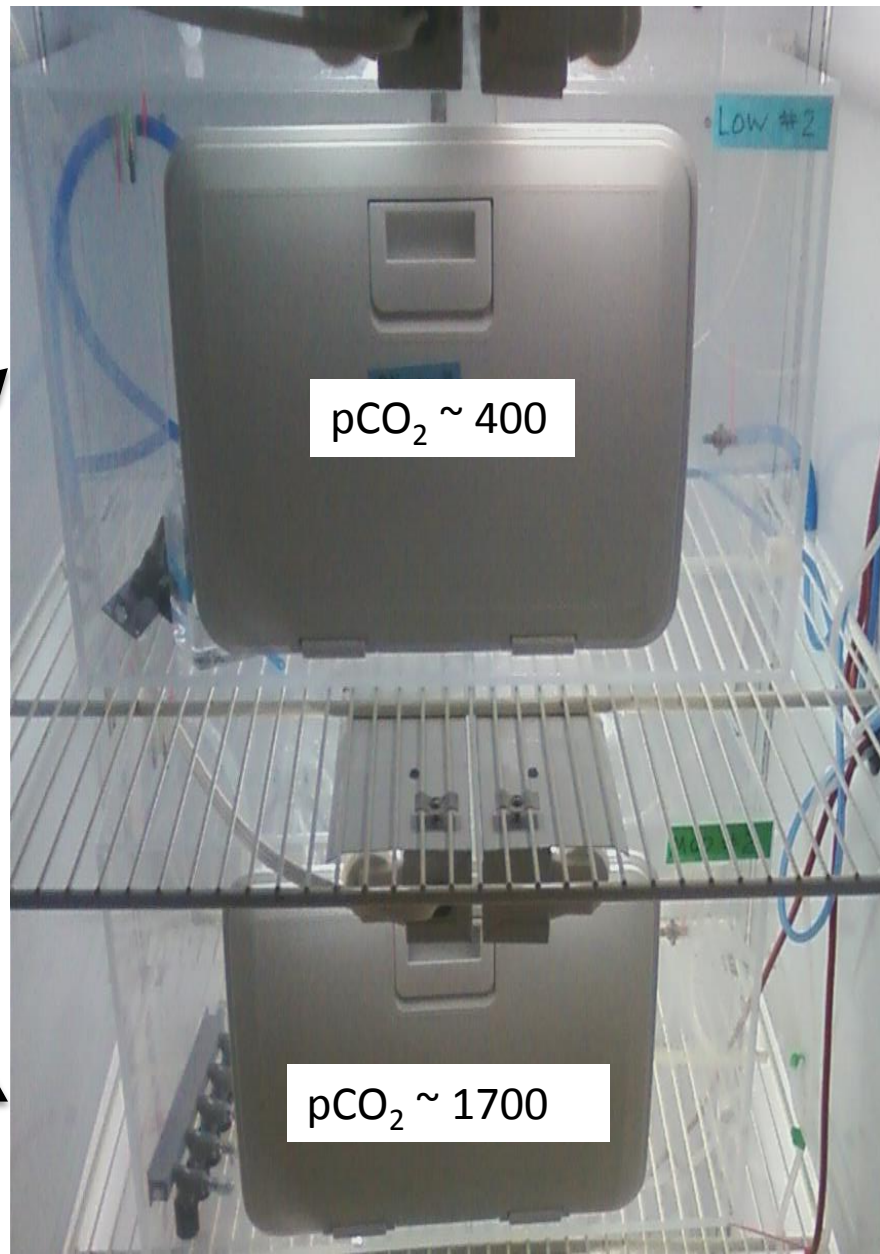
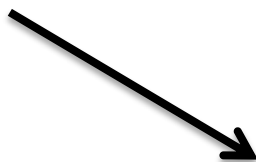
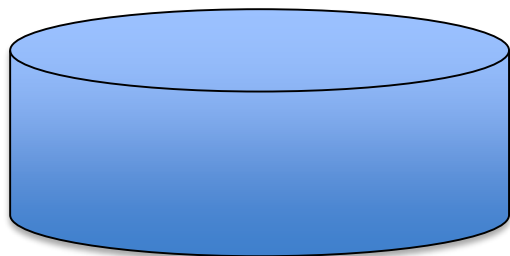
13 °C

19 °C

x10



x1



## Fertilization Success



## Respiration



## Hatching Success

## Larval Weight, Length



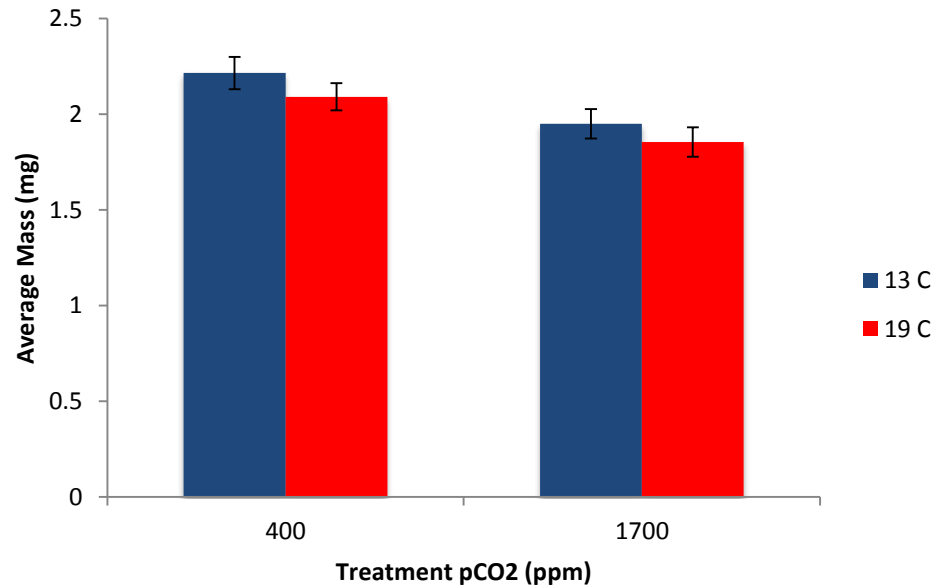
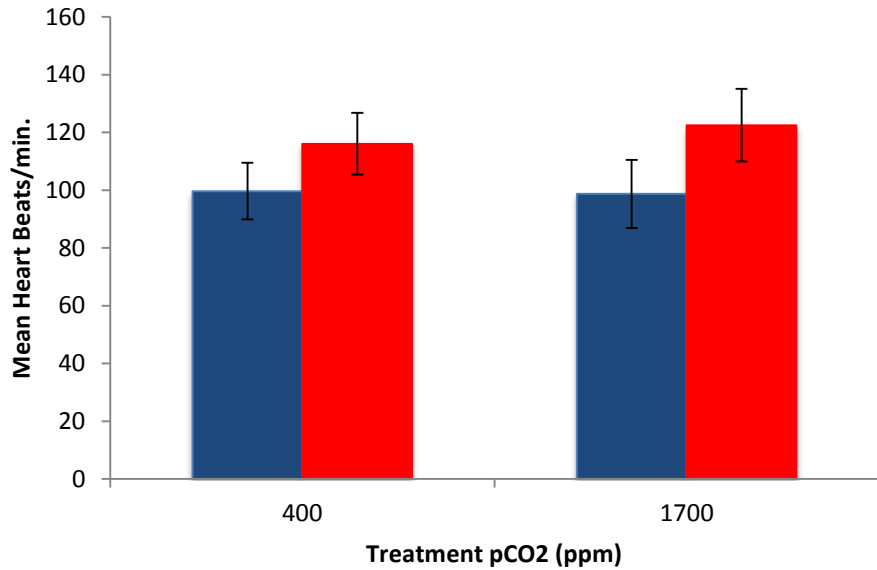
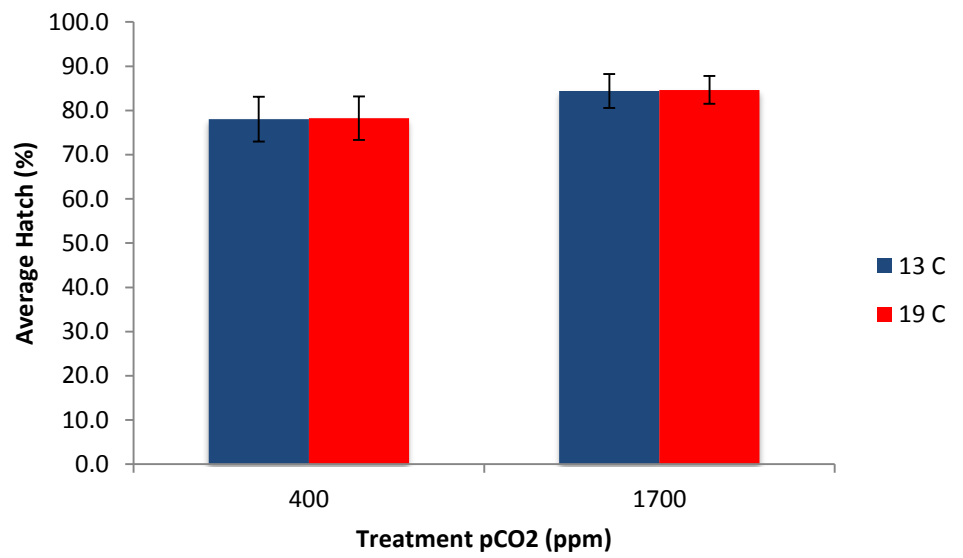
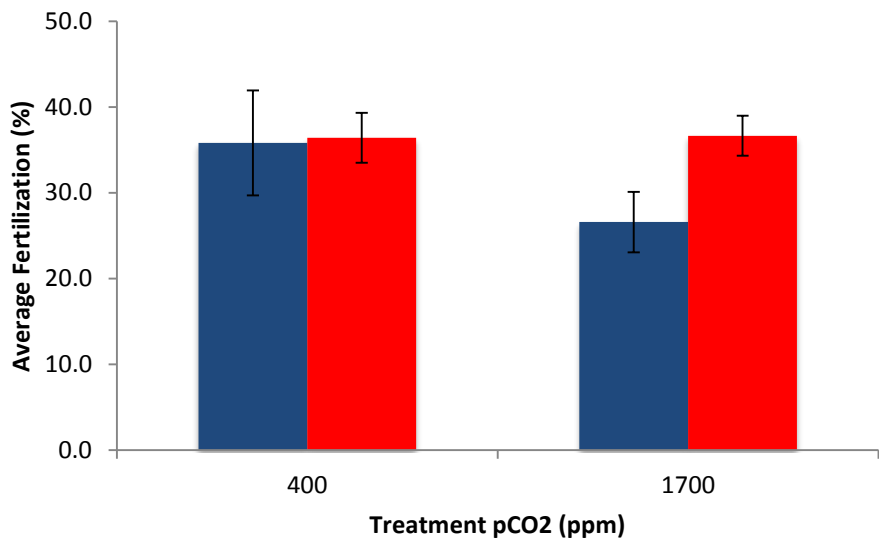
# Hypotheses

	13°C	19°C
Ambient 400 ppm	Standard development	Increased respiration Shorter time to hatch Spinal abnormalities
High 1700 ppm		

# Hypotheses

	13°C	19°C
Ambient 400 ppm	Standard development	Increased respiration Shorter time to hatch Spinal abnormalities
High 1700 ppm	Standard development	Reduced fertilization Reduced hatching Low survivorship

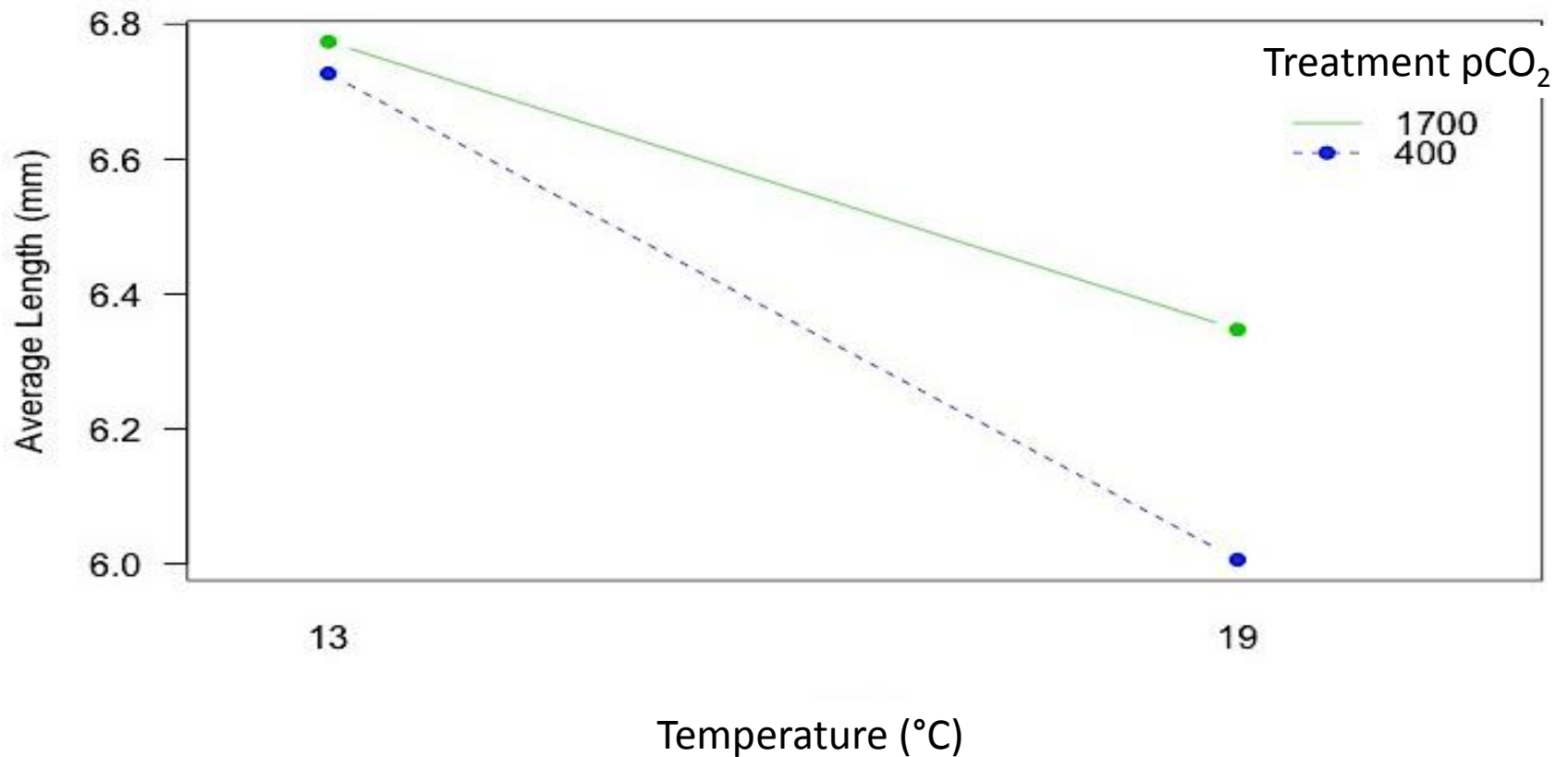




PICES 2016

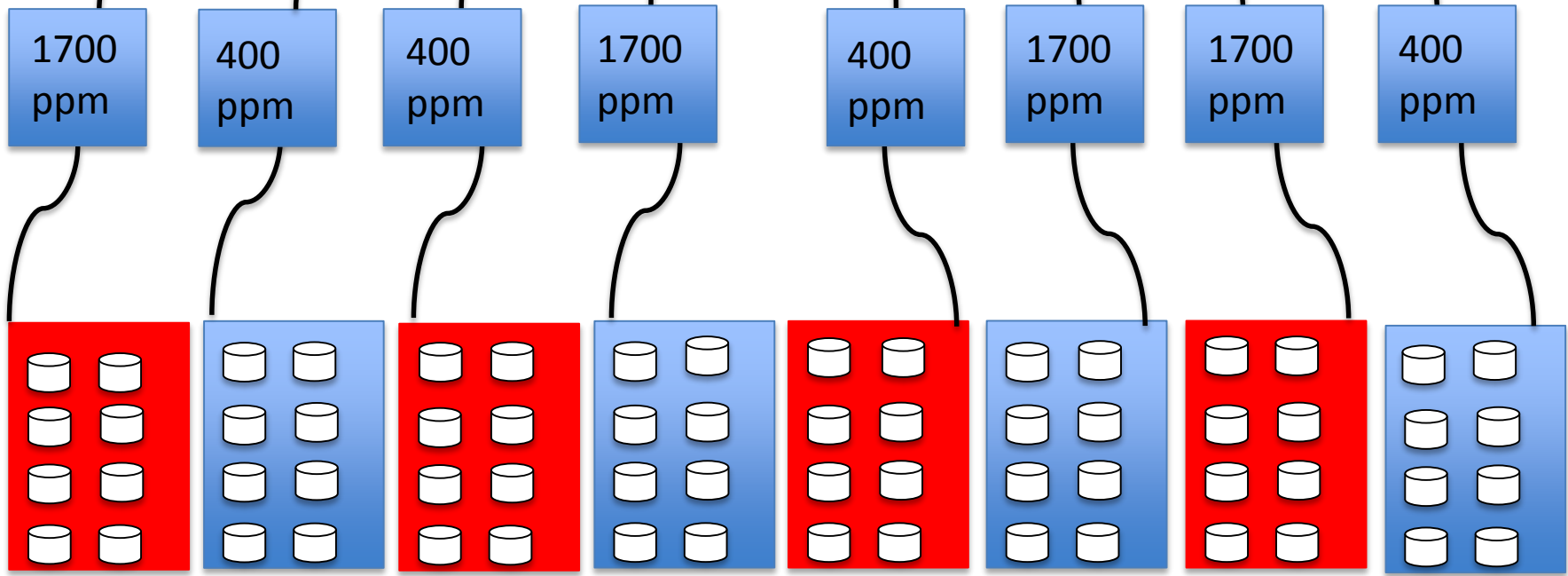
San Diego, CA

# Shorter larvae observed in the warmer temperature

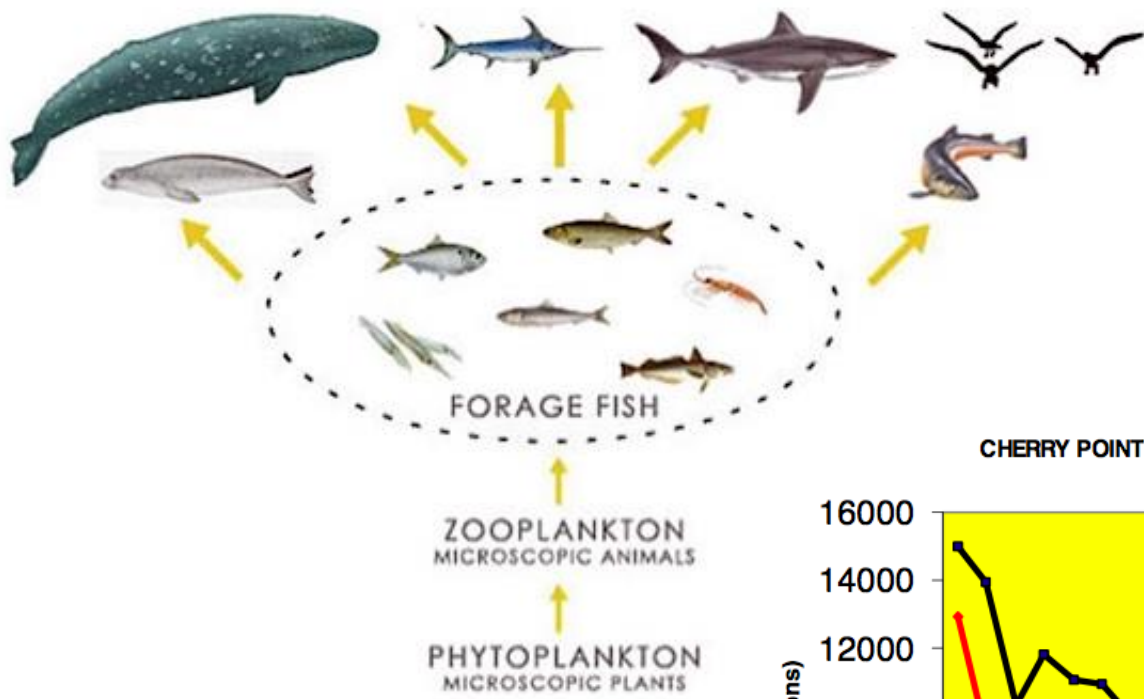


# Storage Tank

pCO<sub>2</sub>  
mixing  
tanks

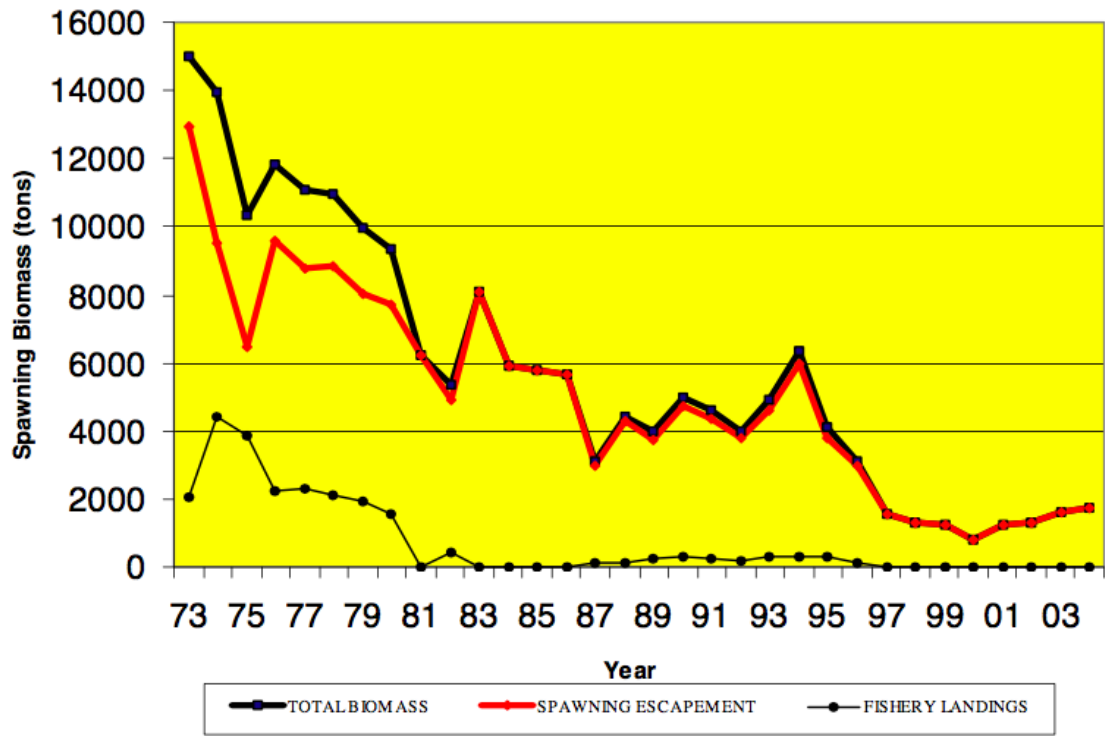


# Forage Fish: The Vital Link of the Ocean Food Web



Spawning biomass at Cherry Point, WA decreased from 15,000 tons in 1973 to 1,700 tons in 2004.

CHERRY POINT HERRING STOCK SPAWNING BIOMASS, 1973-2004



# Acknowledgments

- Dr. Paul Dinnel
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- Dr. Katherina Schoo

