Chemical and Biological Effects on Fishes in a High CO_2 World

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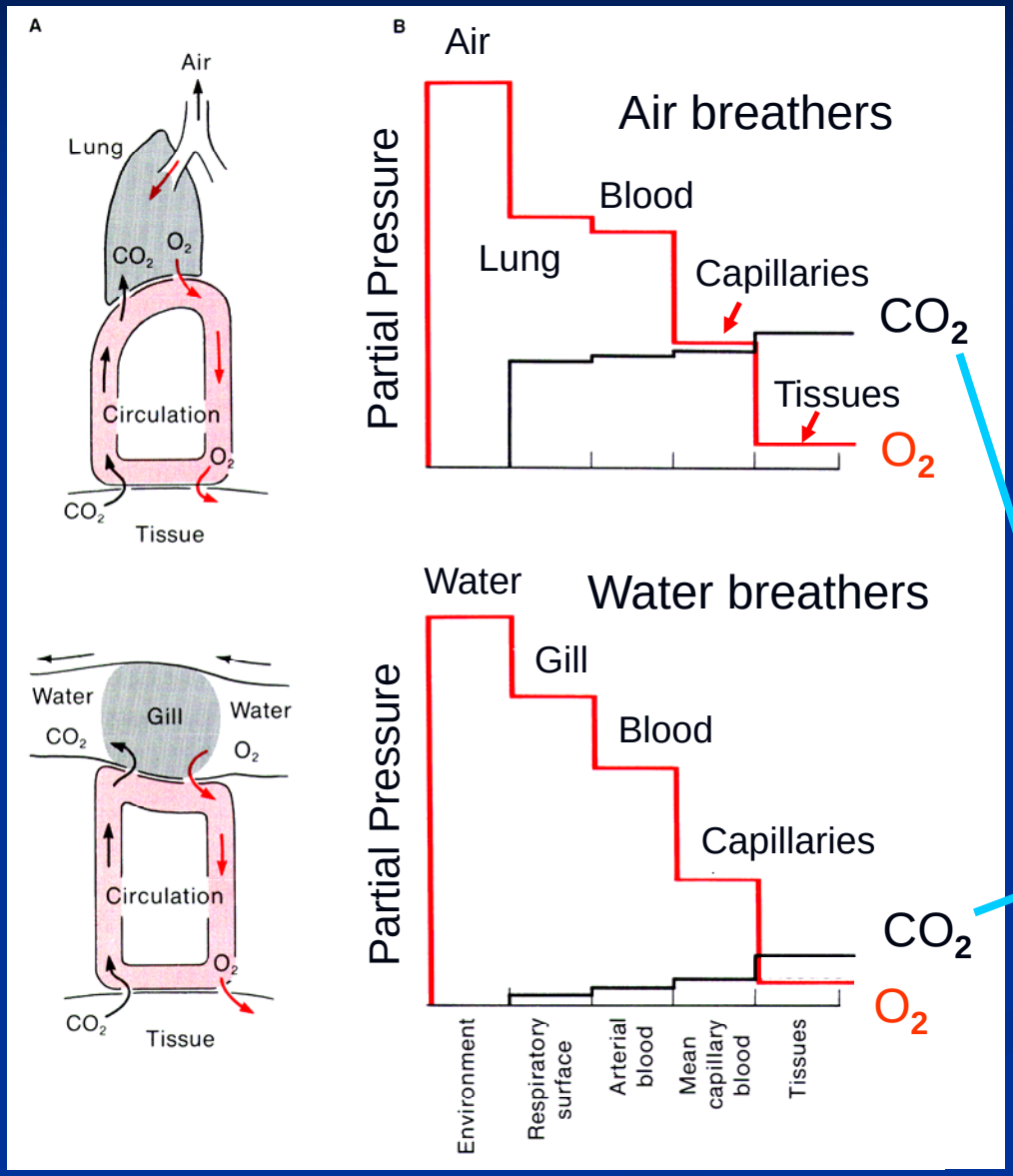
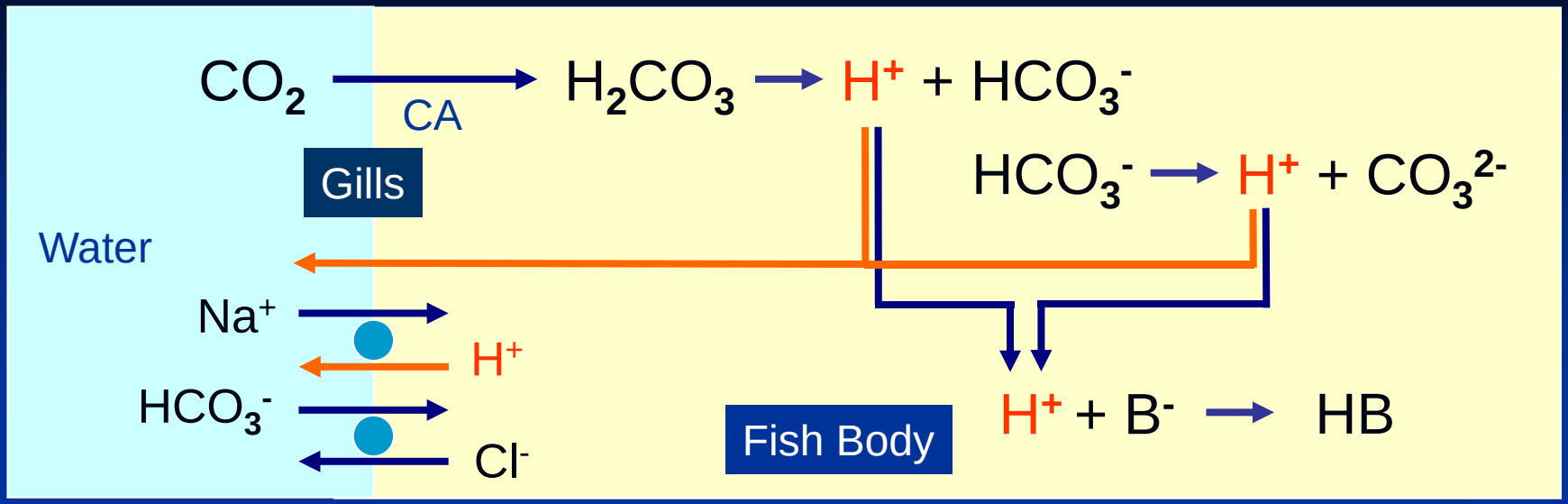
Comparison of body fluid PCO_2 in air- and water-breathers

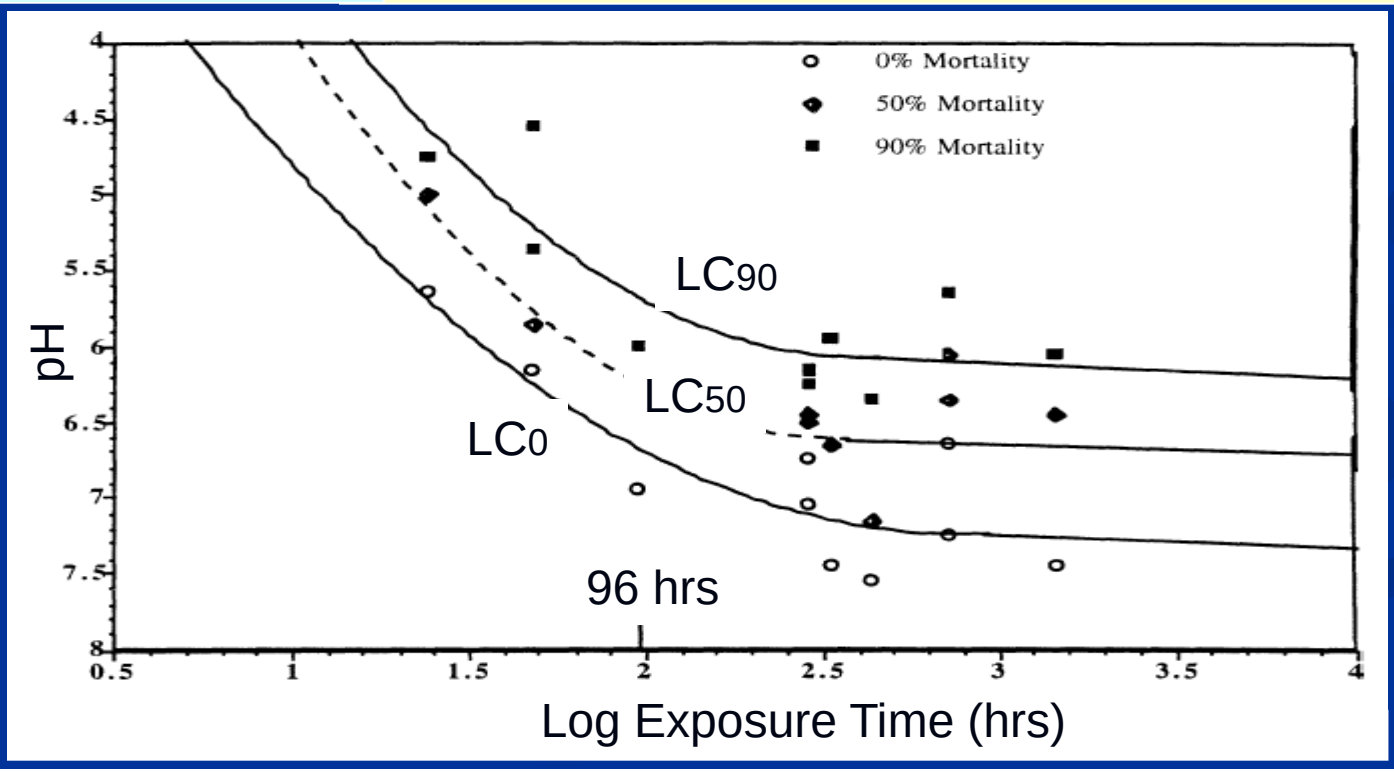


Solubility (μM/torr) at 20 C	O_2	CO_2
Air	54.7	54.7
Sea water	1.5	43.7

Arterial Blood PCO_2	
Air-breathers*	15 - 40 torr
Water-breathers	1 – 4 torr
PCO_2 of air/water	0.2 torr

CO_2 reactions and buffering in animal body





Auerbach et al. 1997

Osmo- and iono-regulation in seawater and freshwater fish

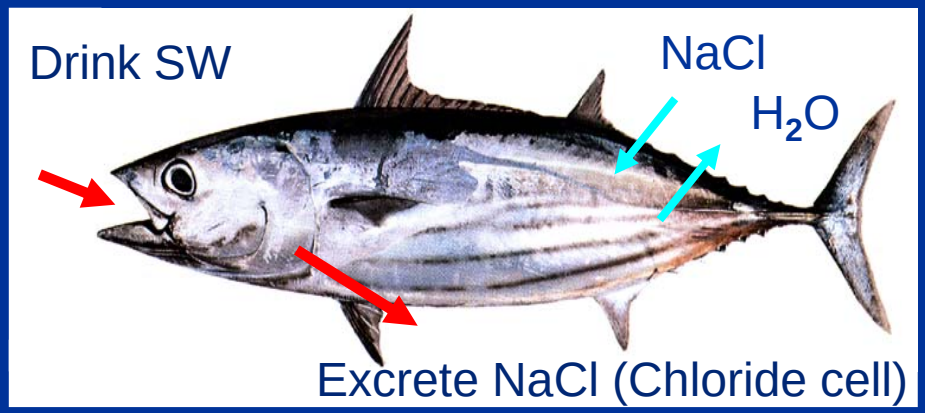
→ Active transport

→ Passive transport

Seawater Fish

Blood

Osmolarity	330 mOsm/L
Na^+	200 mmol/L
Cl^-	160 mmol/L



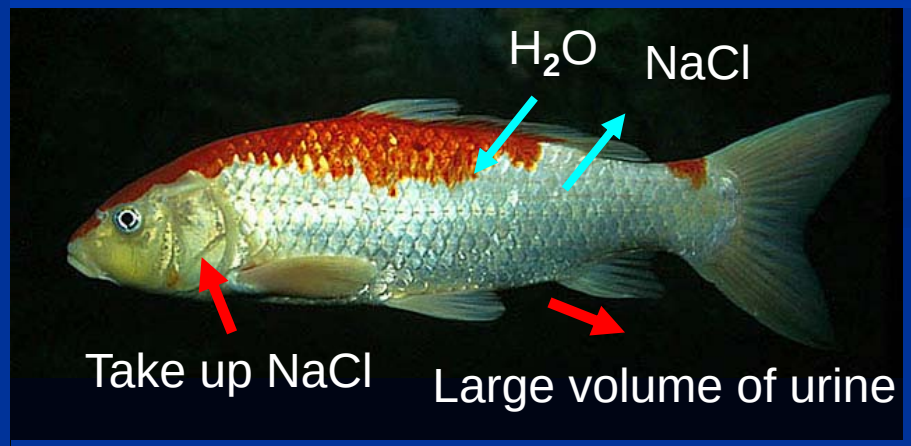
Sea water

Osmolarity	1,000 mOsm/L
Na^+	460 mmol/L
Cl^-	550 mmol/L

Freshwater Fish

Blood

Osmolarity	300 mOsm/L
Na^+	150 mmol/L
Cl^-	120 mmol/L

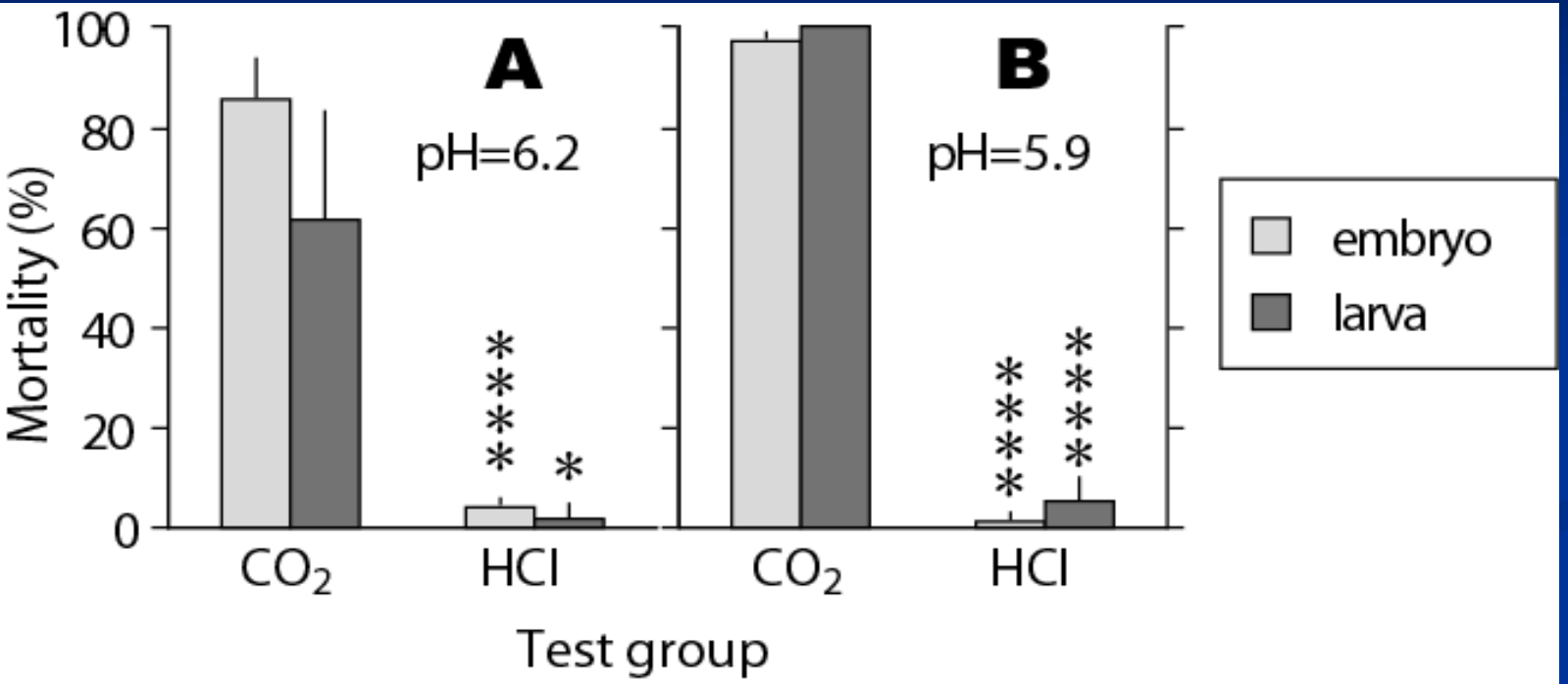


Fresh water

Osmolarity	1 mOsm/L
Na^+	0.08 mmol/L
Cl^-	0.05 mmol/L

- Differences in Biological Effects of CO_2 and H^+ in Water
- Effects of CO_2 Ocean Sequestration on Fishes

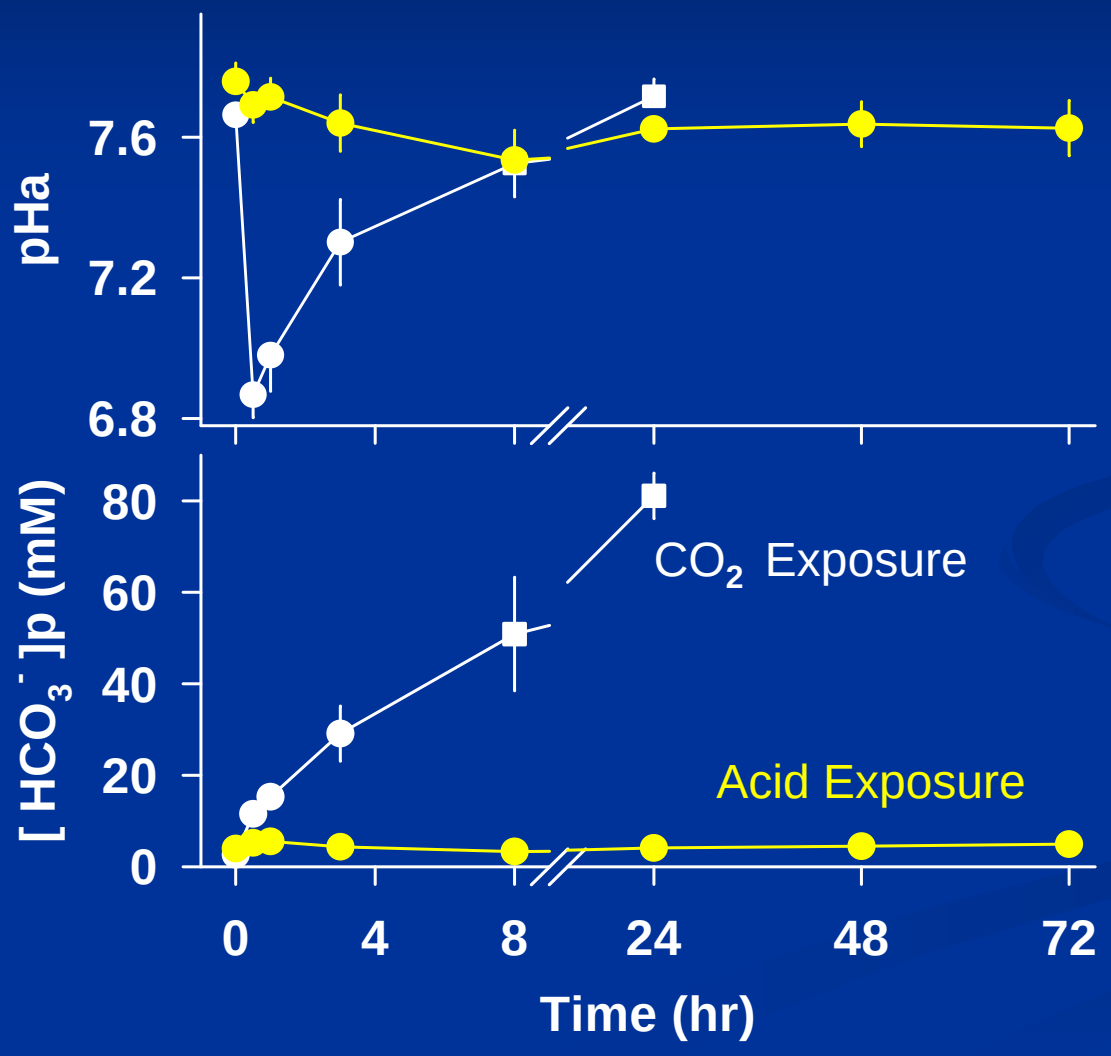
Comparison of fish mortality by CO_2 and acid exposures



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.

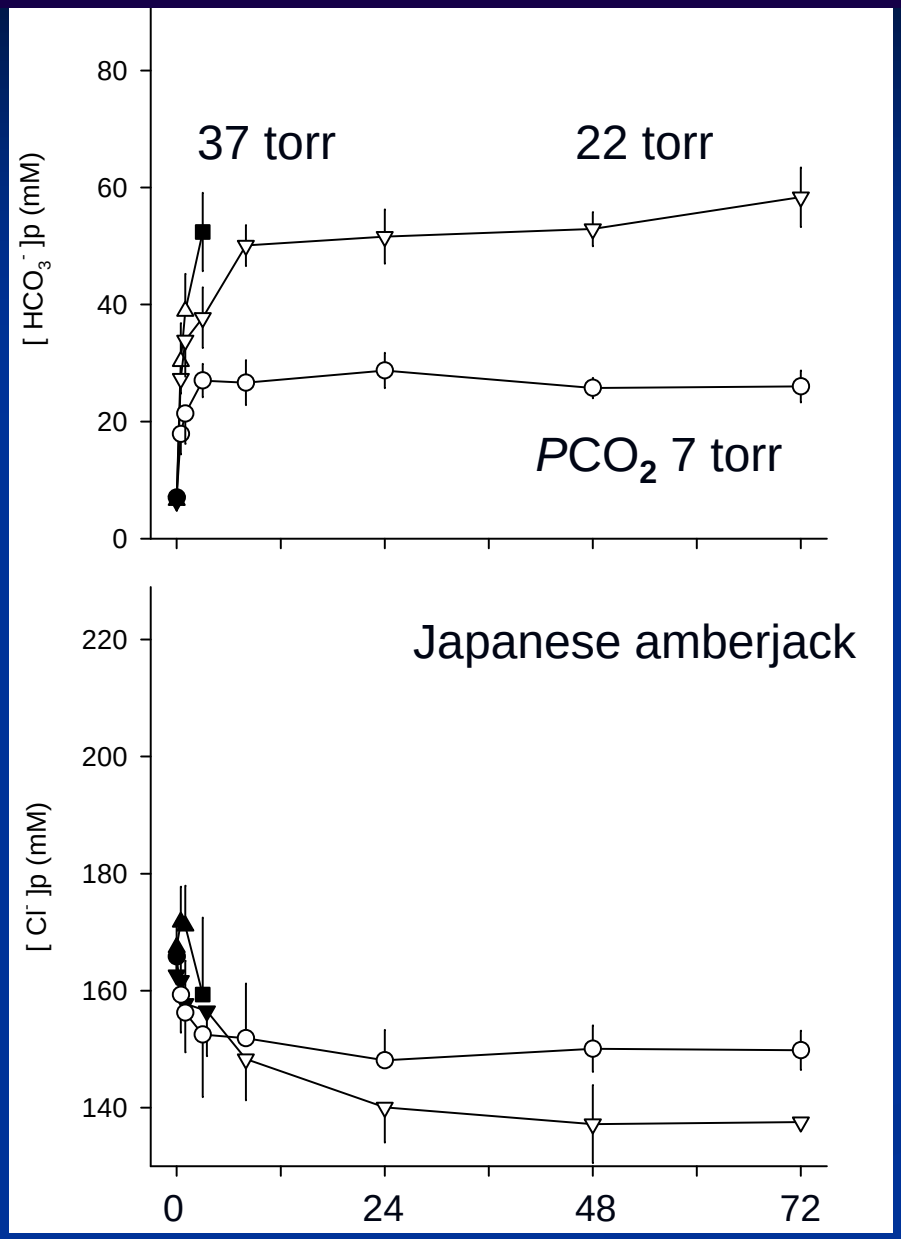
Acid-base responses to CO_2 and acid seawater in bastard halibut, *Paralichthys olivaceus*

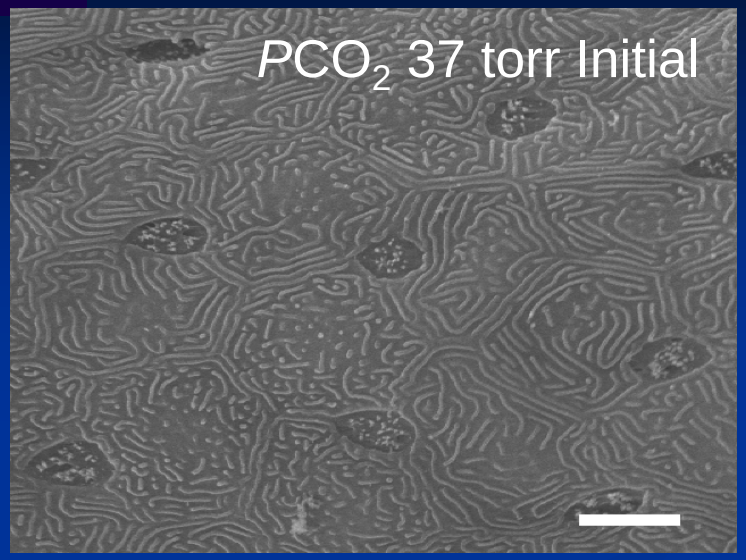


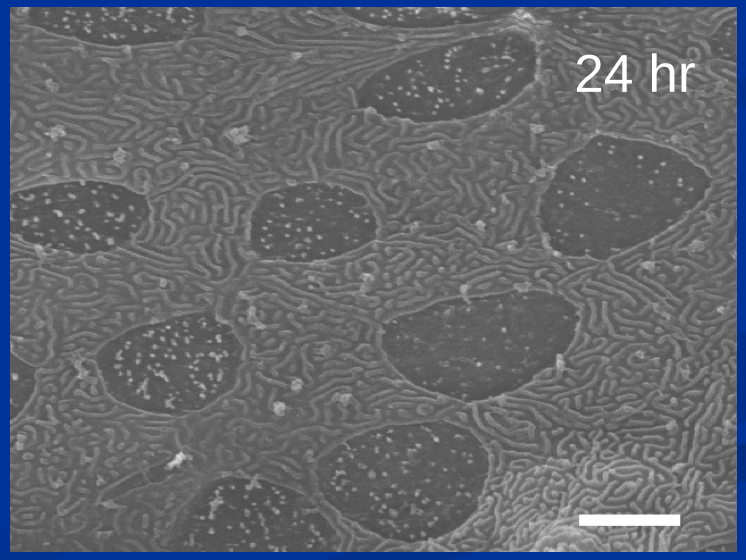
Seawater was acidified by either bubbling with 5% CO_2 in air (●) or adding sulphuric acid (●) to same pH of 6.2.

$$pH = pK' + \log \frac{[HCO_3^-]}{\alpha \times PCO_2}$$

Effects of high CO_2 plasma ions and chloride cells of marine fishes

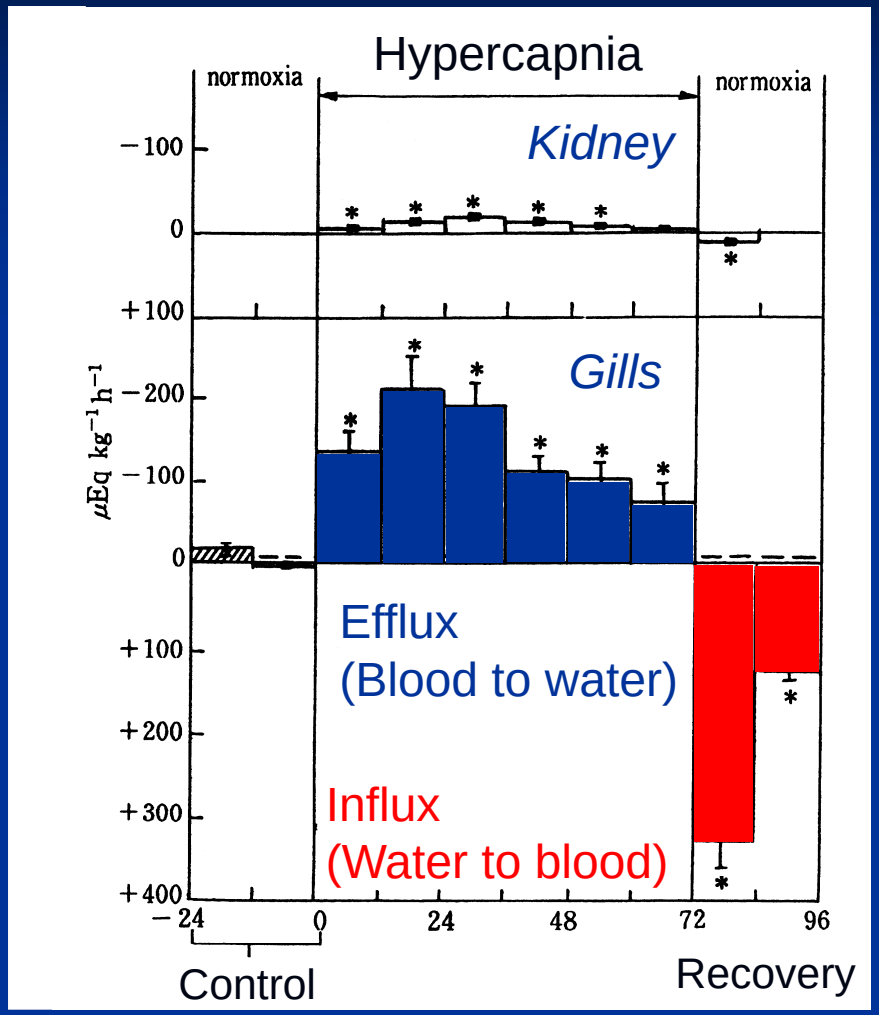


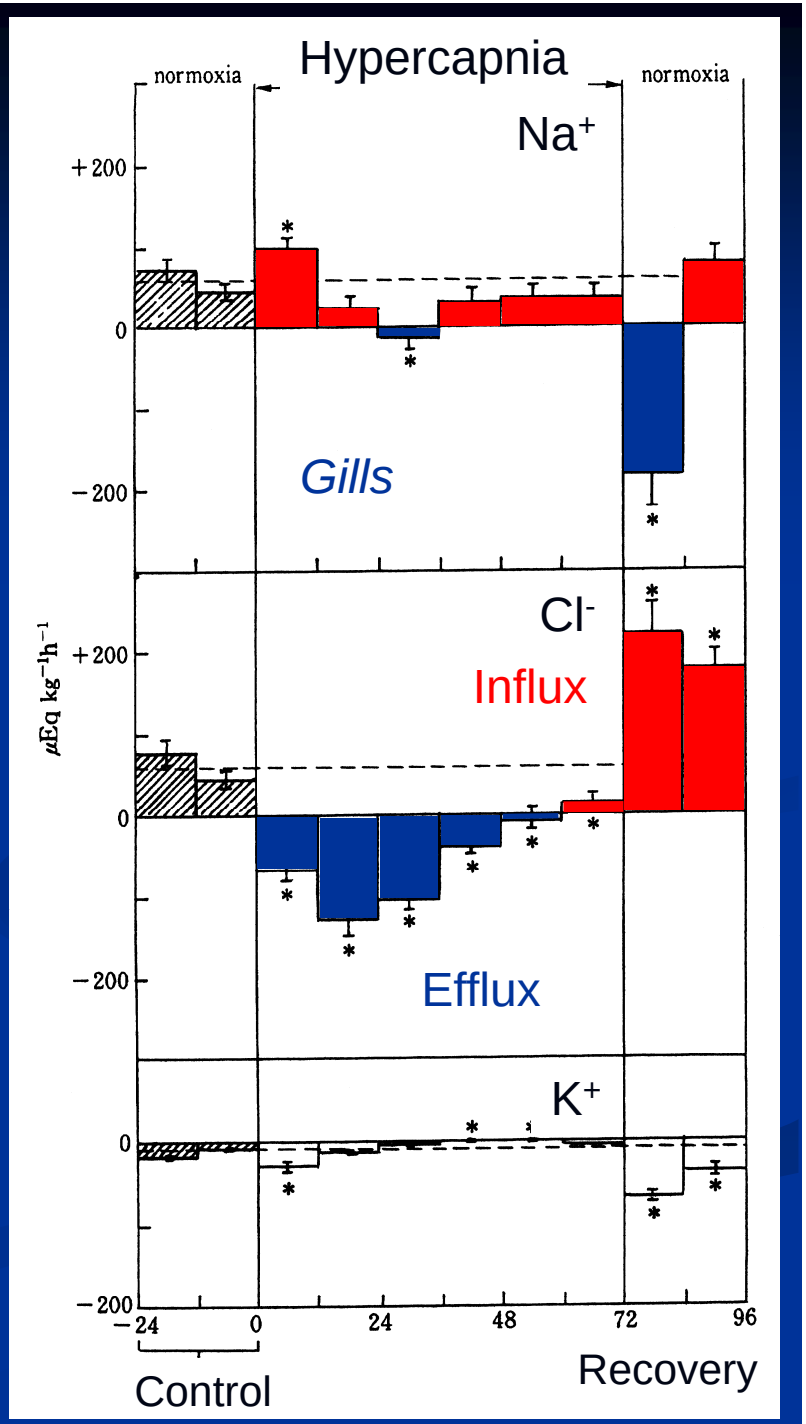




Gill chloride cells in bastard halibut

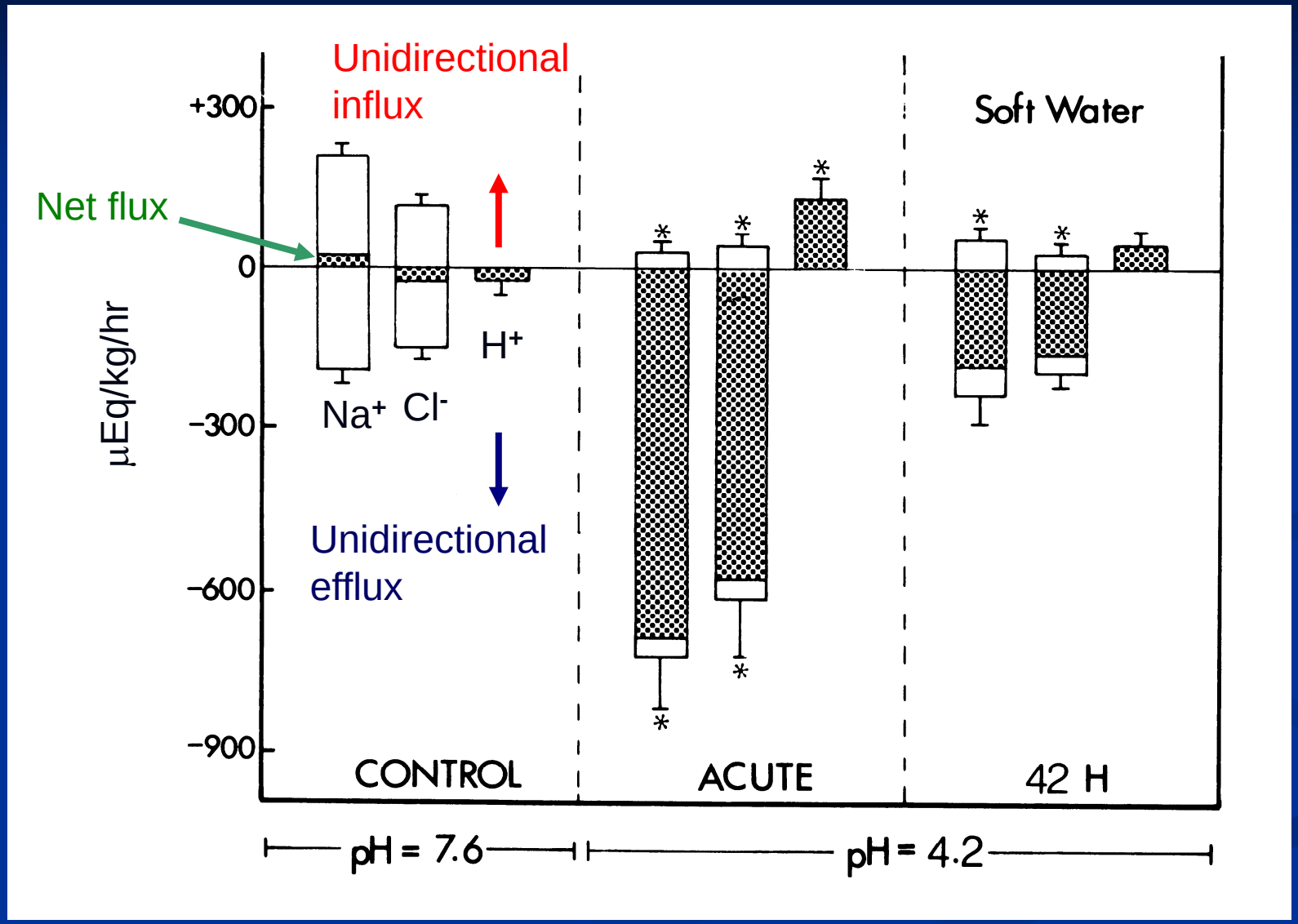
Effects of high CO_2 on ion fluxes of freshwater rainbow trout





Hyperoxia-induced hypercapnia. Wood et al. (1984)

Effect of acid water on ion fluxes of freshwater rainbow trout



[Ca^{2+}] 0.24 mEq/L, McDonald et al. 1983

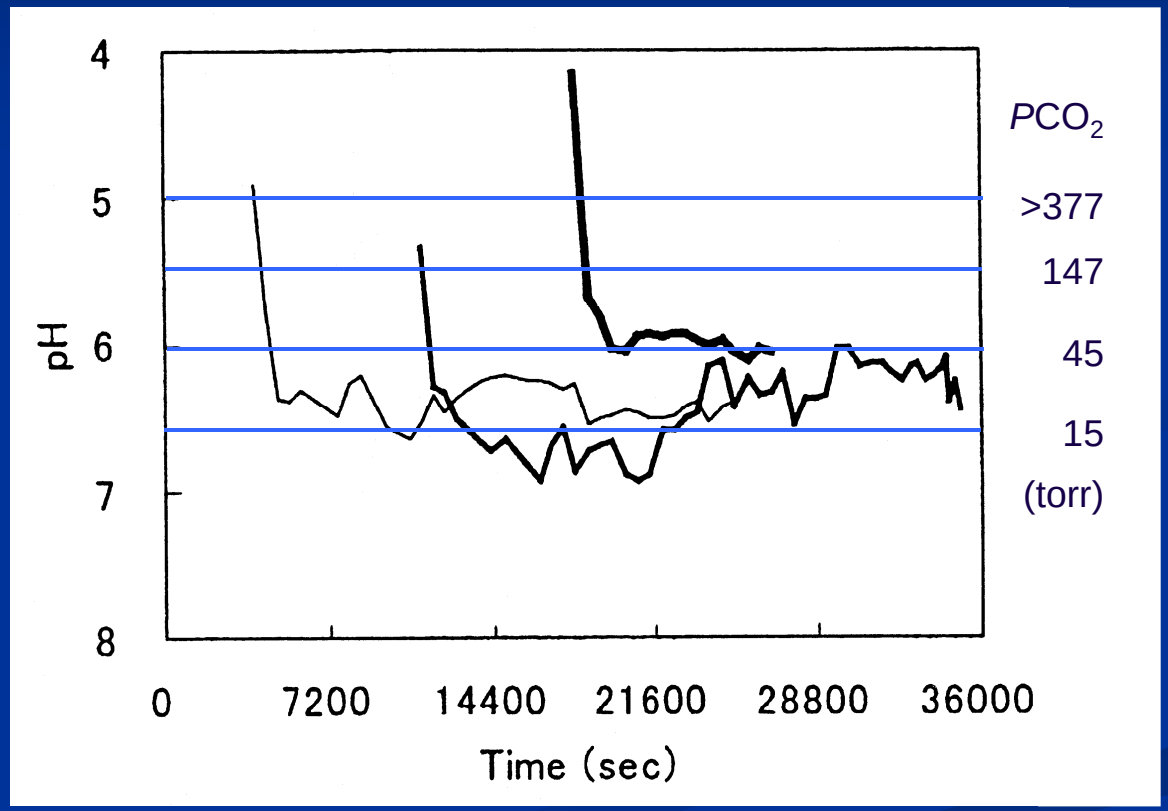
Differences in Biological Effects of CO_2 and H^+

- Physiological responses to CO_2 and acids are different.
- CO_2 readily diffuses into the 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 transports across the gills, and increased passive ion movements. The main cause of fish kill by acid exposure is thought not to be blood acidification but cardiac failure by hemoconcentration.

- Differences in Biological Effects of CO_2 and H^+ in Water
- Effects of CO_2 Ocean Sequestration on Fishes

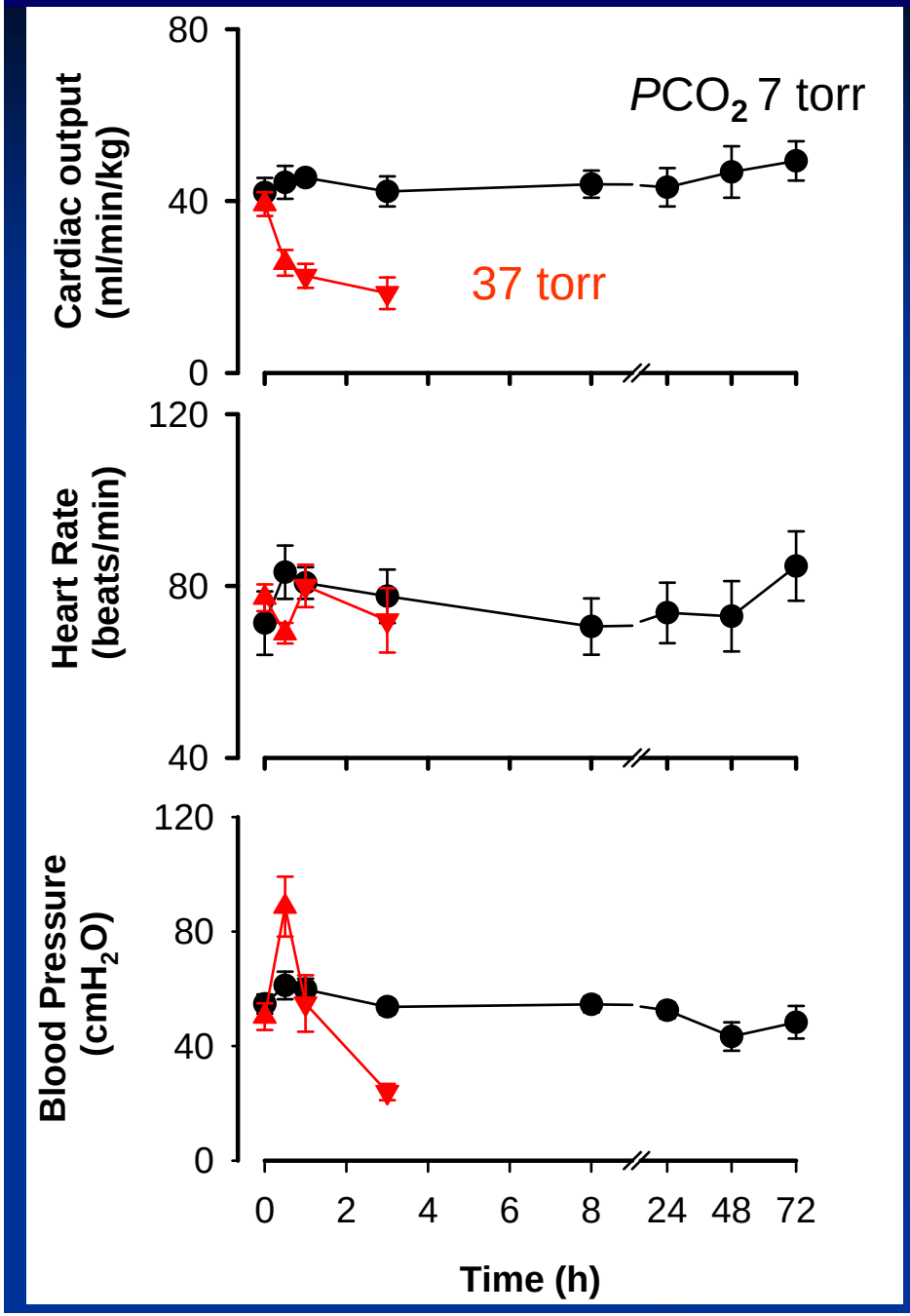
CO_2 sequestration by the moving-ship method

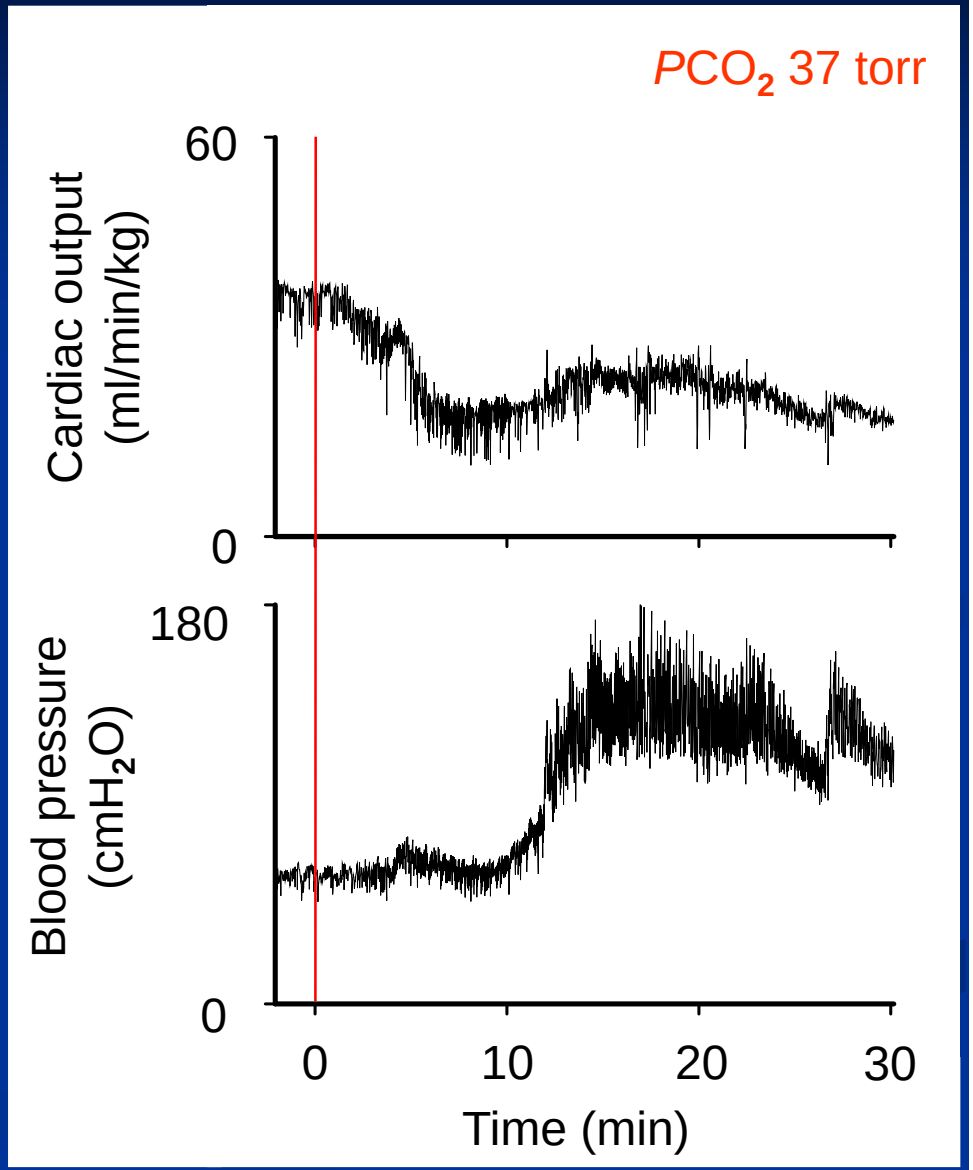
Initial exposure to high CO_2 levels followed by rapid decreases in CO_2.



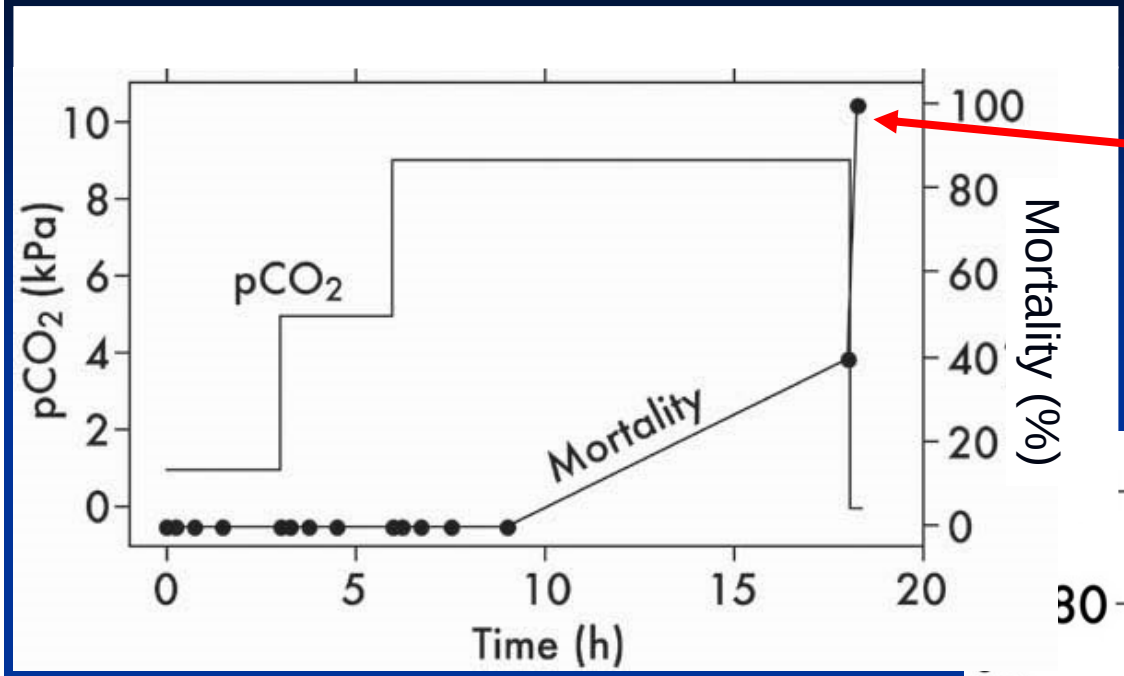
Sato and Sato 2002

Effects of CO_2 on cardiovascular system of amberjack



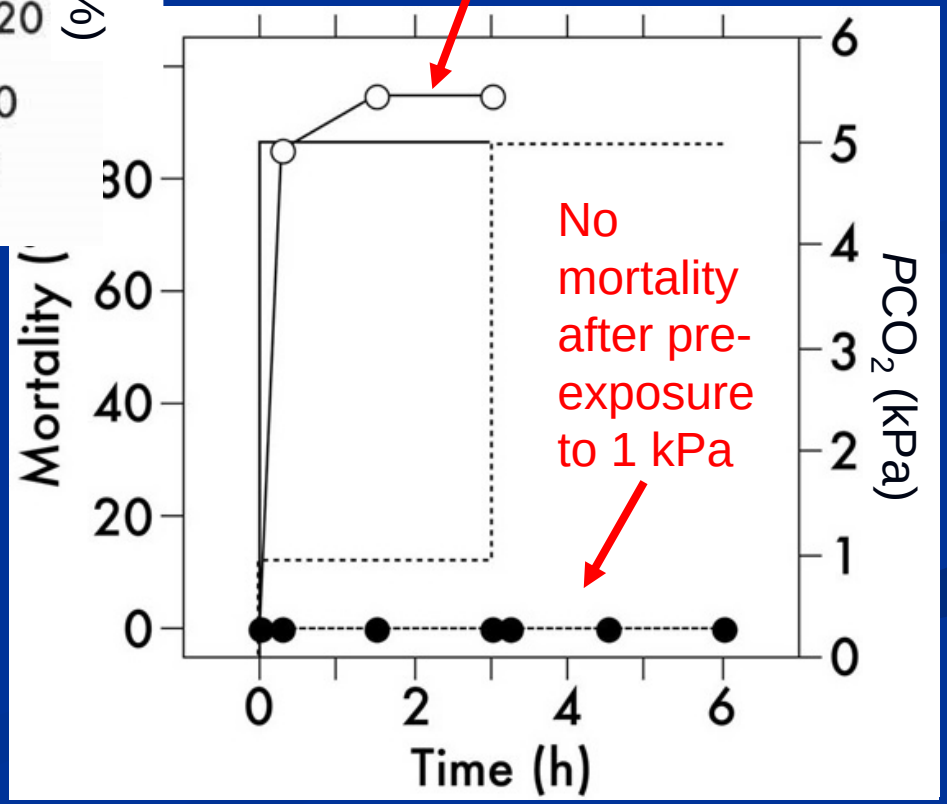


Fish mortality by unsteady exposures to CO_2



Sudden drop of PCO_2 quickly killed the fish.

ca. 100% mortality at 5 kPa



Effect of step-increase CO_2 exposures on fish mortality: Japanese sillago

1 kPa = 7.5 torr

Experiments on deep-sea fish under high pressures

High Pressure Chamber (Max 50 MPa)

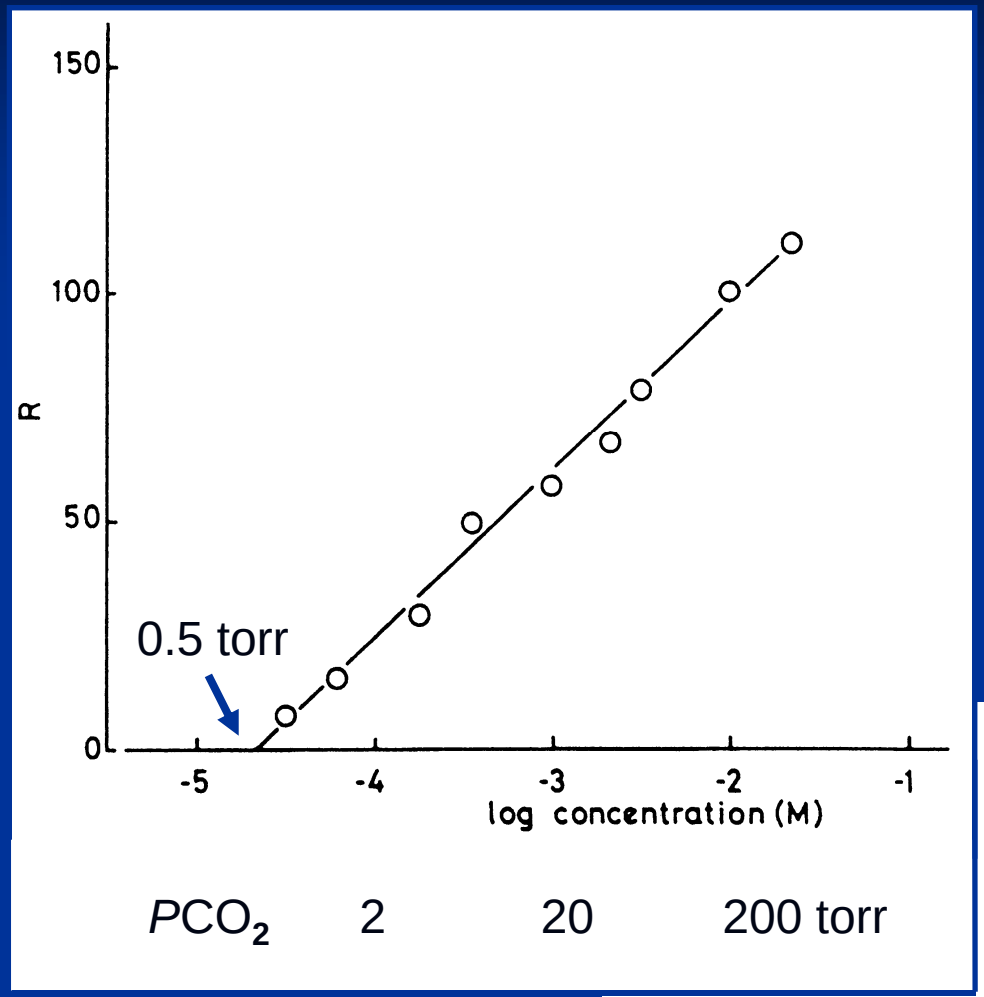
Careproctus trachysoma: Liparididae

Known distribution depth 400-800 m
Water temperature 2 C

Summary

- When tested at the same pH, CO_2 and acids produce different effects on fish. Data on mineral acids cannot be used to evaluate effects of CO_2.
- Still, useful information may be obtained from the literature on the effects of water acidification on fishes, which has already made great impacts on freshwater ecosystems.
- Fish kill mechanism by lethal levels of CO_2 must be clarified, particularly focusing on the role of cardiac response.
- Effects of ocean sequestration need to be investigated; on deep-sea animals, under high pressures, at low temperatures, and in unsteady CO_2 conditions.
- Long-term effects at sublethal CO_2 levels on fishes should also be investigated.

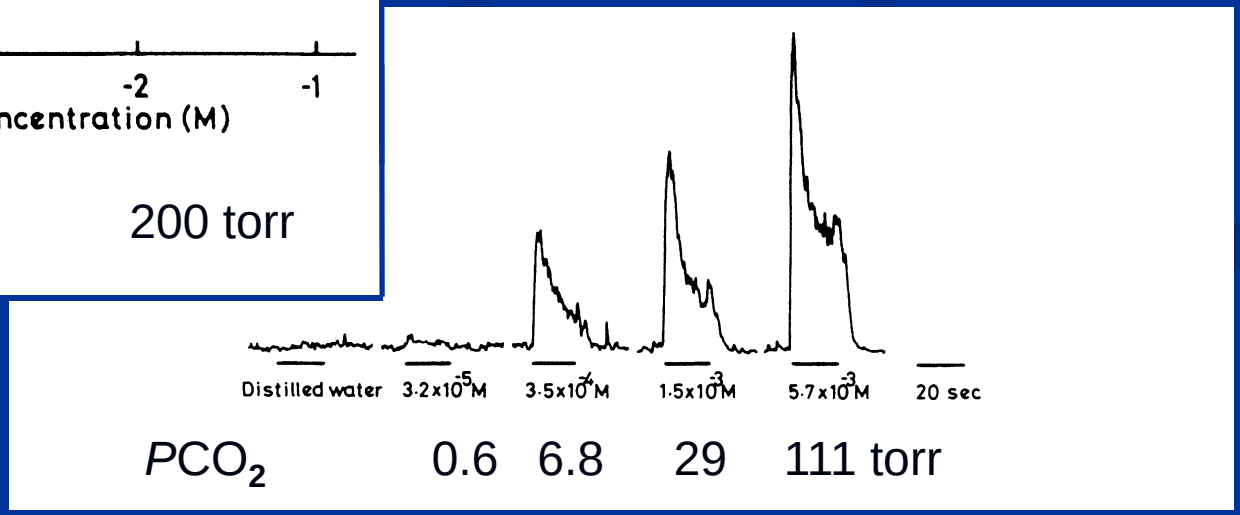
CO_2 reception in fish



Eel palatine CO_2 receptors

pH of the test solution was 5.0
Test solution acidified by HCl
to pH 5.0 gave <u>no response.</u>

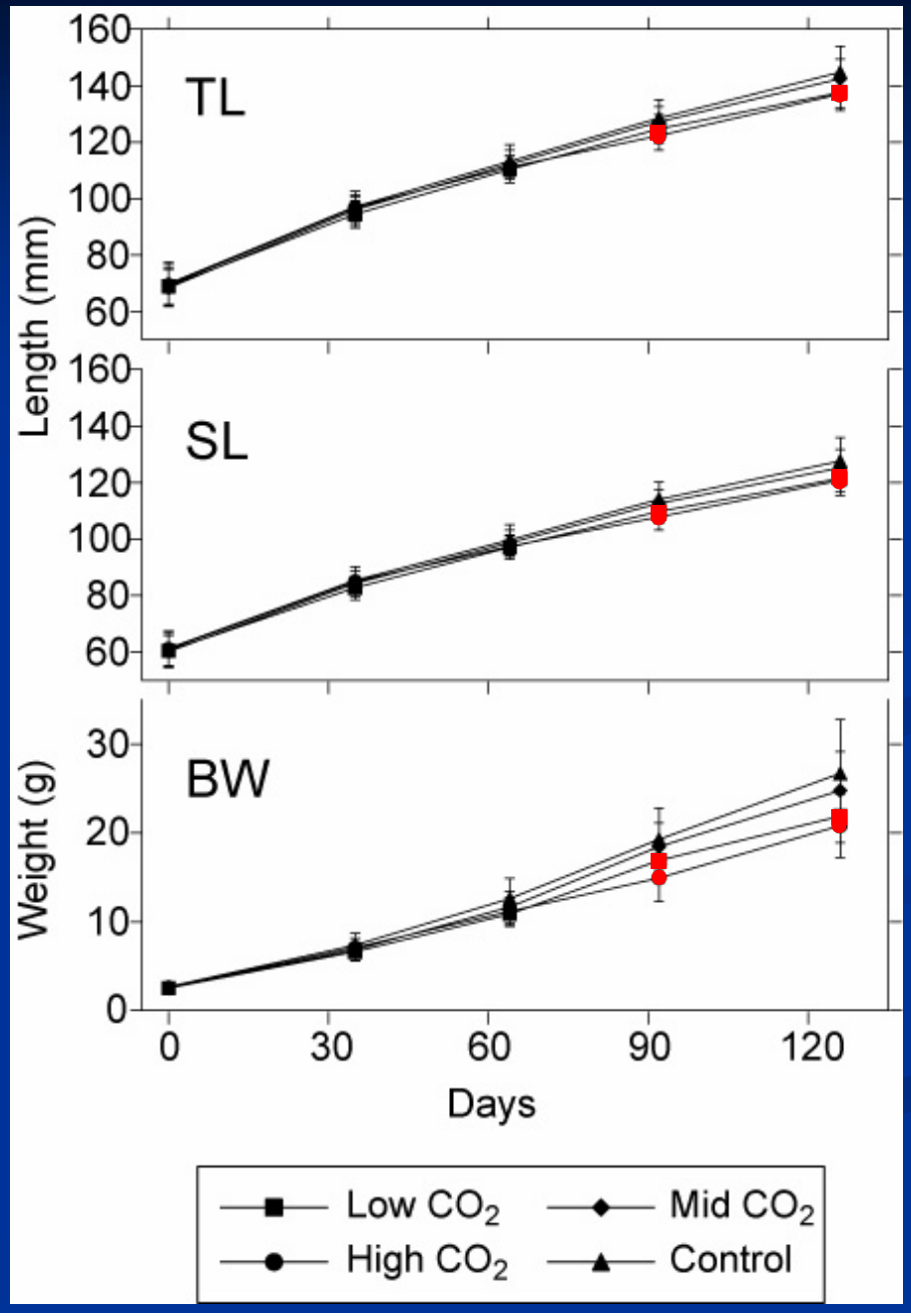
Yoshii et al. (1980)



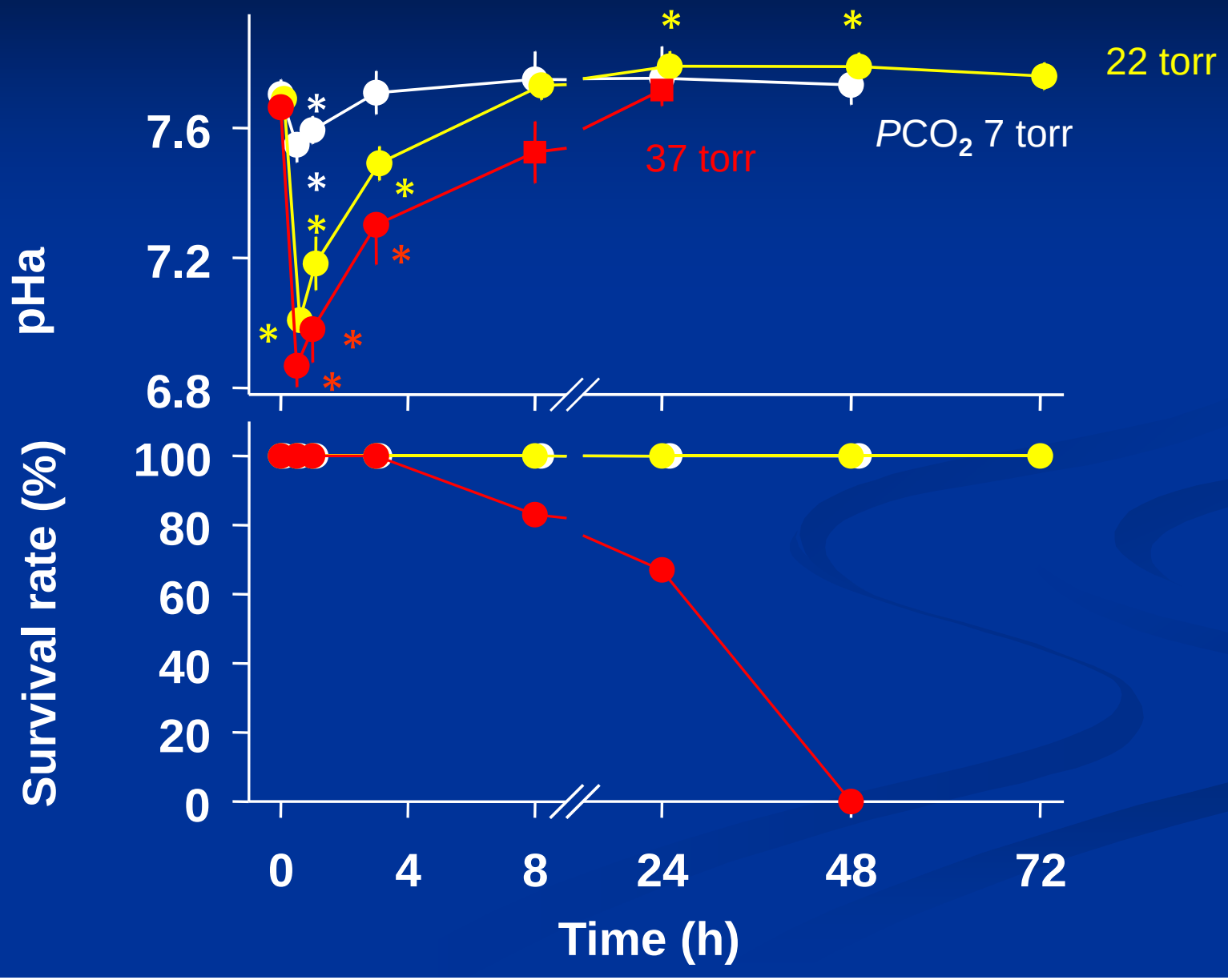
Effects of long-term CO_2 exposure on growth of Japanese sillago

Low 3 torr
Mid 5 torr
Hi 9 torr

WT 25 C
34 psu
Alkalinity 2.3 mEq/L
1 atm



Changes in arterial pH and mortality during hypercapnia in bastard halibut

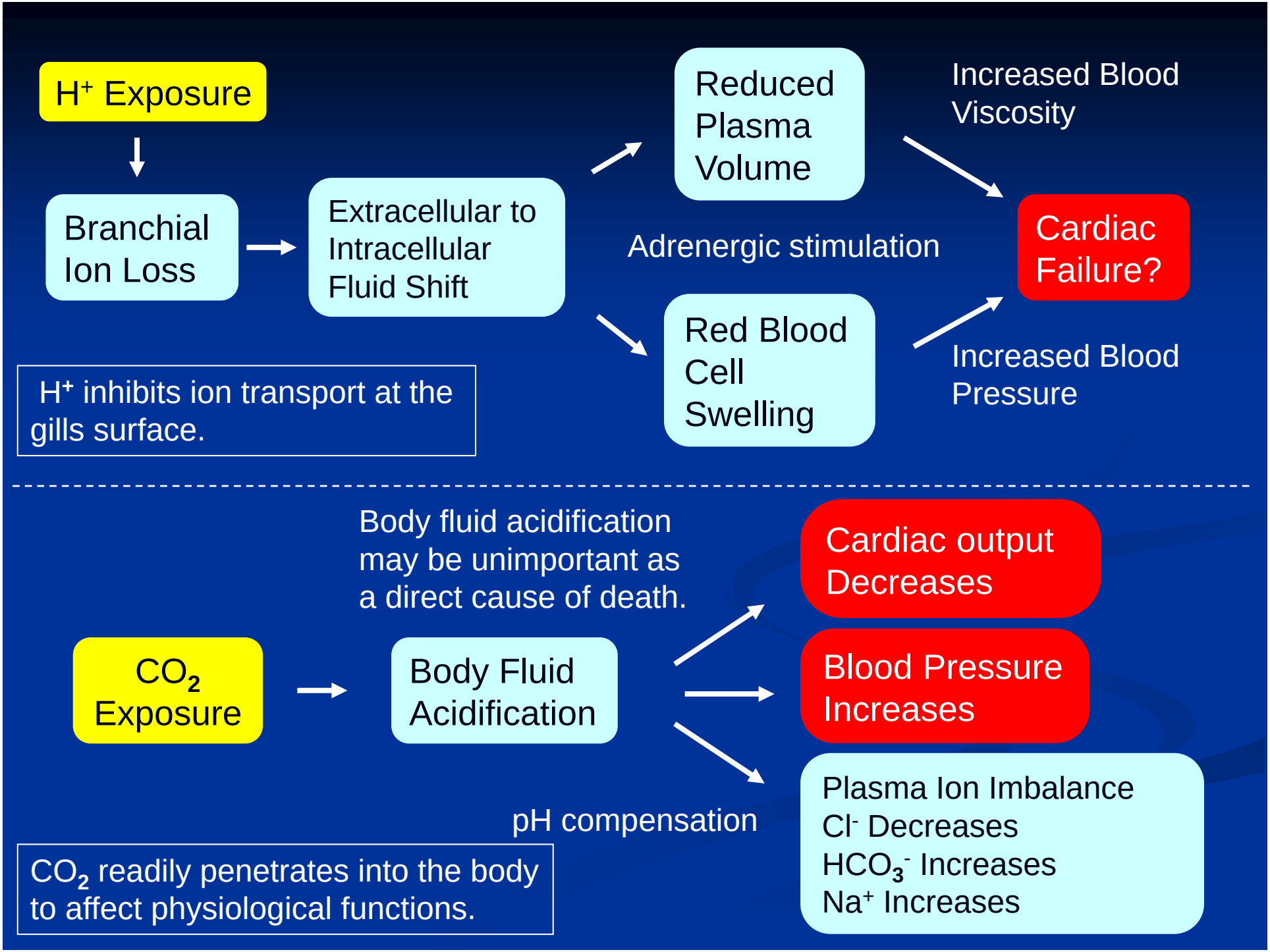


Effect of long-term CO_2 exposure on fish growth

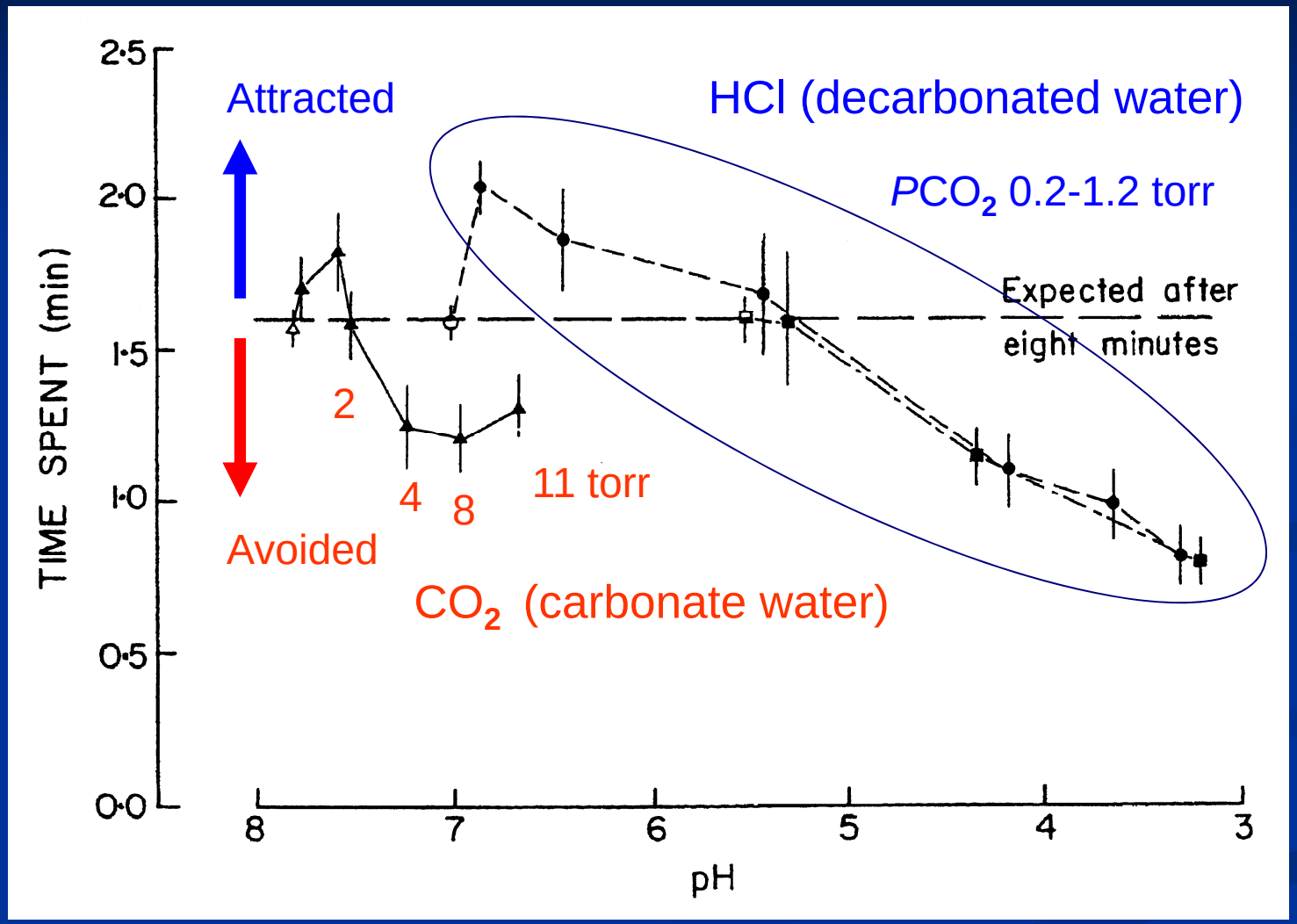
Species	%BW of Cont	PCO_2 (torr)	Temp (C)	Duration (days)	Water pH
Seawater					
Atlantic salmon	63	20	15-16	43	6.4
Spotted wolffish	64	20	6	70	6.5
Fresh water					
Rainbow trout*	52	17	9	275	6.2-6.3
Rainbow trout**	76	17	9	275	6.2-6.3
White sturgeon	62	20	19	28	7.0

*Fed normal mineral diet, **Fed low mineral diet

AS: Fivelstad et al. (1998), SW: Foss et al. (2003), RT: Smart et al. (1979), WS: Crocker and Cech (1996).


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.
CO_2 Exposure
Body Fluid Acidification
Cardiac output Decreases
Blood Pressure Increases
Plasma Ion Imbalance
Cl^- Decreases
HCO_3^- Increases
Na^+ Increases
pH compensation
CO_2 readily penetrates into the body to affect physiological functions.

Locomotor responses to CO_2 and H^+



Avoidance threshold PCO_2 2-4 torr

Arctic char (Jones et al. 1985)