STAC Workshop: Understanding and Explaining 30+ Years of Water Clarity Trends In the Bay’s Tidal Waters

Processes and feedbacks especially important to shallow water clarity

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Overview

- Clarity in shallow water is the least well studied/synthesized of the three areas under consideration in this workshop.
- Improving shallow water clarity is arguably the most directly important aspect of CB water clarity goals because of the SAV criteria.
- Goals of our group are:
  - to identify the processes that make shallow water environments different from open water environments
  - to identify the most important research needs
  - to identify the most effective near-term analyses

Outline

- Sanford – Introduction, physical characteristics, physical-biological interactions
- Gallegos – Shallow water clarity and the benthic “fluff” layer
- Cornwell – Sediment-water fluxes and microphytobenthos
- Porter – Experimental ecosystem studies of resuspension effects

What makes the shallows different?

- Strongly affected by external, often local inputs
  - Horizontal, short time scale variability
- Heterogeneity
  - Small scale (subgrid) variability
  - Very different levels of connectivity to land and open water – one size does not fit all
- Direct coupling between the surface, the water column, and the benthos
  - Occasional stratification due to upwelling or temperature, but not a dominant feature (?)
  - Vertical, short time scale variability
- Physical-biological coupling important at lowest order
  - Positive feedbacks and alternate steady states

Implications of shallow depth

- Tidal (including wind-driven) variation in depth is important at lowest order

Tide’s out – Todd’s Pt on the Lower Choptank

Physical implications of shallow depth

- Tidal (including wind-driven) variation in depth is important at lowest order
- Pressure gradient driven flows (tides and gravitational circulation) and associated bottom stresses are often weak:
  - For example, the same tidal forcing that produces a tidal flow of 0.5 m/s with an associated bottom stress of 0.5 Pa in 10 m depth, produces a tidal flow of 0.16 m/s with a bottom stress of 0.05 Pa in 1 m depth

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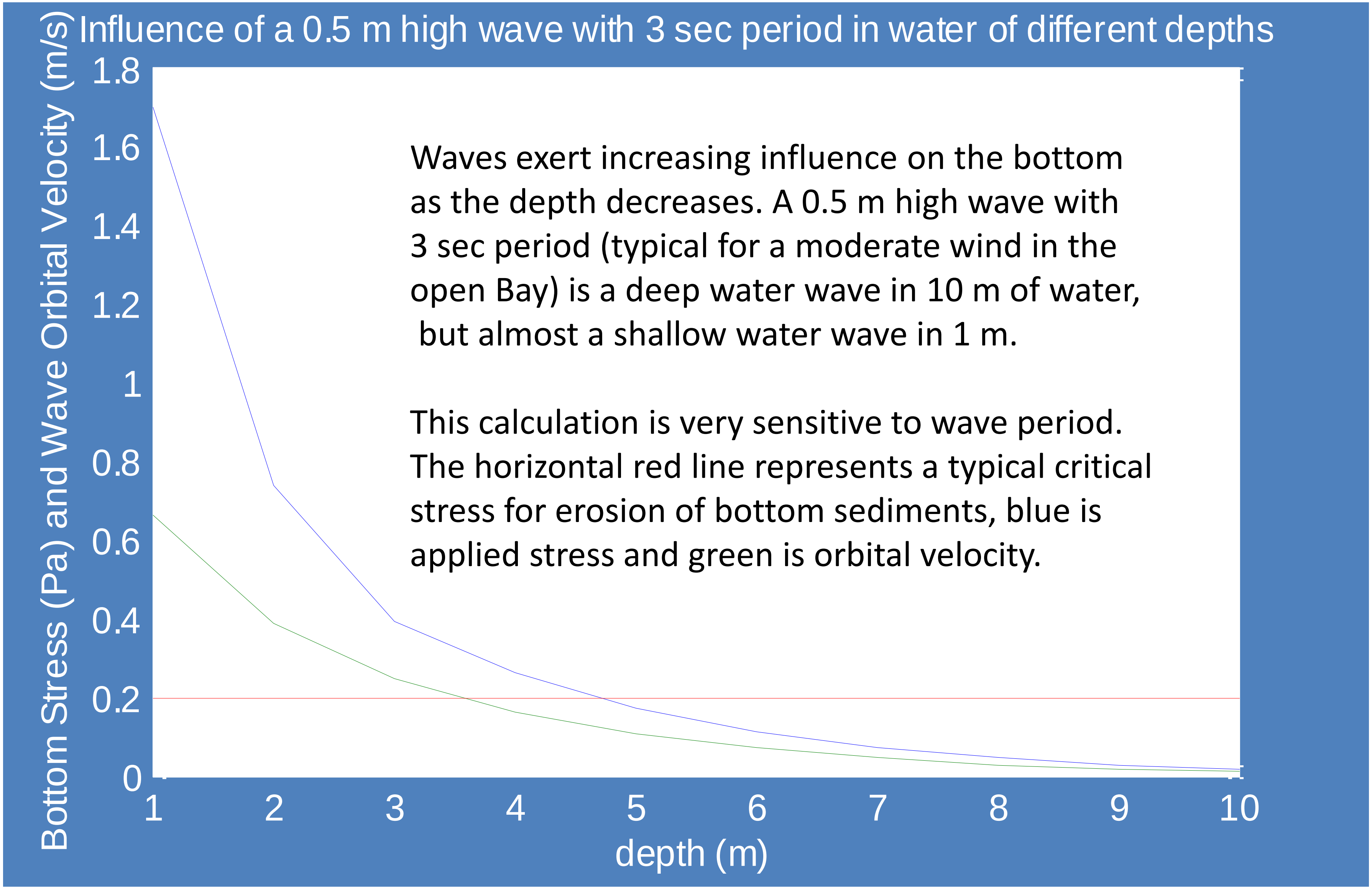
Dependence of wave forcing on depth



Waves exert increasing influence on the bottom as the depth decreases. A 0.5 m high wave with 3 sec period (typical for a moderate wind in the open Bay) is a deep water wave in 10 m of water, but almost a shallow water wave in 1 m.

This calculation is very sensitive to wave period. The horizontal red line represents a typical critical stress for erosion of bottom sediments, blue is applied stress and green is orbital velocity.

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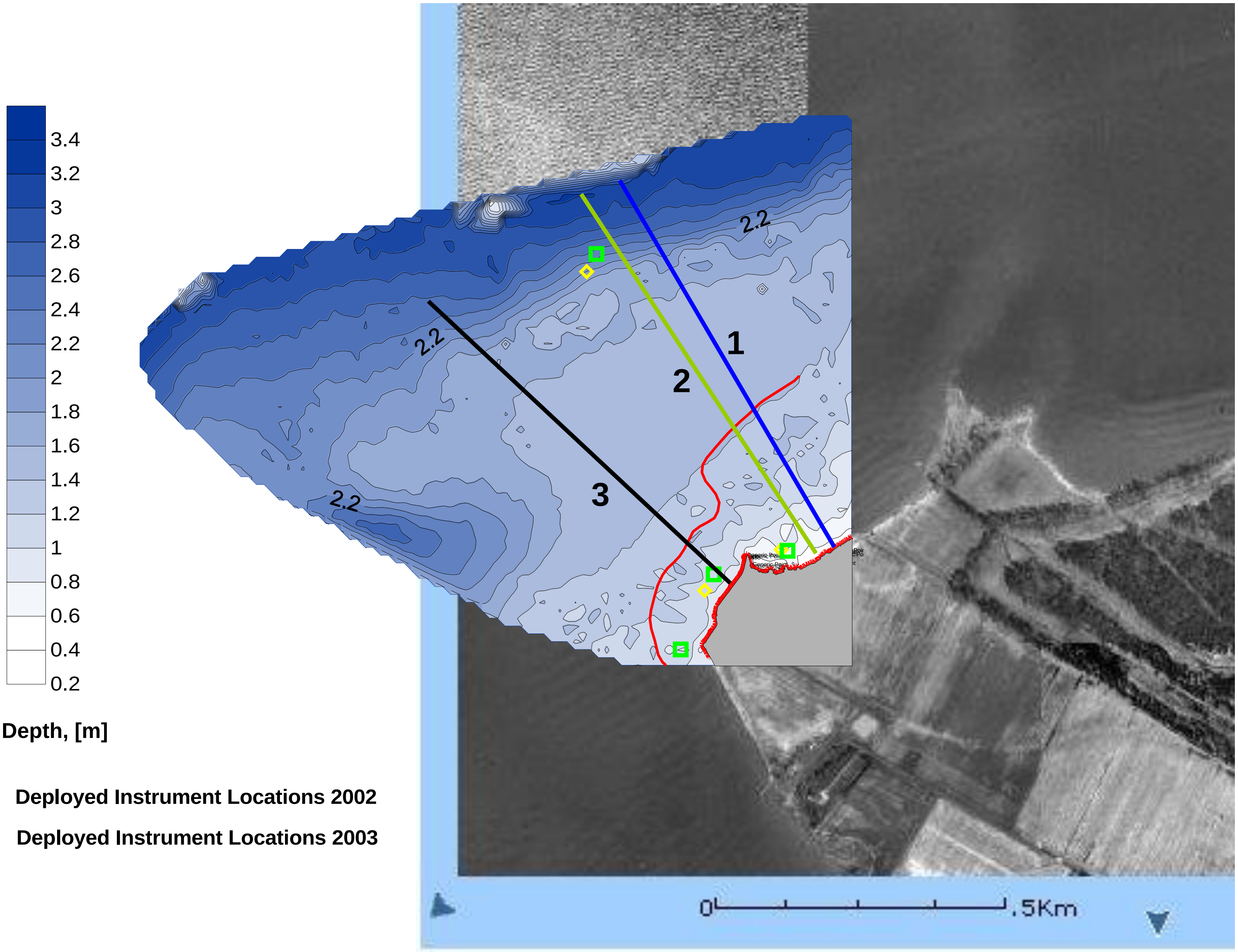
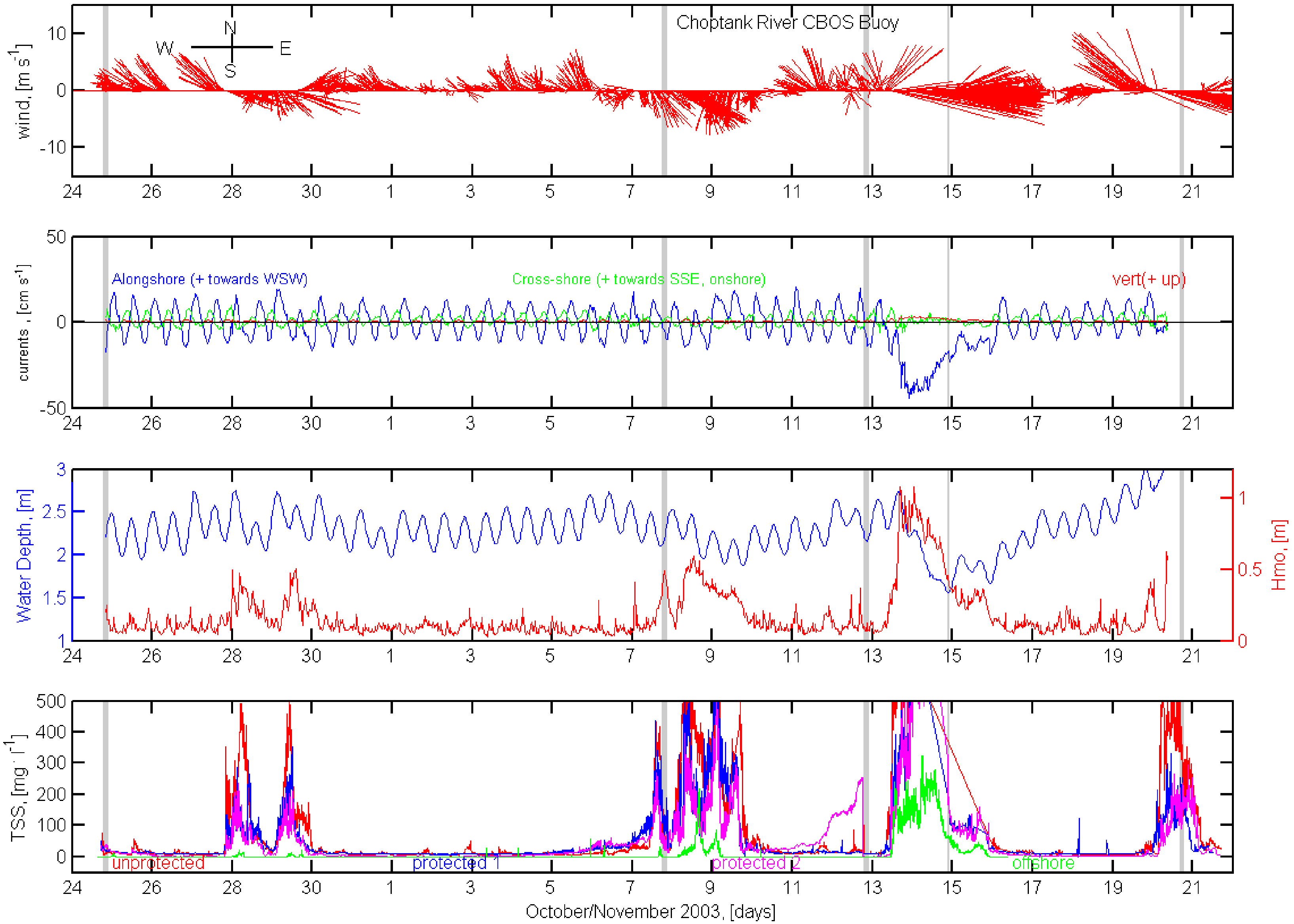
Todd’s Point Bathymetry 2002 on 1998 Aerial Photo

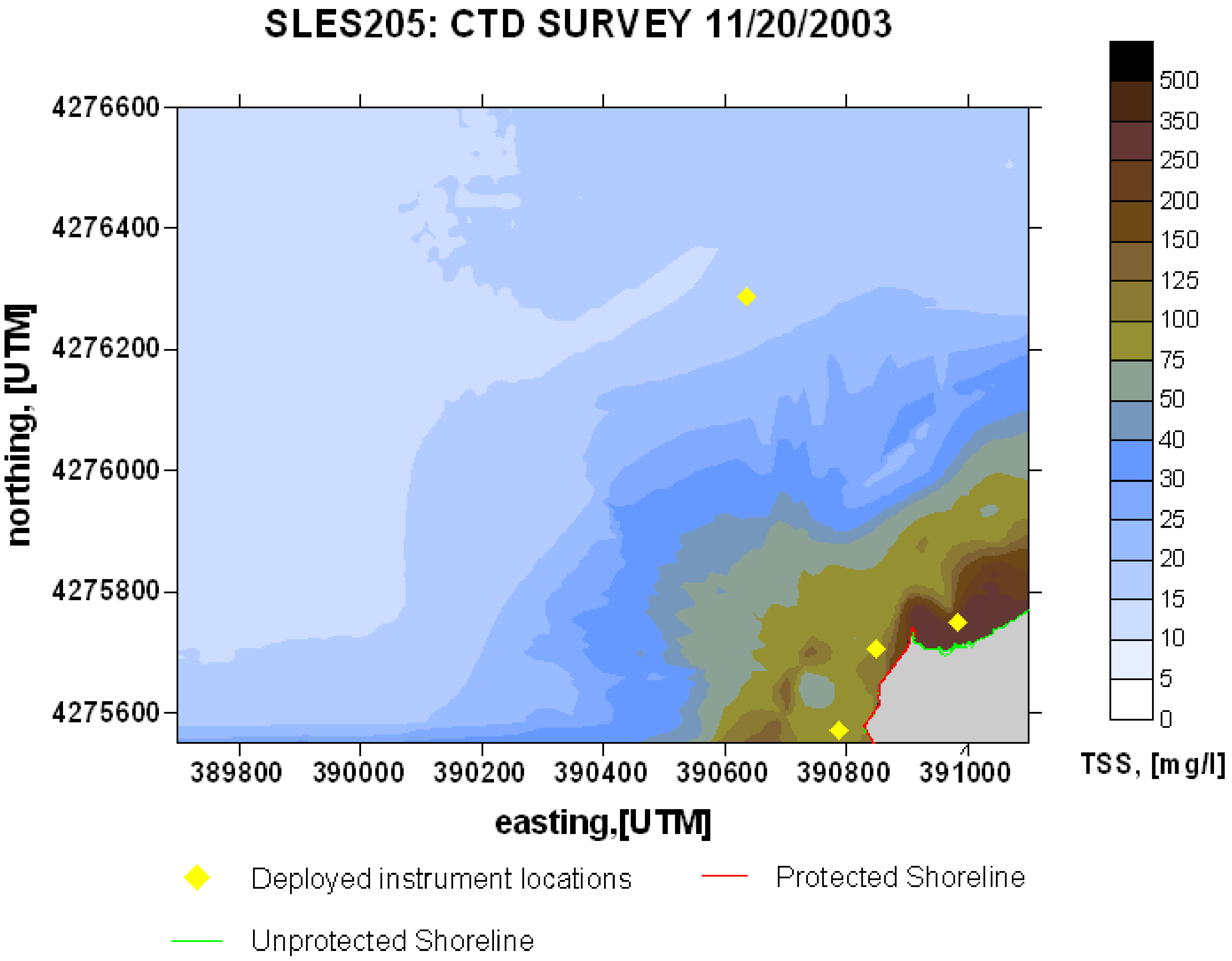


◇ Deployed Instrument Locations 2002

🟩 Deployed Instrument Locations 2003

2003 Moored Observations at Todd's Pt.

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Deployed instrument locations
Protected Shoreline
Unprotected Shoreline

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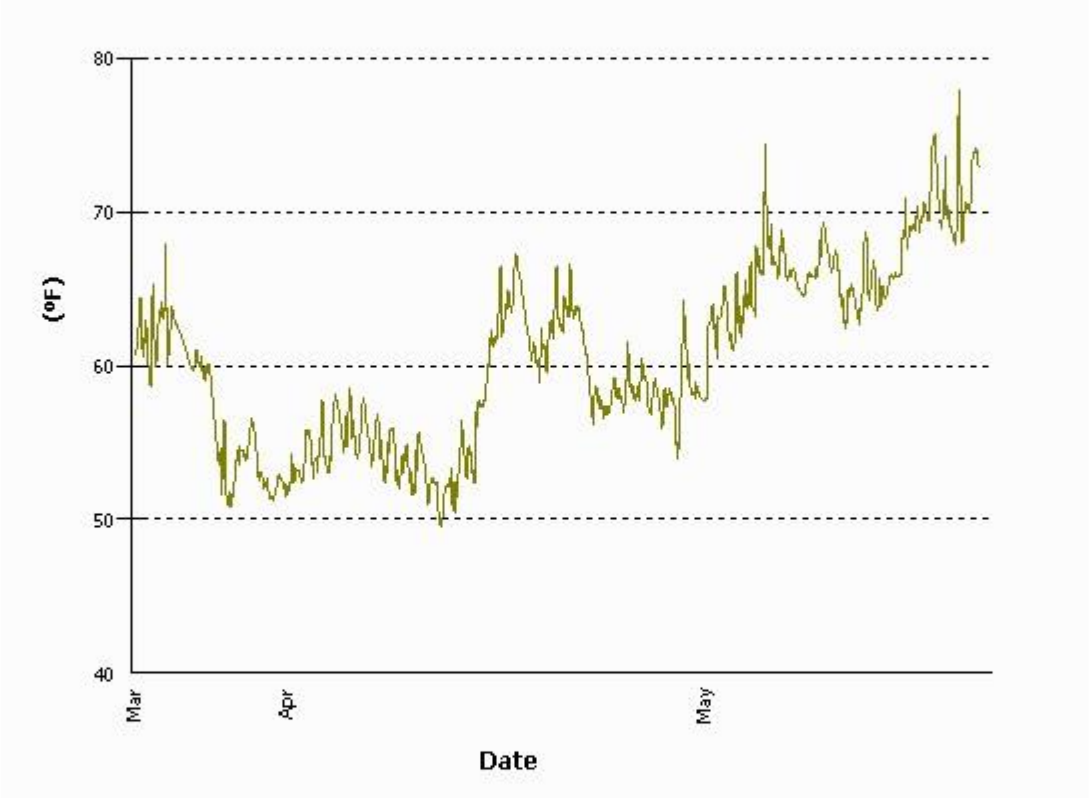
- Temperature and DO can also vary widely over short time scales

“Typical” temperature variability over 2 months

- Daytime heating and nighttime cooling can result in large diurnal temperature swings.
- Rapid changes also occur in response to air temperature changes
- These effects are exacerbated by limited exchange with offshore waters, and by dark bottom sediments.

Patapsco River - Masonville Cove
From MD DNR Eyes on the Bay website



Direct influences of shoreline and nearshore exchanges/fluxes

- Inputs of nutrients, fresh water, and sediment from overland flows/small streams
- Inputs of nutrients (especially P) and sediments from shore erosion
- Inputs of nutrients and other contaminants from groundwater
- Filtering/transformation of suspended particles by advective flows through sands
- Trapping of offshore sediments and/or nutrients in tidal marshes (and intertidal flats, where present)

Physics affected by biology at lowest order

- Primarily through benthic organisms, since dominant physical balance in the nearshore is frictional
  - SAV/Seagrass beds
  - Marsh grasses
  - Reef builders
  - Bioturbators
  - Microphytobenthos
- Light at the bottom is a key aspect of these interactions, the presence or absence of which may lead to different steady states (Susq Flats)
- Dense benthic filter feeding communities are another key aspect of these interactions, the presence or absence of which may lead to different steady states.

What physical processes are affected by biology?

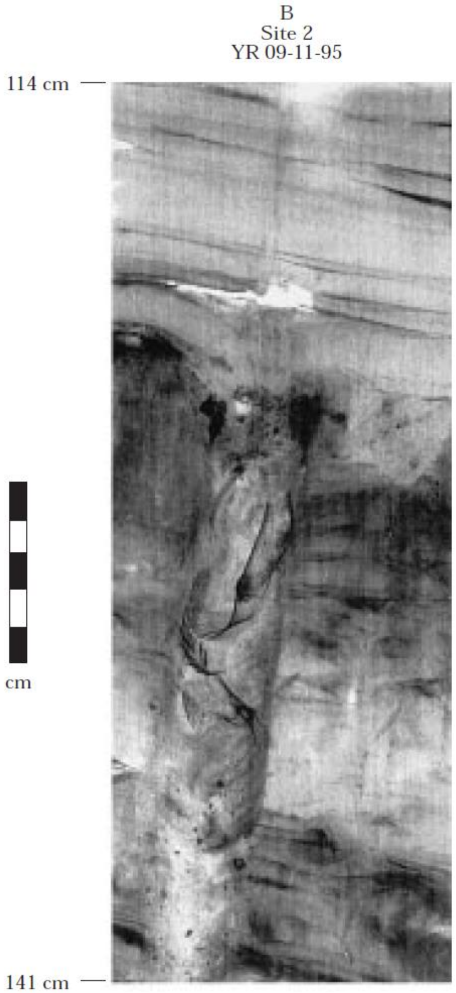
- Current velocities and horizontal fluxes of sediments and nutrients
- Water column mixing
- Bottom roughness (form drag)
- Skin friction (component of stress acting on sediment particles)
- Particle settling velocity
- Particle deposition rate
- Critical stress at the sediment-water interface
- Water content and sediment mixing below the sediment-water interface
- Critical stress below the sediment-water interface

Many of these processes are strongly interconnected

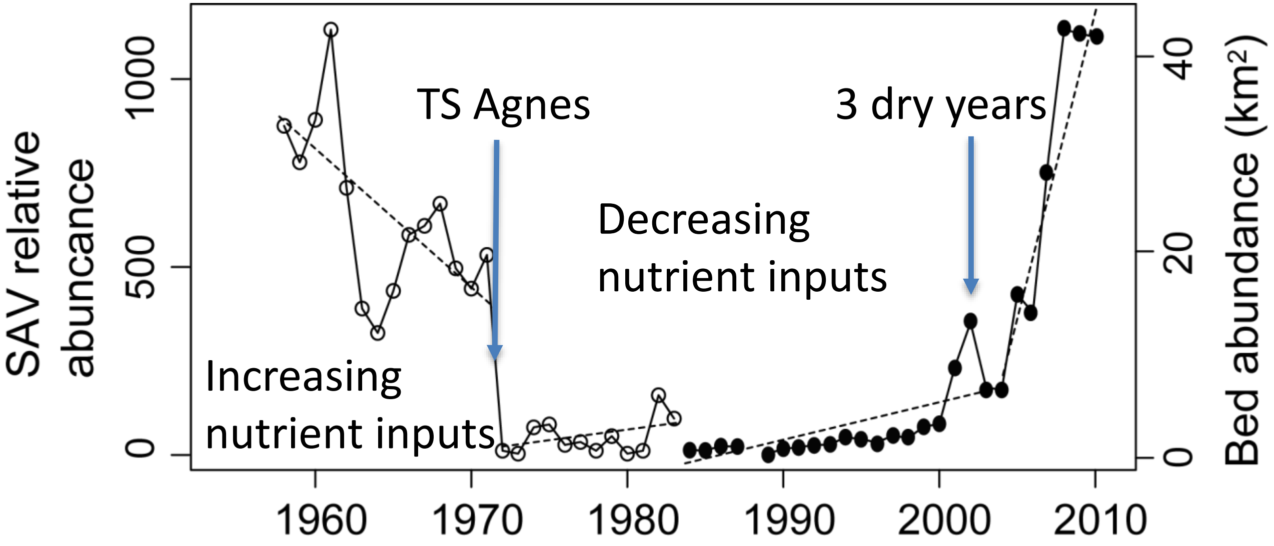
How stable are interacting physical-biological systems?

- Strong physical forcing or excess pollution can overwhelm biological communities, causing them to retreat or disappear
- Positive feedbacks in physically dominated systems can make it very difficult for biological communities to recover, but..
- Extended time windows of favorable conditions may allow some biological communities to begin recovering
- If these communities exert positive feedbacks on their physical environment (if they are “ecosystem engineers”), they can expand and become stable
- Physical-biological interactions characterized by positive feedbacks lead to “tipping points” with more than one steady state possible

Two real world examples:

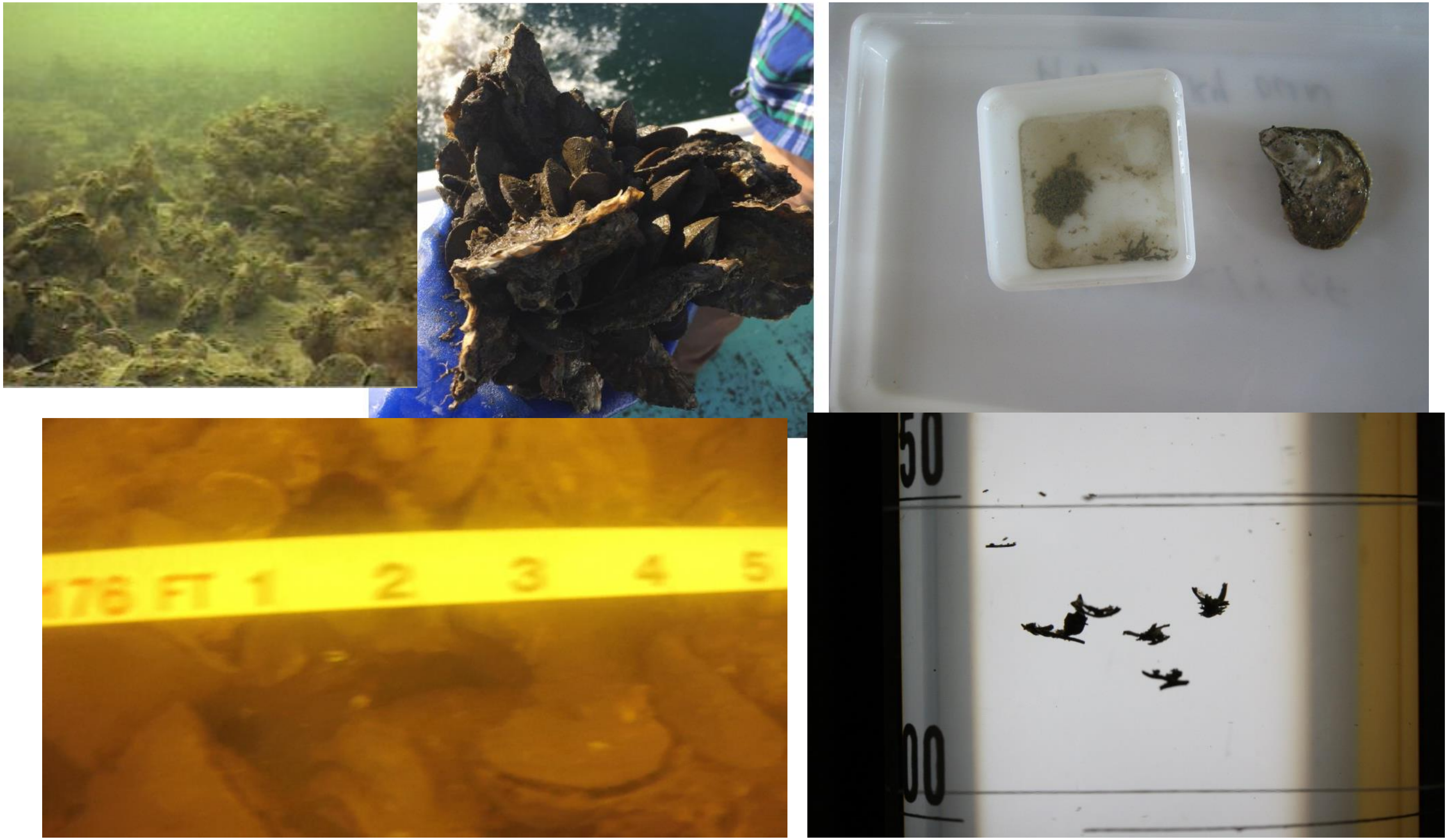


A large underwater grass bed in Chesapeake Bay, USA disappeared after Tropical Storm Agnes in 1972 then recovered suddenly after 30 years (*Gurbisz and Kemp 2014*).



<<<< A highly bioturbated (biologically mixed) region deep in a sediment core suddenly changed to a physically dominated region nearer to the surface, probably when sediment transport intensity made the sediments too unstable for survival of the animals. From the York River, VA, USA. *Dellapenna et al. (1998)*

Restored oyster reefs provide significant new bottom roughness (~10-30 cm). Each animal filters about 10 L h^{-1} of water, removing slowly settling fine sediment and phytoplankton and producing large (~1-5 mm), fast settling (~1 cm s^{-1}) biodeposits.



Summary of physical-biological interactions

- Large benthic ecosystems interact significantly with physical, biogeochemical, and sedimentary processes in their vicinities.
- It is possible to model these physical-biological interactions in a straightforward manner.
- In many cases, these interacting systems may transition rapidly between alternate steady states because of positive feedbacks – “tipping points”.
- Once a new steady state has been established, it can be very difficult to return to previous conditions. The level of difficulty varies from case to case.