Effects of Reduced Shoreline Erosion on Chesapeake Bay water clarity

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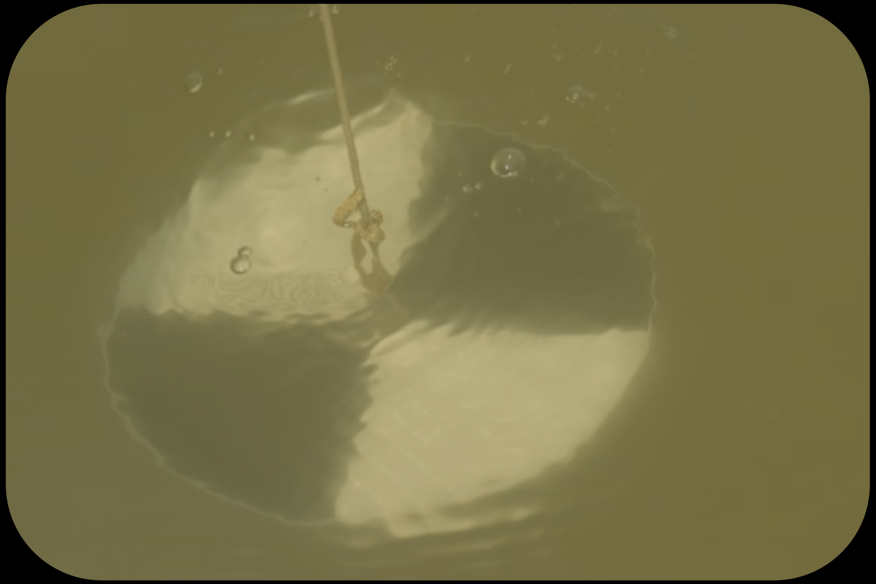
Water Clarity – what is it?

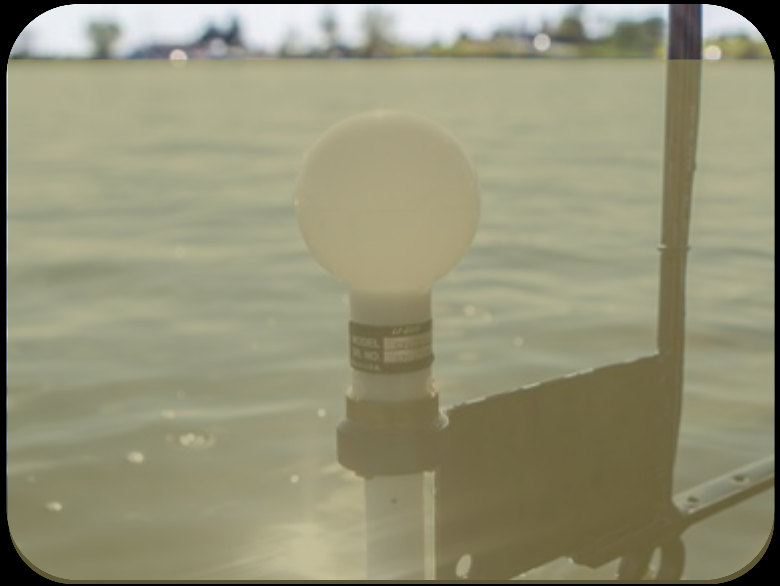
Water Clarity Metrics

Secchi depth (Z_{SD}):
- Depth at which Secchi disk cannot be seen by the human eye ~ transparency

Light Attenuation (K_d):
- reduction in the intensity of photosynthetically-active radiation with depth

Water Clarity Metrics





High K_d

Less light at depth

Shallow Secchi depth

Secchi depth (Z_{SD}):
- Depth at which Secchi disk cannot be seen by the human eye ~ transparency

Light Attenuation (K_d):
- reduction in the intensity of photosynthetically-active radiation with depth

Water Clarity Metrics

↓ Low K_d

↑ More light at depth

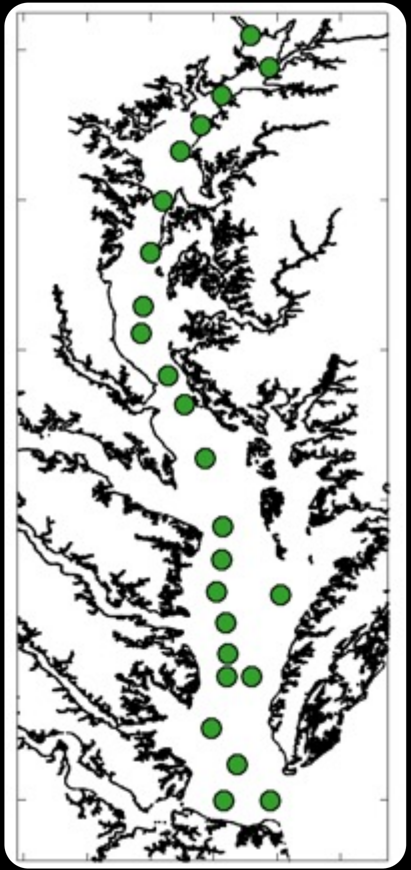
↑ Deep Secchi depth

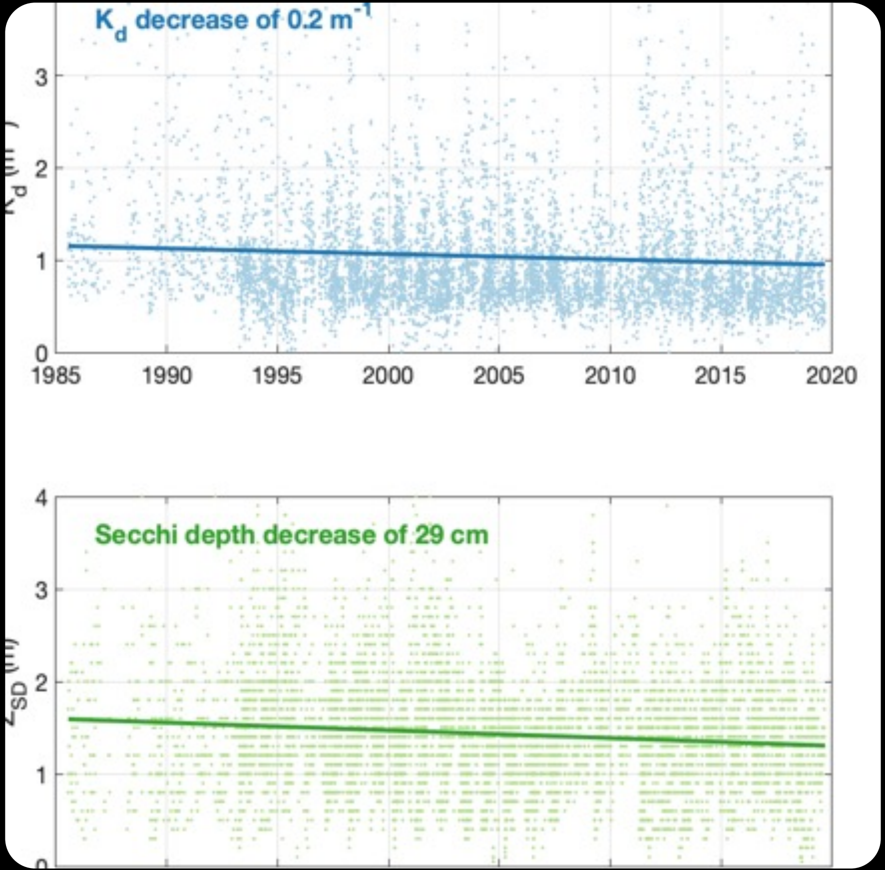
Secchi depth (Z_{SD}):
- Depth at which Secchi disk cannot be seen by the human eye ~ transparency

Light Attenuation (K_d):
- reduction in the intensity of photosynthetically-active radiation with depth

Counterintuitive Trends in Chesapeake Bay

From 1980s to present…





↓ K_d

↑ light at depth

↓ **Shallowing** Secchi depth

Counterintuitive Trends in Chesapeake Bay

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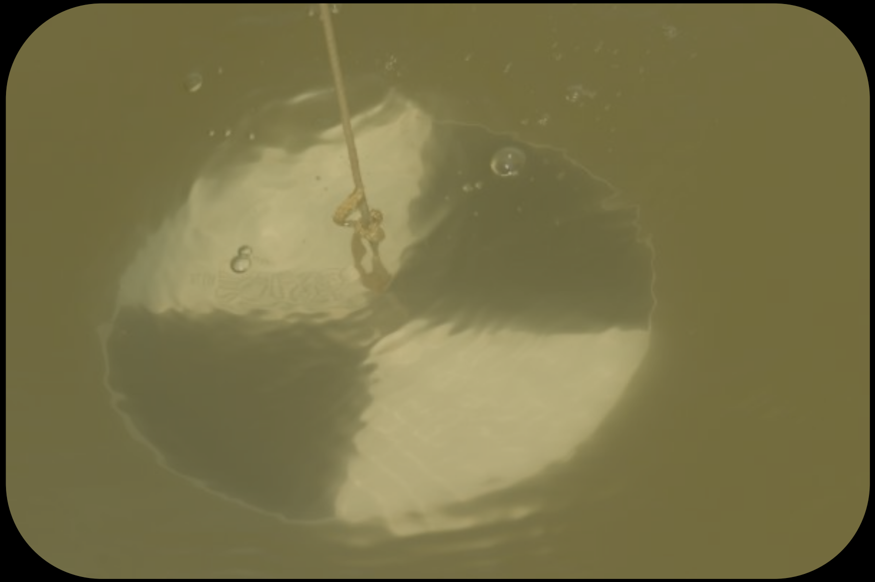

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Counterintuitive Trends in Chesapeake Bay

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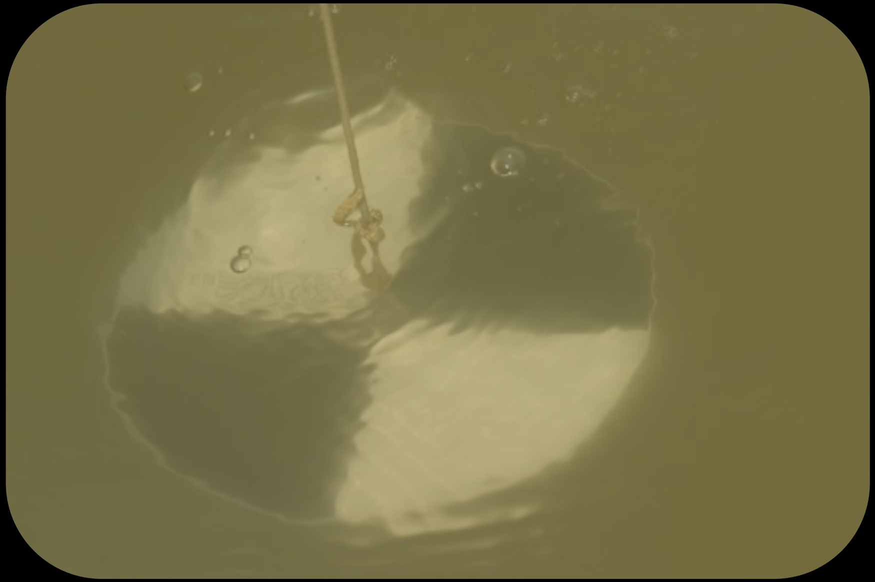


↓ K_d

↑ light at depth

↓ **Shallowing** Secchi depth

HOW?

Sediment Inputs to the Bay

Sediments are managed as pollutants, but are also a resource.
When sediment inputs decrease, what are the effects on water clarity?

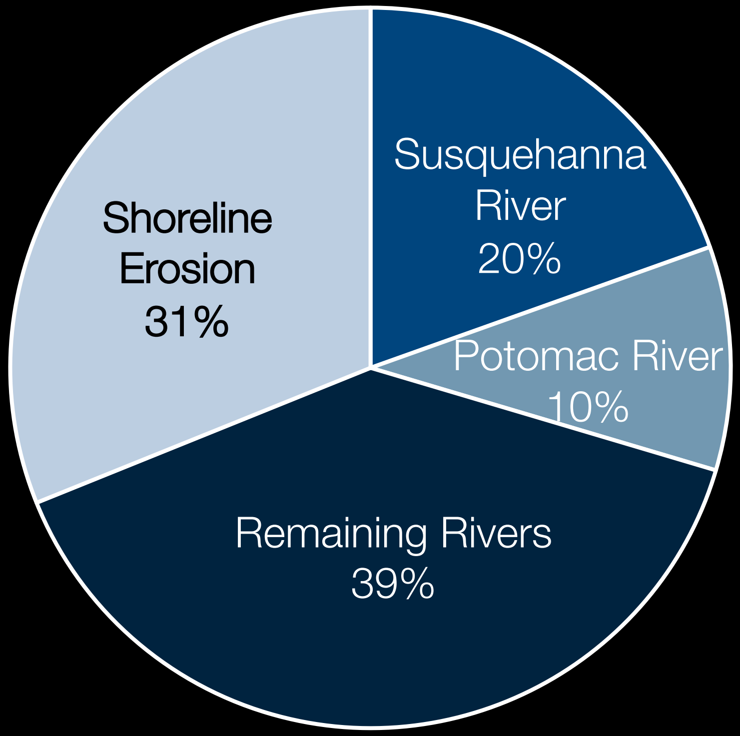
Chesapeake Bay Program

The Nature Conservancy

Sediment Inputs to the Bay

Sediments are managed as pollutants, but are also a resource.
When sediment inputs decrease, what are the effects on water clarity?

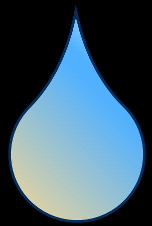
Mean Annual Sediment Input (Tons Yr^{-1})



Over time, armoring of shorelines decreases shoreline erosion

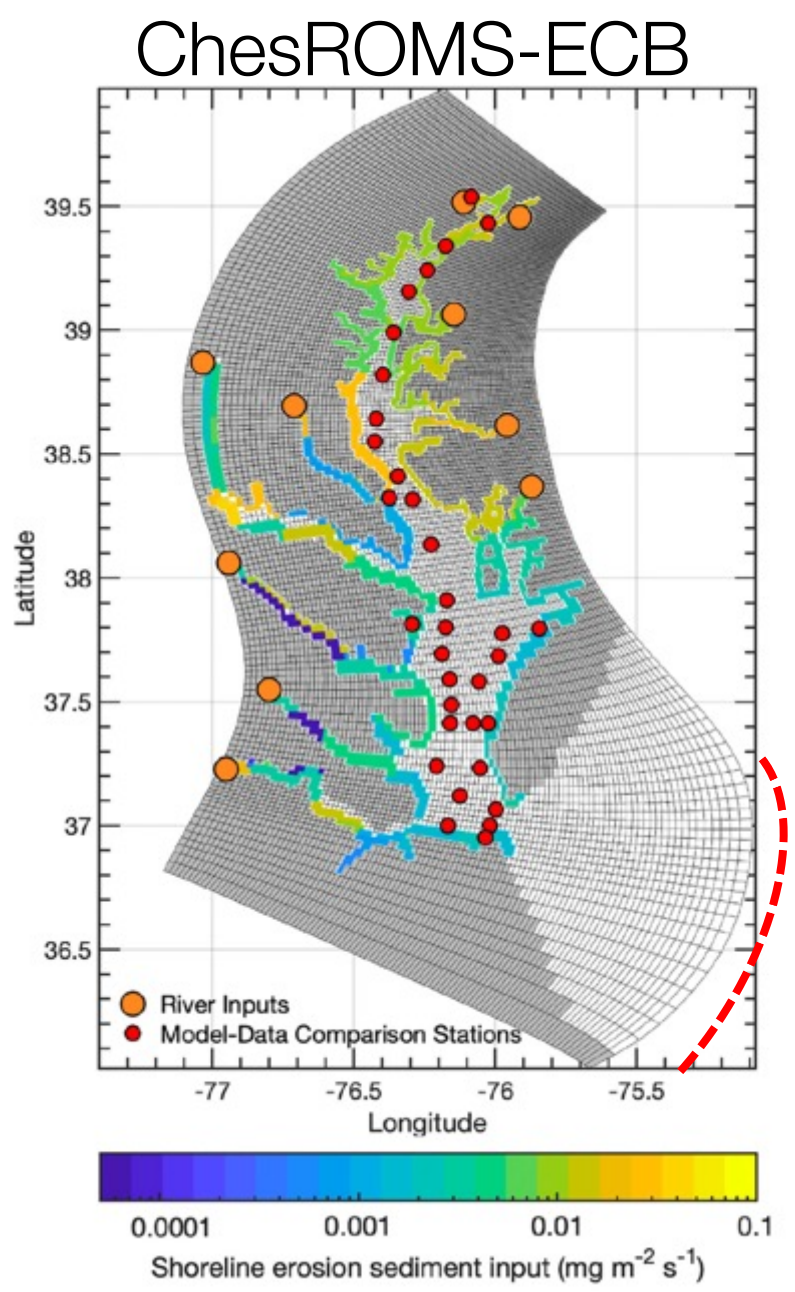
Research Question

How does a decrease in shoreline erosion associated with increased shoreline armoring affect water clarity in Chesapeake Bay?



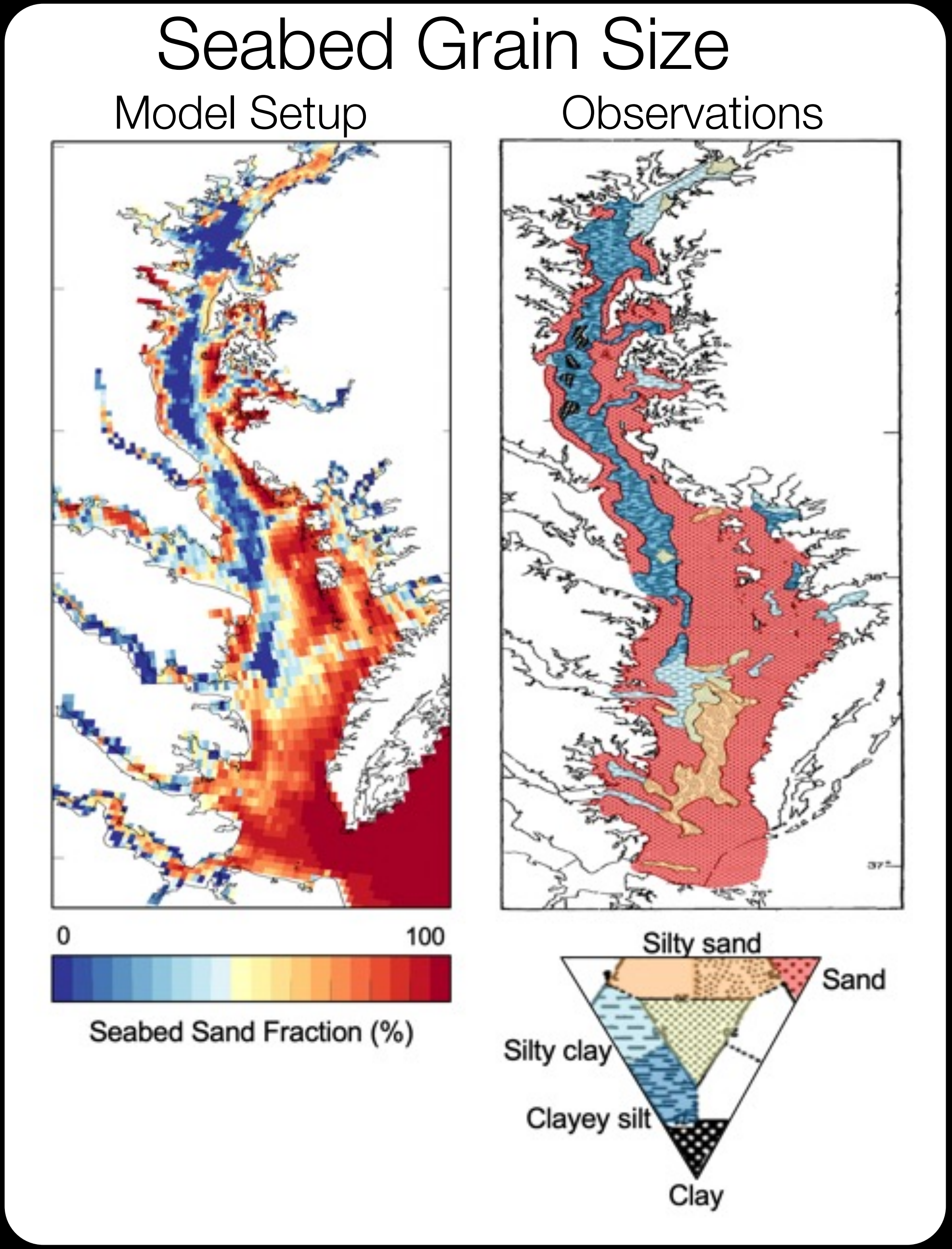
Model Setup

- ROMS hydrodynamic model
- ~1km horizontal resolution
- 20 depth layers
- Estuarine Carbon and Biogeochemistry Model (ECB) including 18 state variables
- 10 realistic river inputs ●
- Realistic ocean boundary - - -
- 33 mainstem surface model-data comparison stations ●



Model Setup

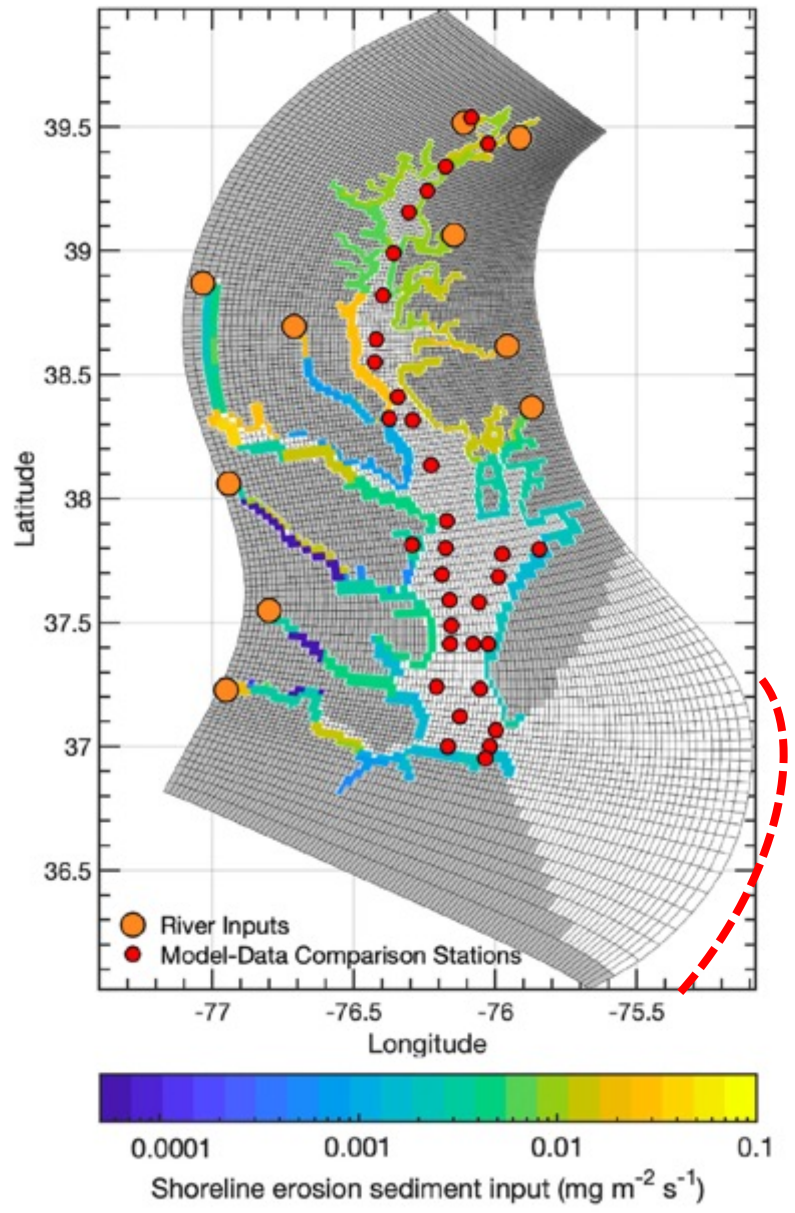
- Rutgers sediment module for ROMS
- 2 bed layers
- 4 sediment size classes
- Mud Critical Shear Stress = 0.09 Pa
- Org. Critical Shear Stress = 0.01 Pa
- Wind waves via SWAN model
- Observed grain size distribution



Model Setup

- Shoreline erosion sediment inputs from Chesapeake Bay Program Watershed Model Phase 6
- Based on observed long-term shoreline migration from aerial imagery and observed bank sediment grain sizes (VIMS Shoreline Studies Program)
- Flux into surface water grid cells

ChesROMS-ECB

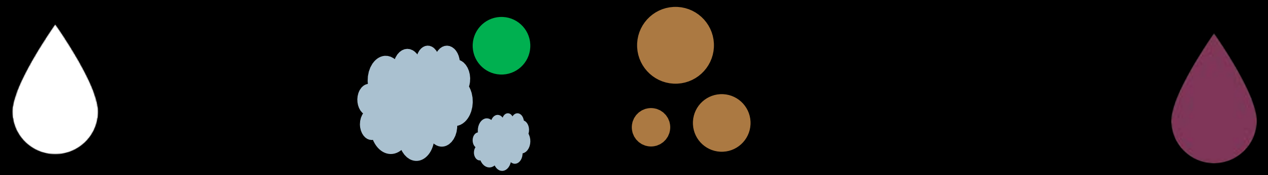


Model Setup

- FSS =Fixed Suspended Solids (mg L^{-1})
- VSS = Volatile Suspended Solids (mg L^{-1})

	Settling rate (mm s^{-1})
Sand	1
Mud Flocs	0.1
	0.03
	0.012
Phytoplankton	0.0012
Detritus	0.06
	0.0012

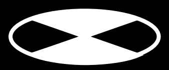
Calculation of light attenuation (K_d) and Secchi depth (Z_{SD}) from model output



$$K_d = 1.4 + 0.063\,(OSS + ISS) - 0.057\,Salinity$$

(Feng et al. 2015)

Proxy for CDOM



$$Z_{SD} = \frac{1.9}{(K_d + 0.2\,OSS)}$$

Calculation of light attenuation (K_d) and Secchi depth (Z_{SD}) from model output

$$K_d = 1.4 + 0.063\,(OSS + ISS) - 0.057\,Salinity$$

(Feng et al. 2015)

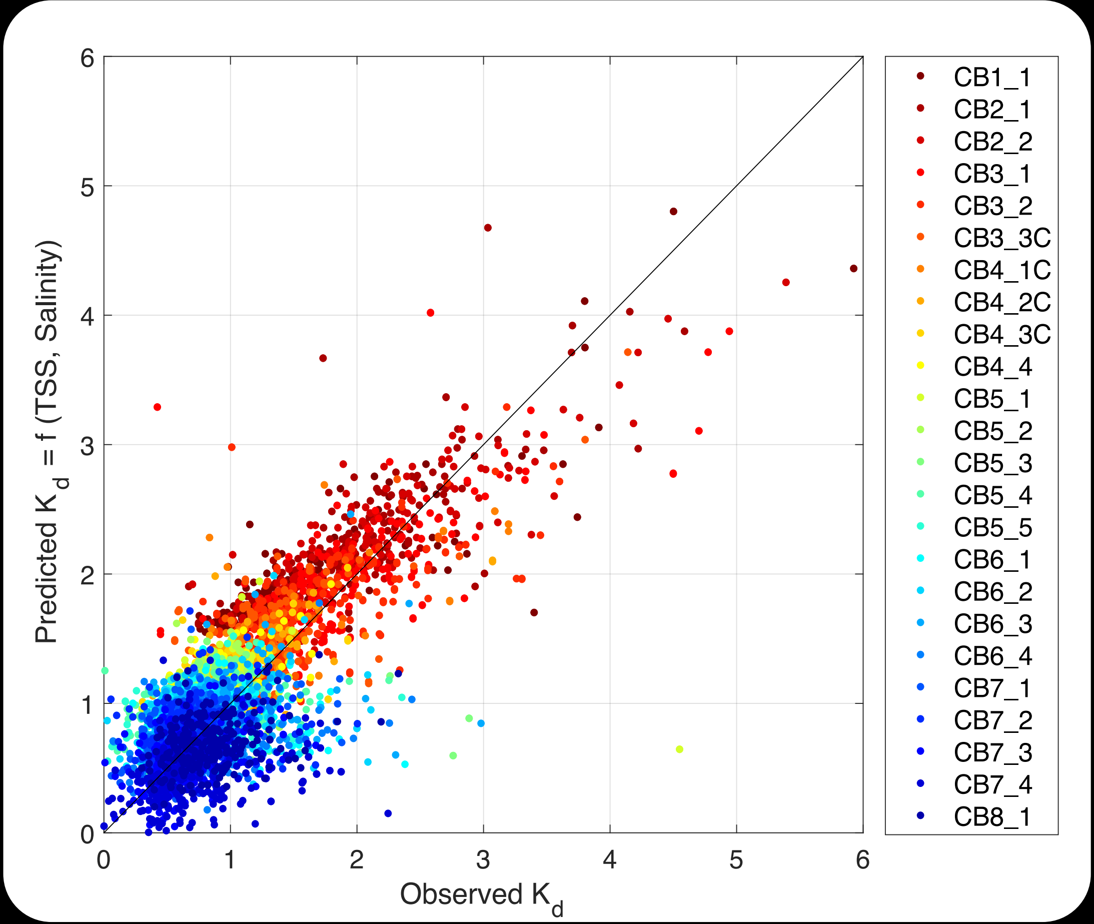
Proxy for CDOM

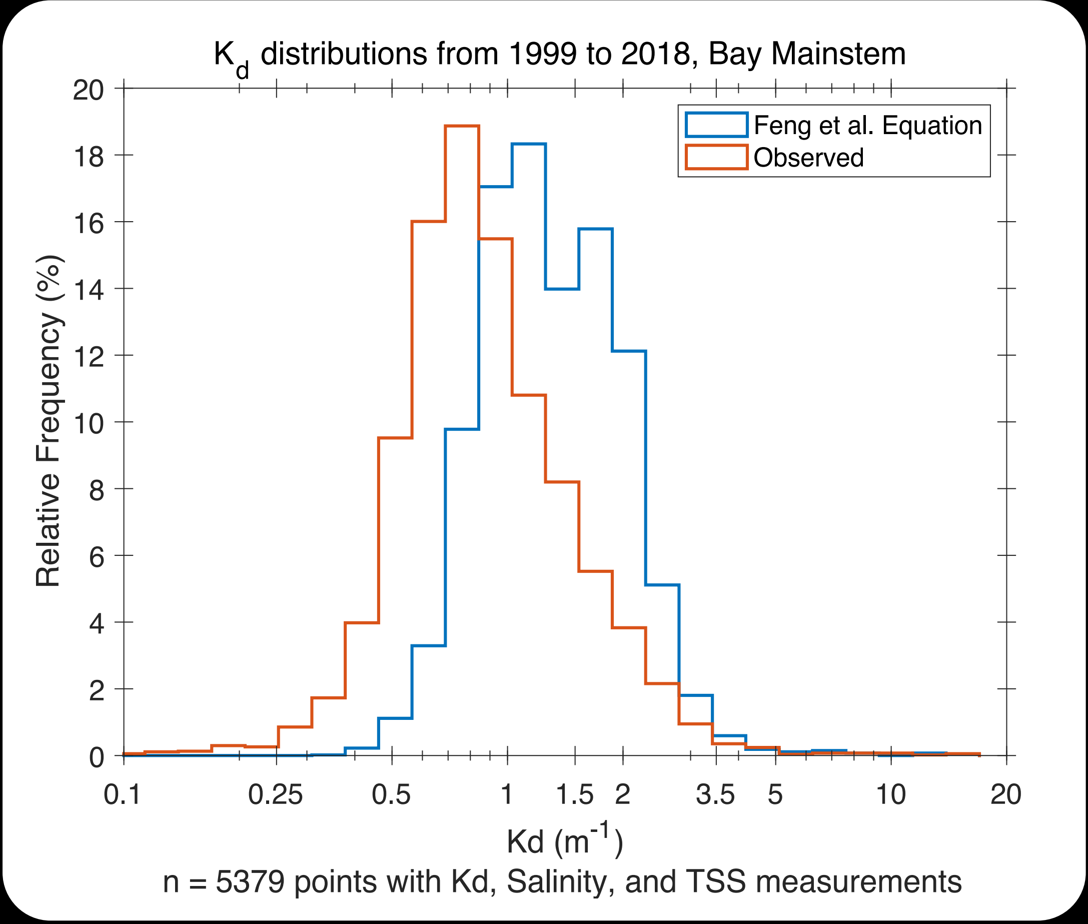
→ Integrated with biogeochem. model

$$Z_{SD} = \frac{1.9}{(K_d + 0.2\,OSS)}$$

→ Post-processing only (doesn't affect light for phyto)

Calculation of light attenuation (K_d) and Secchi depth (Z_{SD}) from model output





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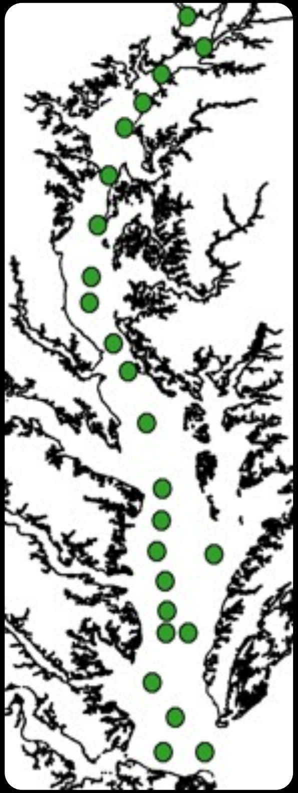
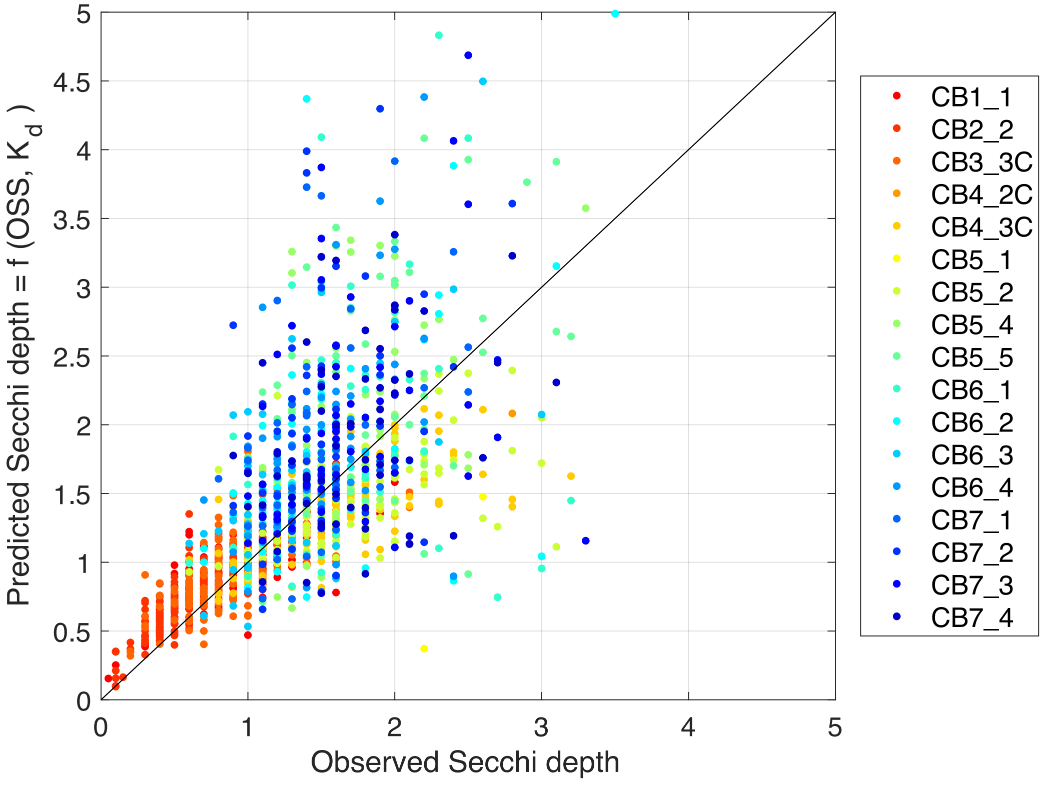
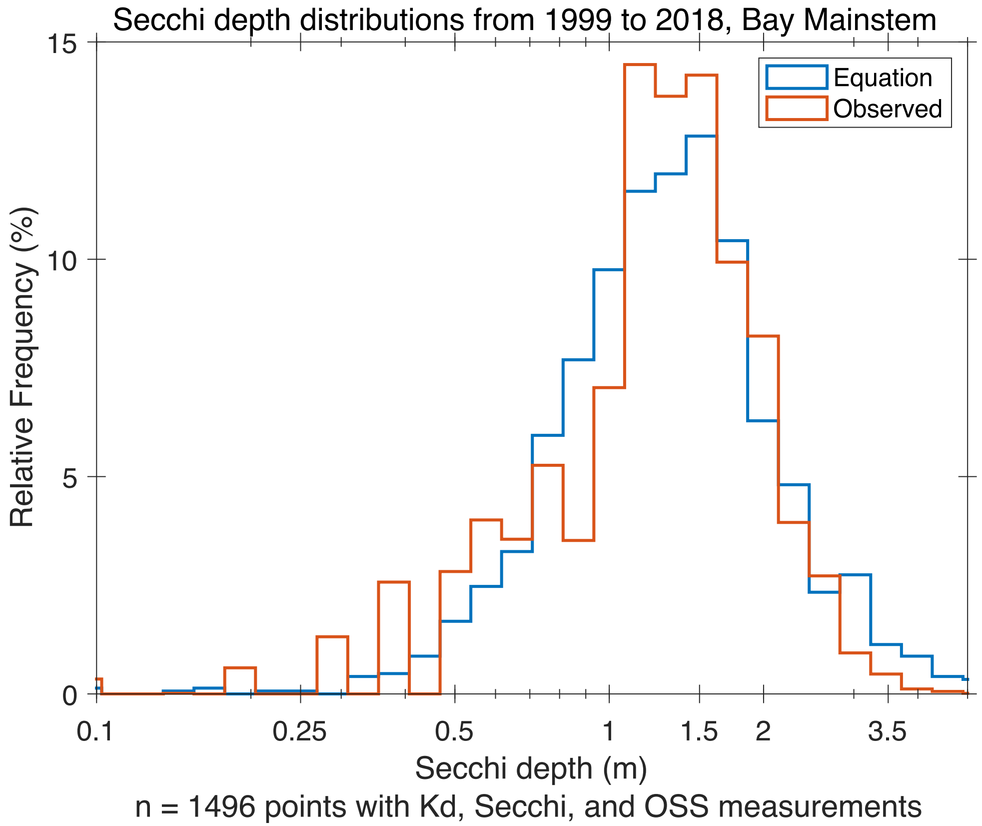


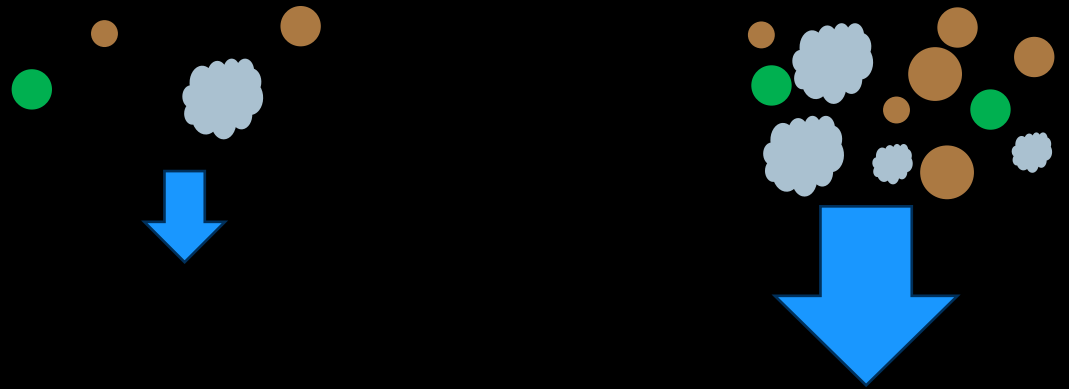


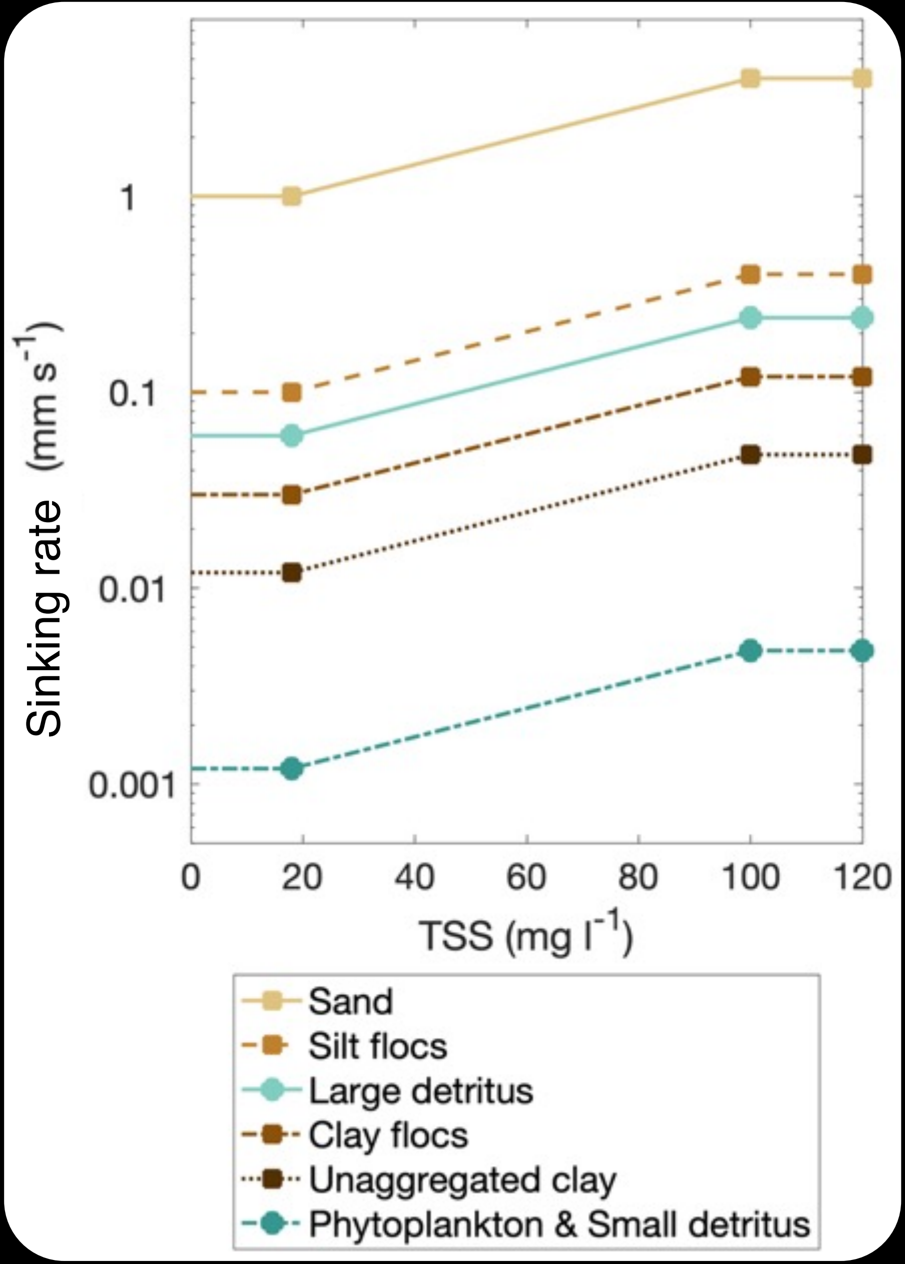


Ballasting effect

(Pseudo-aggregation)

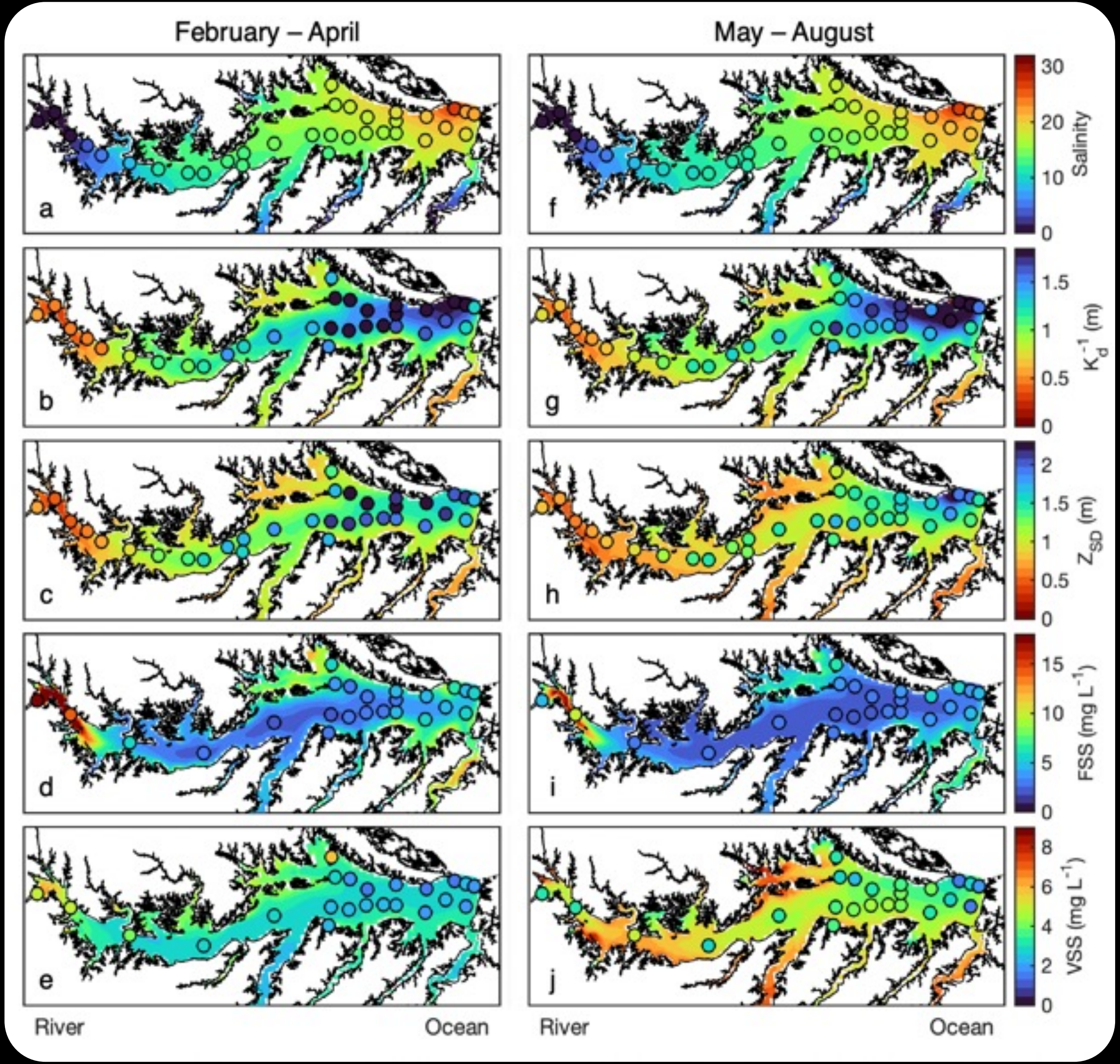
All suspended particles sink faster at higher TSS concentrations.





Model-data comparison – Reference Run

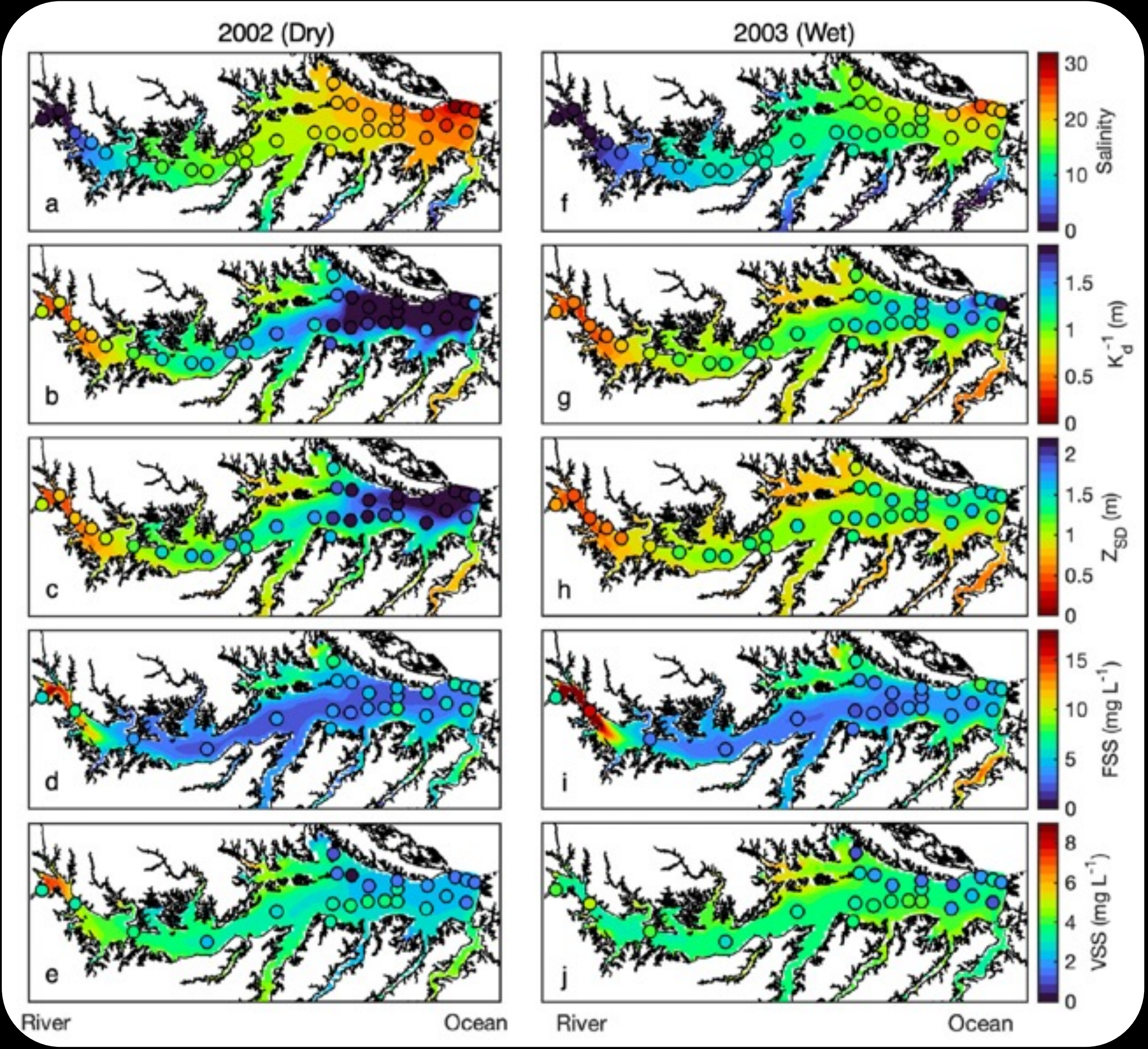
Model captures seasonal variability



Model-data comparison – Reference Run

Model captures seasonal variability

..and interannual variability



Experiments

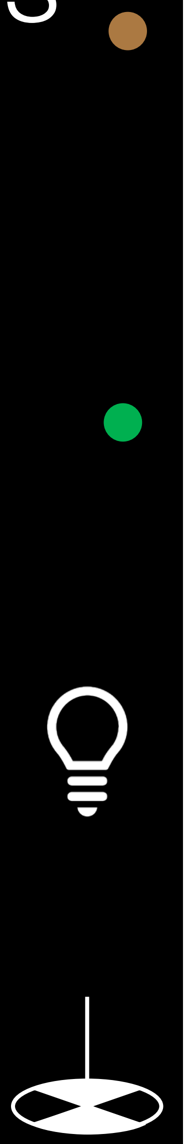
Model Run	*Shoreline erosion?*	*Seabed Erodibility, i.e., Mud Critical Shear Stress (Erosion, Deposition)*
Reference Run	Yes, realistic	Representative, 0.09 Pa
More Shoreline Erosion 	Yes, x2	More Erodible, 0.03 Pa
Highly Armored Shorelines 	No	More stable, 0.12 Pa

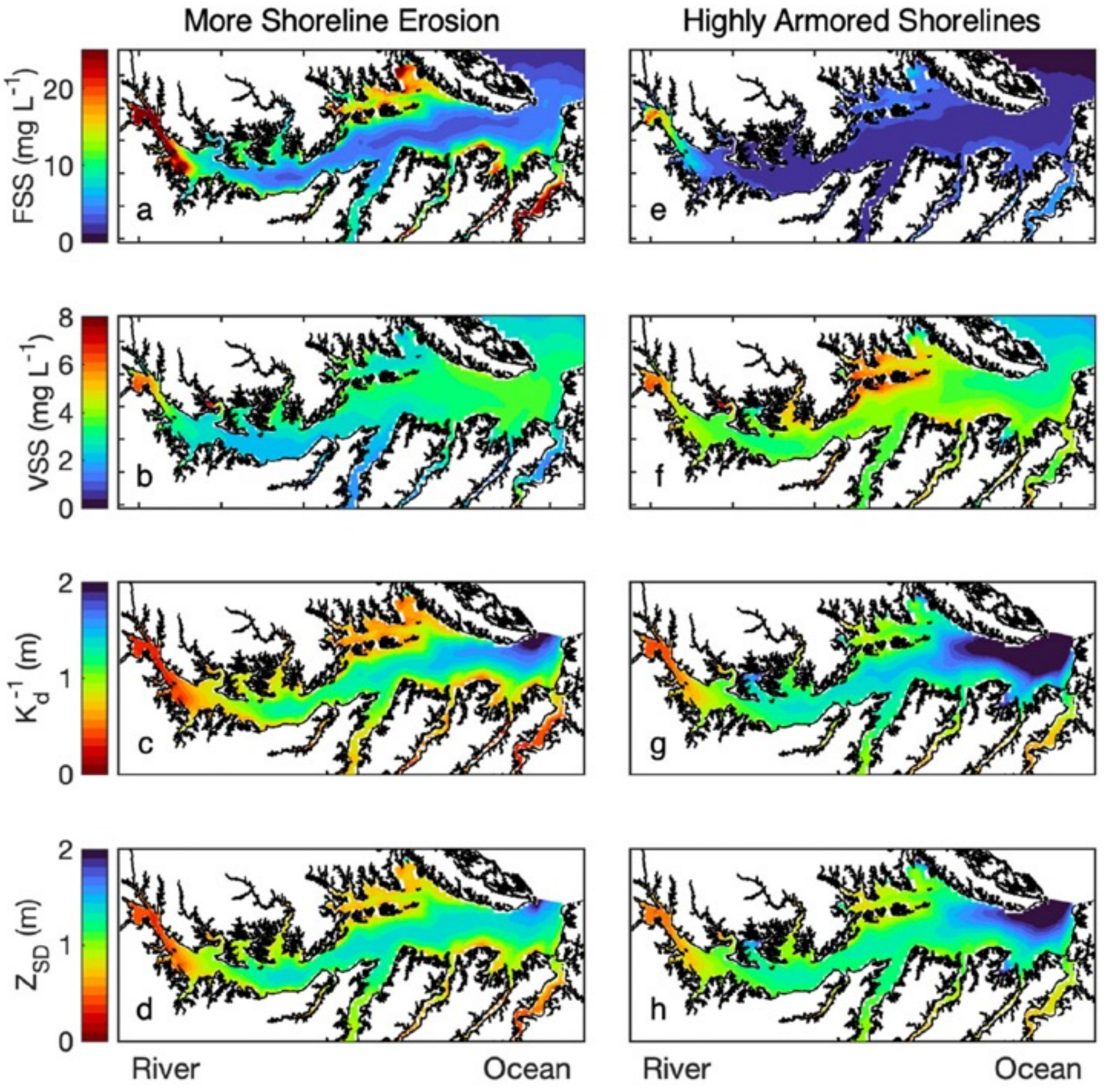
1 year spinup: 2000

5 year analysis: 2001-2005

Results compare the two extreme cases

Results

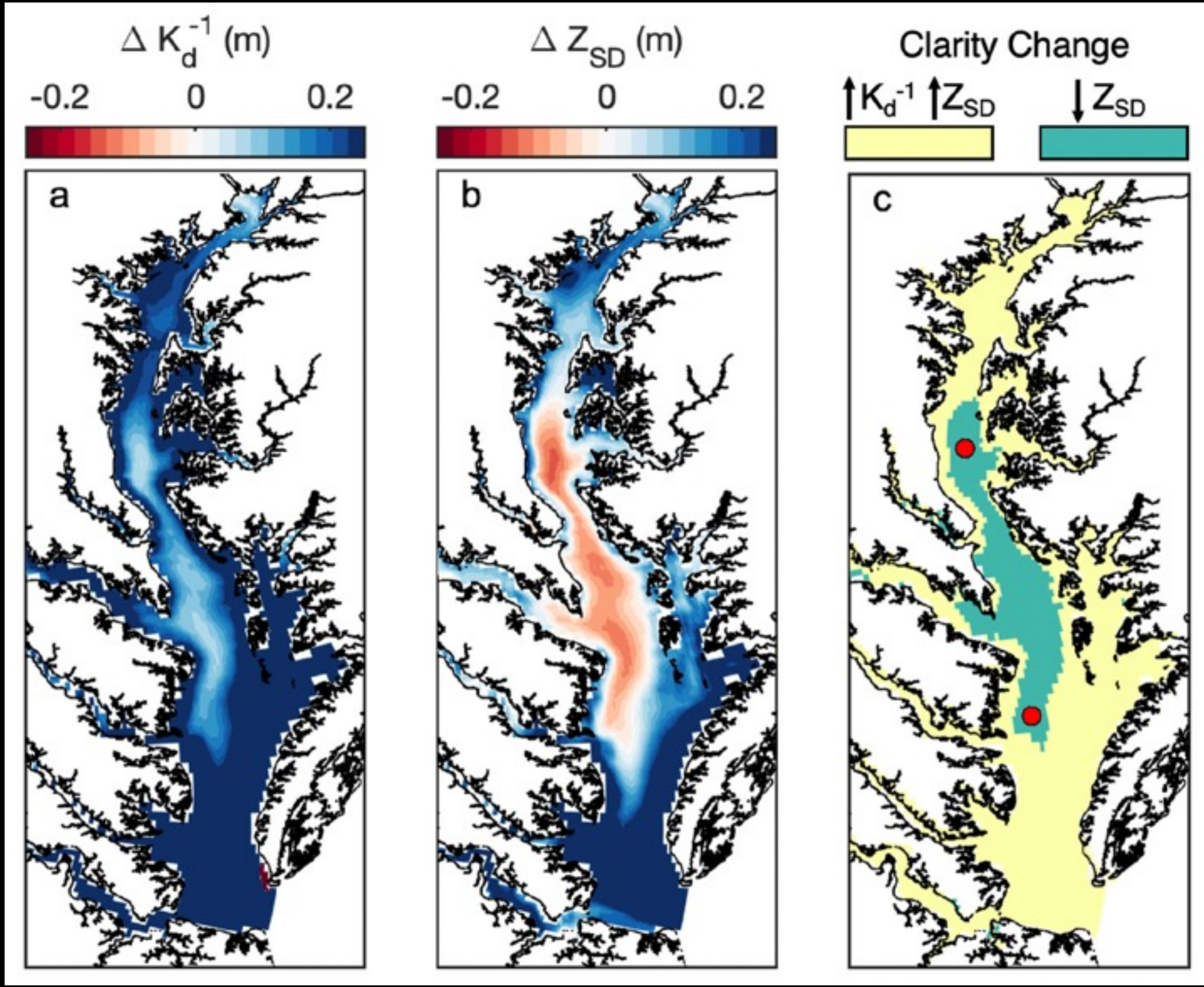




More Shoreline Erosion
Highly Armored Shorelines
FSS (mg L^{-1})
VSS (mg L^{-1})
K_d^{-1} (m)
Z_{SD} (m)
a
b
c
d
e
f
g
h
River
Ocean
River
Ocean

Results

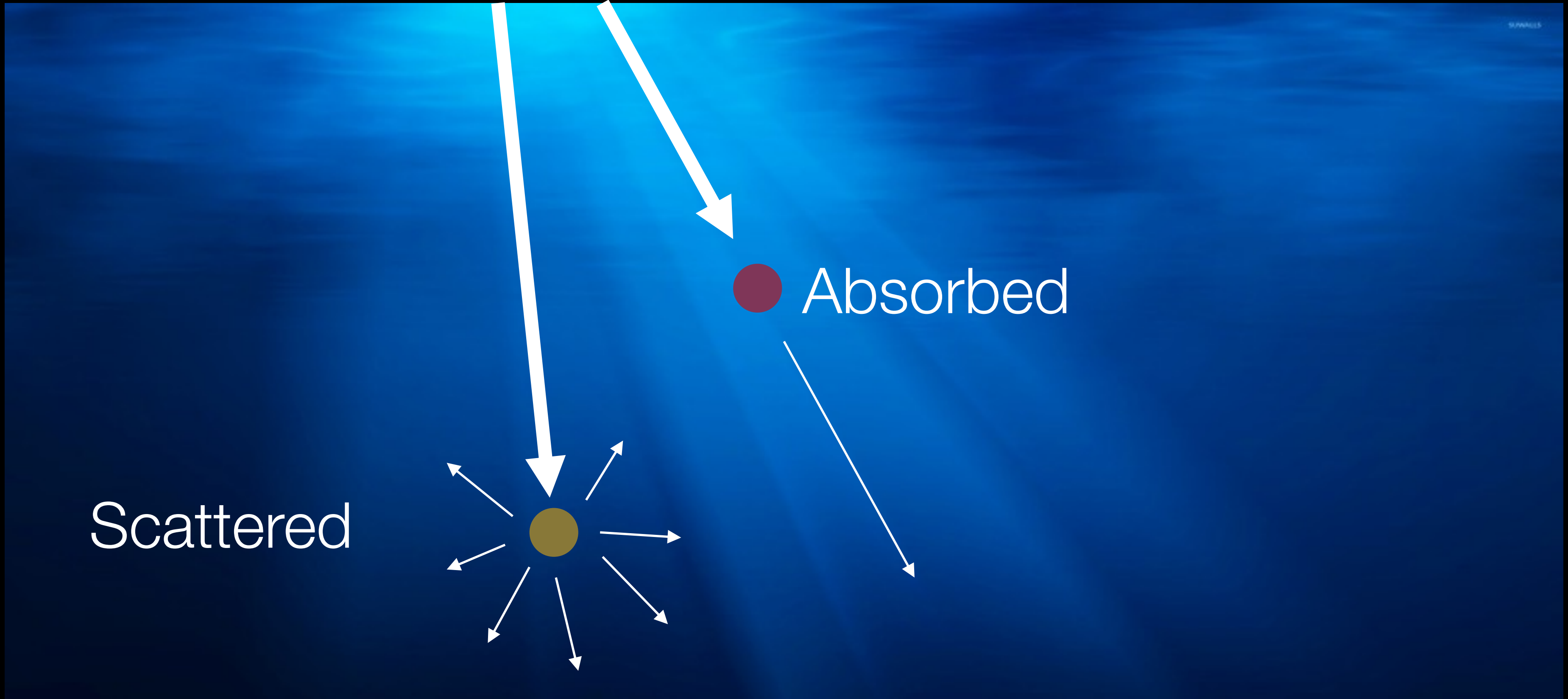
Difference: Highly Armored – More Erosion



In spring (Feb-Apr) in the mid-Bay, deeper Kd-1 but shallower Secchi

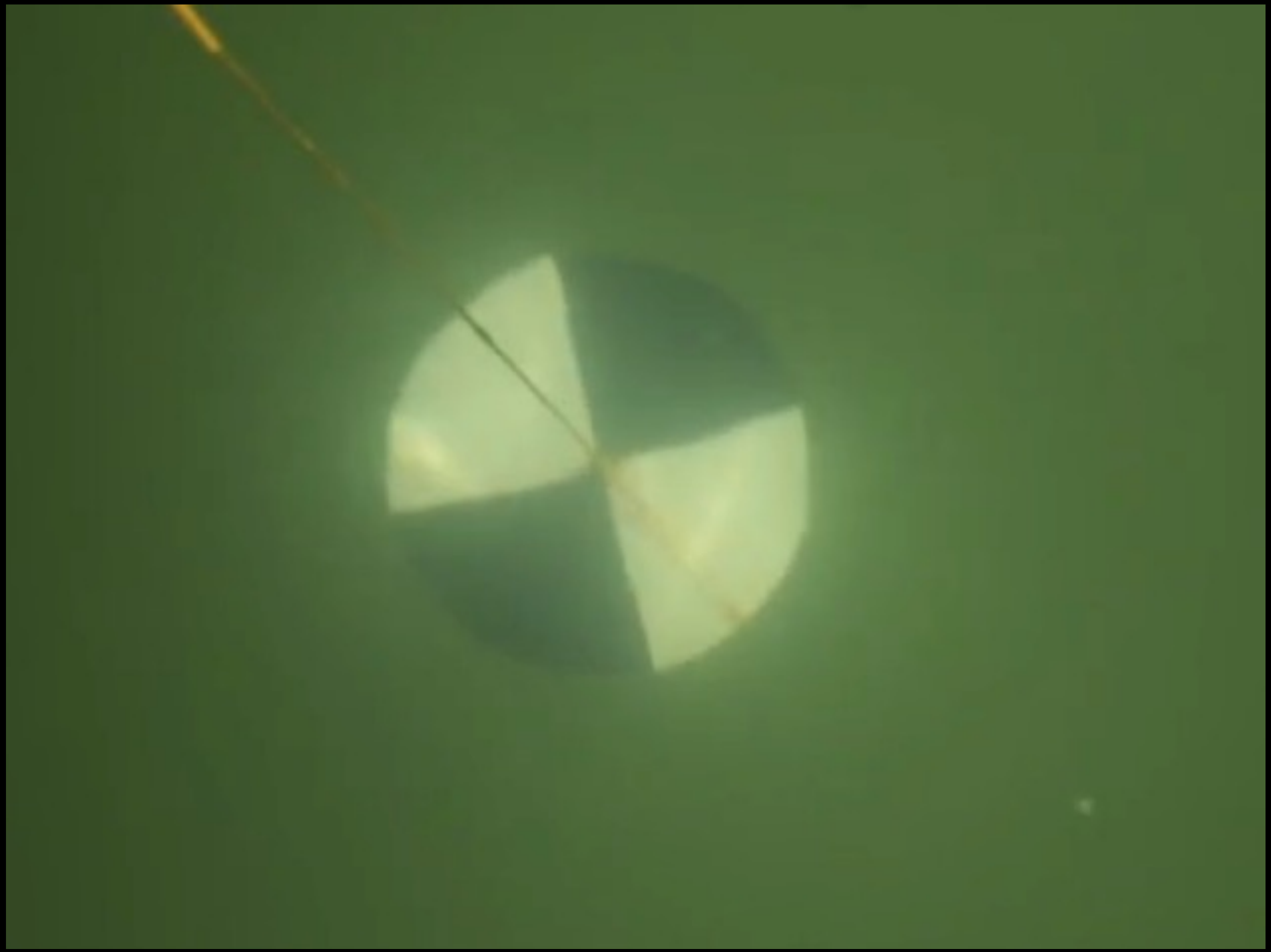
"Organic Fog Zone"

Organic matter leads to counterintuitive effects on clarity



A change in the scattering/absorption ratio affects Z_{SD} and K_d in different ways

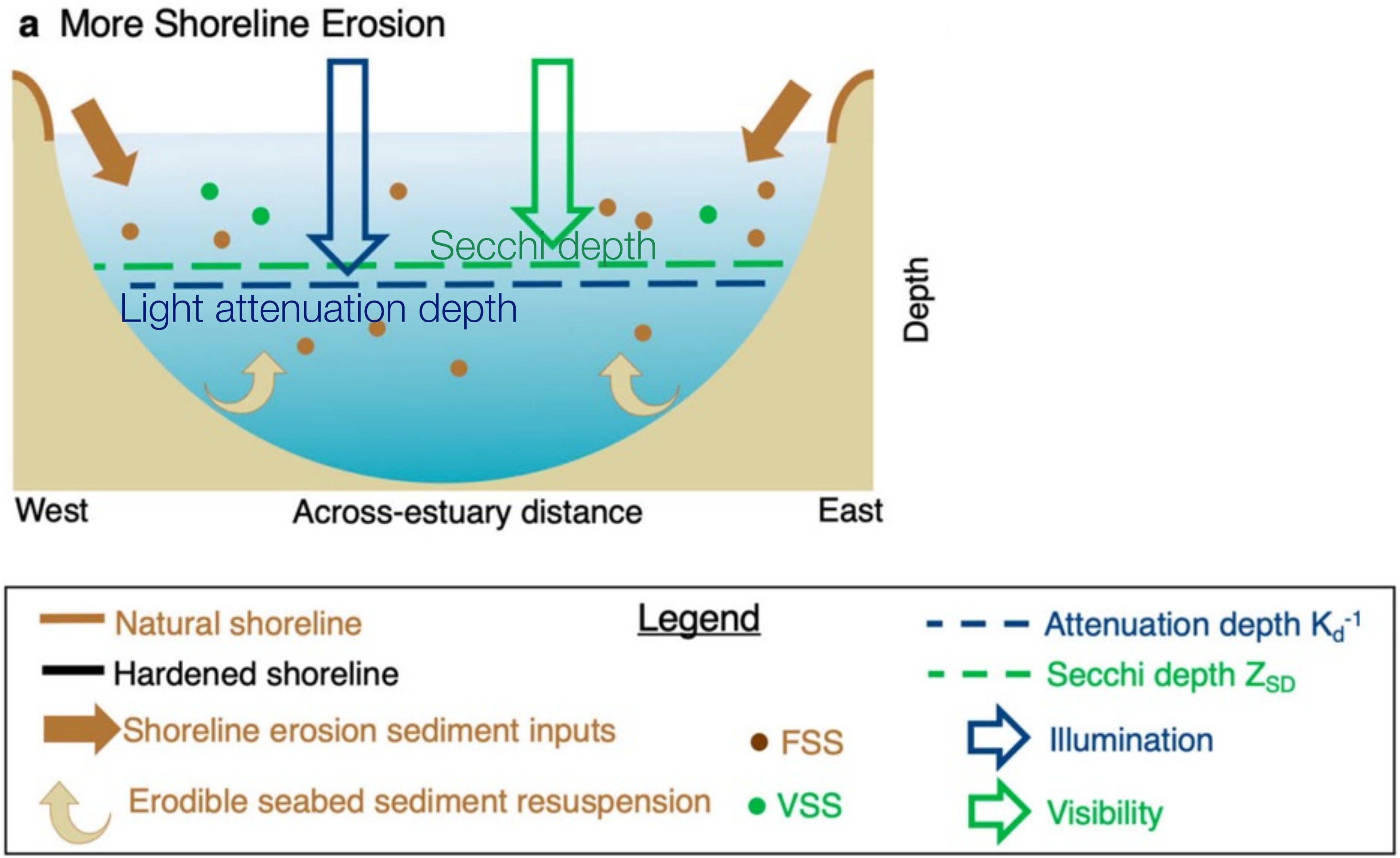
Organic matter leads to counterintuitive effects on clarity



Secchi disk measurement depends on light beam reaching the disk, then back to human eye:

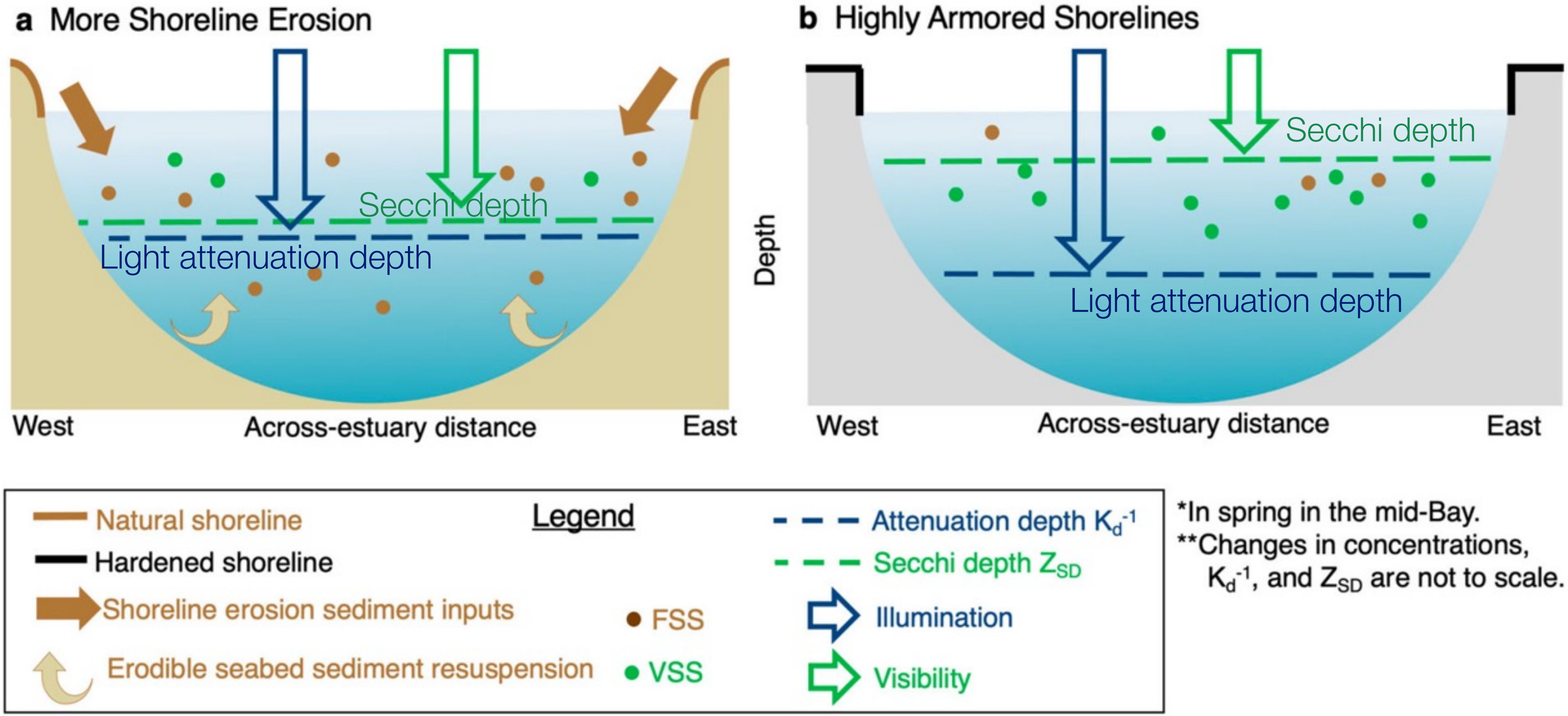
more sensitive to light scattering than Kd

Counterintuitive effects on clarity



*In spring in the mid-Bay.
**Changes in concentrations, K_d^{-1}, and Z_{SD} are not to scale.

Counterintuitive effects on clarity



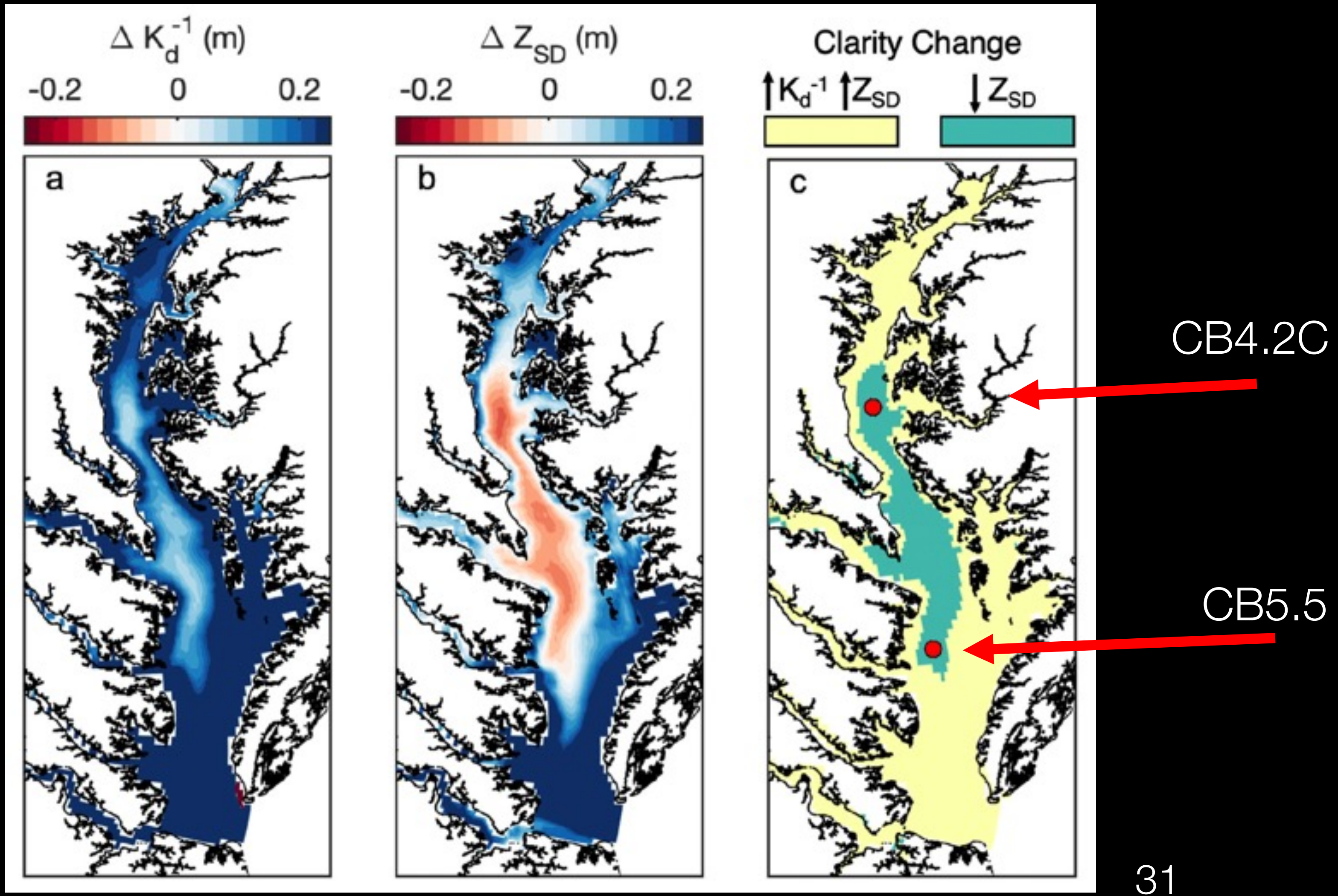
*In spring in the mid-Bay.
**Changes in concentrations, K_d^{-1}, and Z_{SD} are not to scale.

“Zones” of clarity change due to shoreline armoring

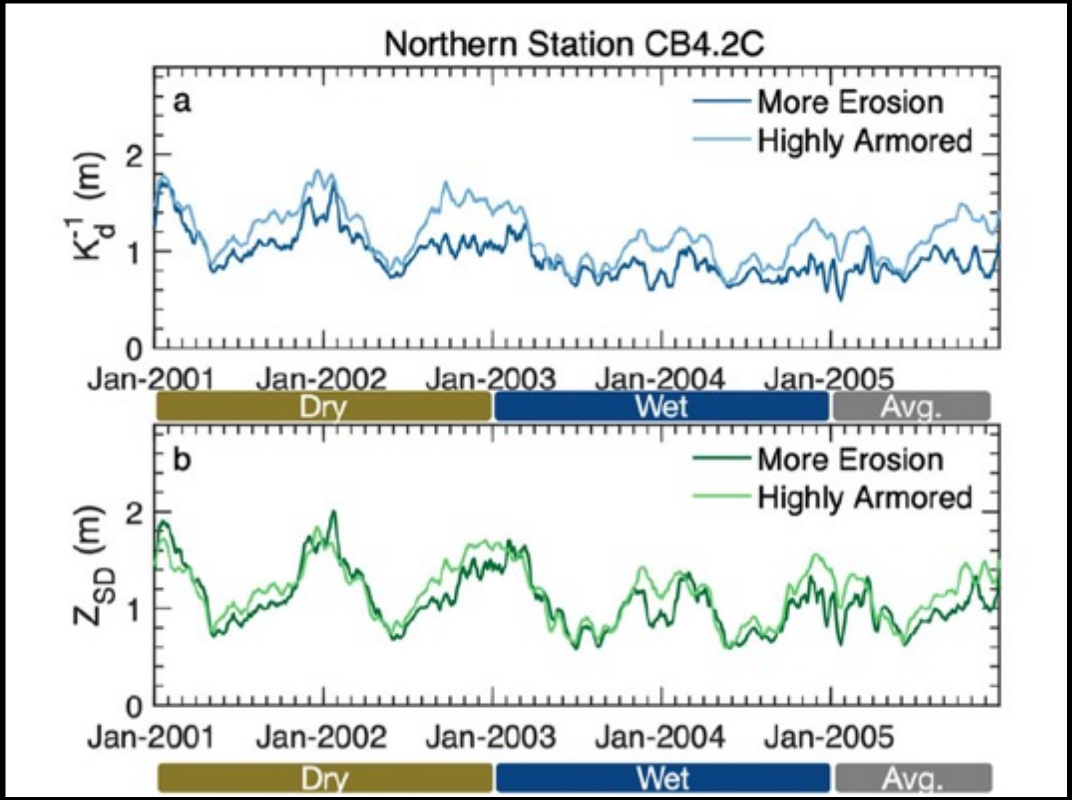
In spring (Feb-Apr) in the mid-Bay, deeper Kd-1 but shallower Secchi

“Organic Fog Zone”

Difference: Highly Armored – More Erosion



Clarity change due to shoreline armoring varies with location within the “Organic Fog Zone”



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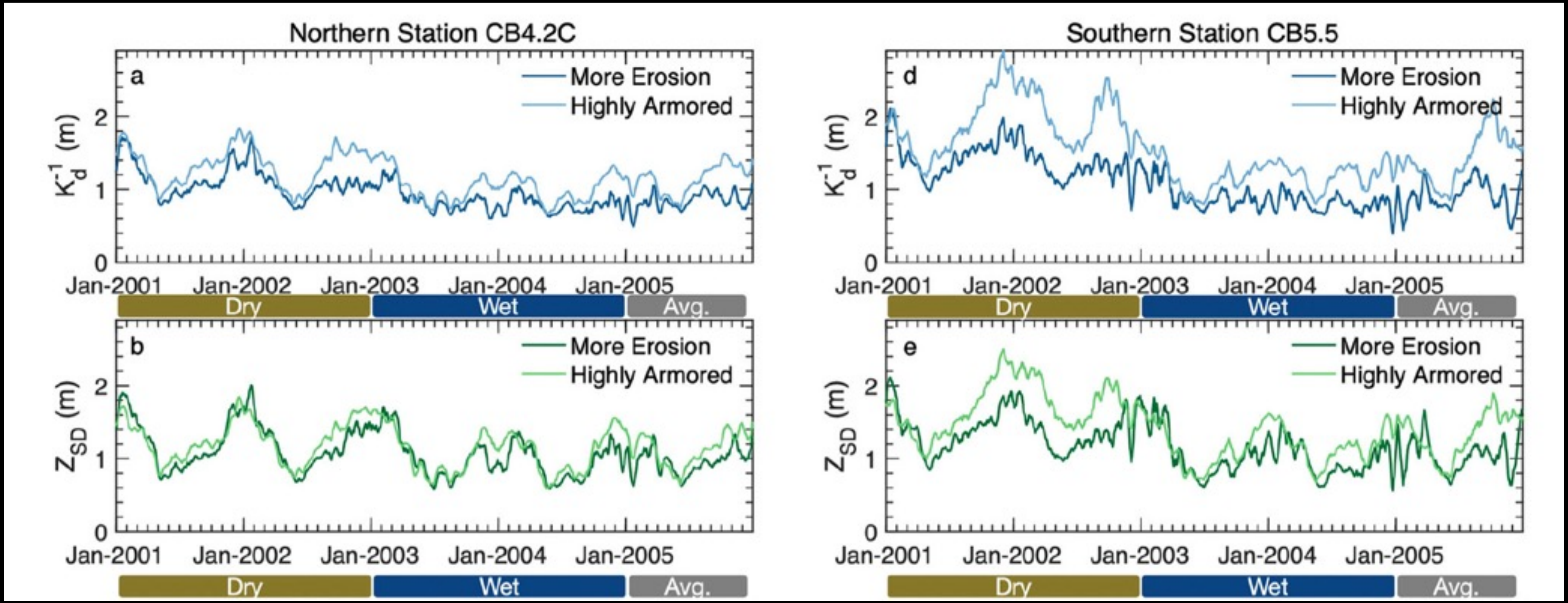
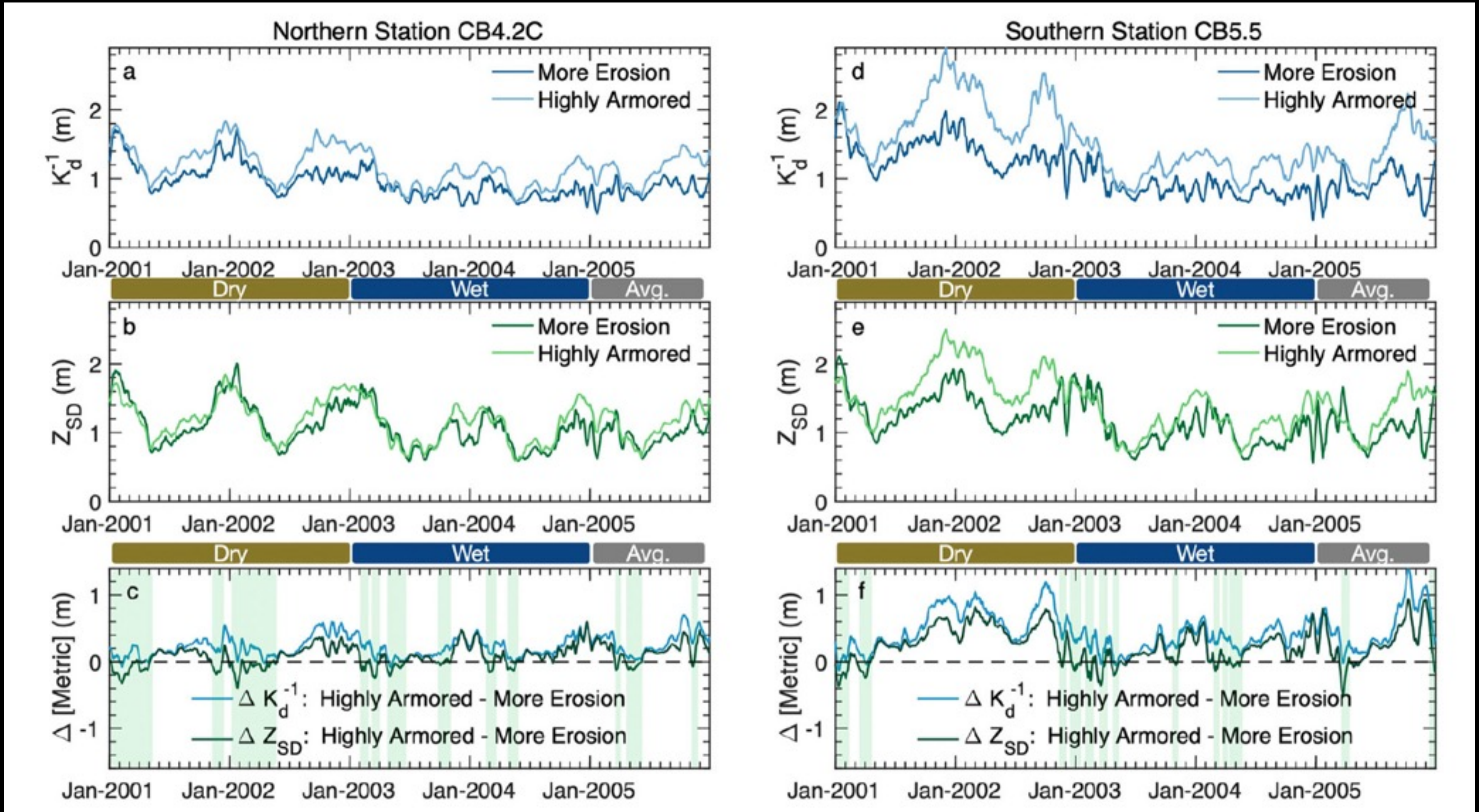


Clarity change due to shoreline armoring varies with location within the “Organic Fog Zone”



Implications

With decreased sediment inputs, clarity doesn't improve at all times.

Organic Fog Zone

Improved clarity

High-erosion


Christopher J. Patrick


@ZosteraR Seagrass Ecosystems


Seagrass-Watch seagrass news

 Low light

 Cloudy

 High light

 Cloudy

 High light

 High visibility

Implications

With decreased sediment inputs, clarity doesn't improve at all times.

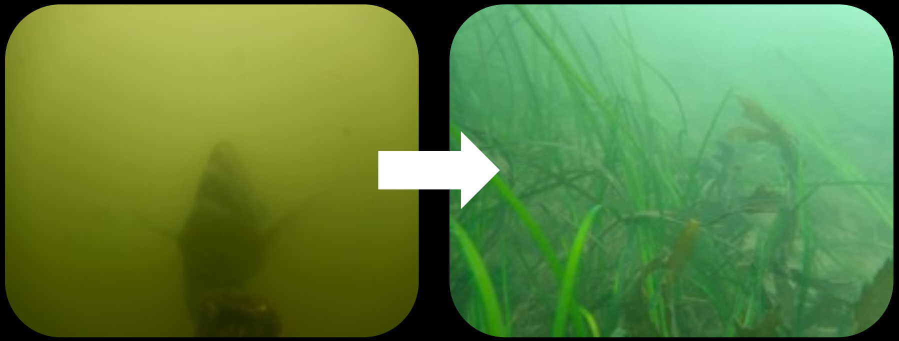
Improved clarity

Expectation:

Fall, early winter
Upper, Lower Bay

Organic Fog Zone

Reality:

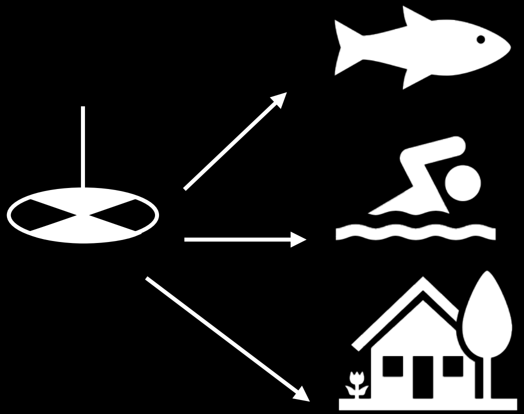


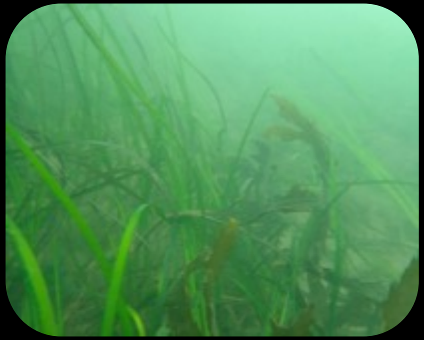
Late winter, spring
Mid-Bay

Implications

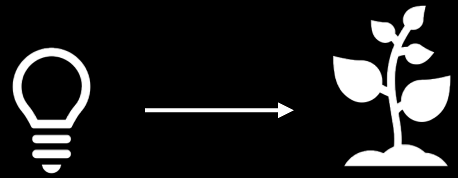
Choose water clarity metric carefully.

Secchi depth may not show effects of sediment reductions in all seasons, but useful for other purposes





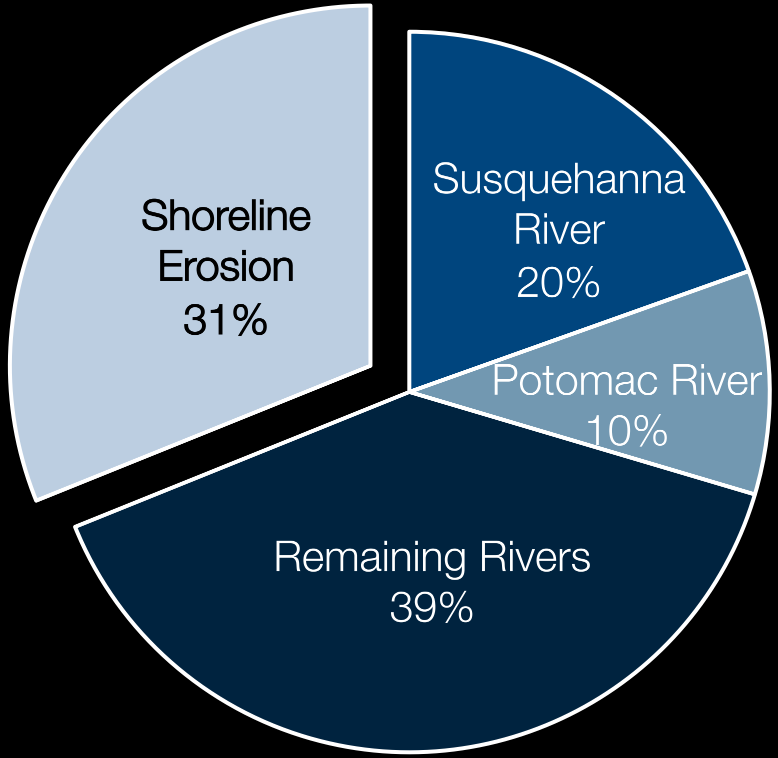
Seagrasses can still thrive if enough light reaches depth even with cloudiness



Implications

What about rivers?

Mean Annual Sediment Input (Tons Yr^{-1})



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Acknowledgements

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