Climate Change & the Chesapeake

TS3 workgroup chapter

Dickinson

Smithsonian Environmental Research Center

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21ST CENTURY CLIMATE CHANGE AND SUBMERGED AQUATIC VEGETATION IN THE CHESAPEAKE BAY

The 20th century story: nutrient pollution, eutrophication, water clarity, dead zones, and disease.

The Chesapeake Bay was once renowned for expansive meadows of marine and freshwater SAV.

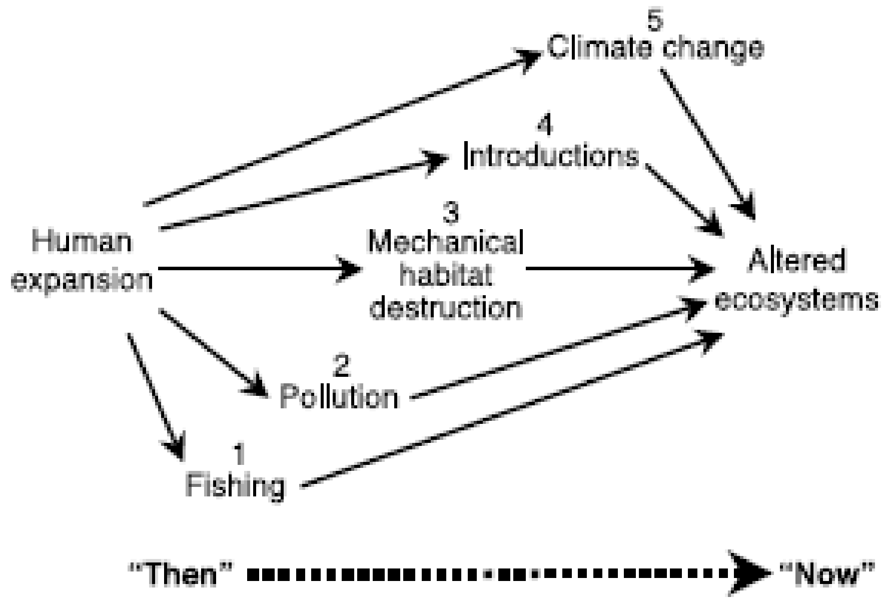
Historically, these species covered an estimated 250,000 ha in the bay, or about 20% of the bottom area. Today, only 10% of the original Chesapeake Bay SAV meadows survive, covering about 2% of the bay floor at depths < 2 m.

For nearly half a century, coalitions of federal, state, and local agencies have sought to restore Chesapeake Bay SAV to "*reflect 1930s abundance*" (e.g., 2000 Bay goal) or, more recently, to restore 185,000 acres (75,000 ha) of SAV by 2010.

However, SAV currently cover less than 100,000 acres (40,500 ha) in the Chesapeake, falling well short of these goals.

The challenges of modern coastal ecosystems

Fig. 3. Historical sequence of human disturbances affecting coastal ecosystems. Fishing (step 1) always preceded other human disturbance in all cases examined. This is the basis for our hypothesis of the primacy of overfishing in the deterioration of coastal ecosystems worldwide. Subsequent steps 2 through 5 have not been observed in every example and may vary in order.



Jackson et al.

VALUATION OF BAY SAV

The value of SAV can be quantified in terms of ecosystem services, estimated at approximately $1.9 trillion per year, globally.

- Waycott et al (2009) estimated at the value of healthy seagrass communities at as much as $28,916 ha^{-1} yr^{-1} (Costanza et al. 2014).
- By this simplistic measure, the estimated value of Chesapeake Bay SAV beds would exceed $2.9 billion yr^{-1}.
- Recently, an additional service of seagrass meadows has emerged: the capture and long-term storage of “blue carbon”. Globally, underwater meadows are powerful carbon sinks which sequester approximately 10% of oceanic organic carbon, an estimated 27.4 Tg carbon yr^{-1}. In total they may store as much as 19.9 Pg of this “blue carbon” in the form of anaerobic, organic-rich loams for thousands of years.

“…the total potential economic loss due to the decline of eelgrass in Chesapeake Bay at $US 1.51–2.54 billion.” Lefcheck et al. (2017) citing Costanza et al.

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Any attempt to predict the future of SAV in the Chesapeake Bay must consider the impacts of accelerating climate change. By the end of the century the Chesapeake region will be subject to:

- a mean temperature increase of 2 to 6°C
- a 50-160% increase in CO_2 concentrations
- 0.7-1.6m of sea-level rise

WARMING

Multiple stressors threaten the imperiled coastal foundation species eelgrass (*Zostera marina*) in Chesapeake Bay, USA

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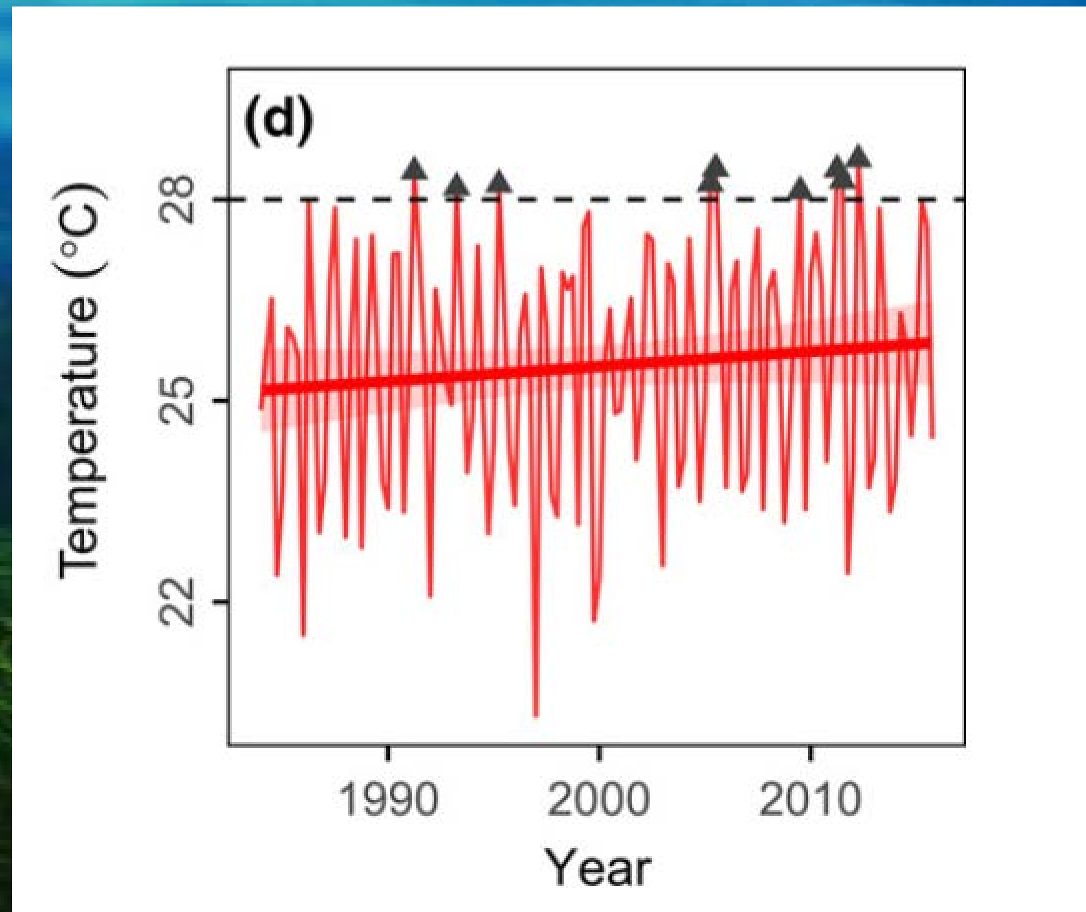
The Chesapeake will transition from a temperate to a subtropical estuary during the 21st century[1]. The most devastating temperature effects may result from an increased in the frequency, duration, and amplitude of periodic summer heat waves.



[1] **there was much discussion of what this term really means. Köppen's climate classification already places the Mid-Atlantic (VA, MD, PA, DE, etc.) in a "humid subtropical" climate zone.**

summertime CB temperatures, thank you for sending the article

WARMING

Eelgrass at Risk

Eelgrass has an optimal water temperature of 10-20°C. High temperatures of 25-30°C inhibit photosynthesis and growth. Above 30°C plants decline rapidly. Short-term exposures to summer temperatures 4-5°C above normal will *“result in widespread diebacks that may lead to* Z. marina *extirpation from historically vegetated areas, with the potential replacement by other species”* and “*severely reduce or eliminate”*

Zostera marina from the Chesapeake Bay (Moore et al. 2012, 2014). Carr et al (2012) concluded that “*an increase in the frequency of days when summer water temperature exceeds 30°C will cause more frequent summer die-offs”* and is likely to trigger a phase change from which *“recovery is not possible”*.

WARMING, ETC.

Warming tolerant species

Widgeongrass. *Ruppia maritina* tolerates temperatures of 7 to 40°C. Ideal growth conditions are 20-25°C. *Ruppia's* superior temperature tolerance may make it a "winner" in a warmer climate but it is unlikely to fully replace eelgrass in the Chesapeake.

Freshwater species. Most exhibit optimal growth between 10° and 20°C, and do not survive temperatures above 45°C. However, the response of freshwater aquatic plants is usually species-specific, and may vary even for locally-adapted "biotypes" of a single species. We lack data to forecast the impacts of climate warming on freshwater plants in the Chesapeake Bay.

Warming: complicating factors

- Grazers, fouling organisms, and pathogens, eutrophication and light penetration, epiphytes, the wasting disease and other pathogens, sediment sulfide levels, anoxia.

- Storms, run-off, sea-level rise.

These interacting forces are likely to trigger episodic events, pass ecological thresholds, trigger tipping points, and induce phase changes, making it unlikely that changes in these communities will occur at a uniform pace, or in a predictable manner. Wood et al (2002) surmised that *"While it is likely that a prolonged warming will lead to a shift in the ecosystem favoring subtropical species over temperature species, physical or ecological factors other than temperature may preclude a smooth transition to a balanced <subtropical> ecosystem."*

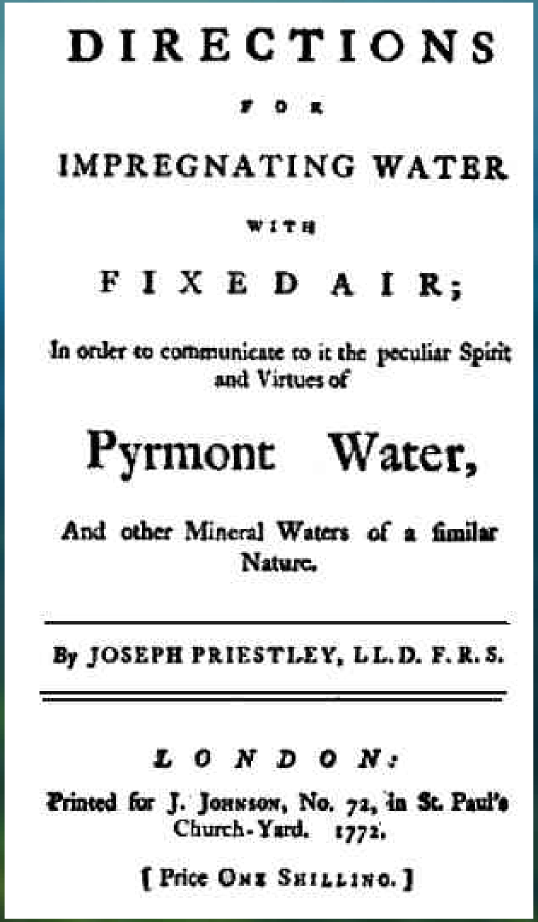
OCEAN ACIDIFICATION

Atmospheric carbon dioxide levels now exceed 400 ppm, on average.

One-third of the CO_2 has been absorbed by the oceans.

Average ocean pH has dropped from 8.21 to 8.10. It will fall another 0.3 to 0.4 units by 2100.

This represents a 150% increase in hydrogen ions and a 50% decrease in levels of carbonate ions (CO_3^{2-}).



DIRECTIONS

FOR

IMPREGNATING WATER

WITH

FIXED AIR;

In order to communicate to it the peculiar Spirit and Virtues of

Pyrmont Water,

And other Mineral Waters of a similar Nature.

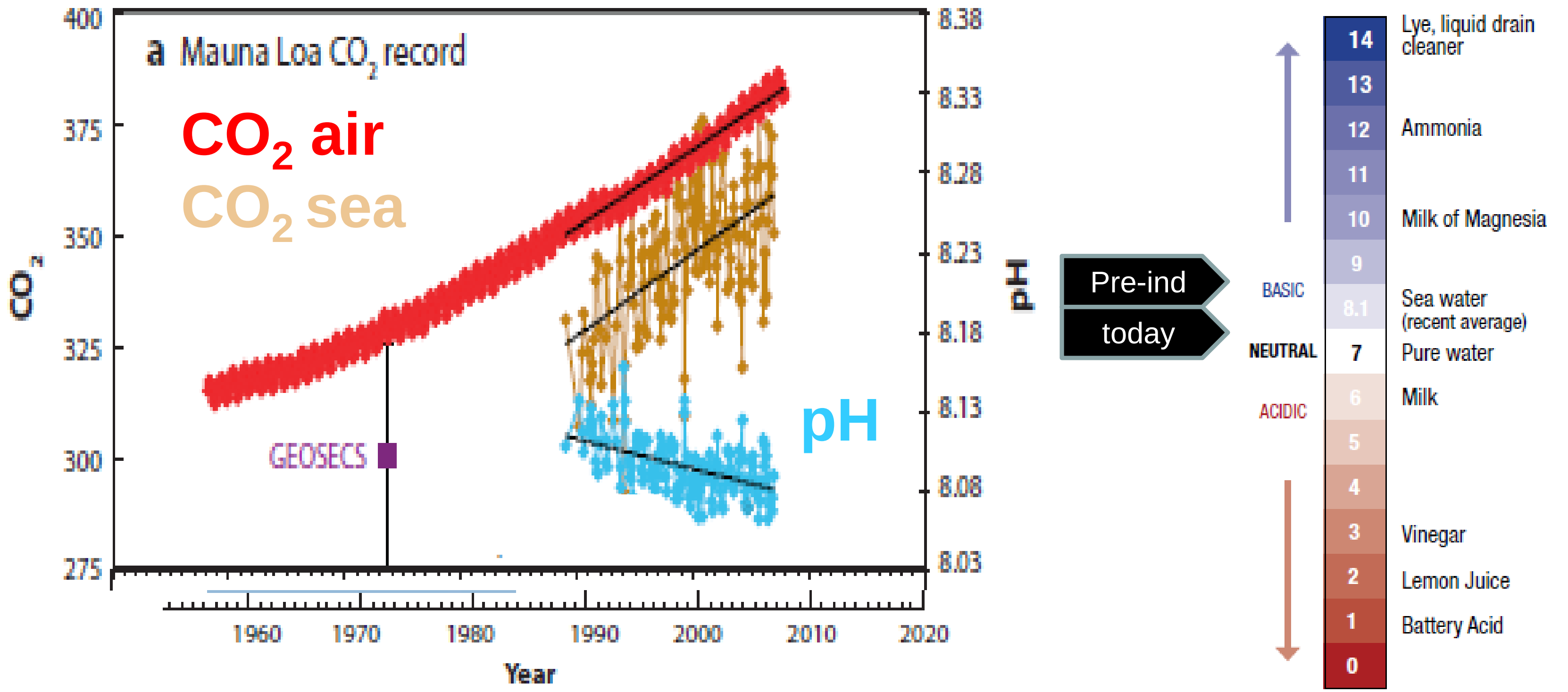
By JOSEPH PRIESTLEY, LL.D. F.R.S.

LONDON:

Printed for J. JOHNSON, No. 72, in St. Paul's Church-Yard. 1772.

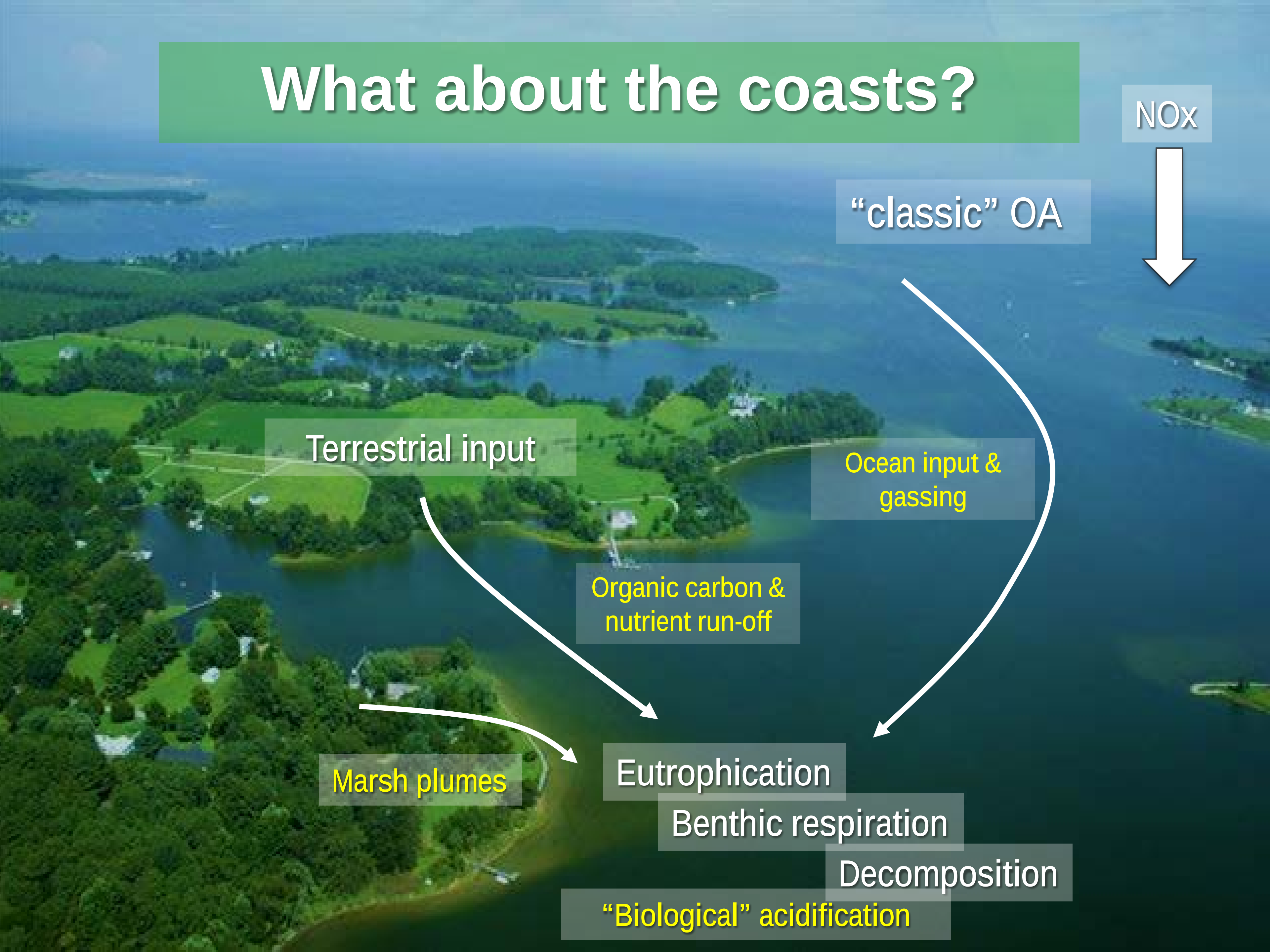
[Price ONE SHILLING.]

Evidence from six decades of open-ocean monitoring



~25% decrease in carbonate ions

What about the coasts?



What about the coasts?

Eutrophication is a common cause of acidification in estuaries: nutrient enrichment stimulates the production of algal DOC, which sinks and fuels microbial respiration in anoxic bottom waters, generating high levels of CO_2.

NOx

“classic” OA

Terrestrial input

Ocean input & gassing

Coastal acidification is likely to intensify with *“increasing rates of sediment runoff and [OC] transport towards the oceans”*

Organic carbon & nutrient run-off

Marsh plumes

Eutrophication

Benthic respiration

Decomposition

“Biological” acidification

What about the coasts?

Ocean acidification

Coastal zone acidification

Precise and stable

High variability

Sunda and Cai (2012) surmised that “*we should expect that eutrophication of Chesapeake Bay, and the subsequent release of CO_2 by the decomposition of algal blooms, will generate acidified conditions in bottom waters*”.

What about the coasts?

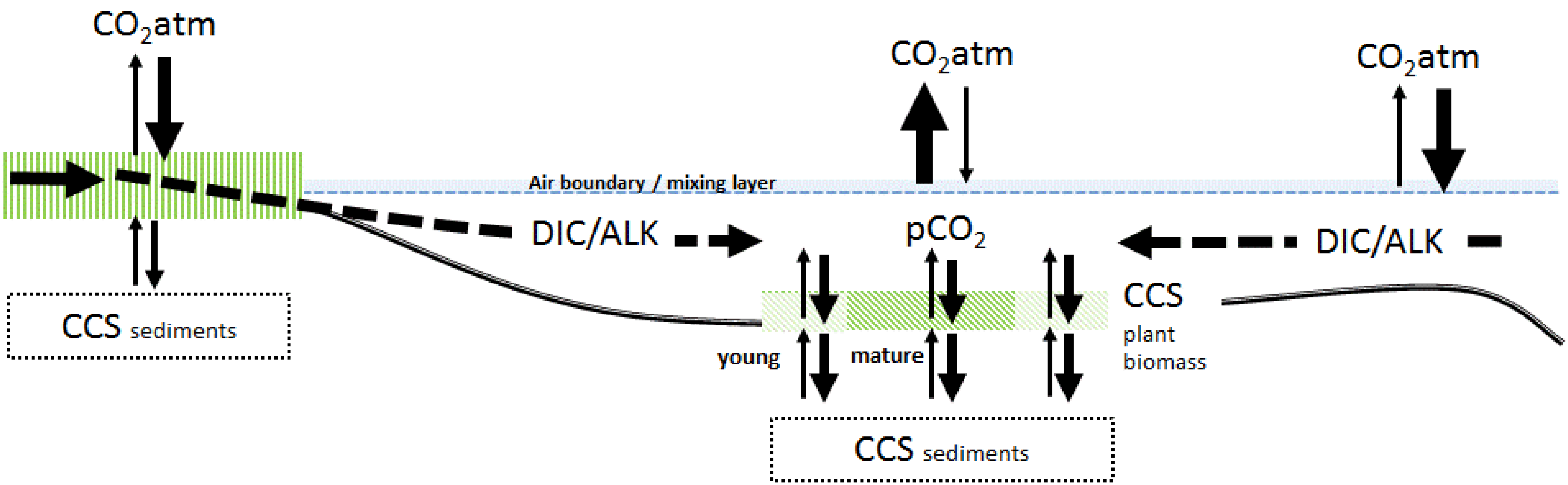
1000-10,000 ppm CO_2 from march efflux

<100 to >800ppm CO_2 within meadows

sources

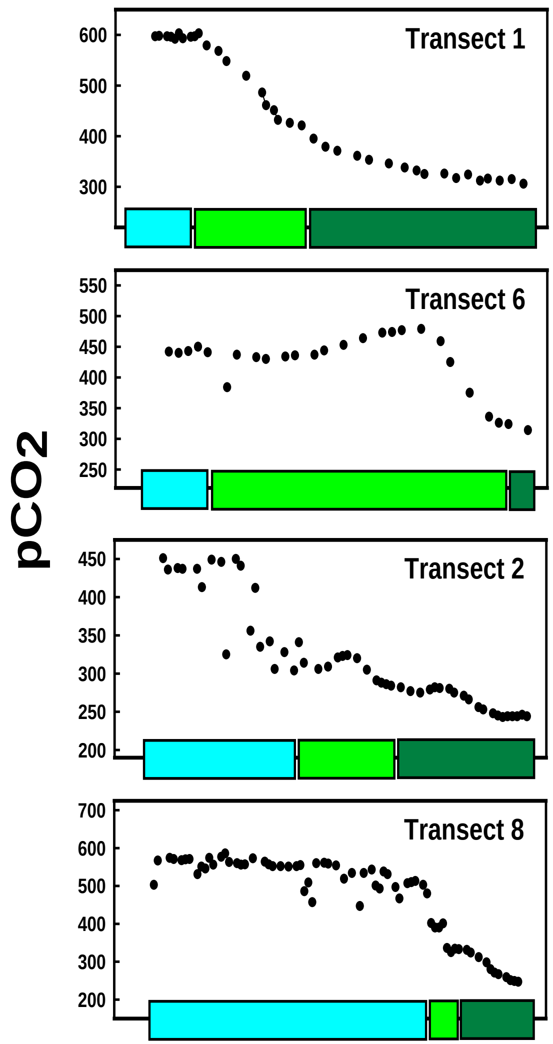
~400ppm CO_2 average ocean surface waters

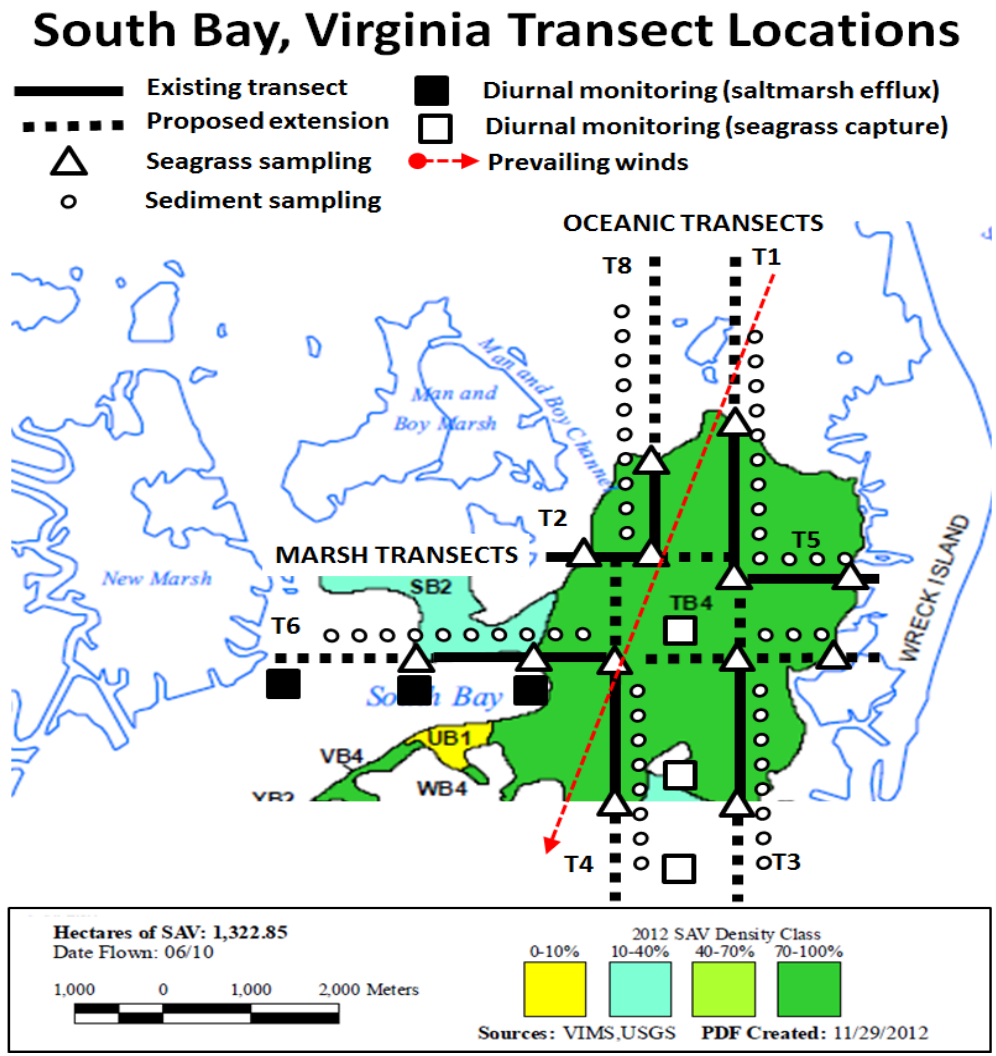
sinks (for now)



Conceptual Model. Inorganic carbon flow in a coastal system with interactions among salt marshes, seagrasses, and ocean waters. Dissolved inorganic carbon (DIC) and alkalinity (ALK) are carried from marshes into the bay or estuary where there is mixing with ocean water, with possible carbon capture and sequestration (CCS).

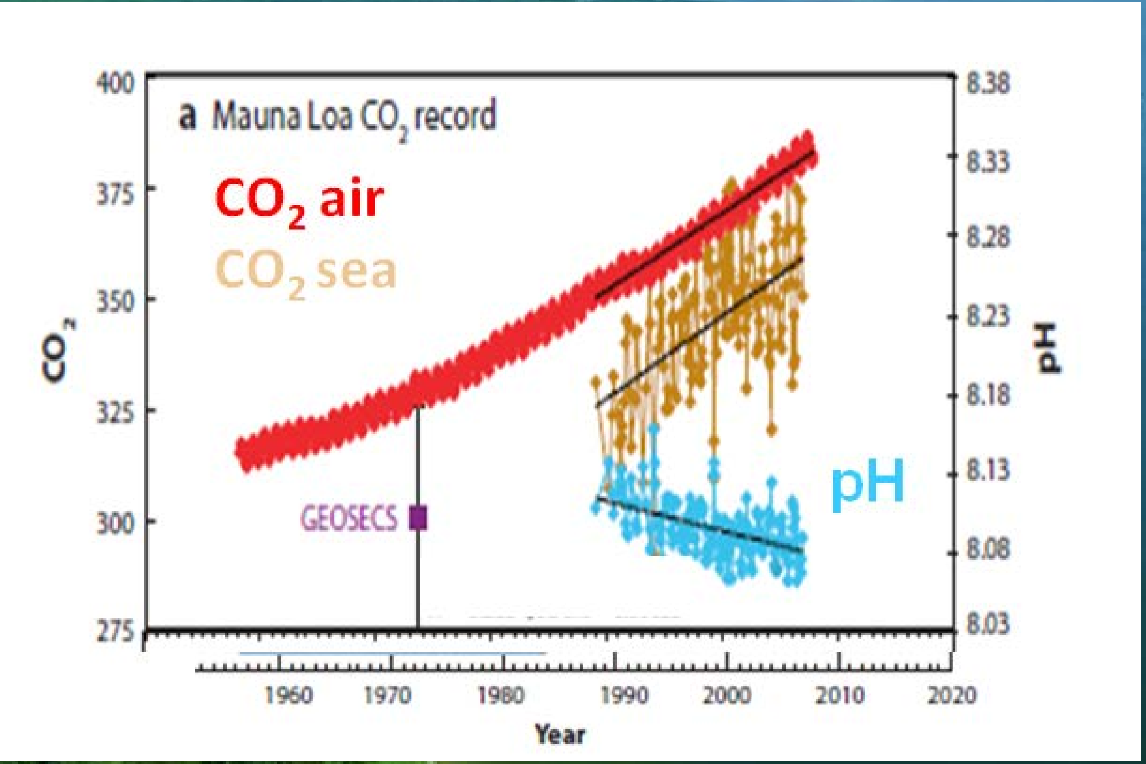
What about the coasts?





Map from Orth et al. surveys

What about the coasts?



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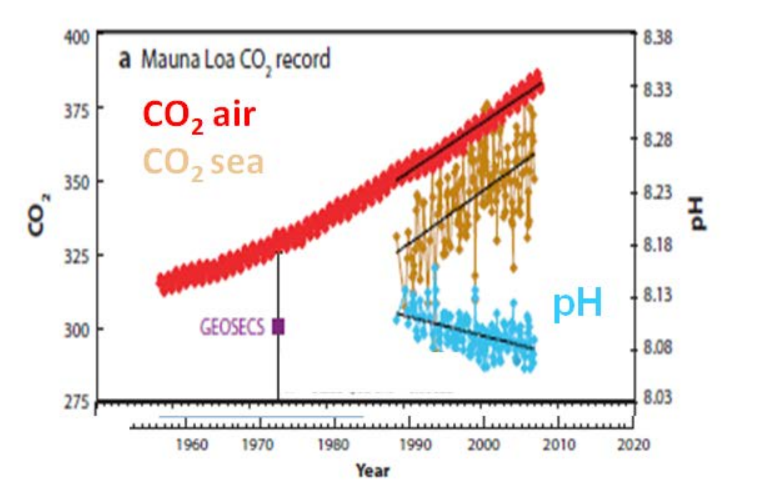
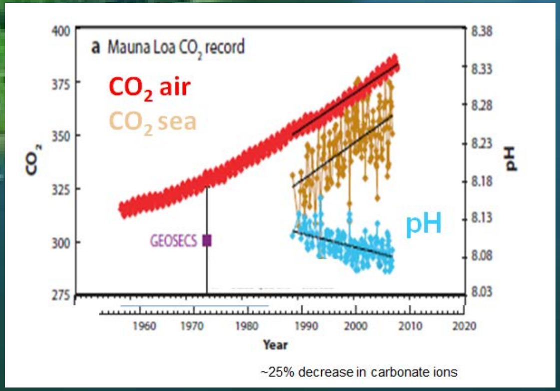


~25% decrease in carbonate ions

What about the coasts?



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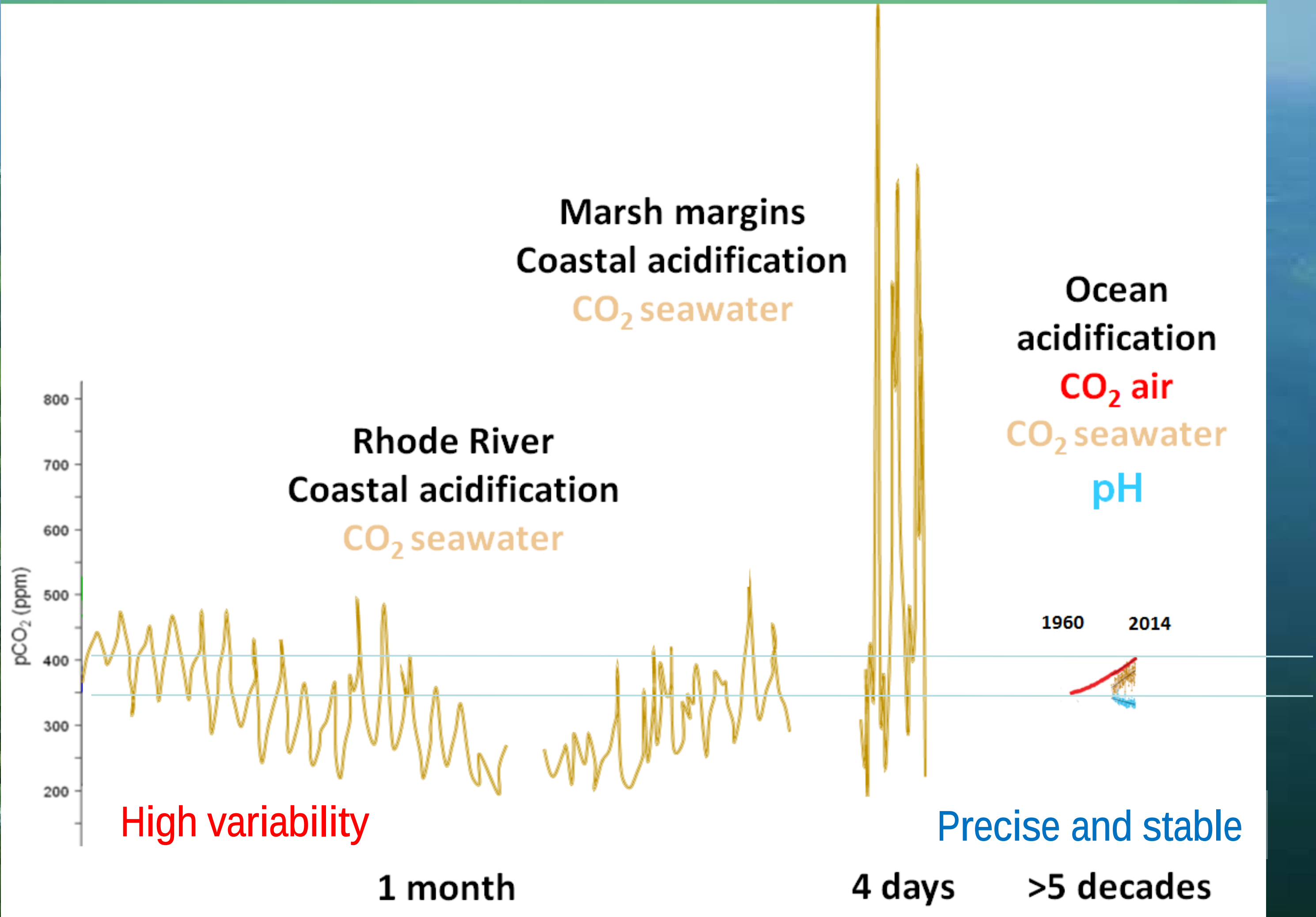

Whitman Miller, SERC

Impacts of high CO_2?

High CO_2 conditions may benefit SAV photosynthesis, which is often CO_2-limited.

The *"CO_2 fertilization effect"* is often beneficial for eelgrass, and other photosynthetic organisms.

In theory, acidification could stimulate eelgrass photosynthesis sufficiently to offset the deleterious effects of thermal-stress, "*facilitating the survival of eelgrass in Chesapeake Bay despite a warmer climate*", <u>if water clarity is sufficient.</u>

Predicting effects of ocean warming, acidification, and water quality on Chesapeake region eelgrass

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[2]Smithsonian Environmental Research Center, Edgewater, Maryland

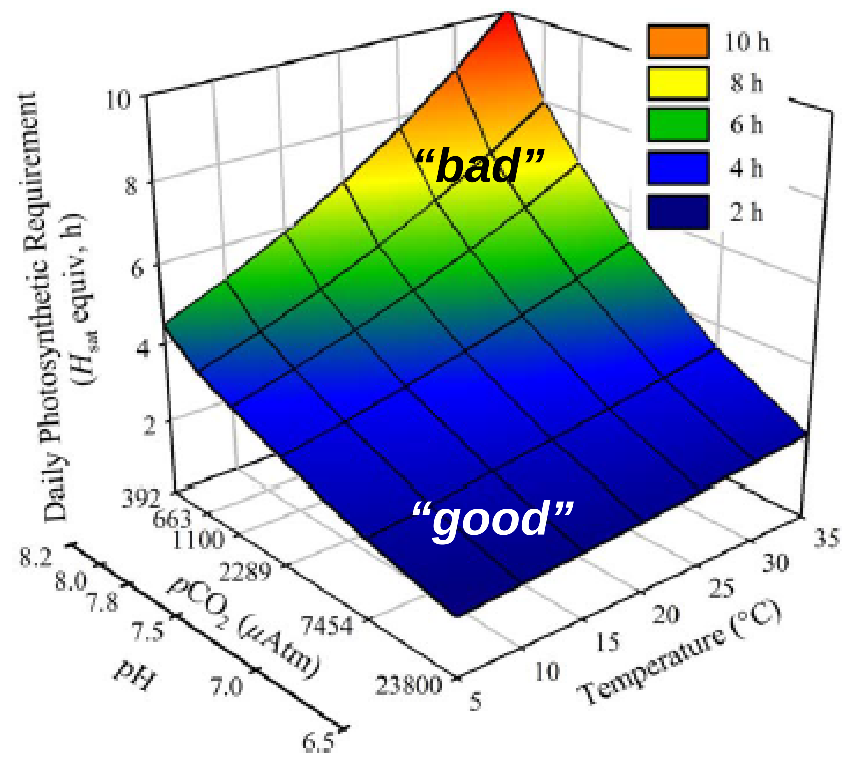
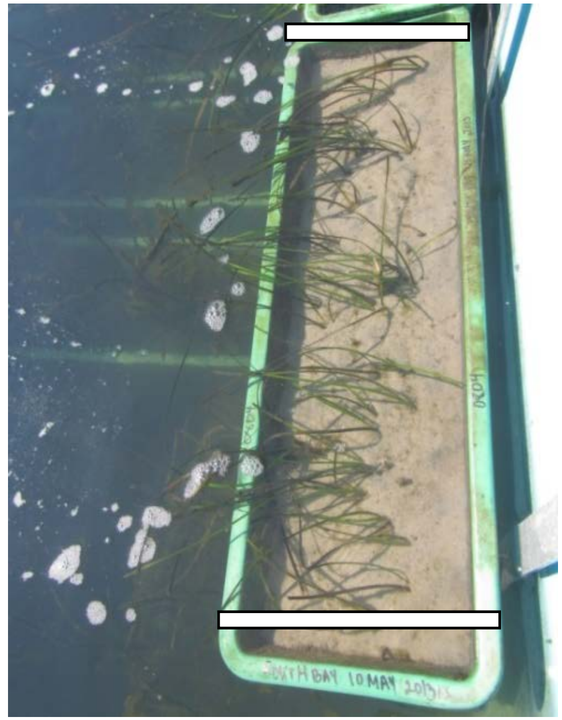


Fig. 4. Combined effects of ambient temperature and CO_2 concentration on the daily photosynthetic requirement to maintain positive whole-plant carbon balance, determined from Eqs. 16–21. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Impacts of high CO_2?

a. 823 μM $CO_{2(aq)}$
pH 6.5



b. 55 μM $CO_{2(aq)}$
pH 7.7 (ambient)

c. 2121 823 371 107 55
μM $CO_{2(aq)}$
6.1 6.5 6.9 7.4 7.7
pH

Zimmerman and coworkers

Community-level impacts

…but SAV are not the only species to get a boost by "CO_2 fertilization".

"Our predictions are limited, however, by our poor understanding of the indirect effects of climate change on community members, including fouling organisms, grazers, and microbes associated with seagrass die-offs. These indirect effects are likely to trigger abrupt, unforeseen changes in these communities." – **TS3 report**

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Conclusions

- *"The Chesapeake will warm by 2-6°C, on average during this century. It will transition from a temperature to a subtropical estuary."* – TS3 report
- Continued warming is likely to reduce or eliminate eelgrass from the Chesapeake Bay.
- The "CO_2 fertilization effect" could facilitate the survival of eelgrass in the Chesapeake Bay…but only if:
  - The CO_2 is sufficiently and consistently high enough
  - Water clarity allows for sufficient light penetration
  - Competing / fouling organisms do not outgrow eelgrass
  - Conditions do not trigger disease outbreaks

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Community-level impacts

"These interacting forces are likely to trigger episodic events, pass ecological thresholds, trigger tipping points, and induce phase changes, making it unlikely that changes in these communities will occur at a uniform pace, or in a predictable manner. These events are likely to preclude a smooth transition to a balanced subtropical ecosystem."

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