

# Ocean Acidification in Washington



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*Image: Wikipedia*

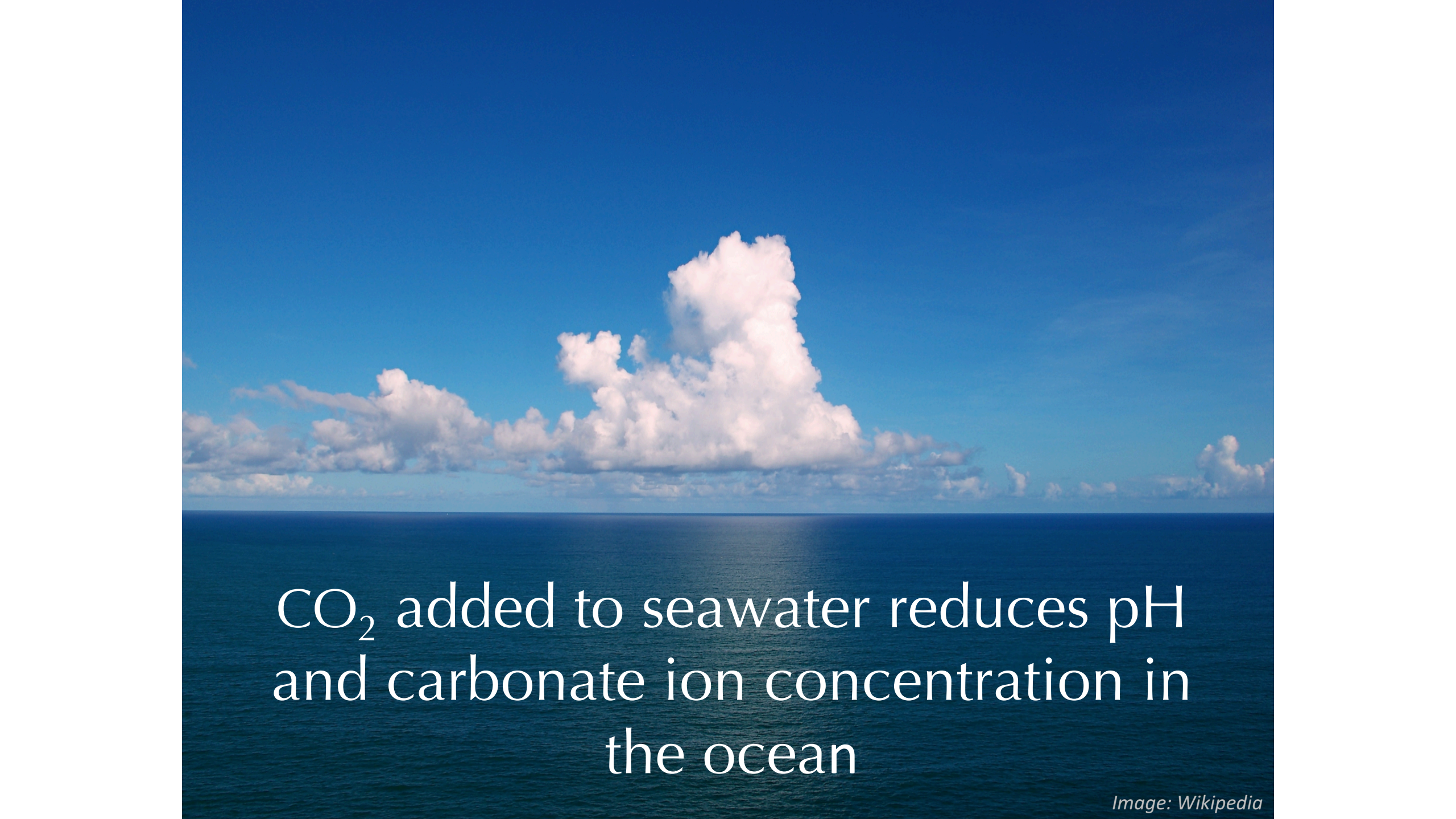


*Image: mit.edu*

The ocean has taken up about 28% of the carbon dioxide released by industry and deforestation

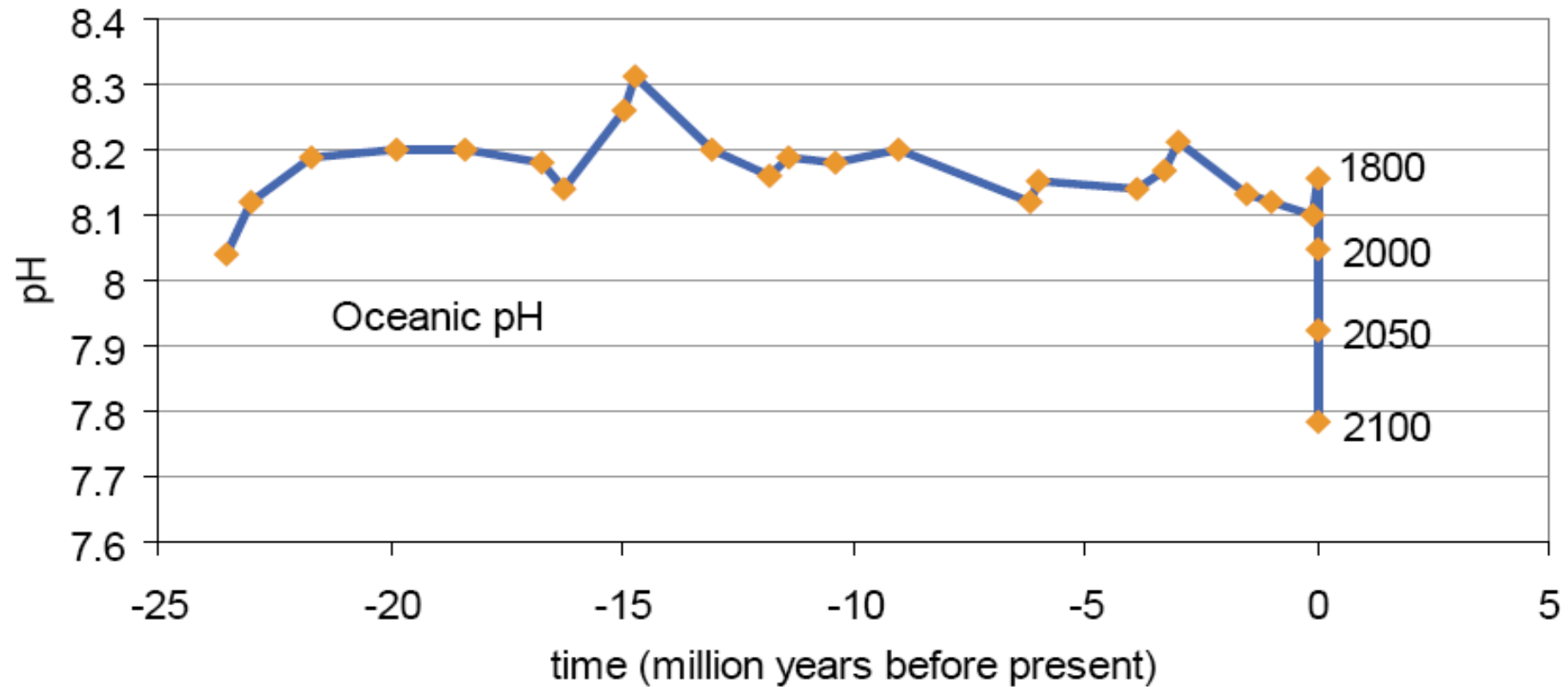
CO<sub>2</sub> in the atmosphere contributes to climate change

CO<sub>2</sub> in the water causes ocean acidification



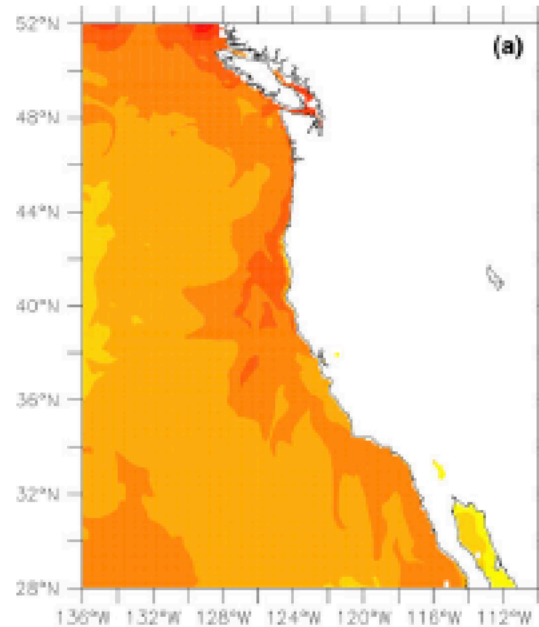
CO<sub>2</sub> added to seawater reduces pH  
and carbonate ion concentration in  
the ocean

# The rate of change is unprecedented in 25 million years

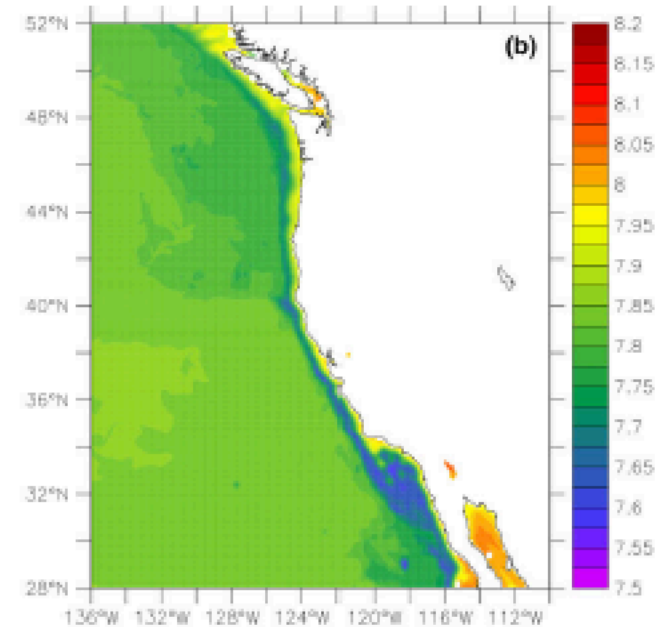


# pH in the California Current System is projected to decline

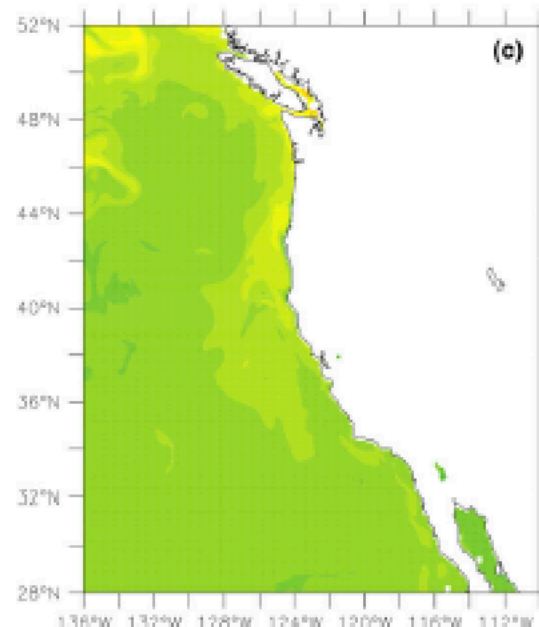
pH at surface  
August 2013



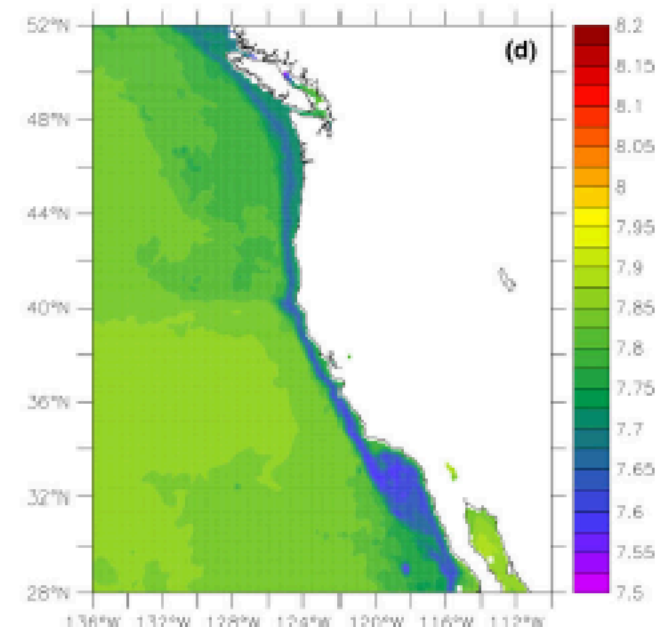
pH on bottom  
August 2013



pH at surface  
August 2063

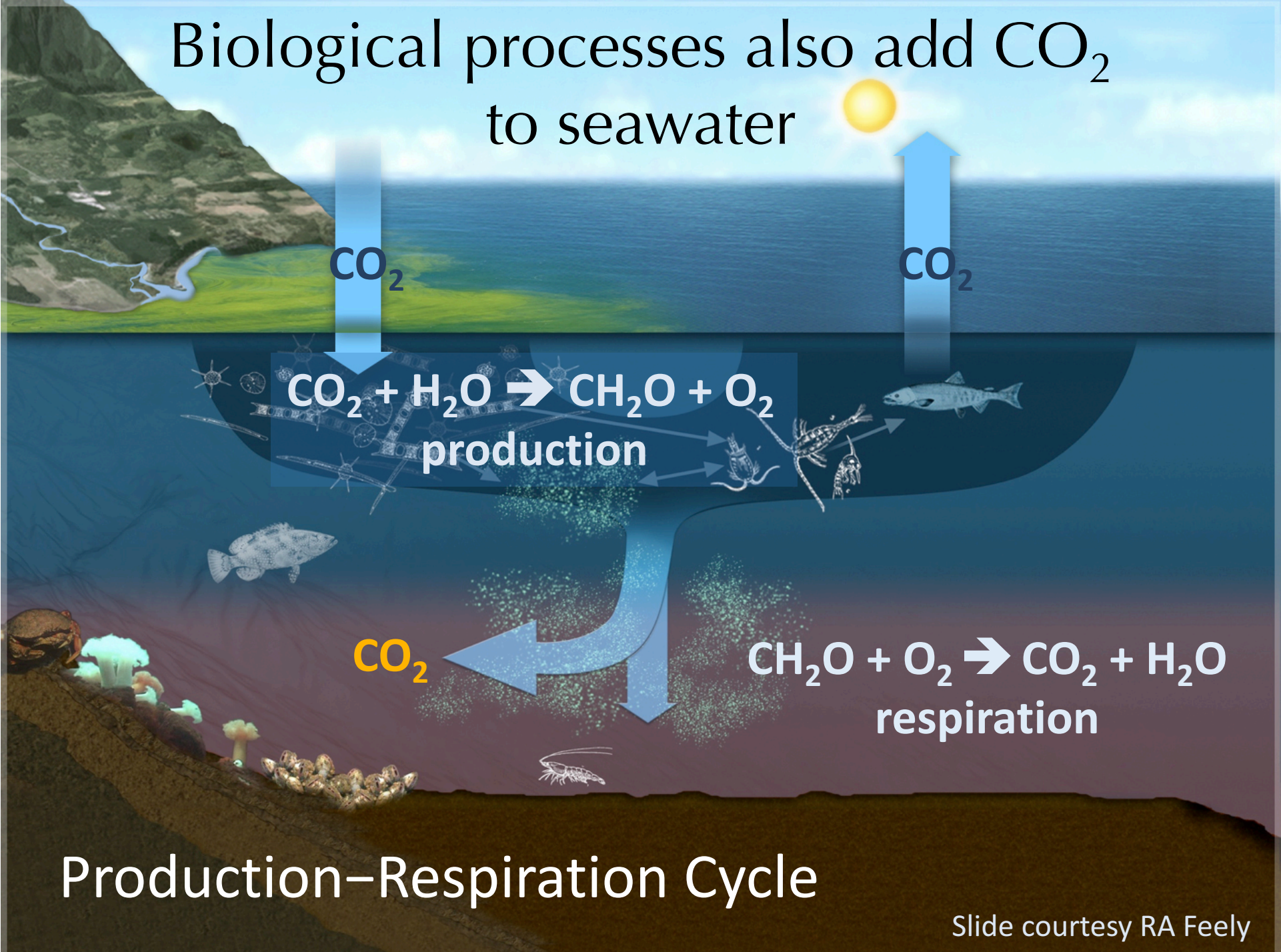


pH on bottom  
August 2063



Source: Marshall et al. 2017

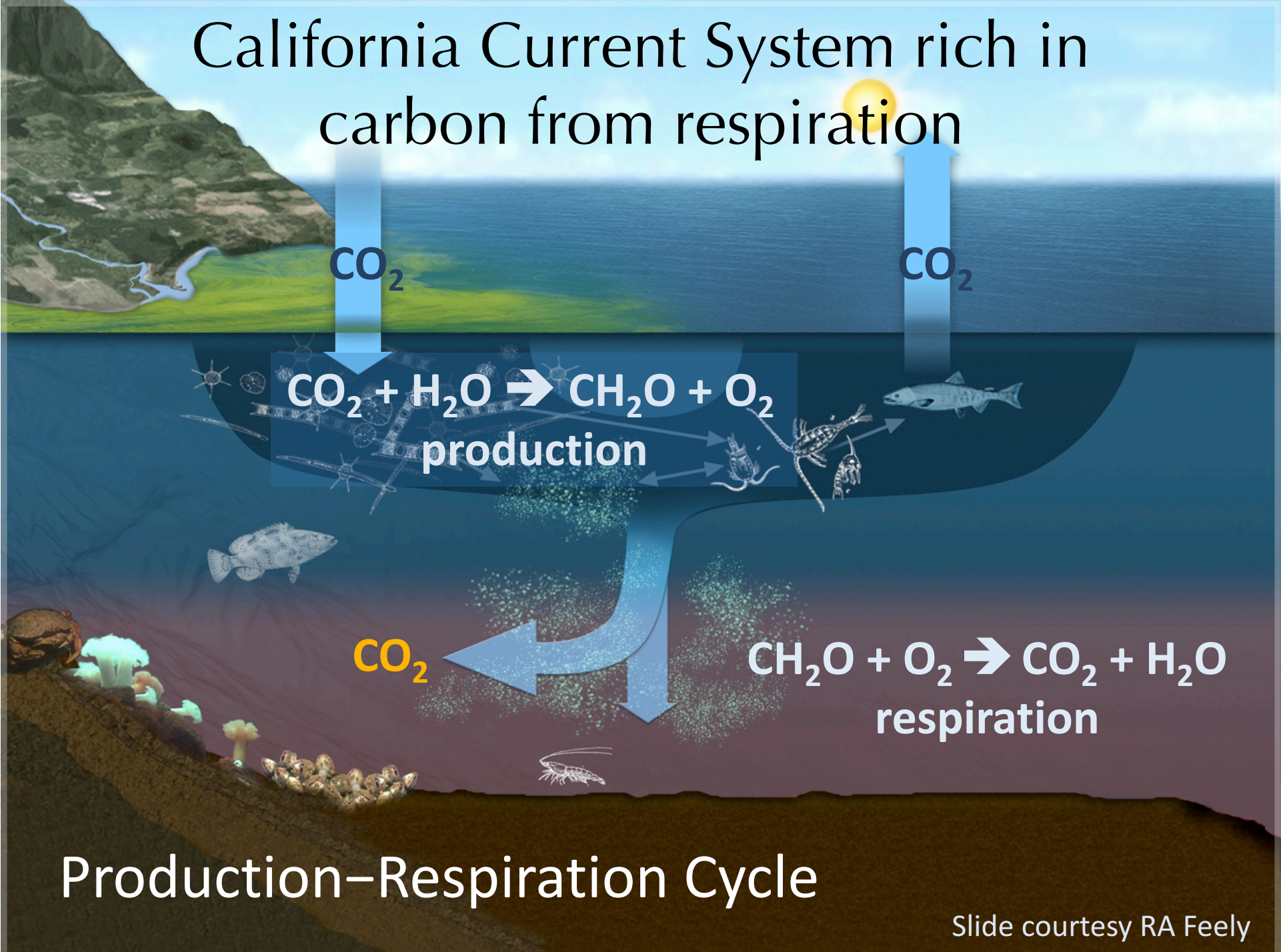
Biological processes also add CO<sub>2</sub> to seawater



Production-Respiration Cycle

Slide courtesy RA Feely

# California Current System rich in carbon from respiration

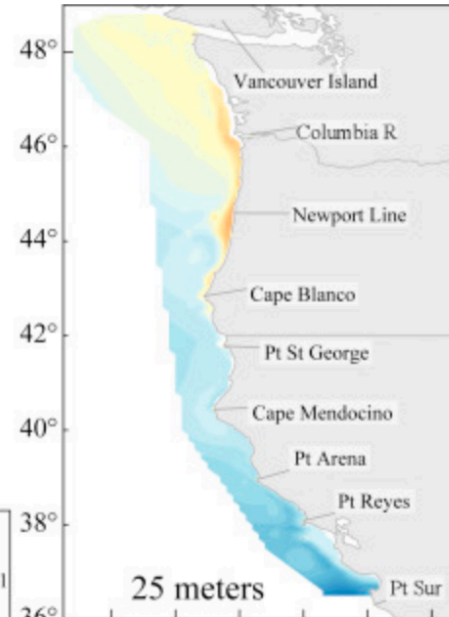
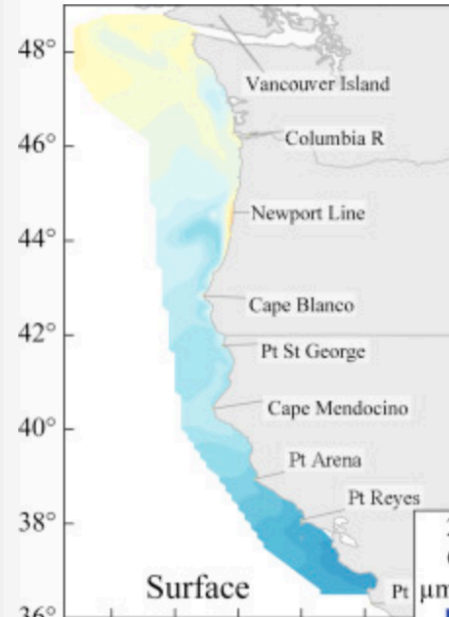


Production-Respiration Cycle

Slide courtesy RA Feely

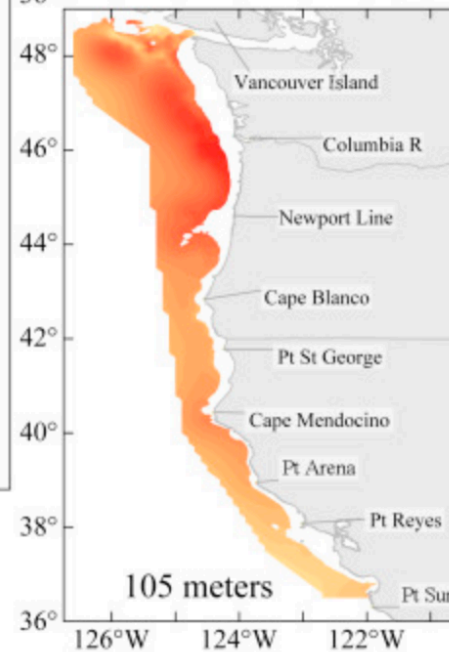
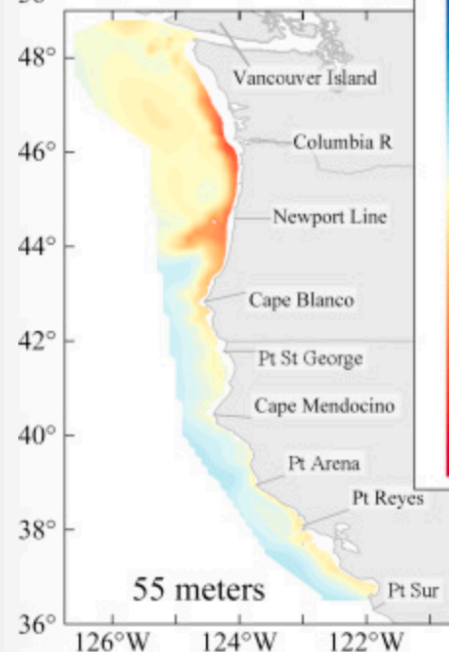
# The anthropogenic fraction of carbon can be calculated

$C_{\text{anth}}$  at surface  
2013



$C_{\text{anth}}$  at 25 m  
2013

$C_{\text{anth}}$  at 55 m  
2013



$C_{\text{anth}}$  at 105 m  
2013

Source: Feely et al. 2016

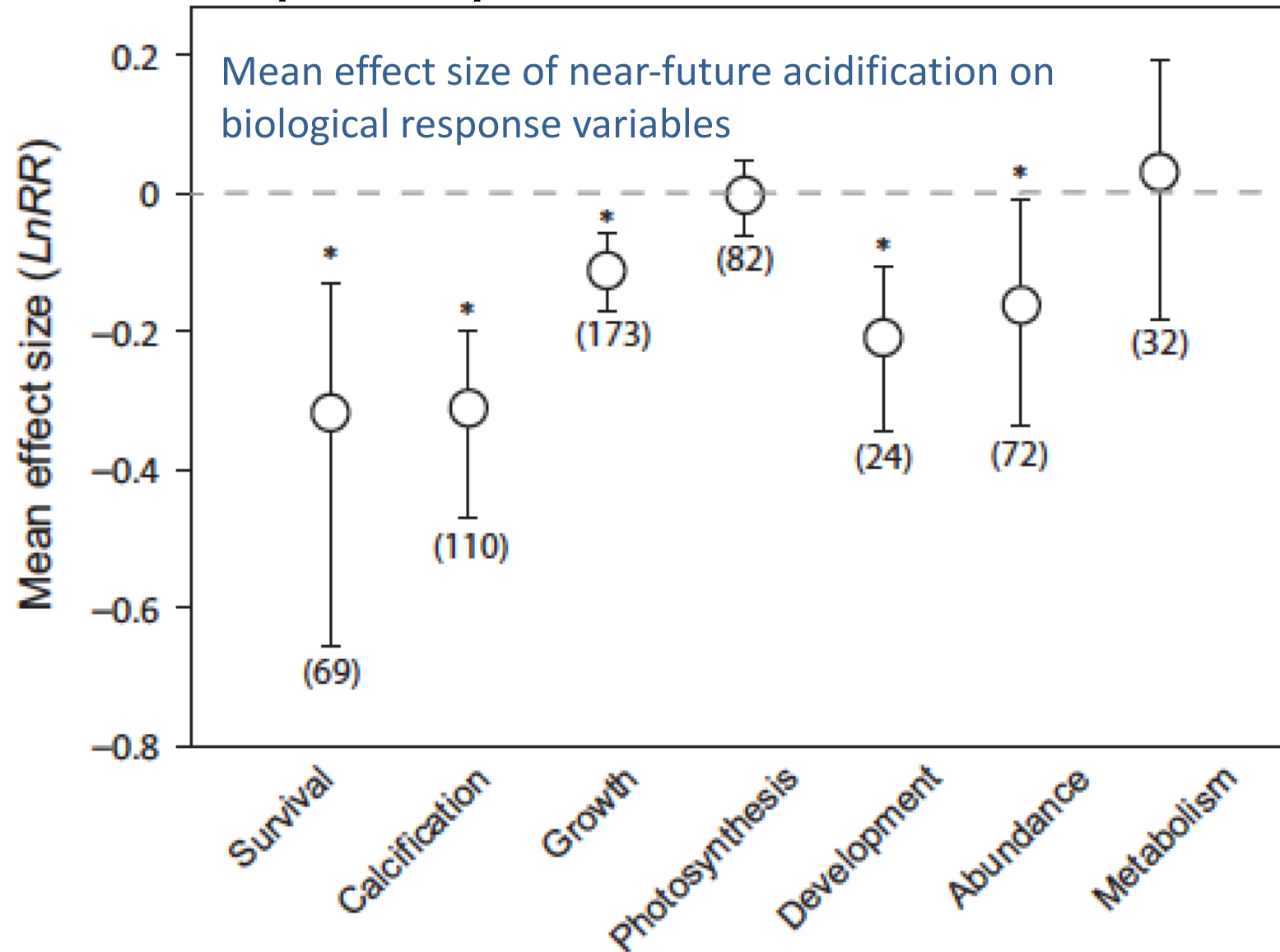


Biological effects?



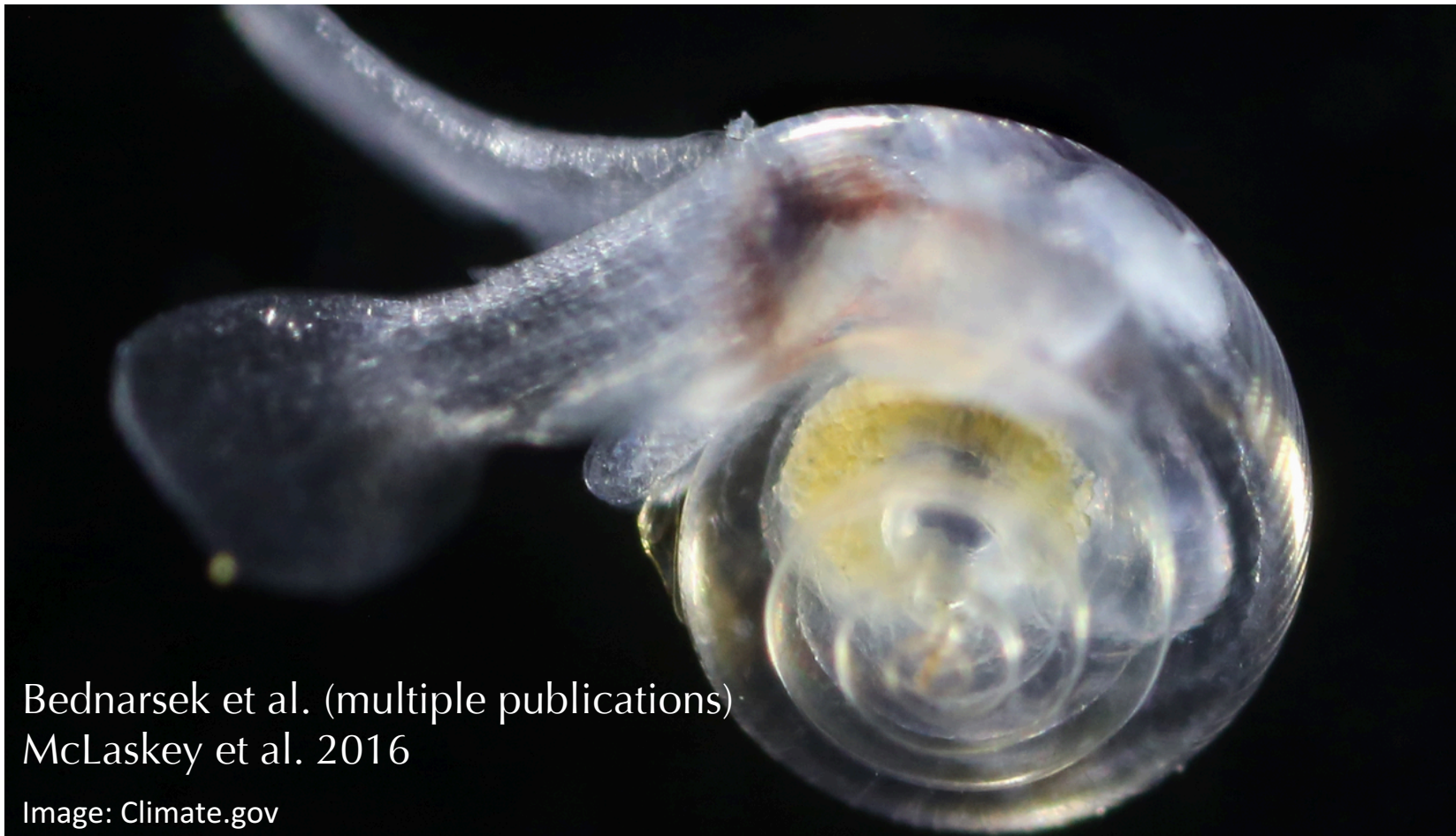
Photo credit: George Grall

# Biological effects occur across critical life processes, multiple trophic levels, and habitats



Kroeker et al. 2013  
Haigh et al. 2015  
Sunday et al. 2016

Planktonic shells are thinner under OA conditions  
Calcification rates decline  
Changes in behavior occur  
Chitinous forms are negatively affected



Bednarsek et al. (multiple publications)  
McLaskey et al. 2016

Image: Climate.gov

Bivalves shells and byssus are smaller, weaker  
under OA conditions



Gaylord et al. 2011  
Carrington et al. 2013  
Sanford et al. 2014

# Mortality of Dungeness crab larvae and juveniles increases under OA conditions



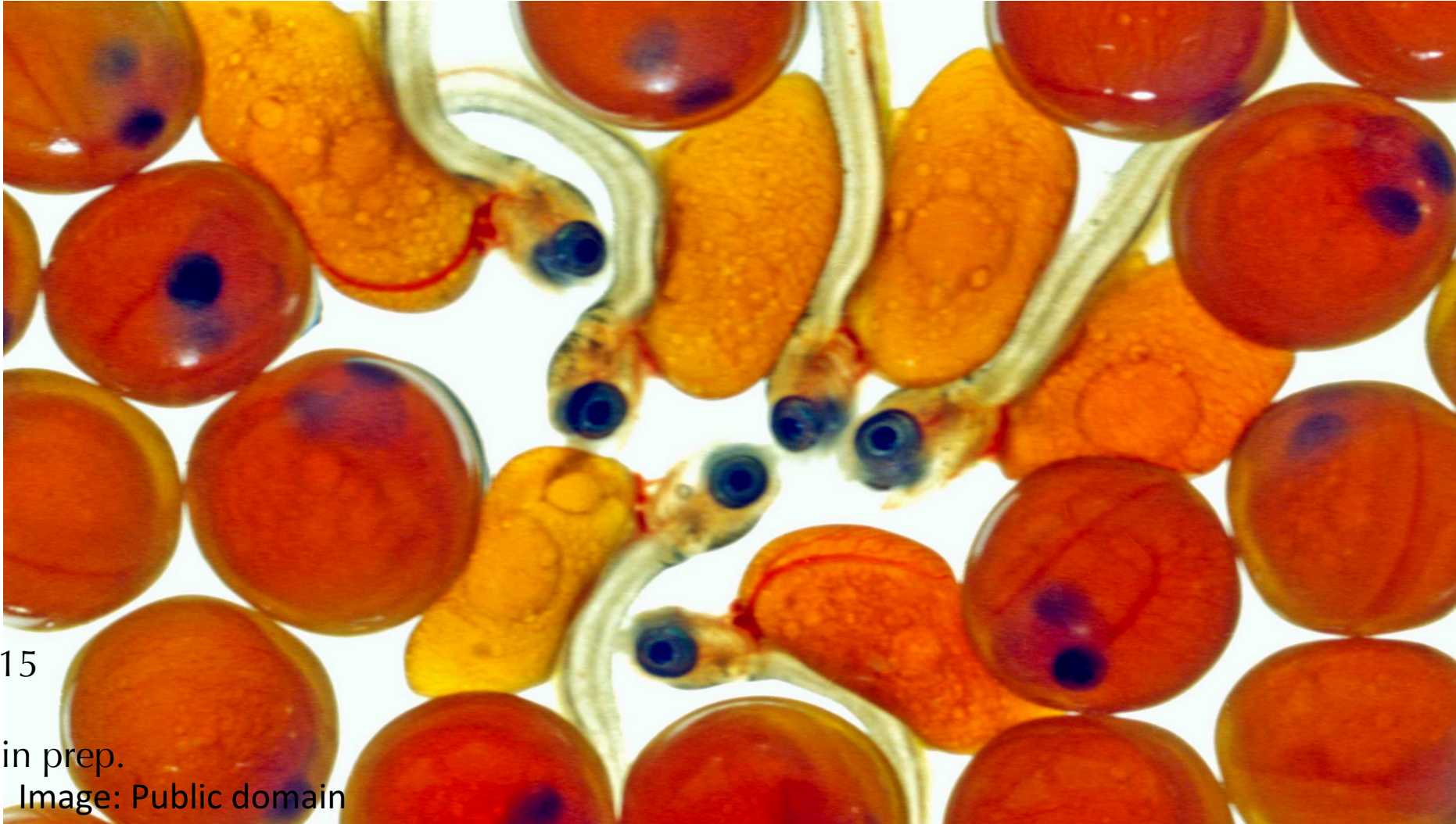
# Copper rockfish show changes in behavior under OA conditions



Hamilton et al. 2017

Image: <https://oceanprodivers.files.wordpress.com/2012/06/rockfish.jpg>

# Pink salmon show dose-dependent reductions in critical life-history and behavioral traits; predator response is affected



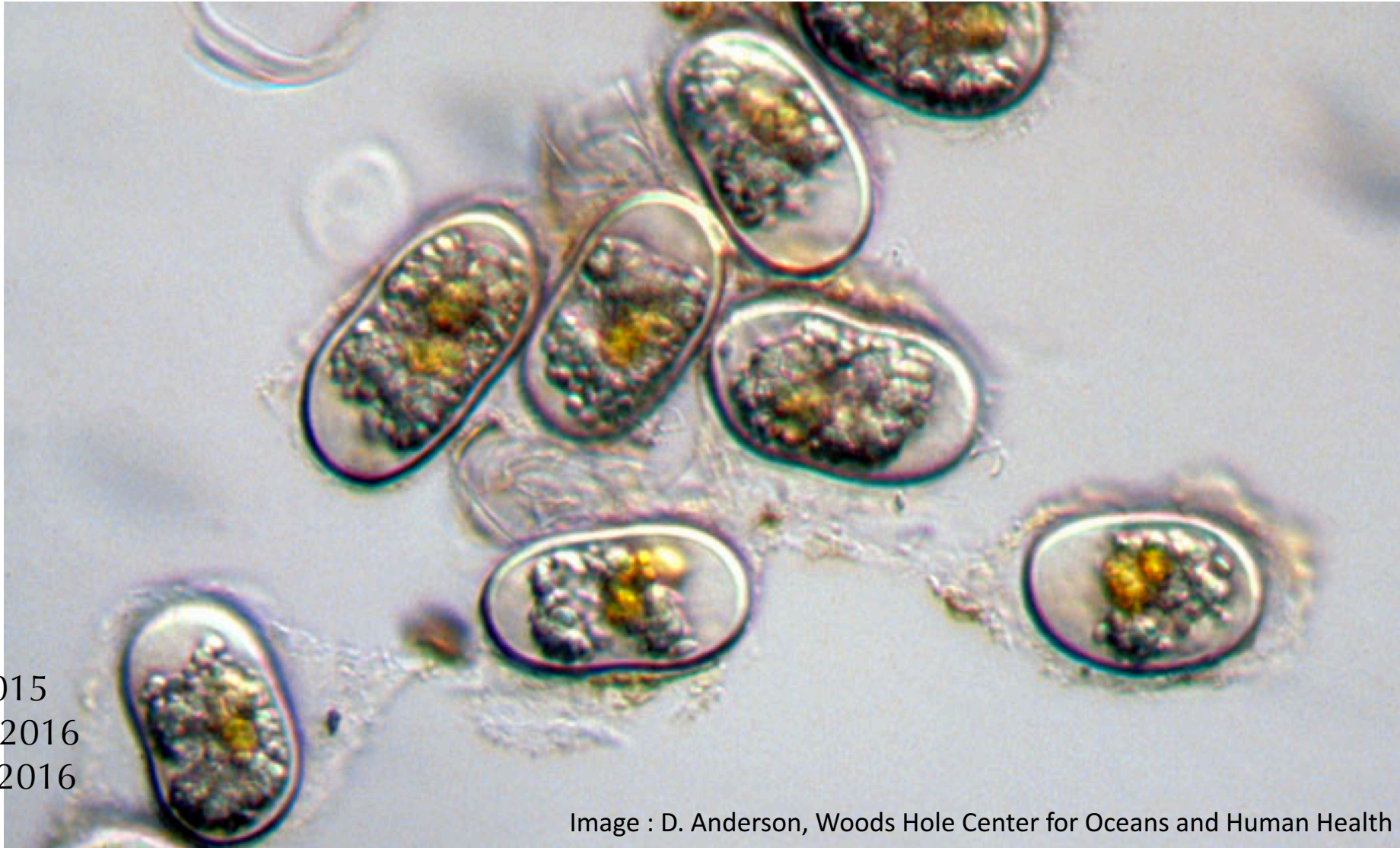
Haigh et al. 2015

Ou et al. 2015

Williams et al. in prep.

Image: Public domain

# Harmful algae grow faster and are more toxic under OA conditions



Tatters et al. 2015  
Cochlan et al. 2016  
Eberlein et al. 2016  
Ou et al. 2017

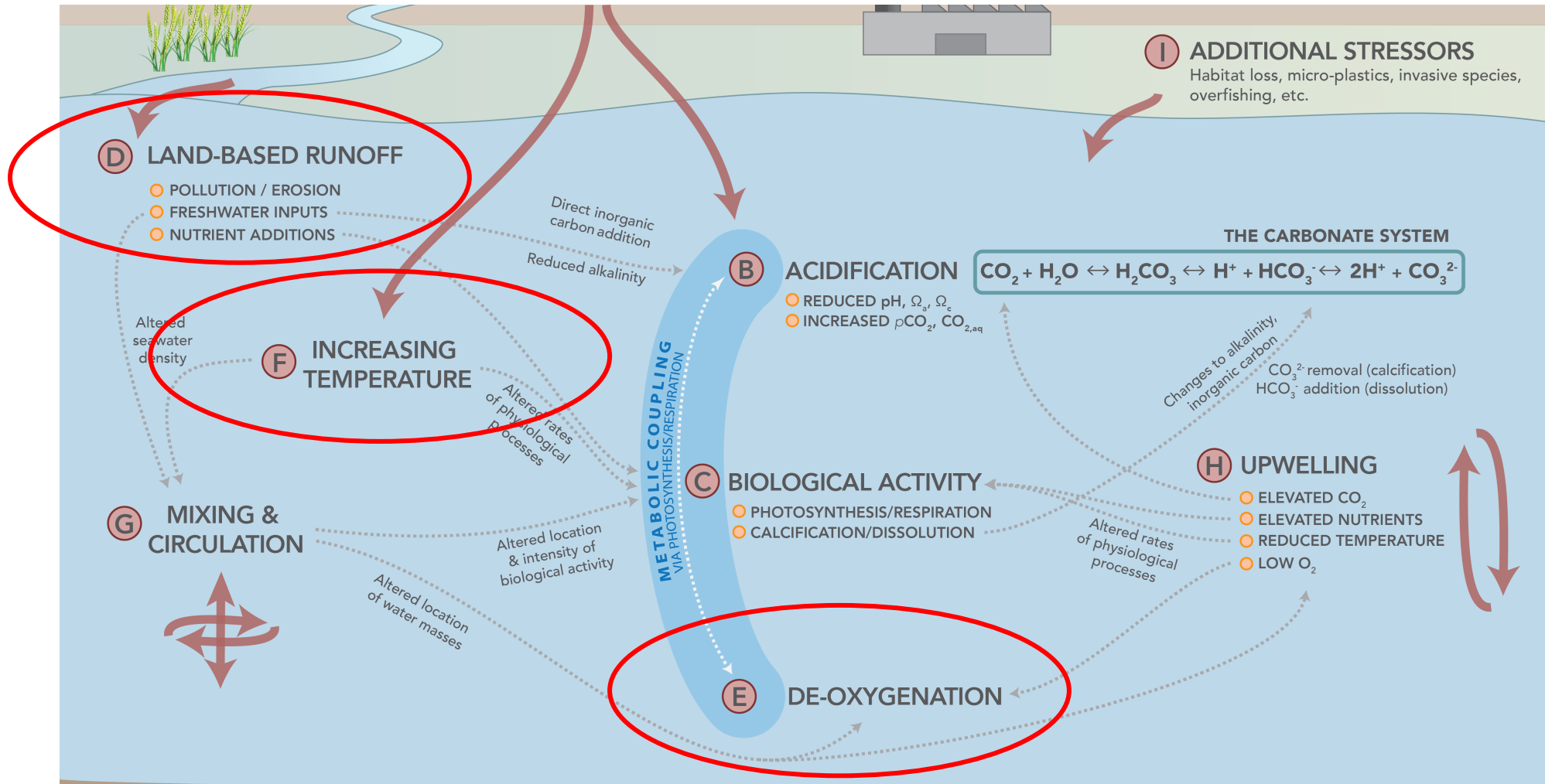
Image : D. Anderson, Woods Hole Center for Oceans and Human Health

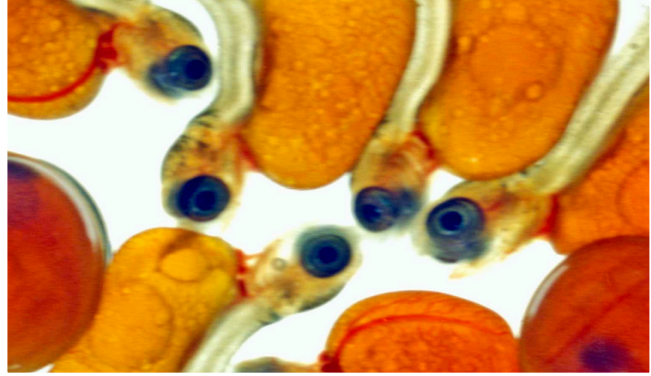
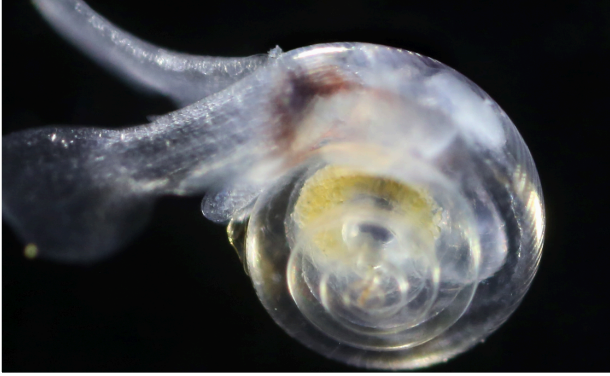


# OA co-occurs with other stressors

## Synergistic effects are known

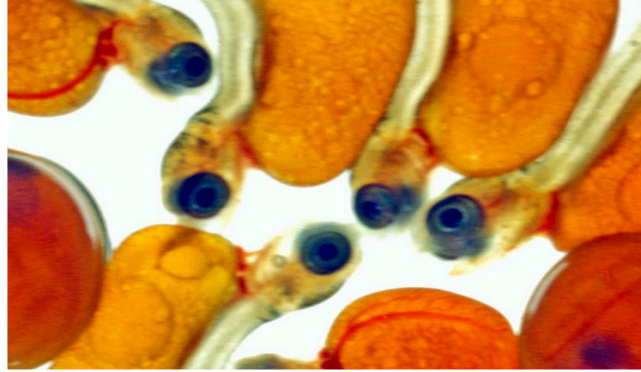
### temperature, dissolved oxygen of particular concern



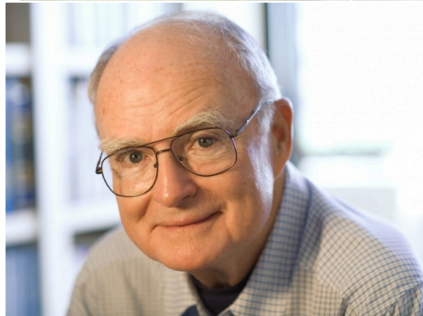
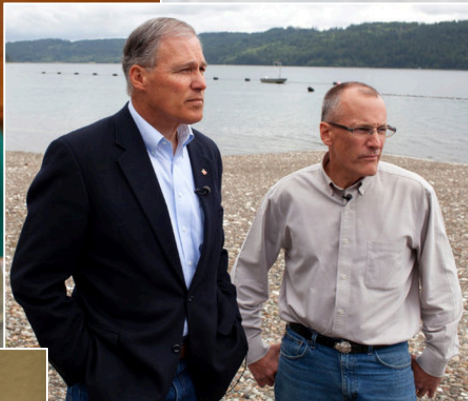
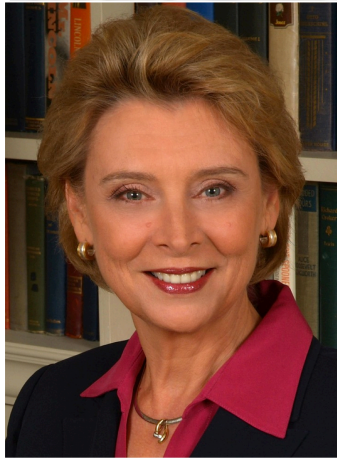


In Washington, threats to valued resources and iconic species spurred action





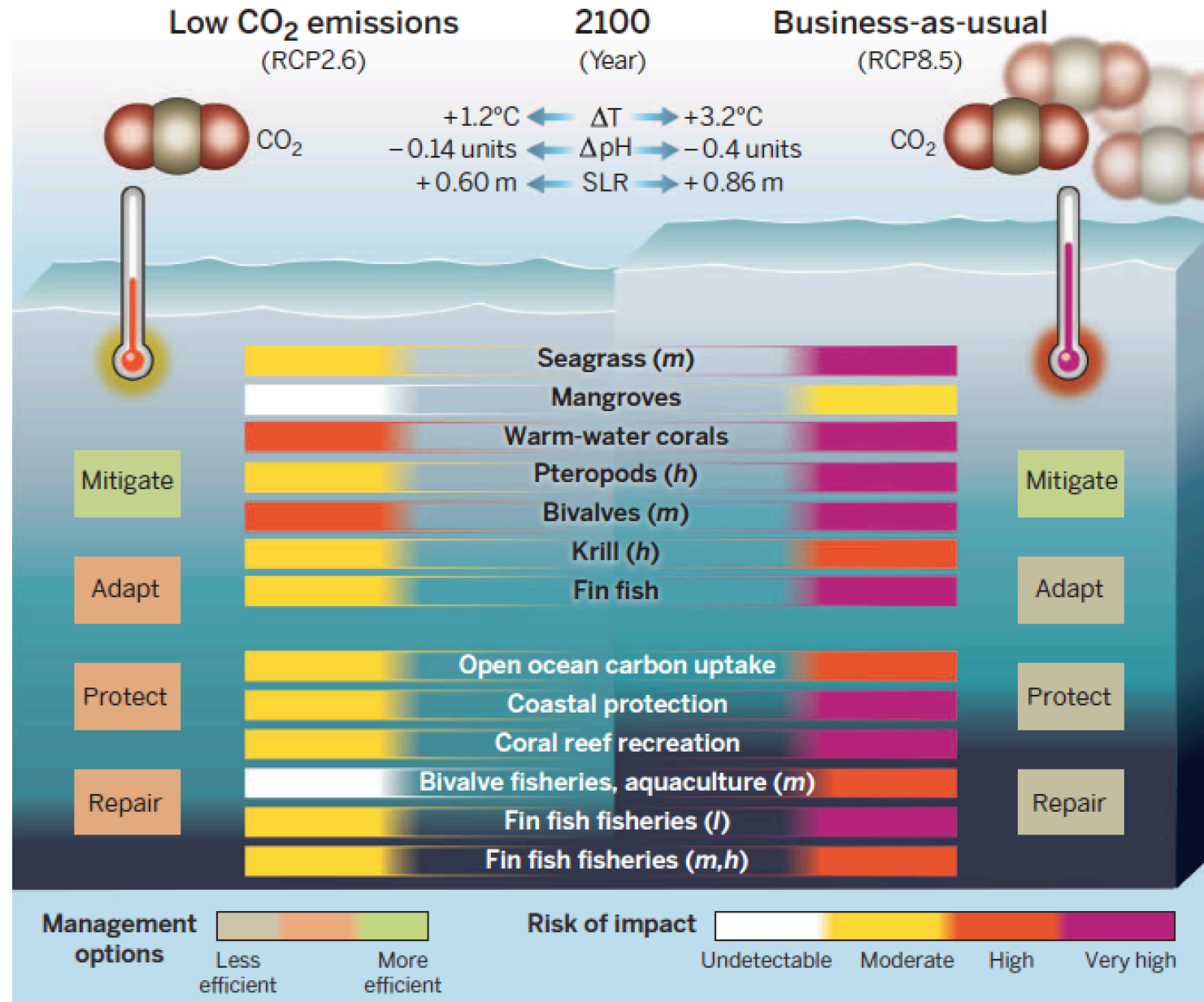
# Political leadership has led to actions in Washington and elsewhere



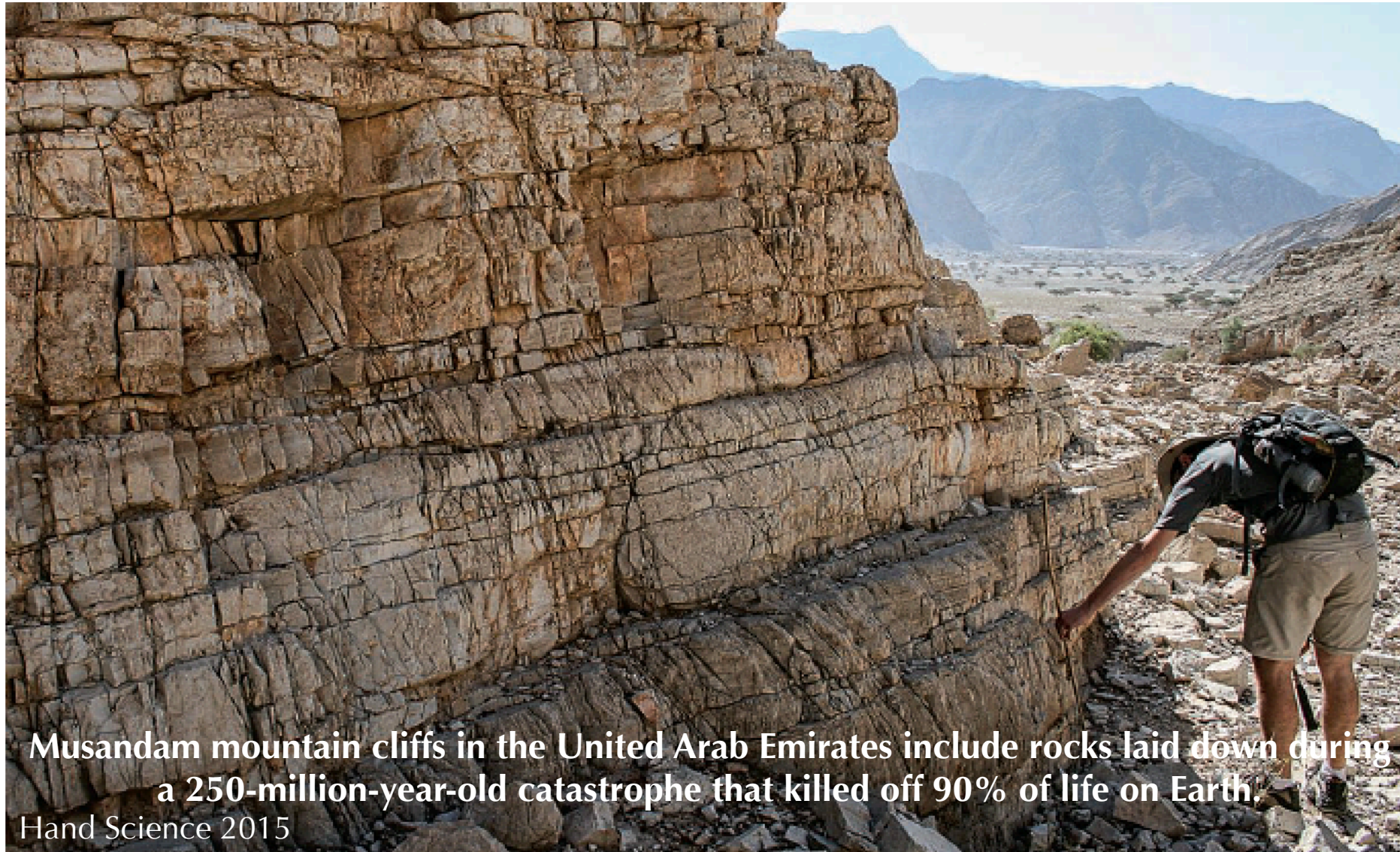
# Research Priorities for Washington

- Understand status and trends of OA in Washington's marine waters
- Quantify the relative contribution of different acidifying factors to OA in Washington's marine waters
- Describe biological responses of local species to OA and associated stressors
- Describe real-time corrosive seawater conditions, develop short-term forecasts and long-term projections of global and local acidification effects

# We can choose between alternative futures



# “Signature of acidification found in Permian extinctions 250 million years ago” [E. Hand, Science 2015]



**Musandam mountain cliffs in the United Arab Emirates include rocks laid down during a 250-million-year-old catastrophe that killed off 90% of life on Earth.**

Hand Science 2015