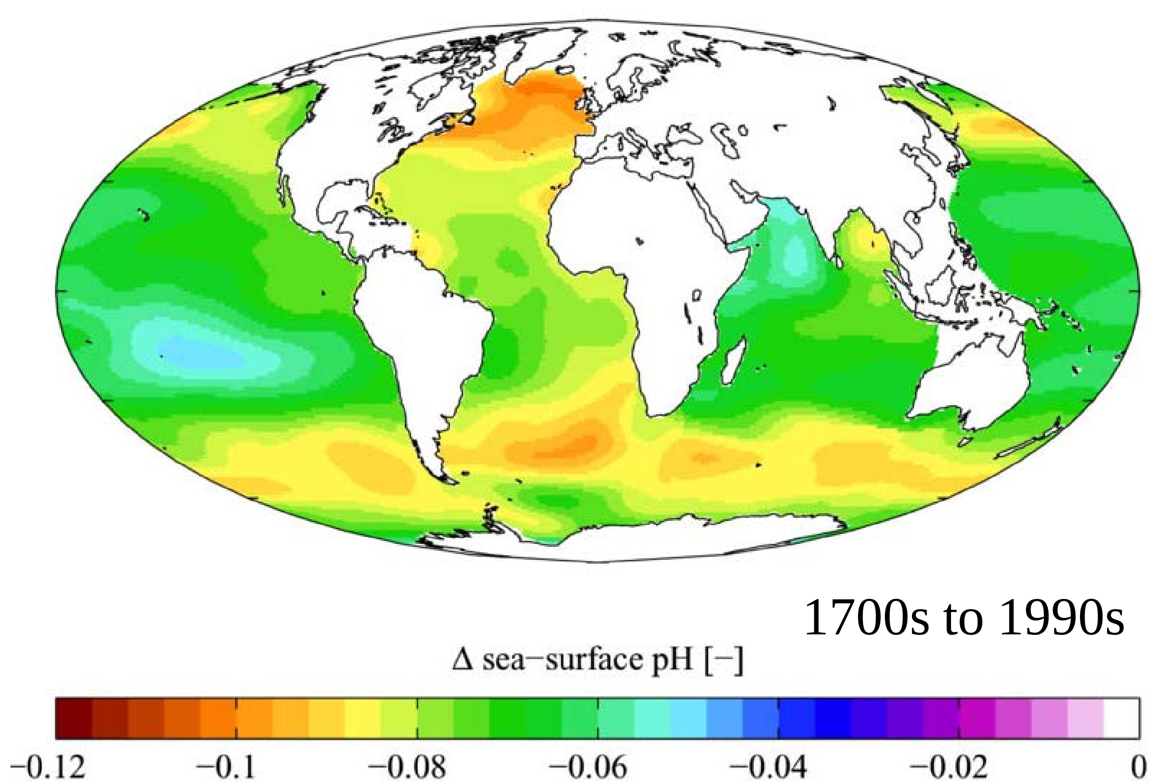
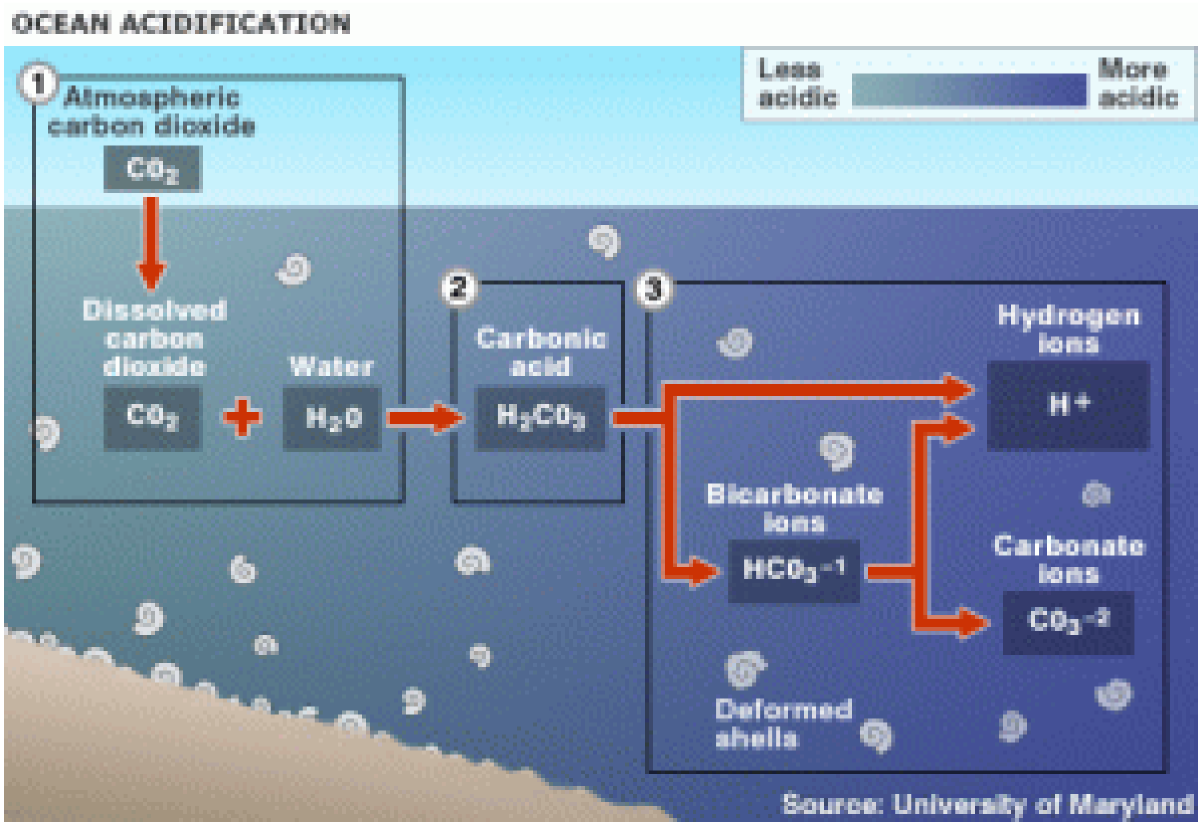
Impacts of Ocean Acidification (Hypercapnia)



LO: extrapolate effects of changing pH conditions to ELH stages of marine fish species

Ocean Carbonate Chemistry



$$CO_2(at) \longrightarrow CO_2(aq) + H_2O \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^- \longrightarrow 2H^+ + CO_3^{-2}$$

carbonic acid   bicarbonate   carbonate

Carbonate and Biology

$$Ca^{2+} + CO_3^{2-} \longleftrightarrow CaCO_3$$

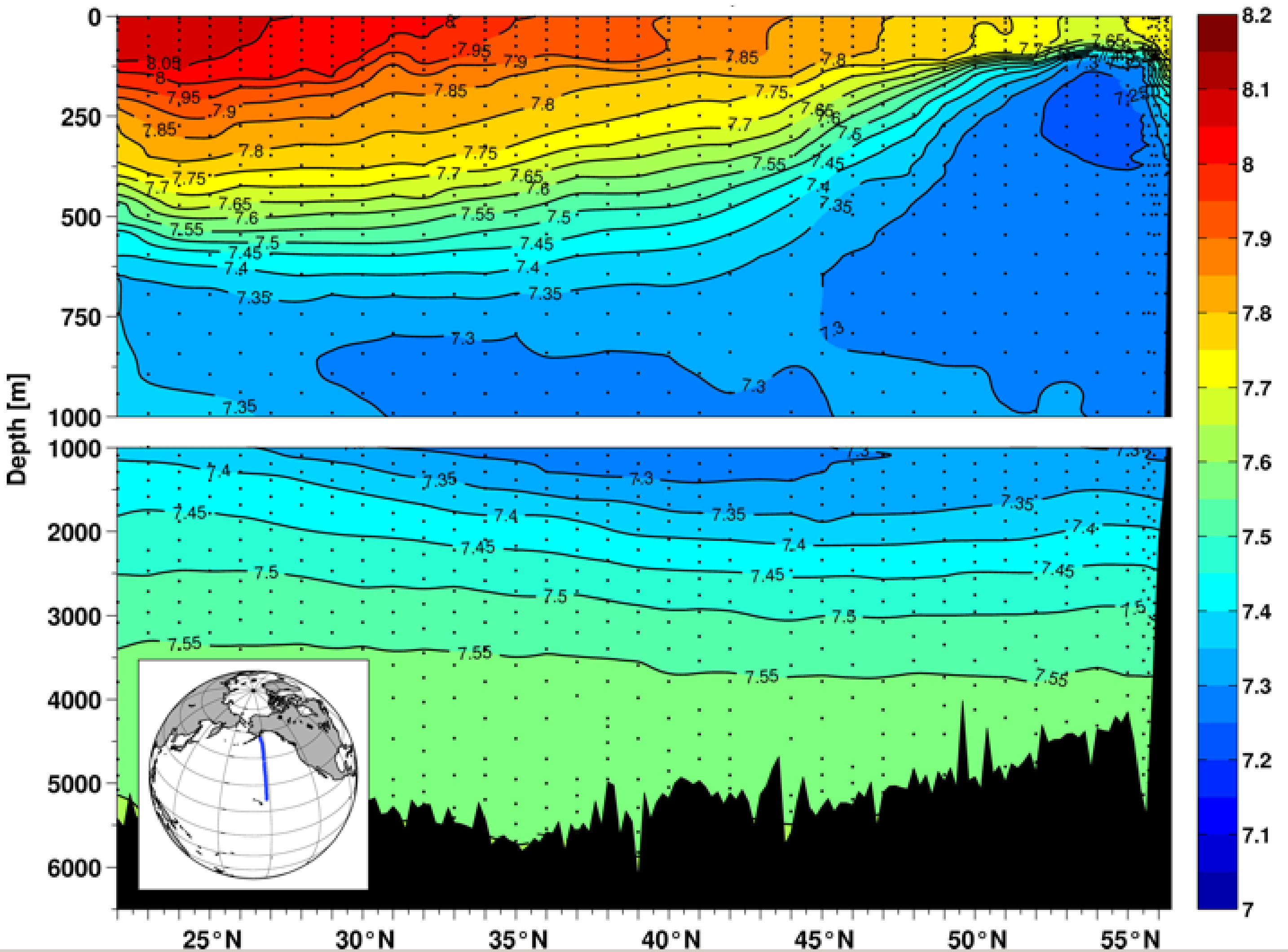
Carbonate ions are combined with Calcium to form Calcium Carbonate

$$pH = -\log [H^+]$$

1/3 of CO_2(at) absorbed by ocean, open ocean pH decreased over past 200 years by ~0.1 units (Caldeira and Wickett 2003)

biologically important below pH 7.8

North Pacific pH



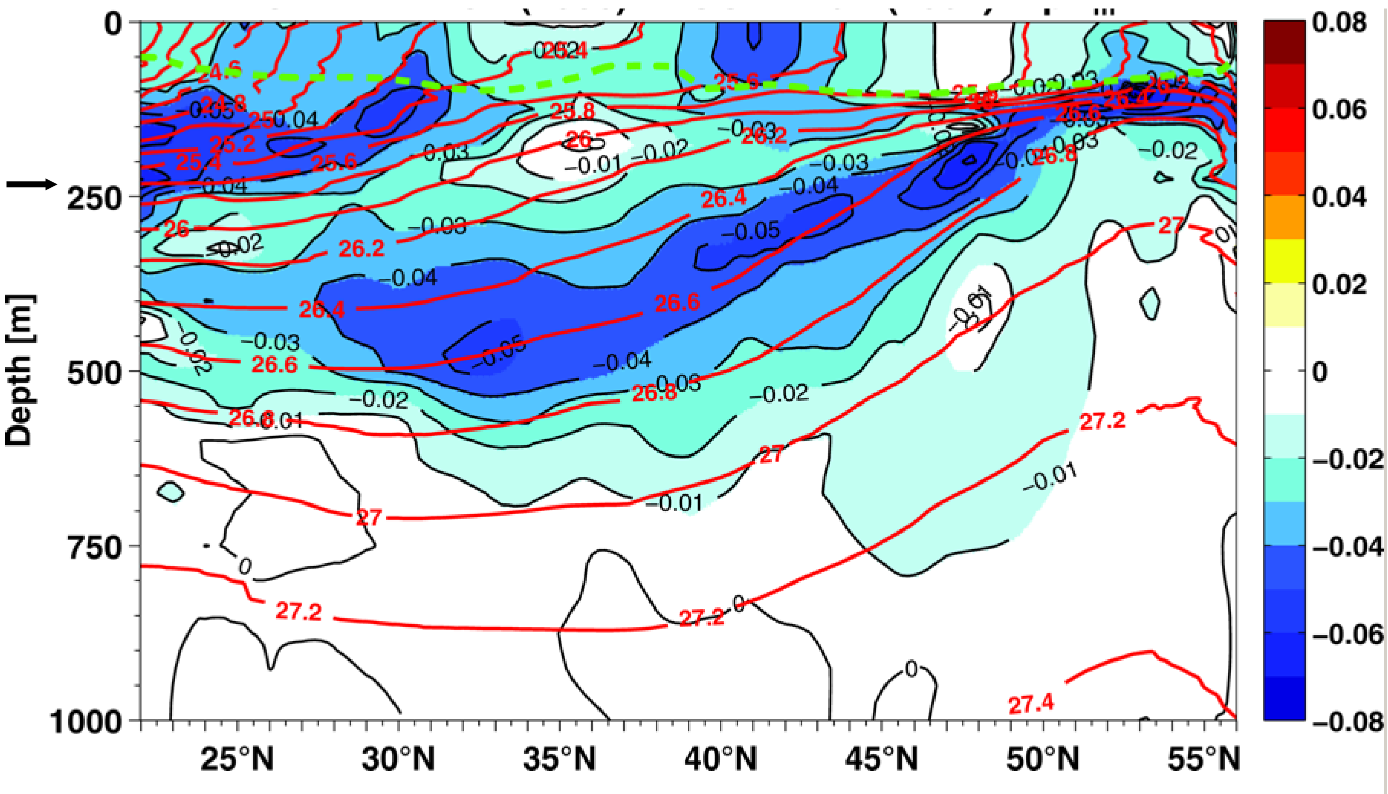
- Pacific 10% higher than Atlantic due to respiration products

- cruise in 2006

- long 152^{o} W

Bryne et al. 2010

Change in North Pacific pH

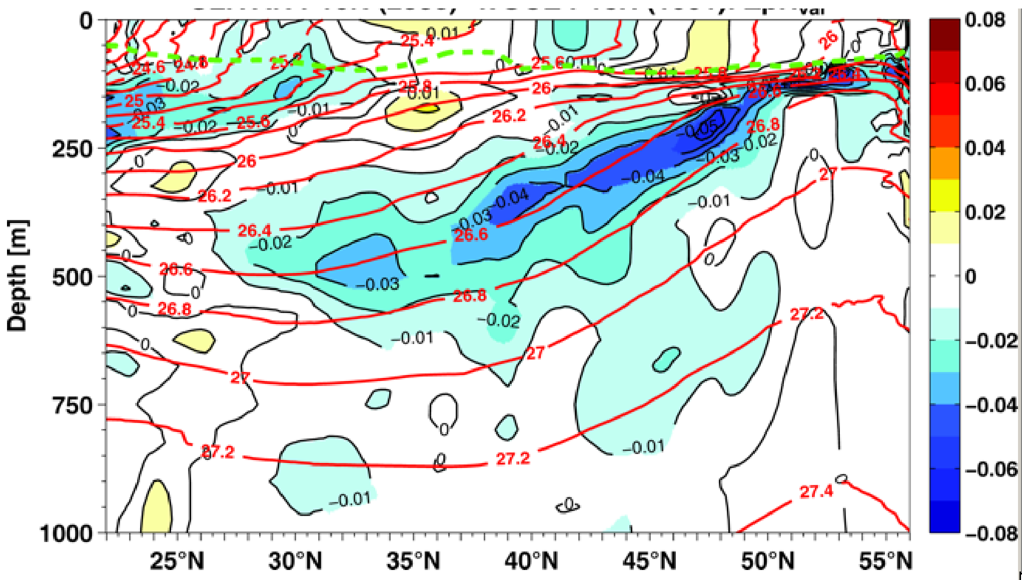


- 1991 vs 2006
- red contours isopycnal surfaces
- arrow indicates mixed layer depth
- dashed green line estimated winter mixed layer depth at 152^{o} W

Generally decline but no significant changes
Overall average change over lat and depth: - 0.023
Between surface and 150 m: - 0.03

Bryne et al. 2010

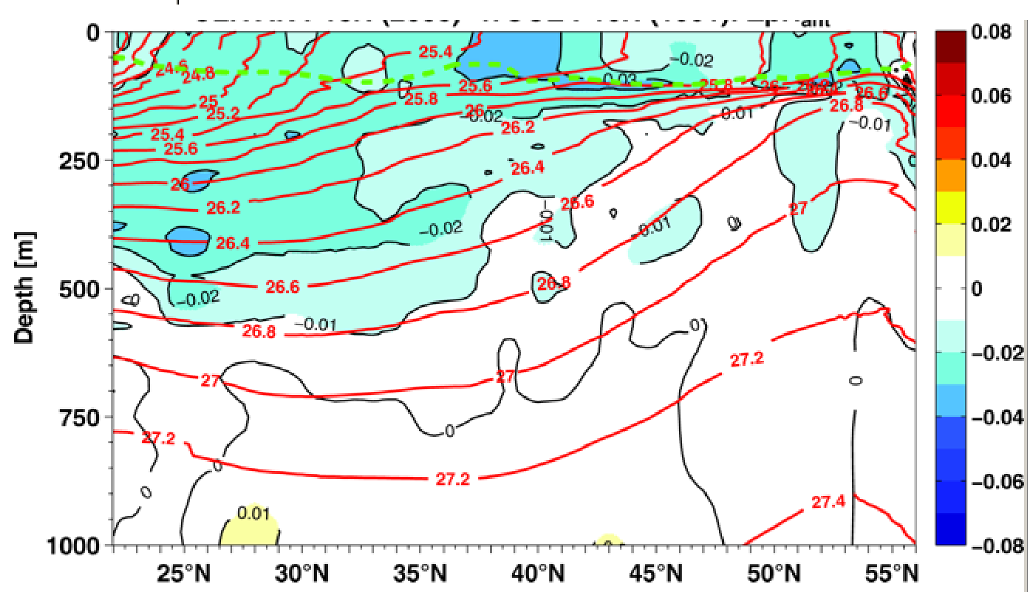
Sources of Carbon



pH change attributed to natural variability

- acidification ≈ CO_2(at)

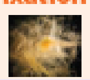
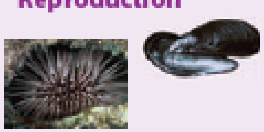
pH change attributed to anthropogenic sources



Bryne et al. 2010

Non-Fish Biological Impacts

Response to increasing CO_2

Physiological response	Major group	Species studied	a	b	c	d
Calcification 						
	Coccolithophores[1]	4	2	1	1	1
	Planktonic Foraminifera	2	2	–	–	–
	Molluscs	4	4	–	–	–
	Echinoderms[1]	3	2	1	–	–
	Tropical corals	11	11	–	–	–
	Coralline red algae	1	1	–	–	–
Photosynthesis[2] 						
	Coccolithophores[3]	2	–	2	2	–
	Prokaryotes	2	–	–	1	–
	Seagrasses	5	–	–	–	–
Nitrogen Fixation 						
	Cyanobacteria	1	–	1	–	–
Reproduction 						
	Molluscs	4	4	–	–	–
	Echinoderms	1	1	–	–	–

1) Increased calcification had substantial physiological cost; 2) Strong interactive effects with nutrient and trace metal availability, light, and temperature; 3) Under nutrient replete conditions.

- tipping point for calcareous species below 7.8 pH

Doney et al. 2009

Undersaturation of Aragonite

pteropod

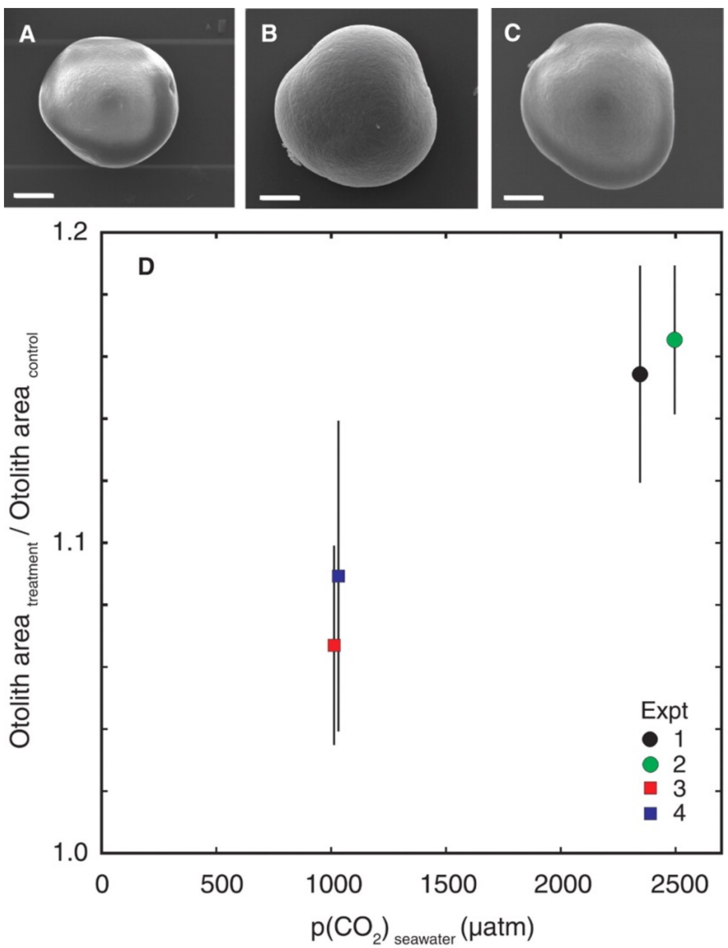
- surface waters in high latitudes predicted undersaturated by 2050
- pteropods prey for zooplankton & fish
- pink salmon in N. Pacific >60% diet
- pteropod range may contract to shallower depths & lower latitudes
- potential to reorganize planktonic and benthic communities

Doney et al. 2008

pH Effect on Otoliths

Otoliths: aragonite-protein bilayers

Doney et al. (2009): decreased pH slows calcification



White sea bass
(*Atractoscion nobilis*)

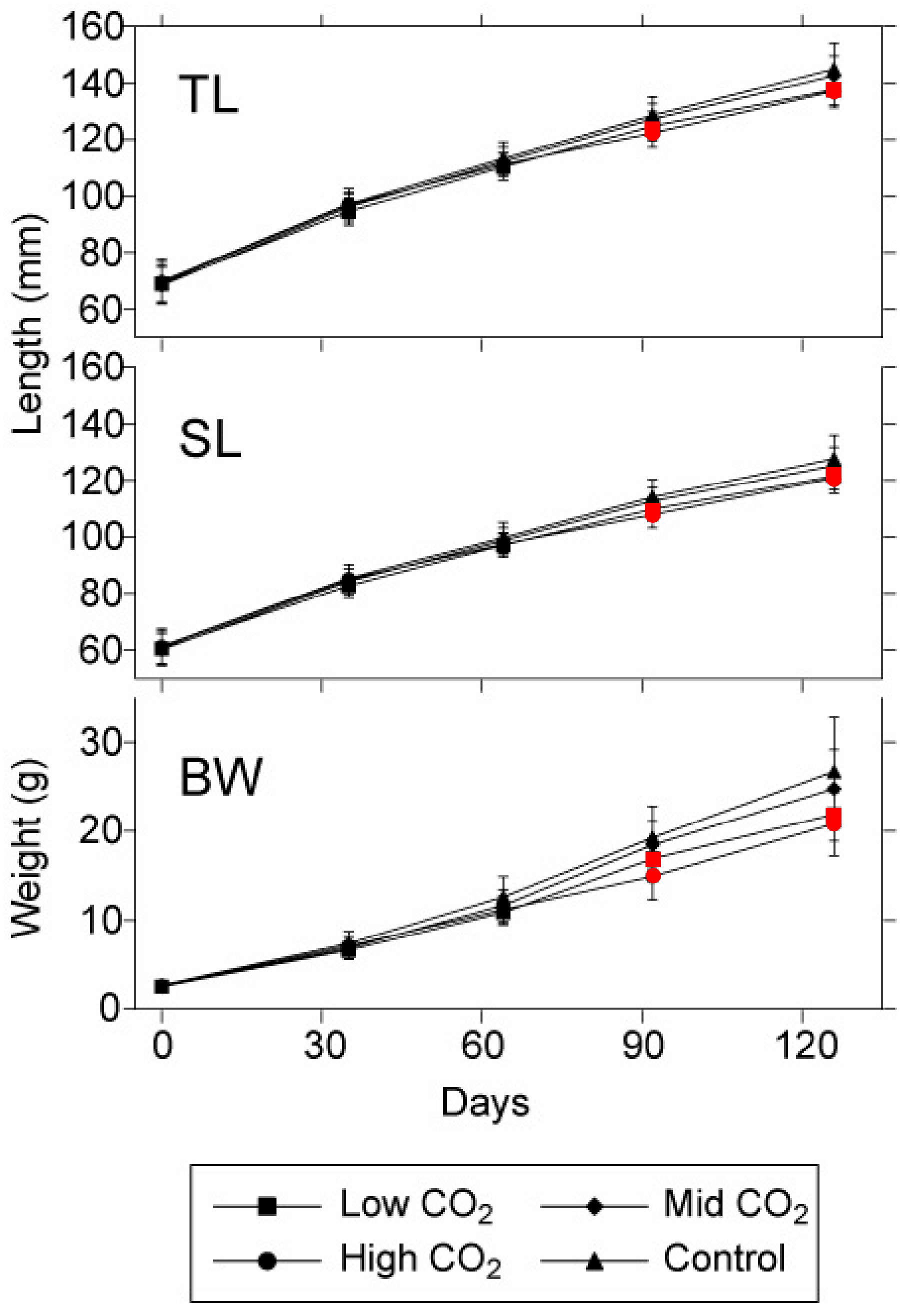
A=430 (control)
B=1000
C=2500 μatm p(CO_2) seawater

Increased area and mass of otoliths
B: 7-9% area, 10-14% heavier
C: 15-17% area, 24-26% heavier
Dry mass did not vary

Control H^+ and Ca^+ but not CO_2 around otolith, which increases CO_3^{2-}

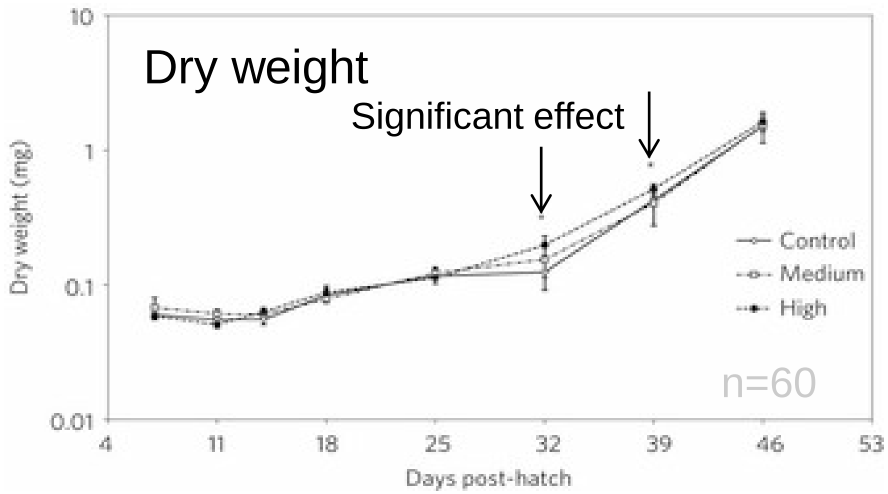
Checkley et al. 2009

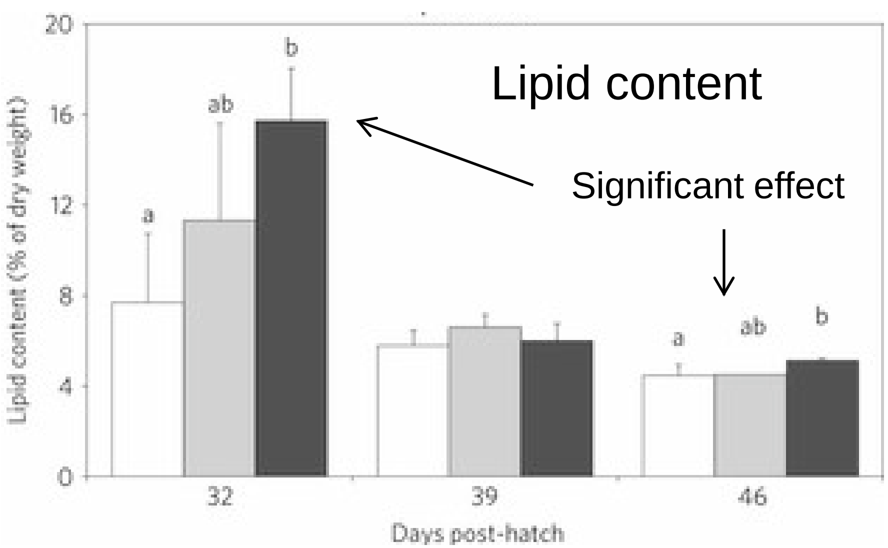
Fish Growth



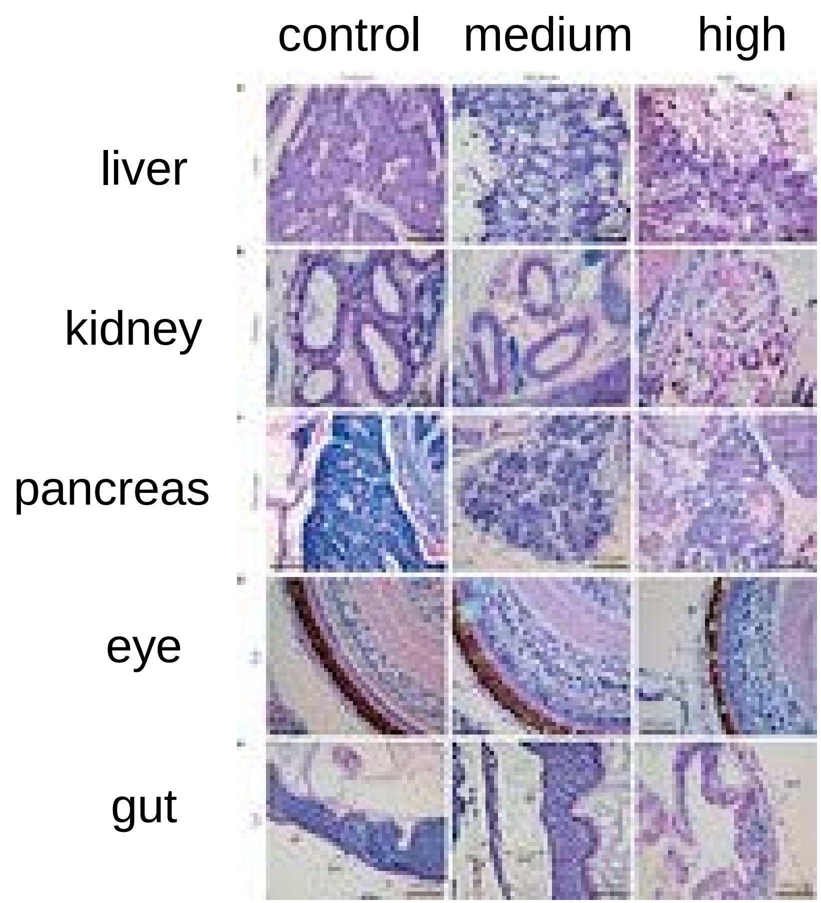
- Japanese sillago (*Sillago sihama*) whiting
- growth significantly reduced in 90 days (red symbols)

Larval Fish Tissue Damage





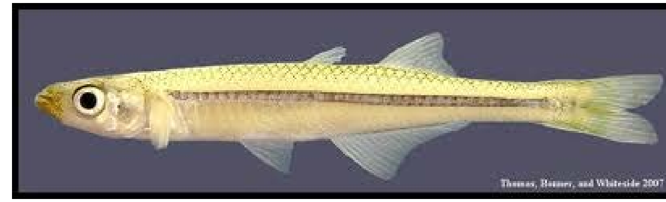
Atlantic cod (*Gadus morhua*)



380; 1,800; 4,200 μatm pCO_2

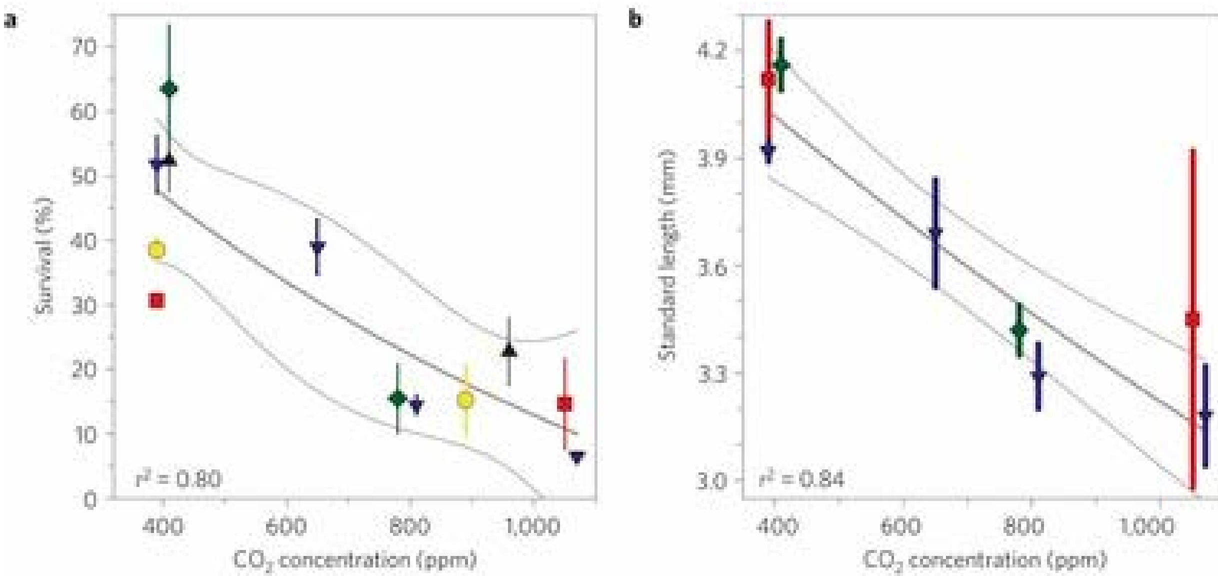
Frommel et al. 2011

Fish Reduced Survival



Inland silverside
(*Menidia beryllina*)

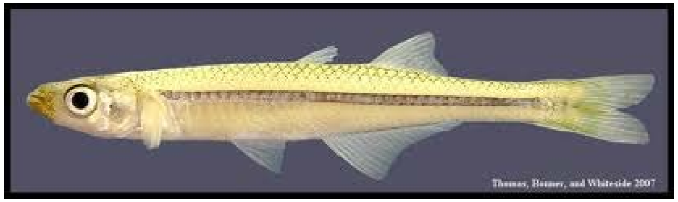
Embryos – 1 week post hatch survival



now mid end century

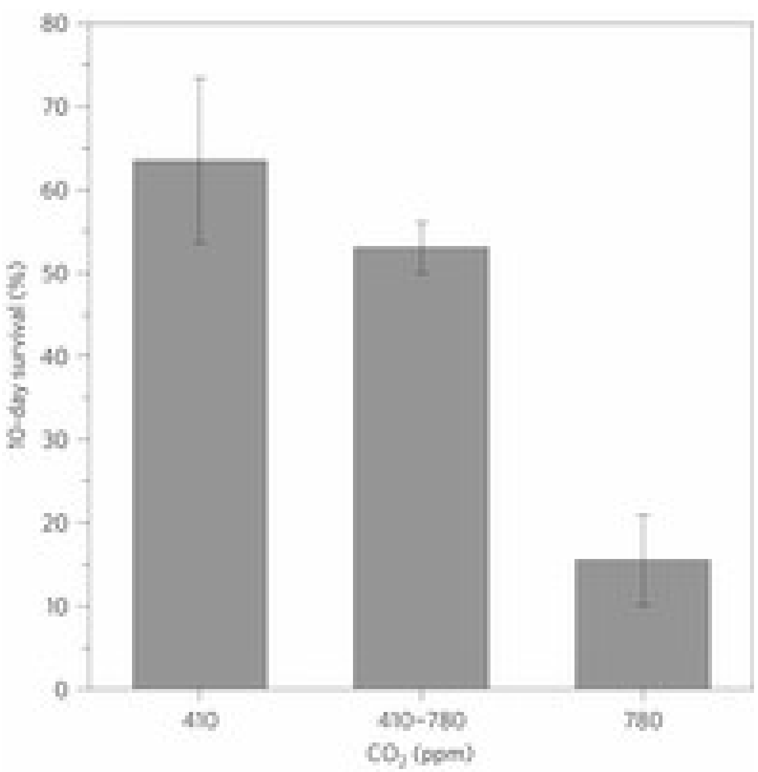
Baumann et al. 2011

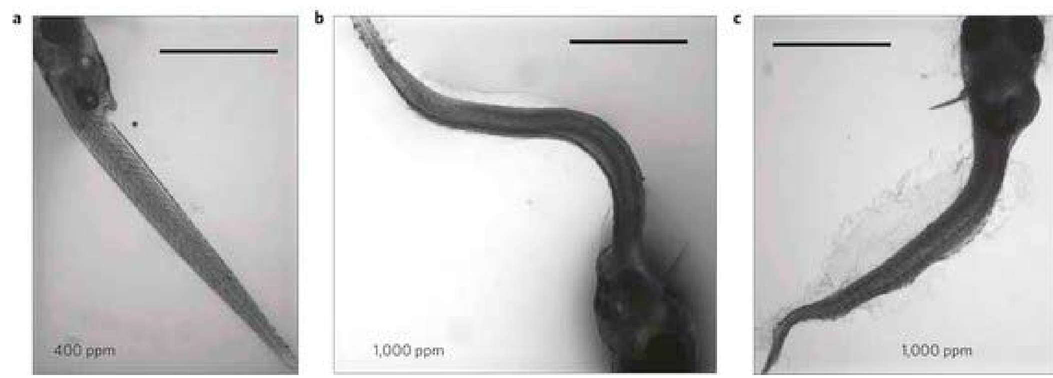
Fish Reduced Survival



Inland silverside
(*Menidia beryllina*)

10 d survival (%)





CO_2 (ppm)

increased after 5 d post fertilization

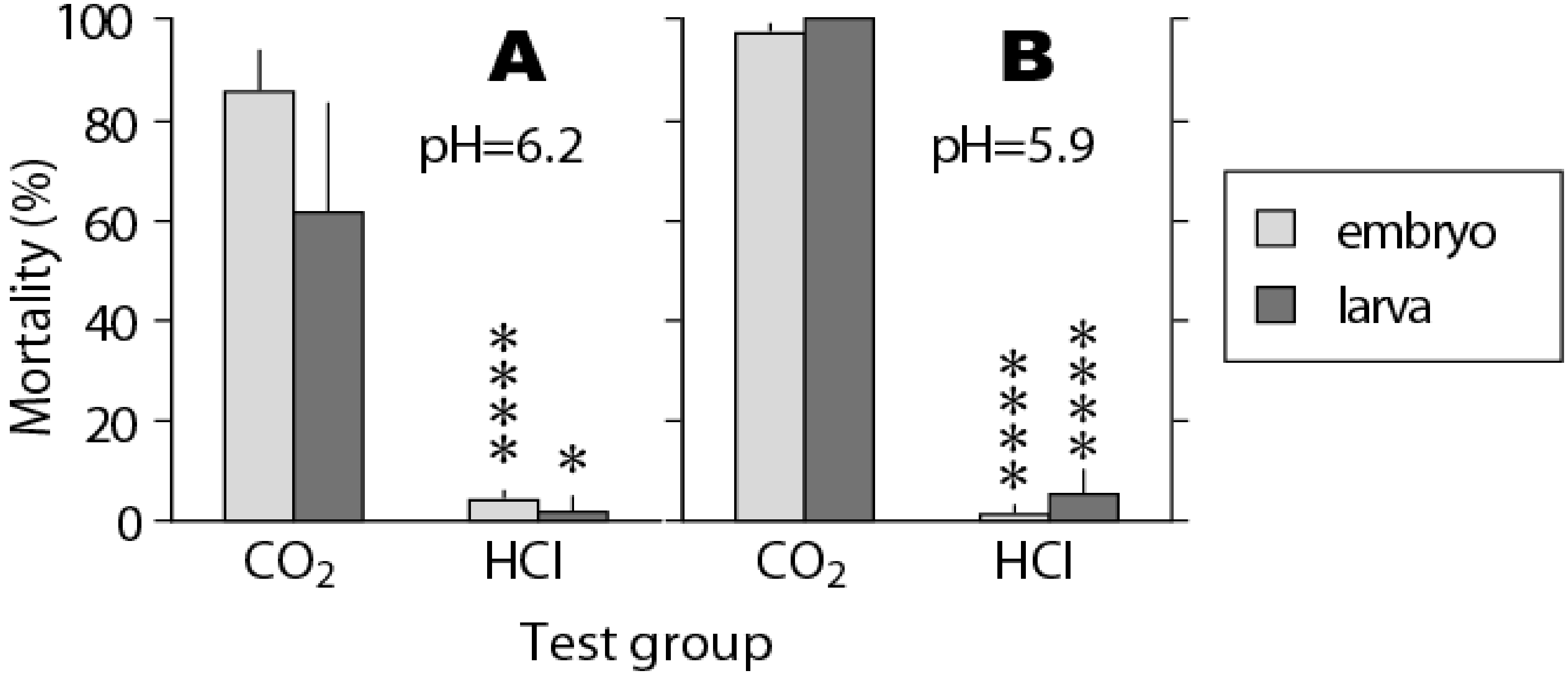
400 ppm

800 ppm

1000 ppm

Gobler et al. 2011

Fish Mortality Cause: CO_2 vs H^+



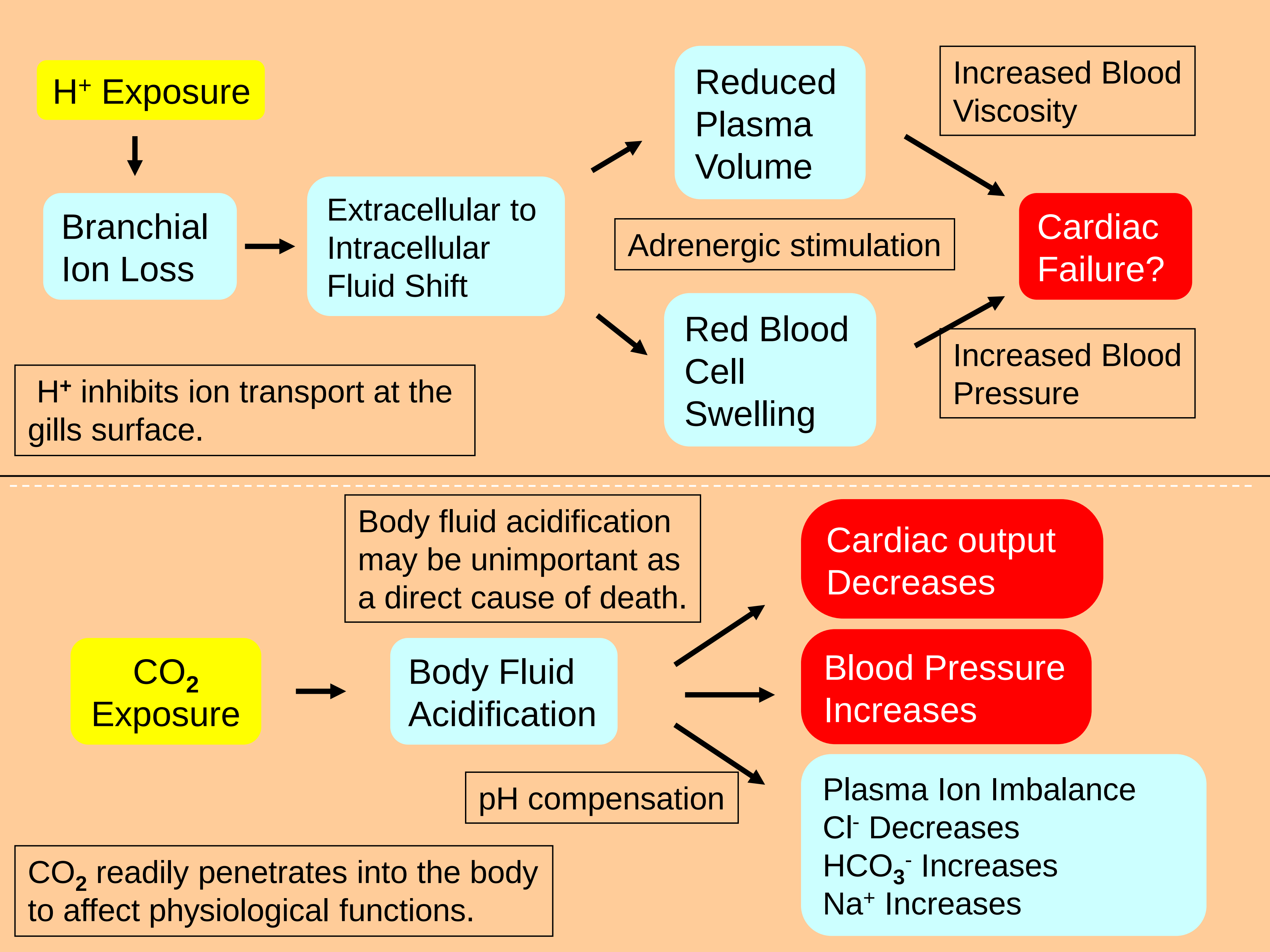
Lethal effect of CO_2 and acid on embryos (N = 5) and larvae (N = 3) of silver seabream at two pH conditions. Exposure period: embryo 360 min, larva 24 h
*Significant difference between groups.

Kikkawa et al. (2004): Marine Pollution Bulletin 48, 108.

Mortality Due to CO_2 and H^+

- Physiological responses to CO_2 and acids are different.
- CO_2 diffuses into body, and acidifies body fluid of both intracellular and extracellular compartments. Fish kill mechanism by high CO_2 is not fully understood.
- Acid exposure inhibits active ion transport across gills, and increased passive ion movements. Cause of fish kill by acid exposure is thought **not** to be blood acidification but cardiac failure by hemoconcentration.

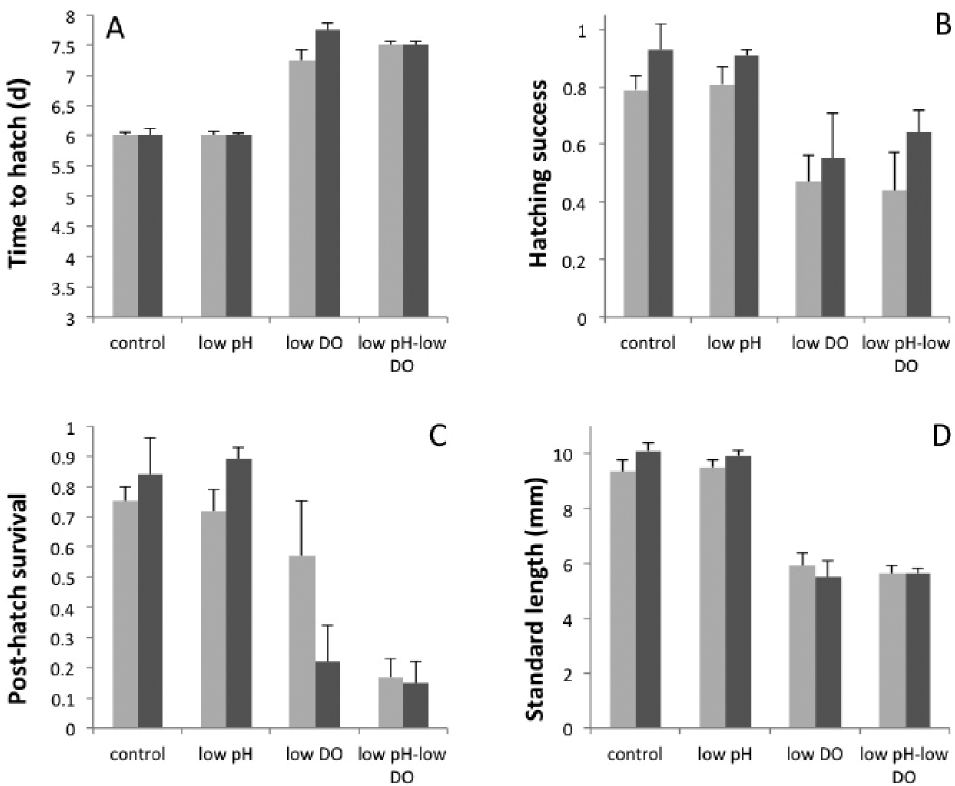
Atsushi Ishimatsu 2004



H+ Exposure
Branchial Ion Loss
Extracellular to Intracellular Fluid Shift
Reduced Plasma Volume
Increased Blood Viscosity
Adrenergic stimulation
Cardiac Failure?
Red Blood Cell Swelling
Increased Blood Pressure
H+ inhibits ion transport at the gills surface.
Body fluid acidification may be unimportant as a direct cause of death.
Cardiac output Decreases
CO2 Exposure
Body Fluid Acidification
Blood Pressure Increases
pH compensation
Plasma Ion Imbalance
Cl- Decreases
HCO3- Increases
Na+ Increases
CO2 readily penetrates into the body to affect physiological functions.

Combined Effects of pH and O_2

Forage fish: Silverside (*Menidia beryllina, Menidia menidia); Sheepshead minnow (Cyprinodon variegatus)*
- egg through early larval, May & June experiments



Low pH differed little from the control, but when combined with low DO, had a significant effect (dependent on variable and species)

DePasquale et al. 2015

Other Effects

Effect	Stage	Cause	Reference
mercury toxicity	larval	mercury vs selenium	MacDonald et al. 2015 Metallomics 7: 1247-1255 MacDonald et al. 2015 J. inorganic Biochem 151: 10-17
Spinal deformities, hatching delay, mortality	larval	heavy metals	Sfakianakis et al. 2015 Envionmental Research 137: 246-255
endocrine disruptors	juveniles	gene expression for contolling homoe balance	Liao et al. J. Hazardous Materials 277:141-149 Chu et al. Chemosphere 152:181-189
lost orientation due to loss of hearing	settling larva	CO2 on hearing (assume enlarged otolith development)	Rossi et al. 2016 Biology Letters 12: 20150937
noisier ocean	all	reduced noise absorption	Hester et al. 2008. Geophys. Res. Letters 35: L19601

Summary Effects

Factor	ELH stage & response	Management
Increased acidity (decrease in pH) H^+ and Carbonate	*Adult spawning:*	
	Egg stage:	
	Early larvae:	
	Juvenile:	
Temperature		