



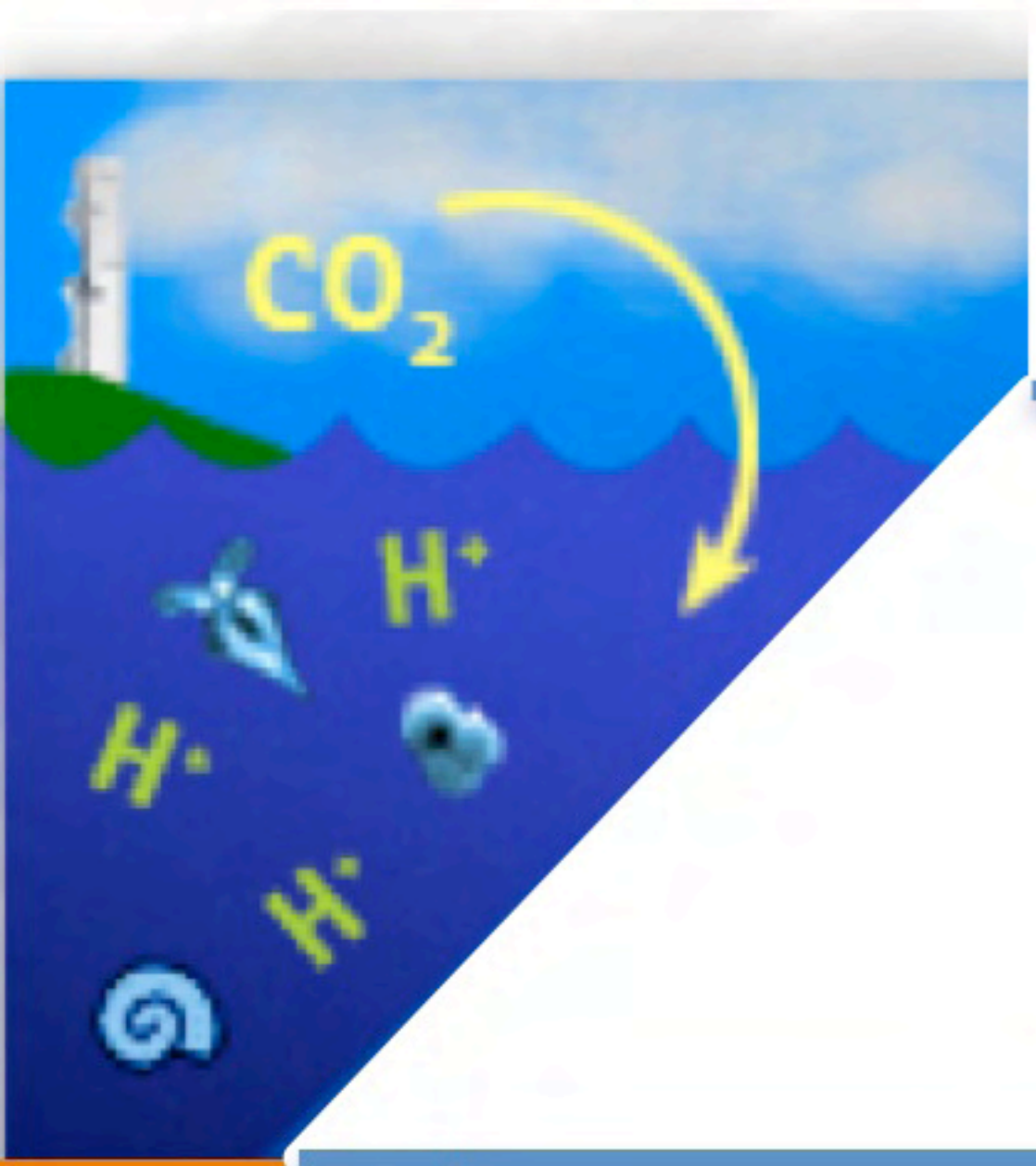
Ocean Acidification

*Studying ocean acidification's effects
on marine ecosystems and biogeochemistry*

PHYSIOLOGICAL RESPONSES

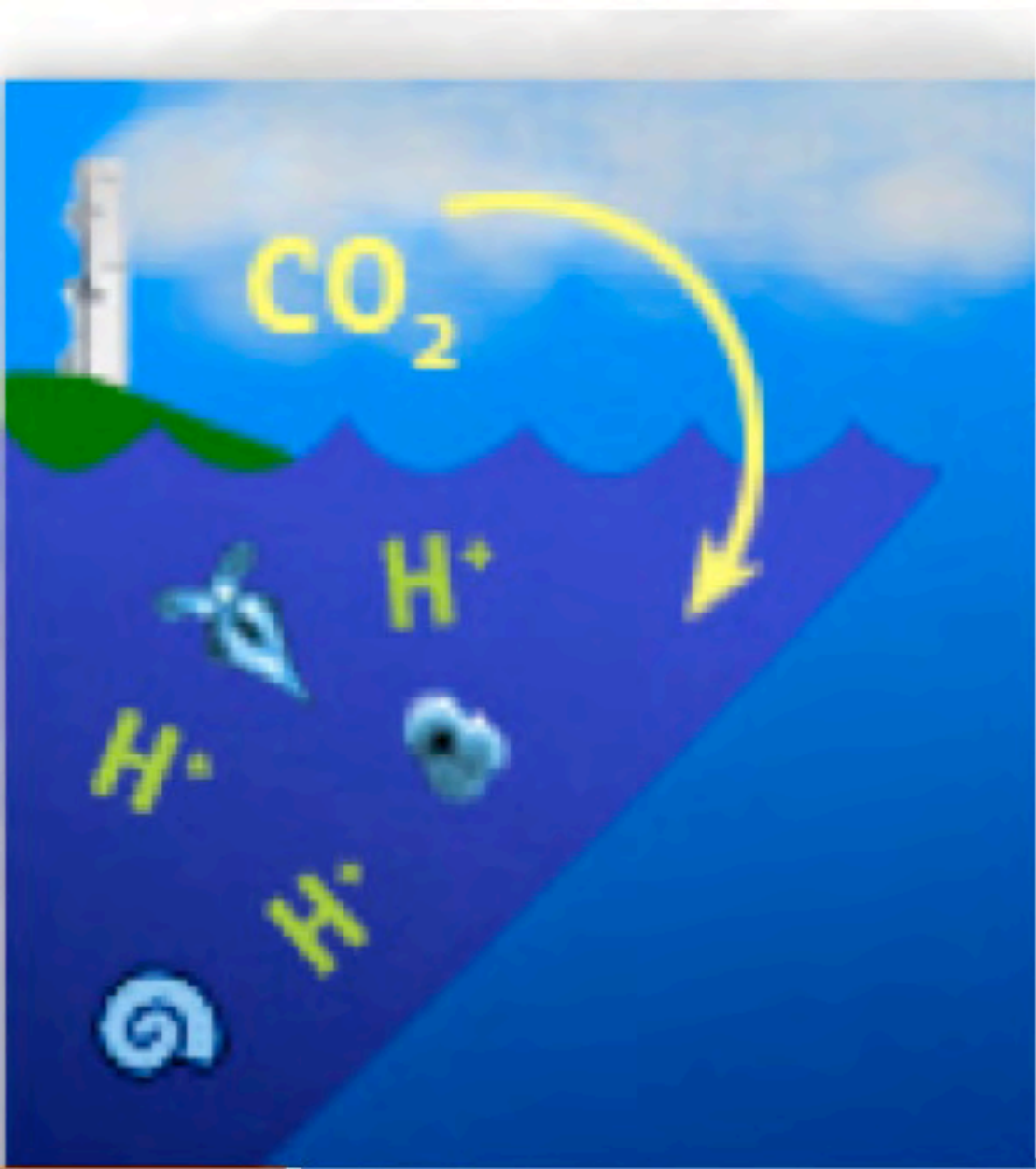
Physiological Responses of Organisms to Ocean Acidification

Synthesis of Projects addressing
Multicellular Organisms



Bird's eye view of what we have

- Taxa
- Ecosystem
- Mechanism & Process



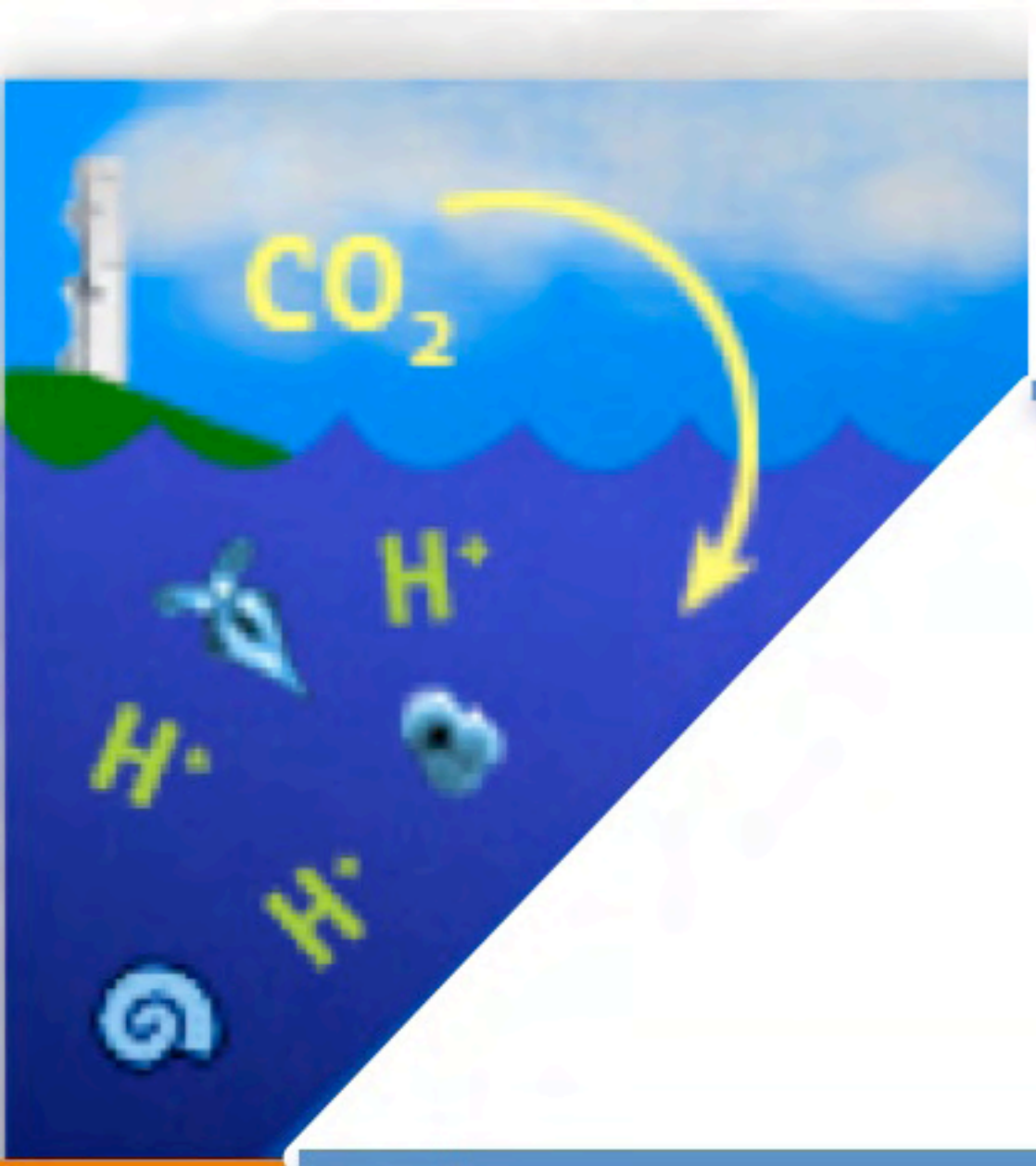
Physiological Responses

- Metazoans 1 -

WHO

Coral:

- Influence of temperature and acidification on the dynamics of coral co-infection and resistance ([Burge, Harvell, Mydlarz](#))
- Comparative study on corals – Moorea ([Carpenter et al](#))
- An investigation of the role of nutrition in the coral calcification response to ocean acidification ([Cohen, McCorkle, Tarrant, de Putron](#))
- Bermuda ocean acidification and coral reef investigation (BEACON) ([Andersson et al.](#))
- Climate change and coral reefs ([Chris Landgon – FL](#))
- Interactive effects of temperature, nutrients, and ocean acidification on coral physiology and calcification ([Cai/Grottoli/Warner](#))
- The molecular basis of ocean acidification effects on calcification in zooxanthellate corals ([Falkowski](#))
- The ecophysiological basis of the response of coral larvae and early life history stages to global climate change ([Edmunds](#))
- Long-term monitoring of coral and algal calcification in the Florida Keys, USA ([Kuffner/Hickey/Poore](#)) USGS
- NOAA Pacific Reef Assessment & Monitoring Program ([Brainard et al.](#)) NOAA



Physiological Responses

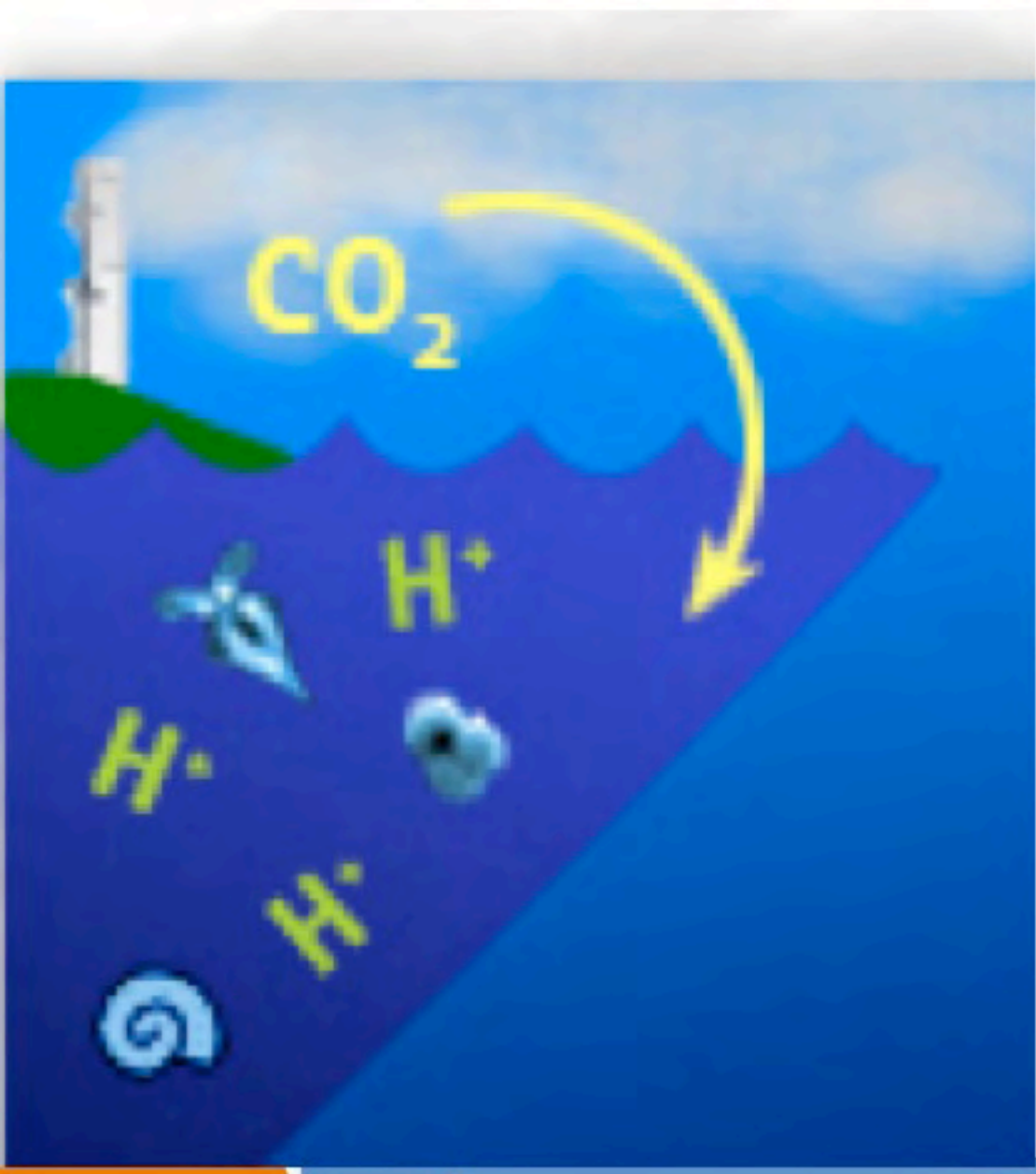
- Metazoans 2 -

Echinoderm:

- Acclimation and adaptation to ocean acidification of key ecosystem components in the CCLME ([Menge et al.](#))
- Interacting stressors and physiological response in early life history stages of purple urchins ([Hofmann](#))
- Current pH dynamics and response to future acidification of embryos & larvae of an Antarctic urchin ([Hofmann](#))

Mollusk:

- The transcriptomic responses of the eastern oyster *Crassostrea virginica*, to environmental conditions ([Chapman](#))
- Impact of ocean acidification on survival and early shell development by the bay scallop *Argopectin irradians* ([McCorkle/Cohen](#)) [NOAA SeaGrant]
- OA study on estuarine and open-coast species ([Gaylord et al.](#))
- A mechanistic understanding of the impacts of ocean acidification on the early life stages of marine bivalves ([Waldbusser/Hales/Langdon/Haley](#))
- Dissolution mortality of juvenile bivalves in coastal marine deposits ([Green/Waldbusser](#))
- River and sediment-modulated stress in planktonic and early settlement *Mya arenaria* ([Green](#))
- Effects of temperature and elevated CO₂ levels on biomineralization and metabolic physiology of marine bivalves ([Sokolova/Beniash](#))
- Behavioral responses of oysters to diel-cycling of pH ([Breitburg](#)) (Smithsonian)



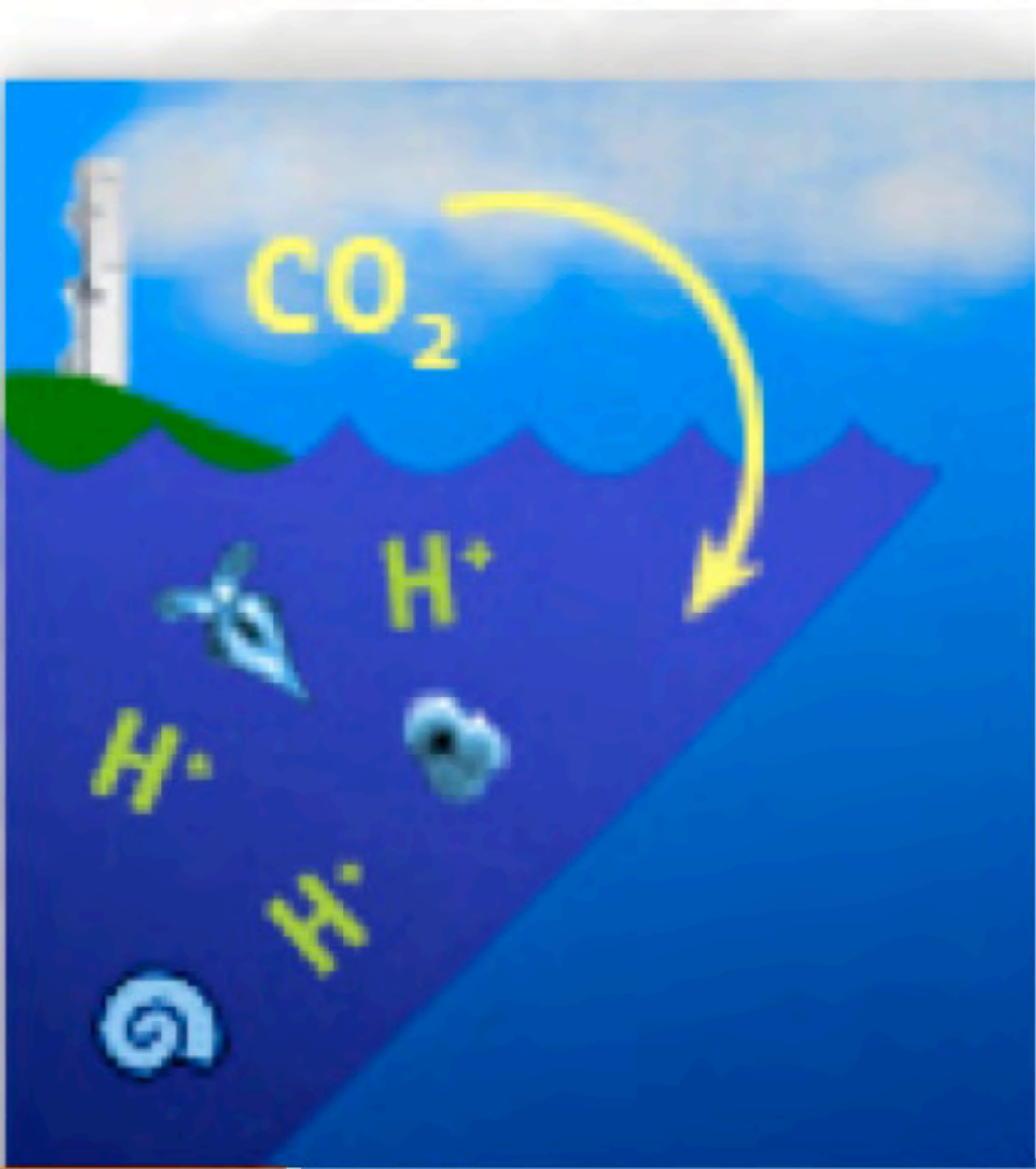
Physiological Responses

- Metazoans 3 -

WHO

Crustaceans:

- Physiology of deep sea crustaceans ([Barry et al.](#))
- Genomic and evolutionary approaches to understanding physiological responses to ocean acidification ([Burton](#)) [copepod *Tigriopus californicus*]
- Impact of ocean acidification on survival of early life stages of planktonic copepods in the genus *Calanus* in the northern oceans ([Runge/Christensen](#))
- Synergistic effects of temperature and pH variability on physiology (transcriptome and proteome) of crabs ([Tomanek/Stillman](#))
- Copepod growth studies ([Caldarone et al](#)) NOAA



Physiological Responses

- Metazoans 4 -

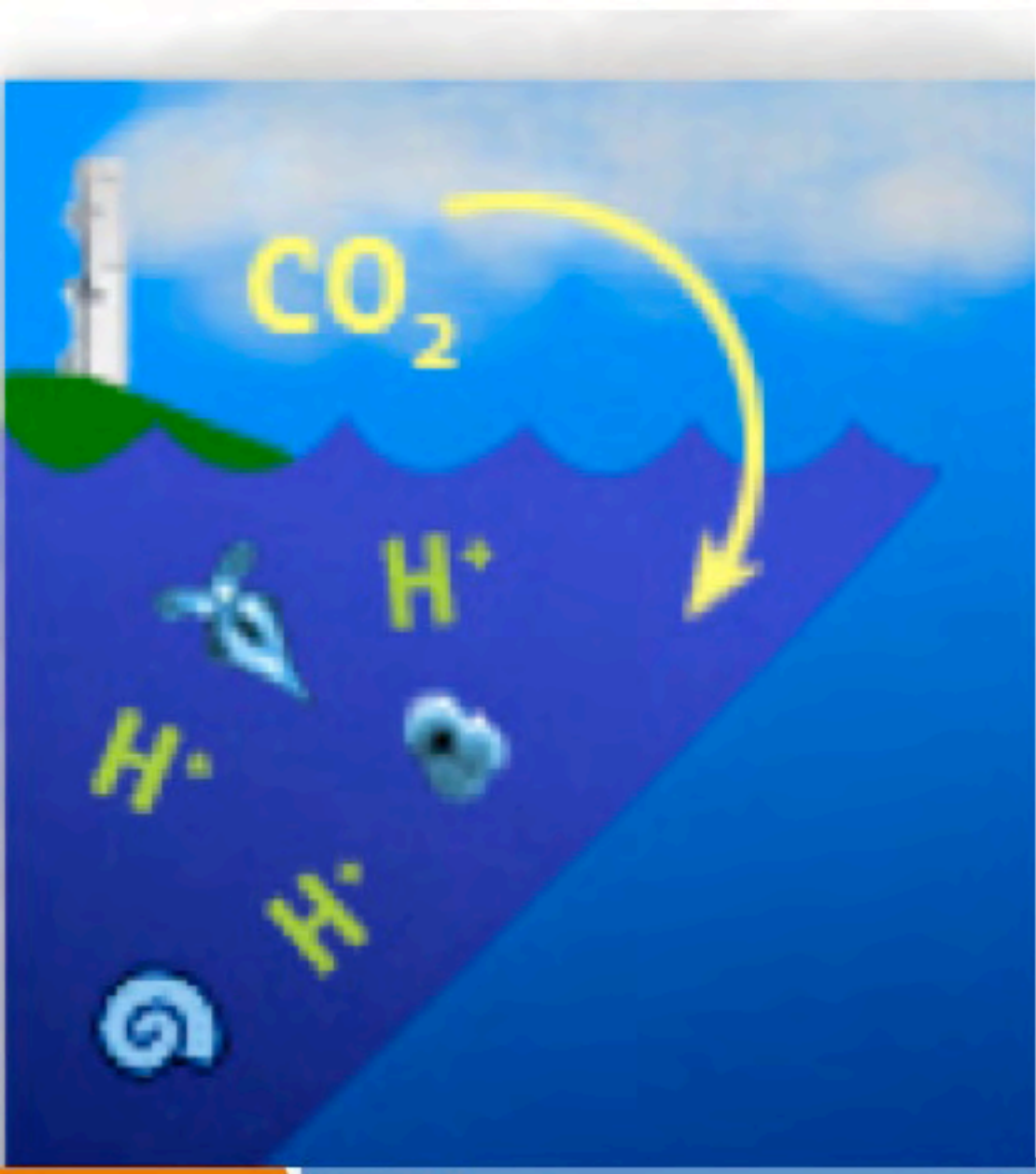
WHO

Fish:

- Impact of CO₂ on acid-base balance, rectal base excretion and intestinal carbonate formation in marine fish ([Grosell](#))
- Present and future impacts of ocean acidification on juvenile walleye pollock metabolic processes and growth rates ([Mathis/Hurst](#)) [joint w/NOAA??]
- Identifying adaptive responses of polar fishes in a vulnerable ecosystem ([Place/Dudycha](#))
- Behavioral responses of fish to diel-cycling of pH ([Breitburg](#)) (Smithsonian)

Mixed:

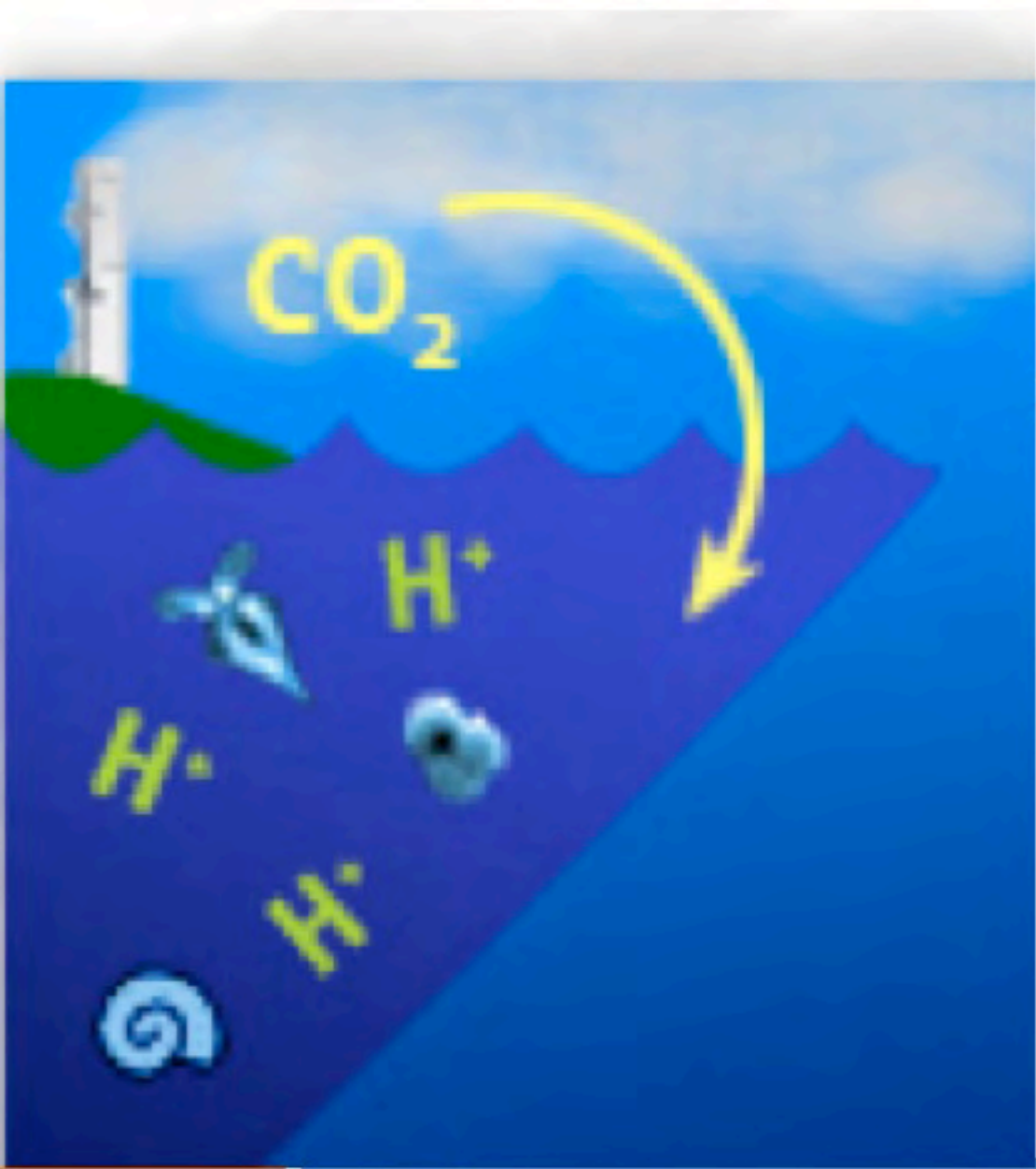
- Investigating the effects of CaCO₃ saturation state and temperature on the calcification rate and skeletal properties of benthic calcifiers ([Ries](#))
- Effects of ocean acidification on coastal organisms – an ecomaterials perspective ([Carrington](#)) (Mollusks/coralline algae/crustacean)
- Midwater animal models: optical measurement of metabolic transitions in pelagic biota ([Johnsen/Seibel](#)) (broad spectrum: fishes, larvaceans, chaetognaths, polychaetes, jellies, salps, amphipods, and gastropods; focus on cephalopods)
- Responses to pH change: performance and interactions ([Wootton/Pfister/McCoy](#)) [key intertidal species]



Physiological Responses

- Macroalgae-

- Crustose coralline algae in tropical ecosystems ([Carpenter](#))
- Crustose coralline algae in temperate rocky intertidal zone ([Menge et al.](#))
- Effects of ocean acidification on coastal organisms – an ecomaterials perspective ([Carrington](#)) (coralline algae)
- Physiological response of fleshy, calcified benthic algae ([Price and Smith](#))



Physiological Responses

- Metazoans 3 -

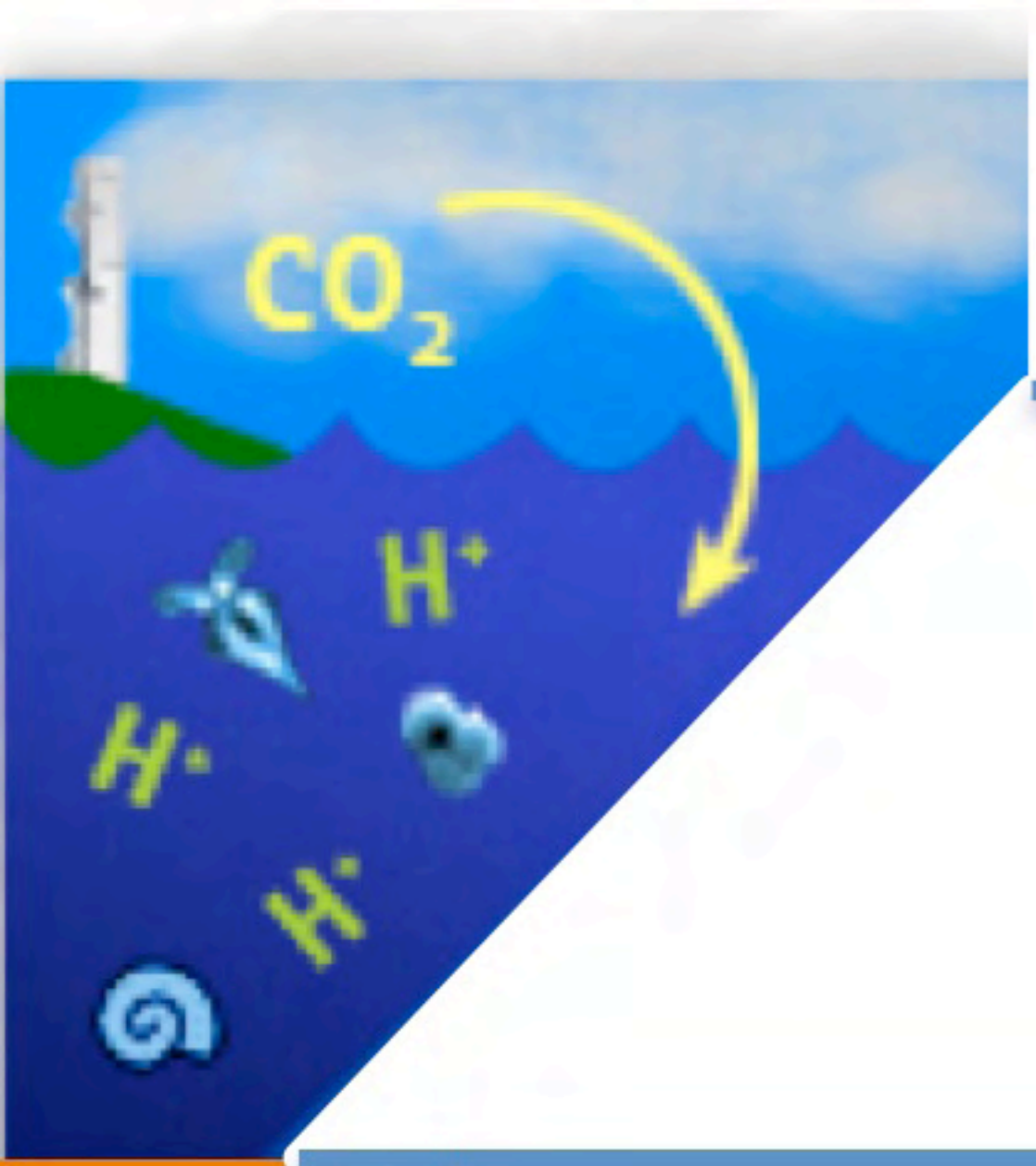
NOAA Studies

Northwest Fisheries Science Center

- Responses of coastal species to ocean acidification ([Busch/McElhany](#)) [mollusks, crustaceans, fish) NOAA/NWFSC

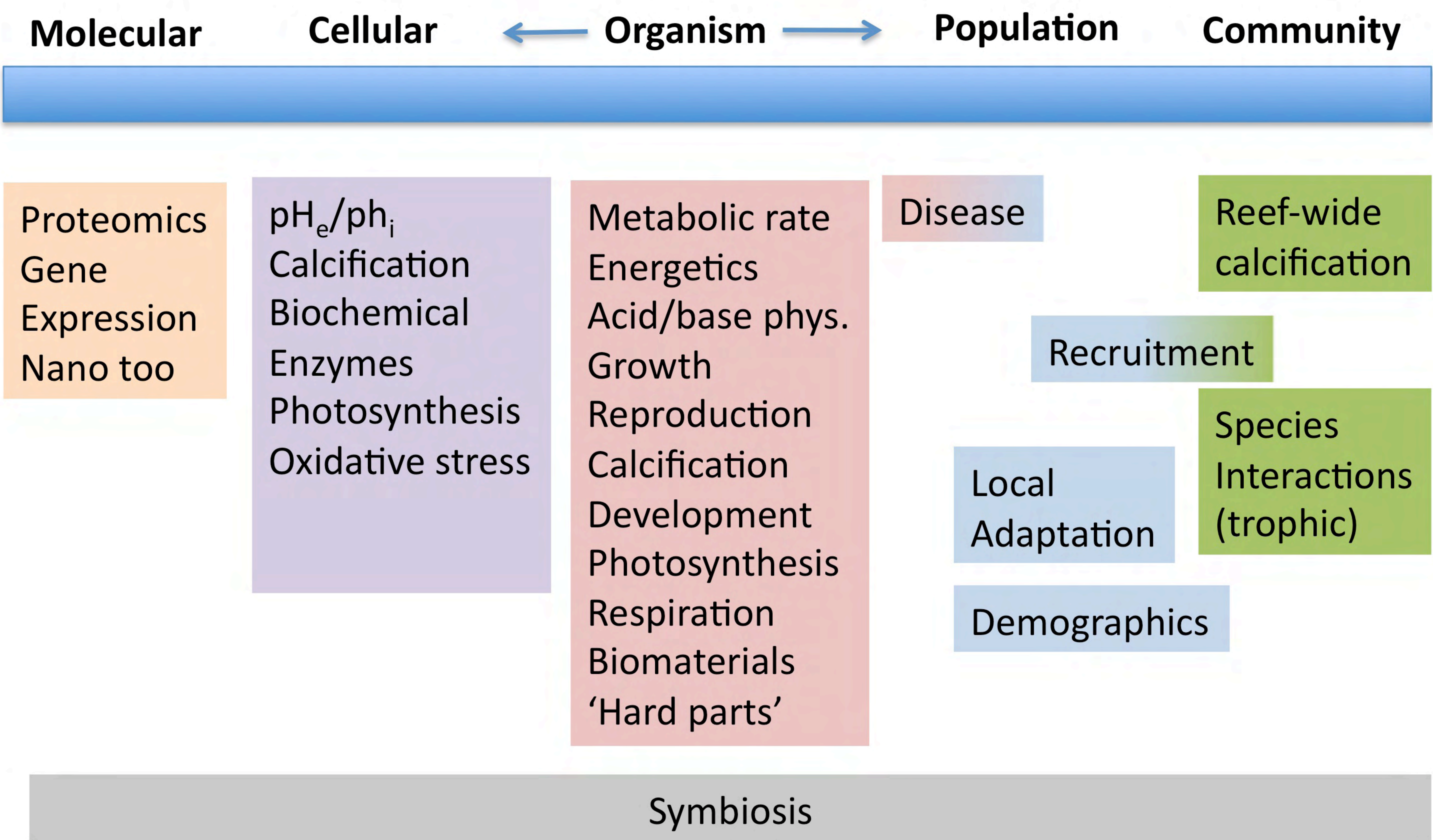
National Marine Fisheries Service

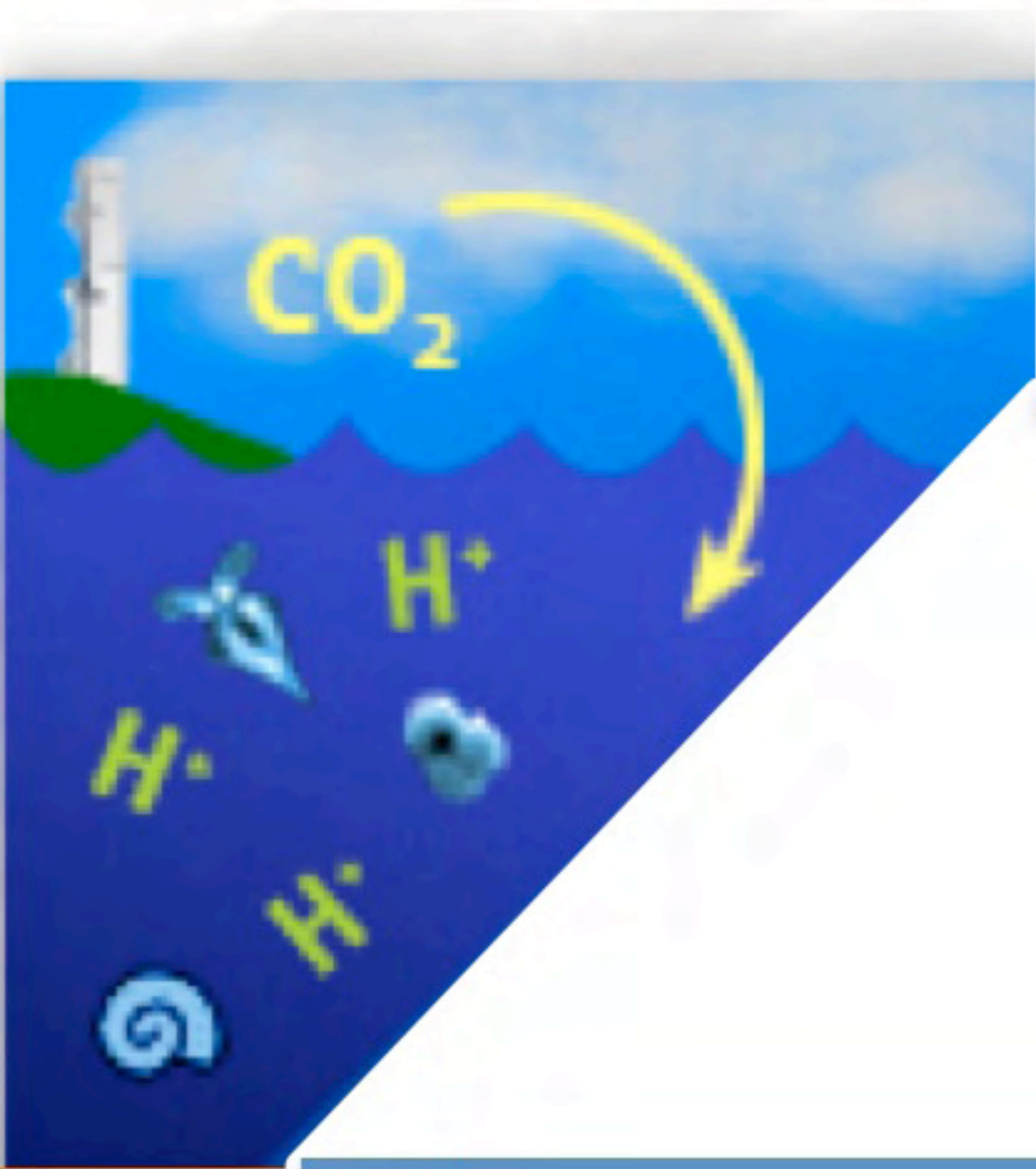
- The response of king crab hemocytes to ocean acidification ([Meseck/Wikfors/Foy](#)) NOAA/NMFS
- Physiological resiliency of bivalve hemocytes, primary calcifying cells, to extracellular acidification ([Meseck/Croxton/Alix/Wikfors](#)) NOAA/NMFS
- Effects of OA on embryogenesis, larvae condition, and adult survival of commercial crab species in Alaska ([Foy/Long/Swiney](#)) NOAA/NMFS/AFSC
- Ocean acidification effects on resource finfish species ([Phelan-Hill/Chambers/Poach, Wieczorek](#)) NOAA/NMFS
- Effects of elevated levels of carbon dioxide on otolith condition and growth of juvenile scup ([Phelan-Hill/Perry/Redman/Meseck](#))



“Skin in, Skin out”

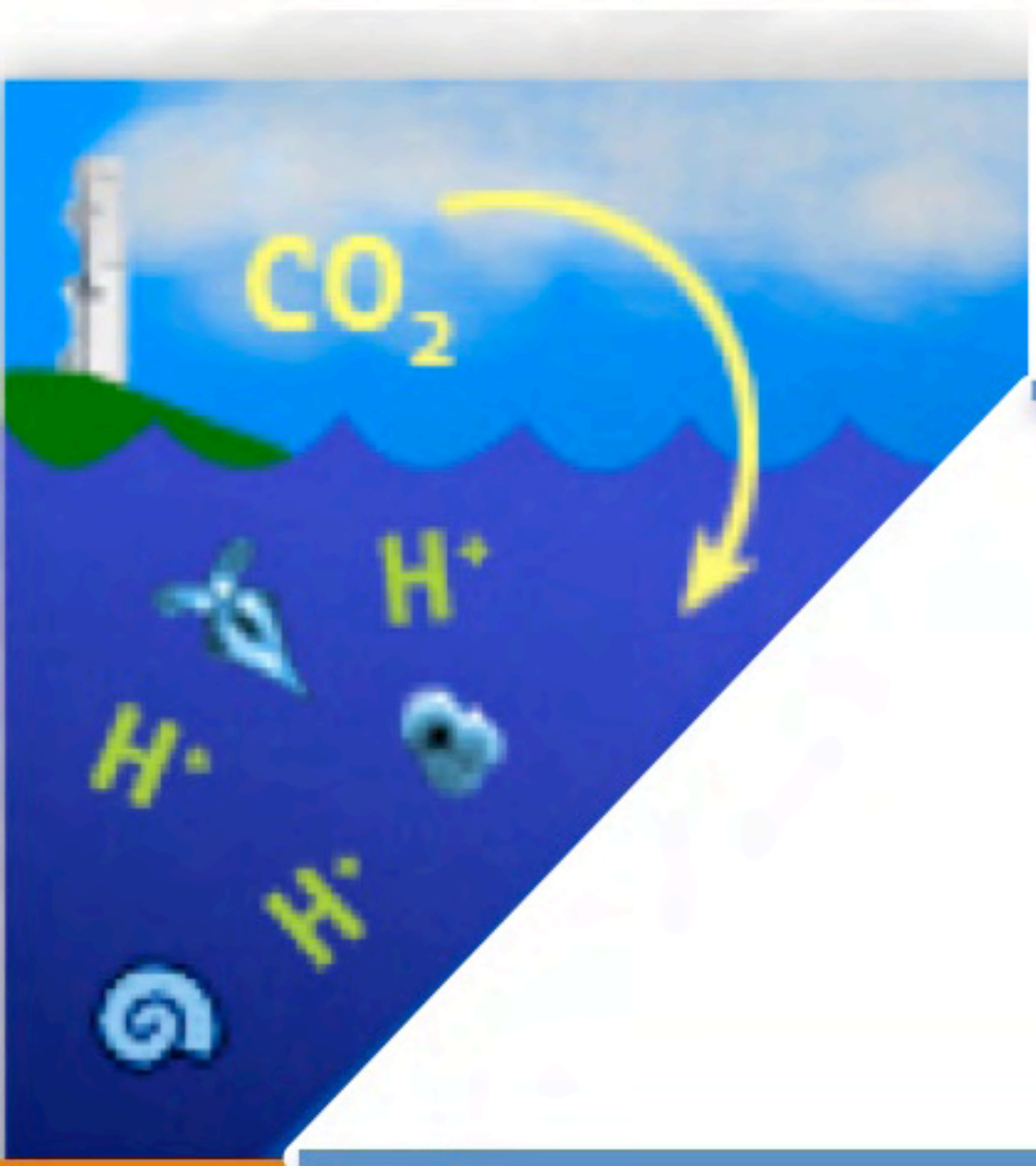
PHYSIOLOGICAL RESPONSES





Ecosystem (where)

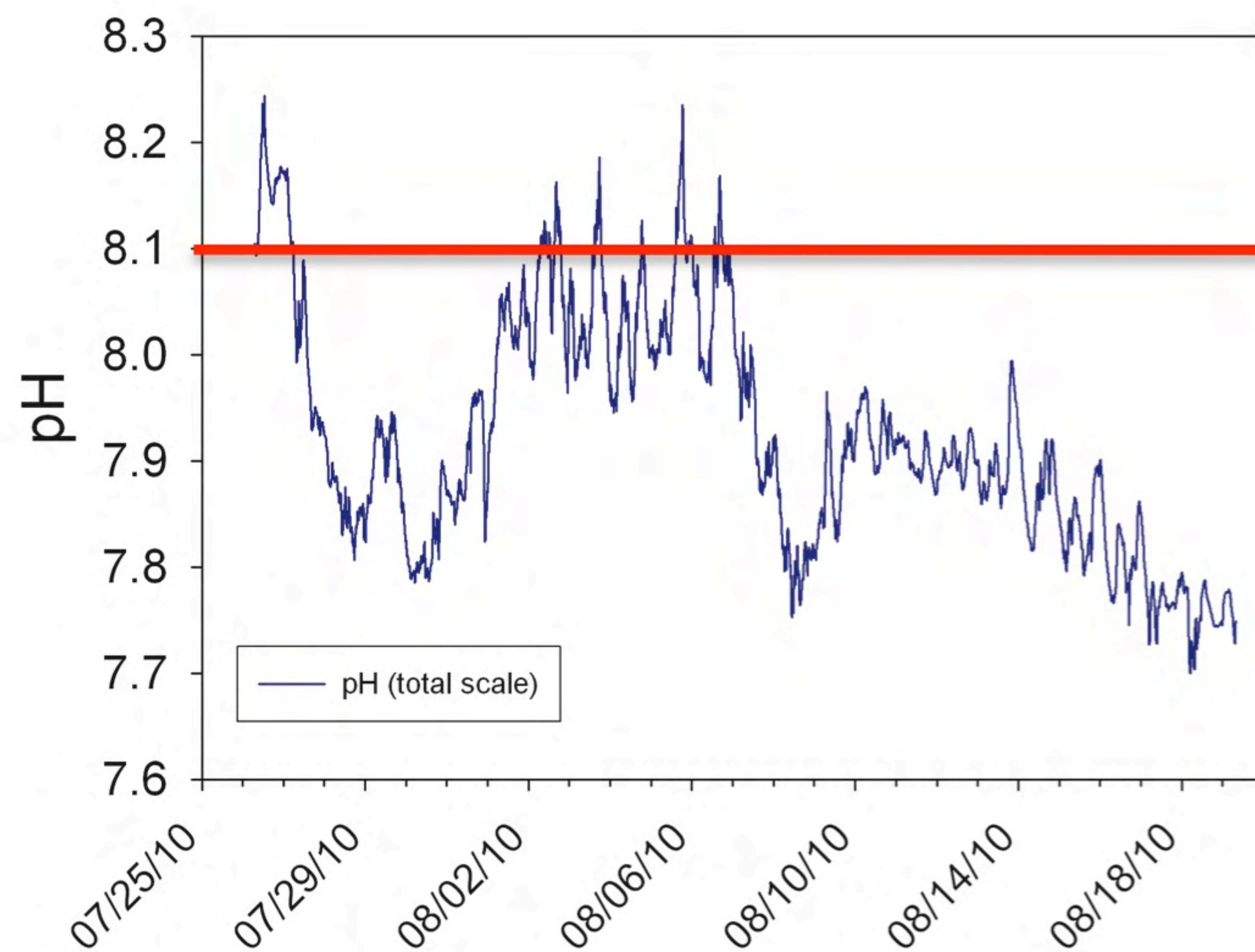
- **Tropical**
 - Burge/Harvell/Mydlarz
 - Cohen/McCorkle
 - Carpenter et al.
 - Andersson et al.
 - Cai/Grottoli/Warner
 - Edmunds
 - Kuffner et al
 - Atkinson
 - Chris Langdon (FL)
 - Price and Smith
 - Brainard et al
- **Temperate/Benthic/Coastal/Upwelling**
 - Chapman
 - McCorkle/Cohen
 - Waldbusser/Hales/Langdon (OR)/Haley
 - Green/Waldbusser
 - Green
 - Sokolova/Beniash
 - Grosell
 - Gaylord
 - Menge & Chavez (OMEGAs)
 - Breitburg et al (Smithsonian)
 - Hofmann
 - Busch/McElhany
 - Meseck/Croxton/Alix/Wikfors
 - Phelan-Hill et al.
- **Temperate Rocky Intertidal**
 - Menge x 2
 - Burton
 - Stillman/Tomanek
 - Carrington
 - Wootton et al.
 - Gaylord et al.
- **High Latitude Seas**
 - Mathis/Hurst
 - Place/Dudycha
 - Runge/Christensen
 - Hofmann
 - Meseck/Wikfors/Foy
 - Foy/Long/Swiney



Present-day pH Environment

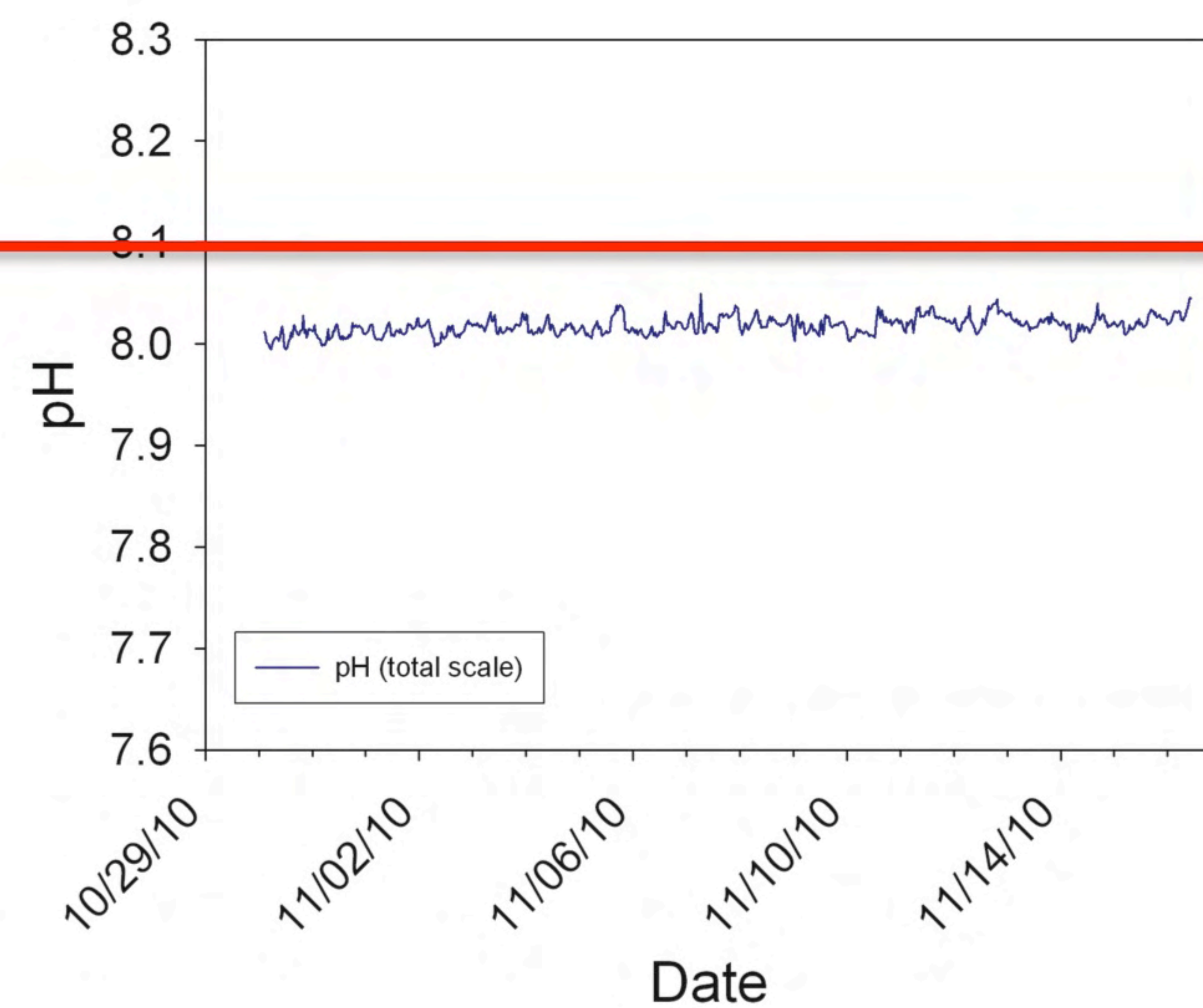
PHYSIOLOGICAL RESPONSES

Santa Barbara Channel

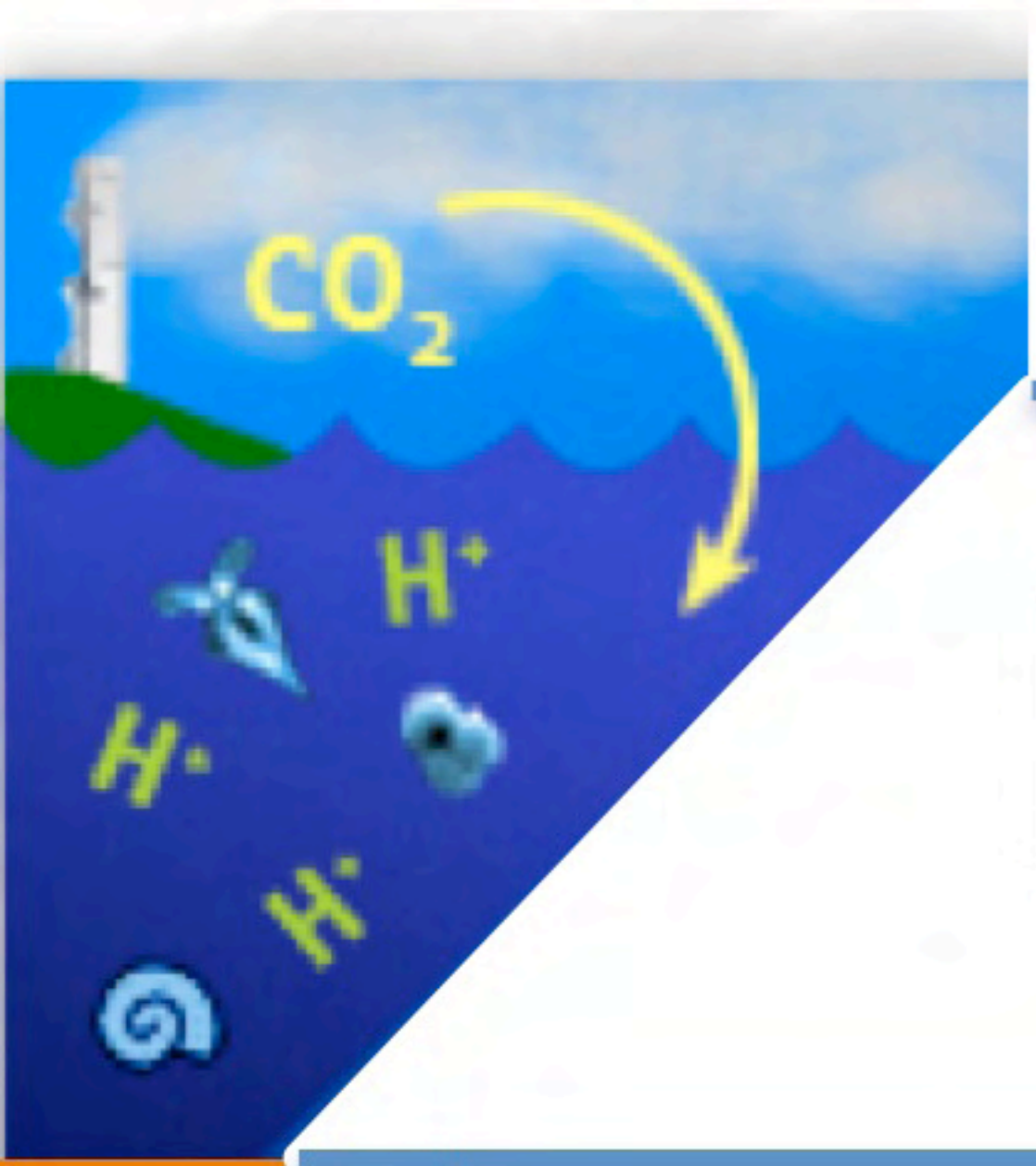


Yu, Martz, Hofmann (2011)
DOI: 10.1016/j.jembe.2011.02.016

McMurdo Sound, Antarctica



Matson, Martz, Hofmann (2011)
(unpubl. results)



Emerging complexities & nuances

- Biomaterials, microsensors, pH_i & atomic level considerations
- Multiple stressors/factors
- Role of nutrition & N/P cycle (e.g.)
- Complexities of metabolic cost
- Life history stage, a closer view
- Local adaptation, role of adaptation
- Experimental evolution
- Role of the present-day environment?