Indicators, Diagnosis, Reduced Uncertainty, Criteria Assessment, Policy Setting and Discovery: Advancing Applications Using High Frequency Water Quality Monitoring Data in the Chesapeake Bay Program Partnership

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USGS
science for a changing world

Chesapeake Bay Program
A Watershed Partnership

Vignettes: Applications of High Frequency Data

- Diagnosing causes of fish kills: Two cases.
- Realtime fisheries management decision support
- Reducing estimation uncertainty
- Criteria assessment
- Bay health status/condition tracking
- Discovery

Case I. Fish Kill Assessment

Specific Issues for the Corsica River Watershed, MD.

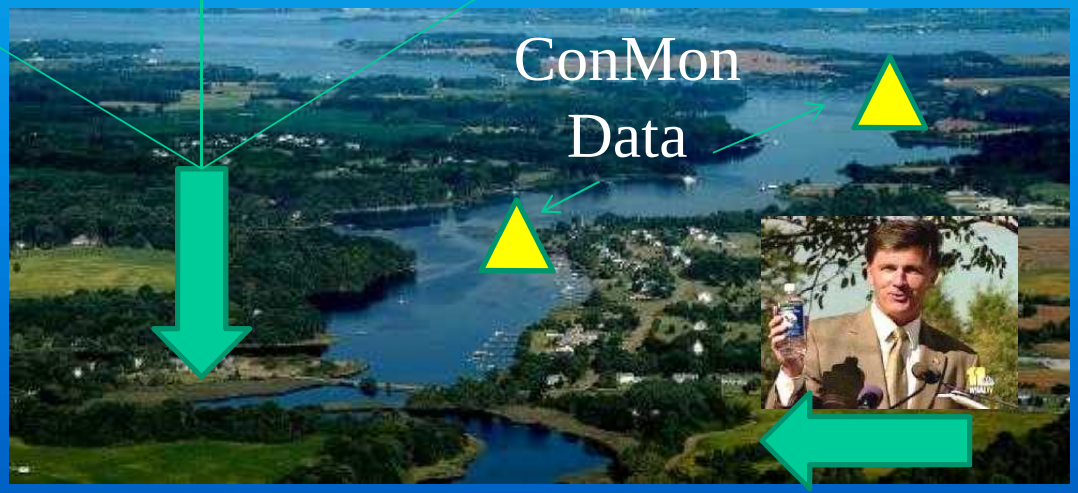
- Excessive sediments
- Overenrichment with nutrients
- PCBs
- Fecal coliforms
- Biological community impacts

September 27, 2005
State To Sell Bottled Water For Bay Fund

CENTREVILLE, Md. -- The state will start selling bottles of water later this week to raise money for Chesapeake Bay restoration.

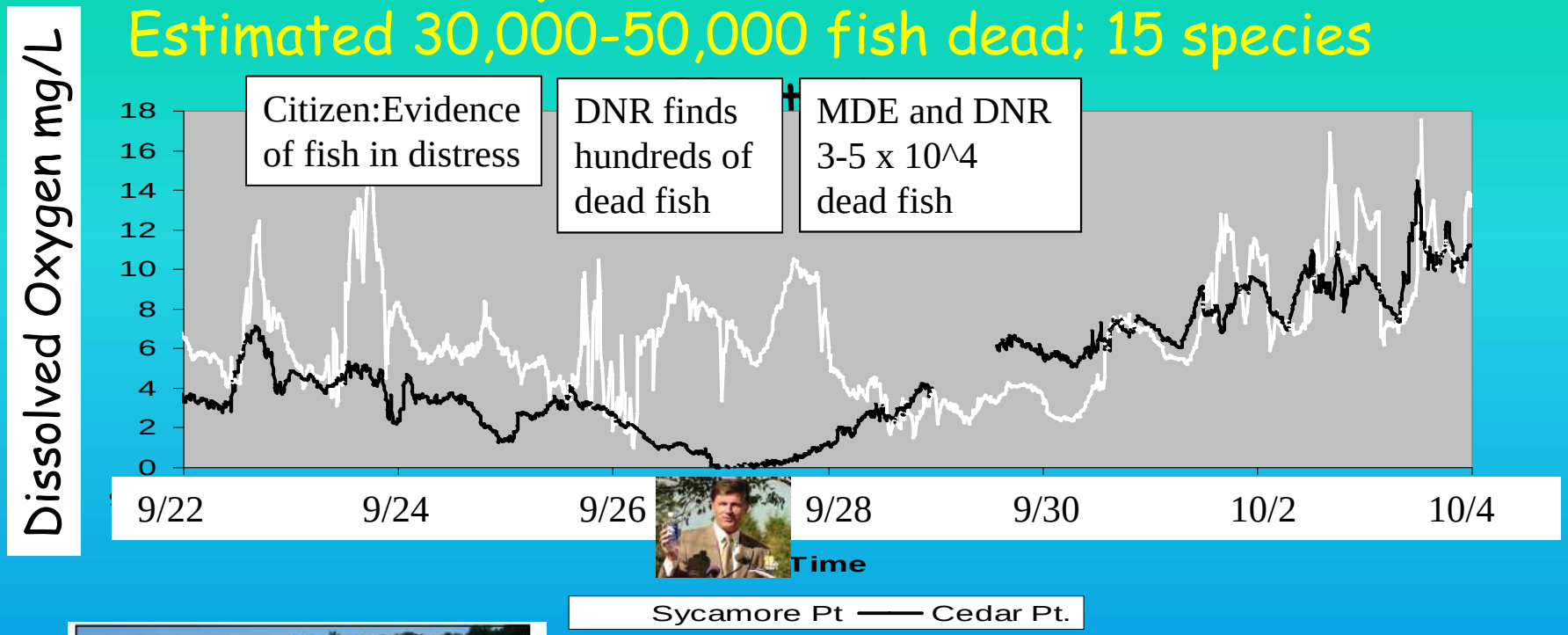
September 27, 2005
State To Sell Bottled Water For Bay Fund

September 26, 2005
MD DNR investigates local fish kill

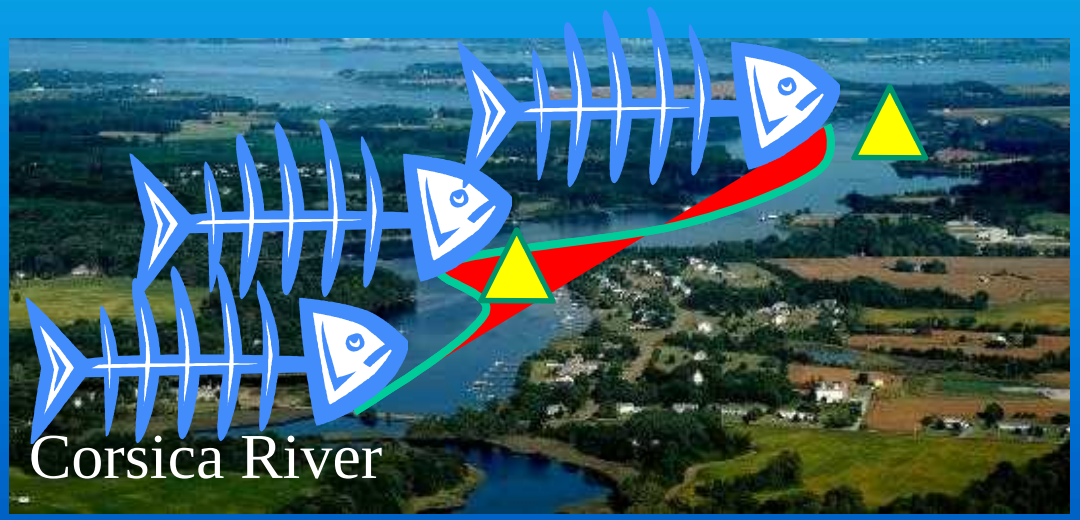


September 28, 2005

Estimated 30,000-50,000 fish dead; 15 species



Fish Kill in the Corsica



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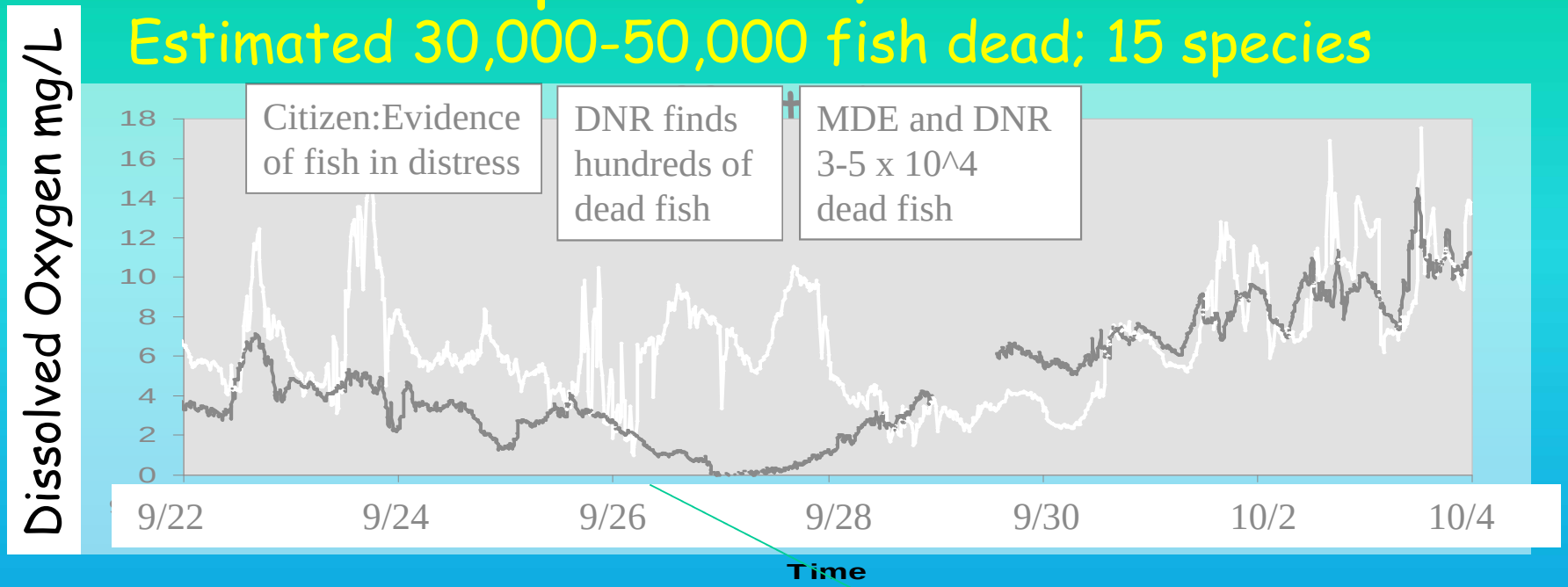


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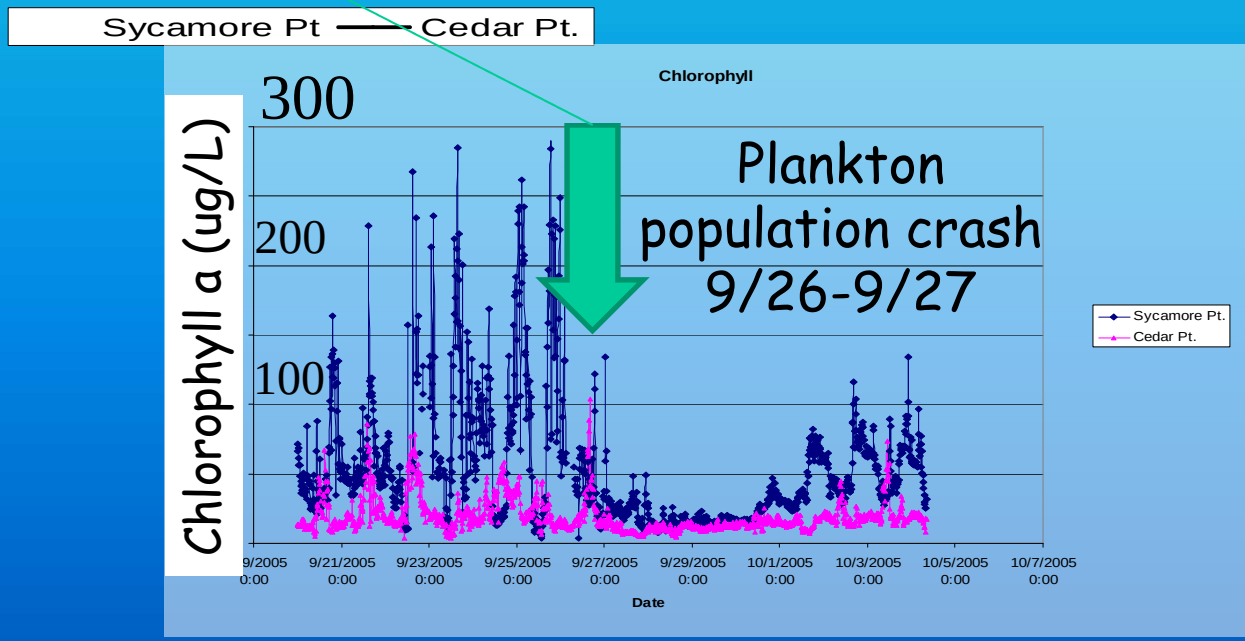

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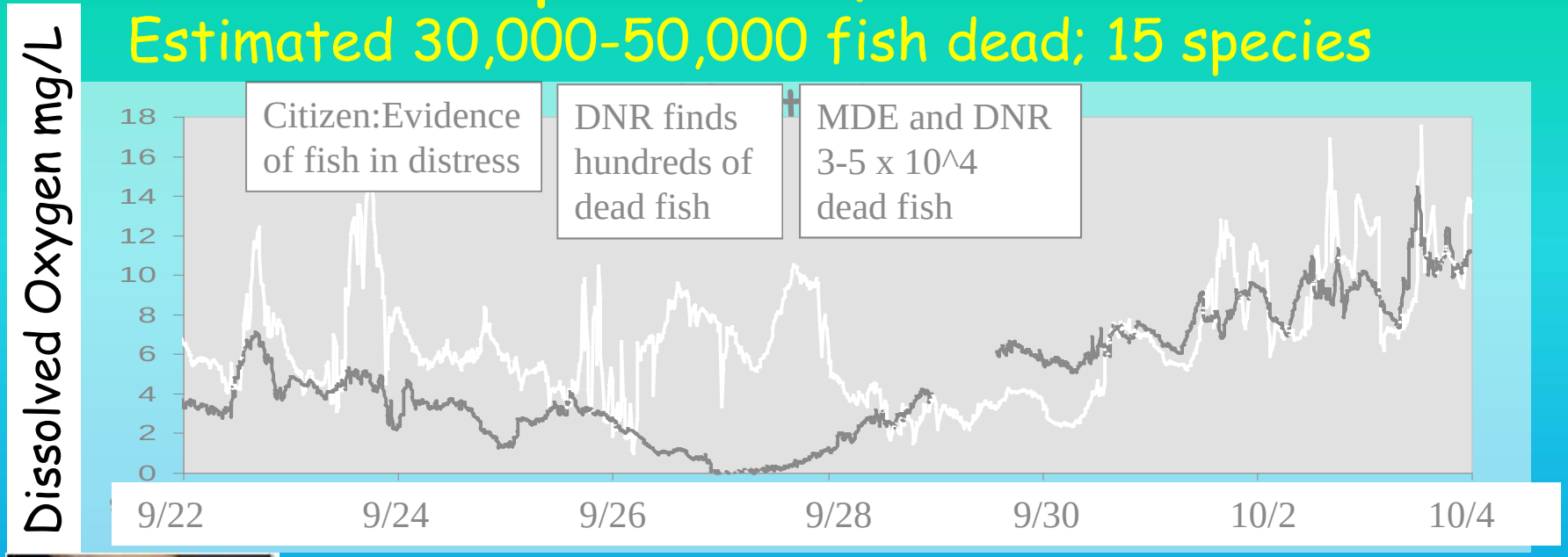
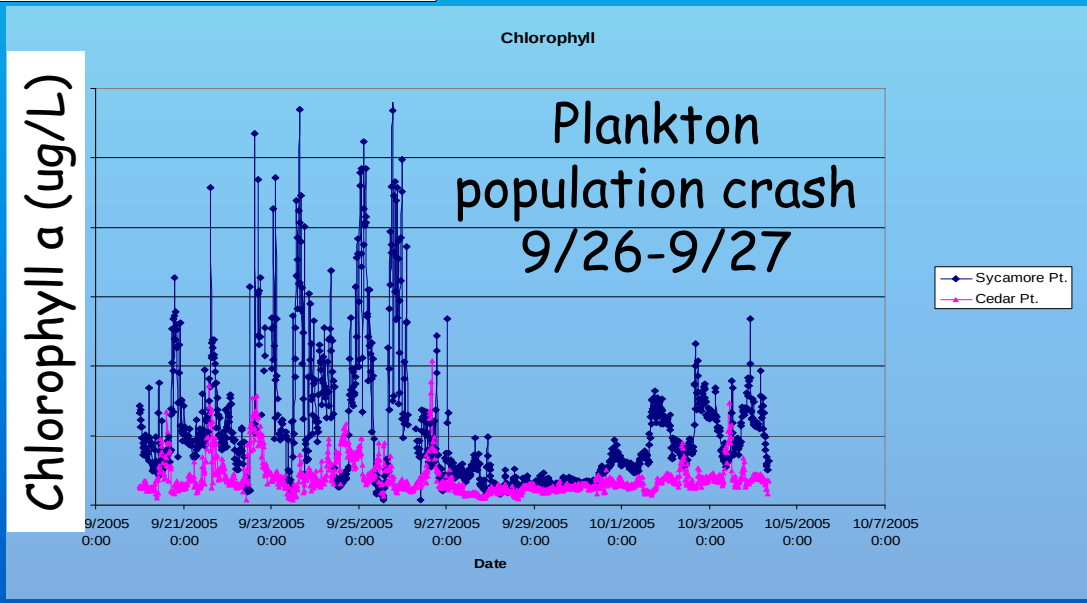


Karlodinium veneficum (toxigenic) Microscope and PCR results



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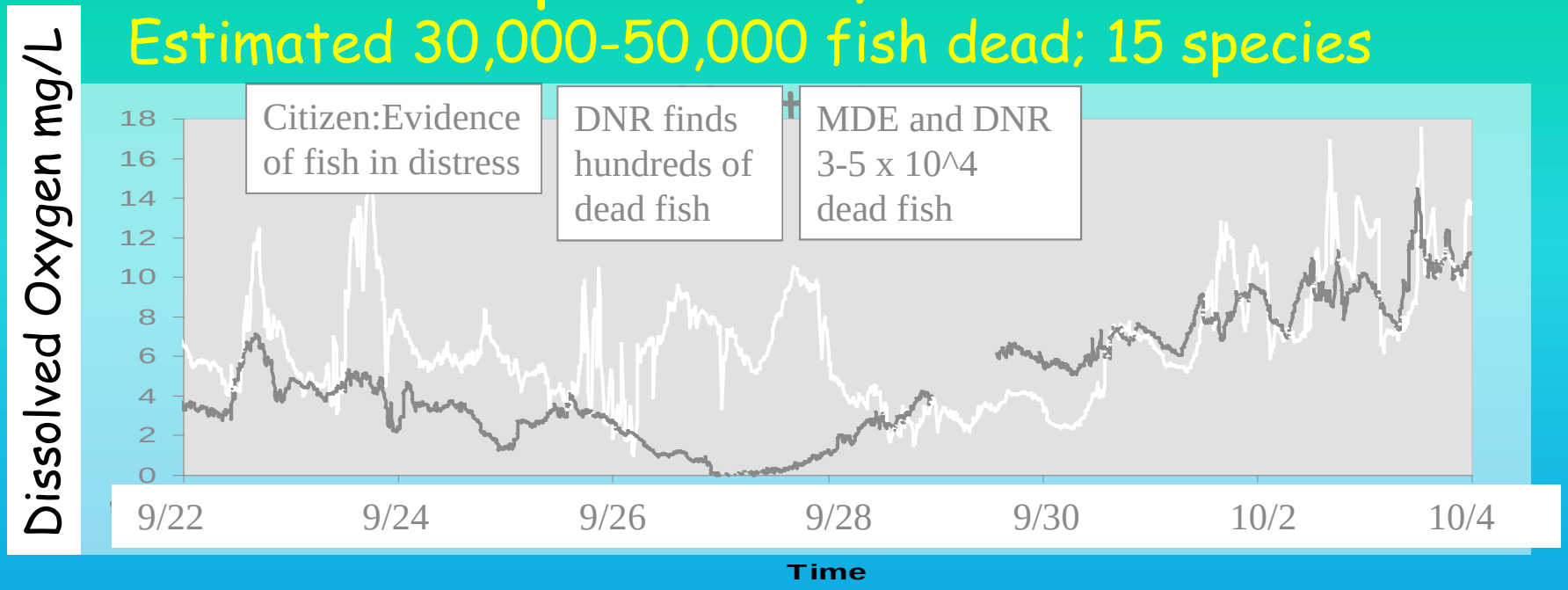
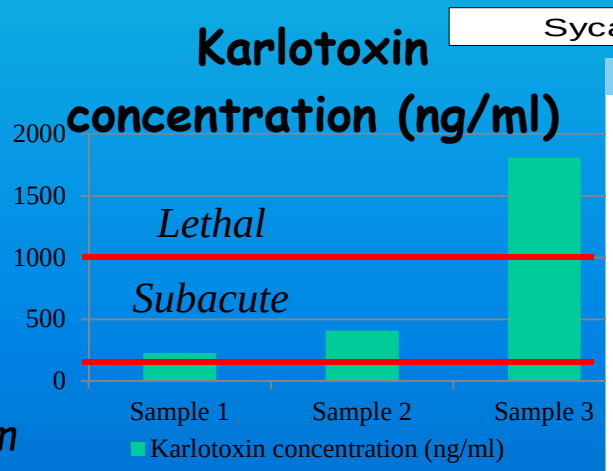
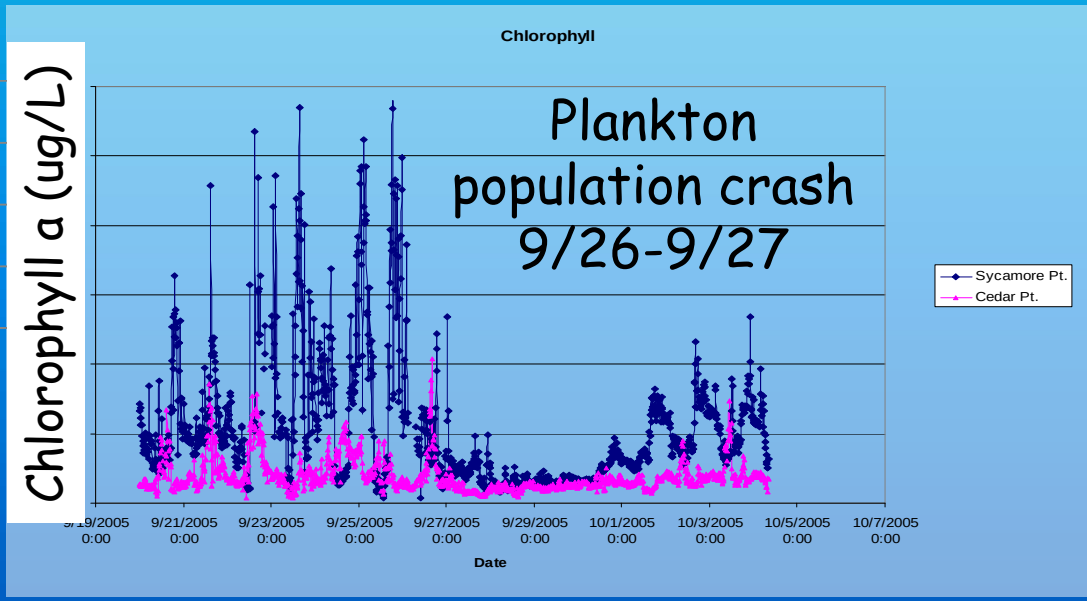


Karlodinium veneficum (toxigenic)



Ichthyotoxin



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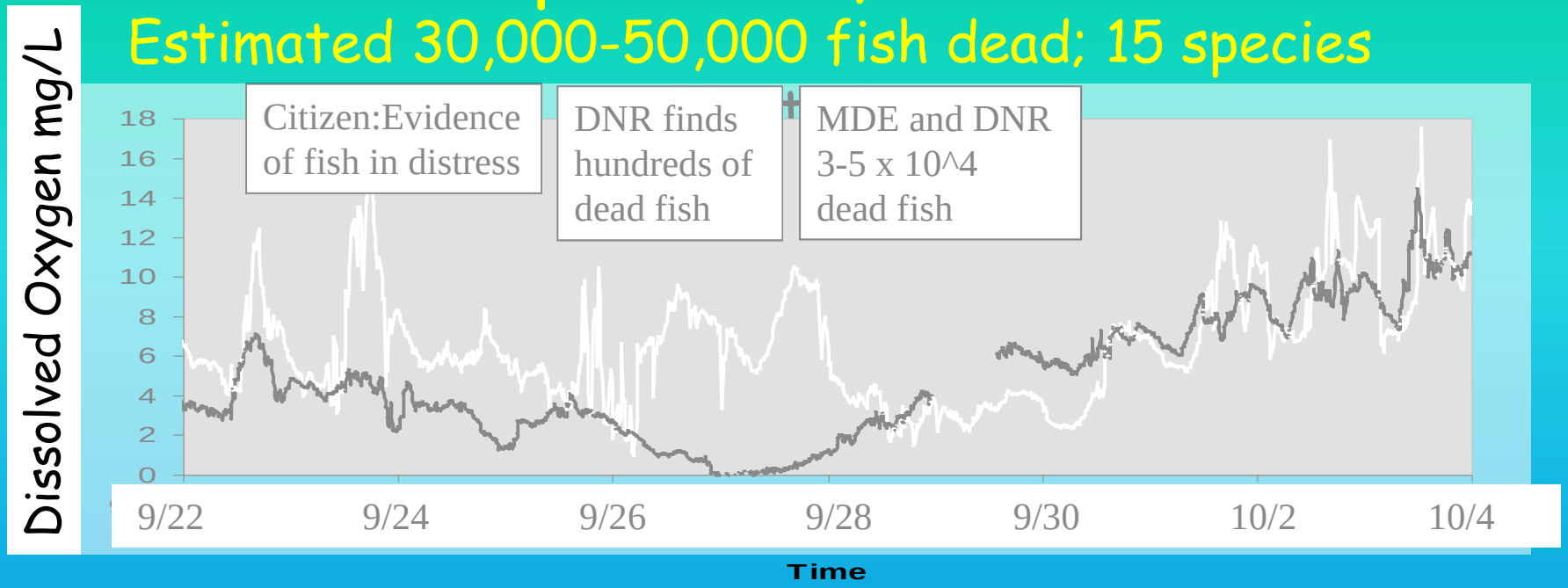

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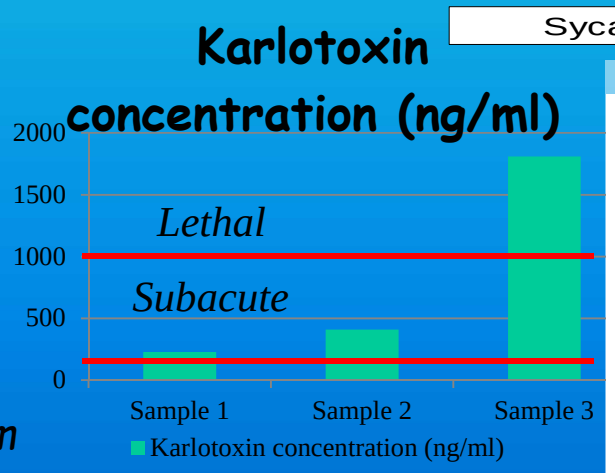
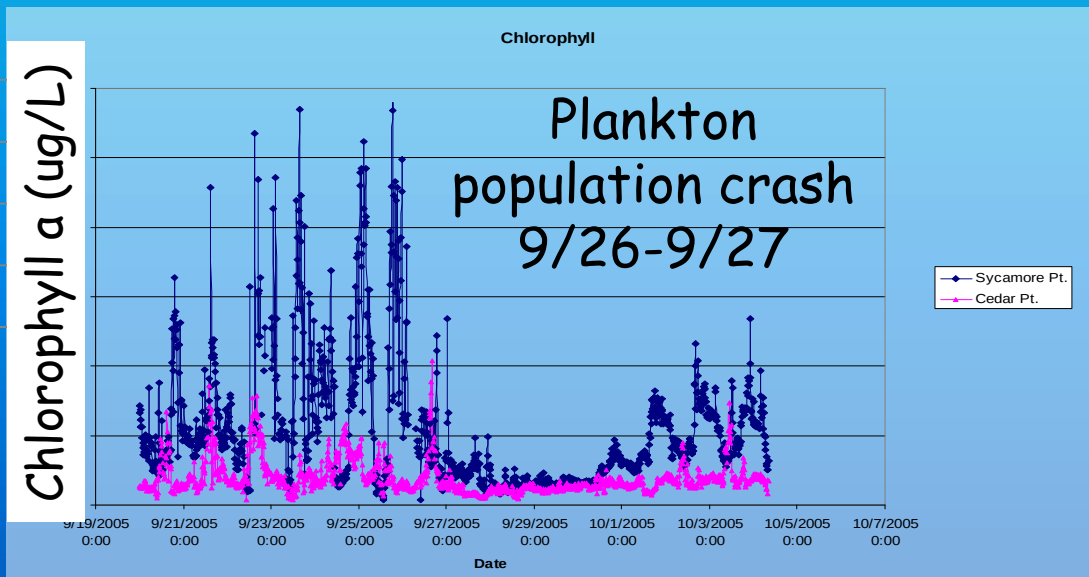


Healthy

Necropsy

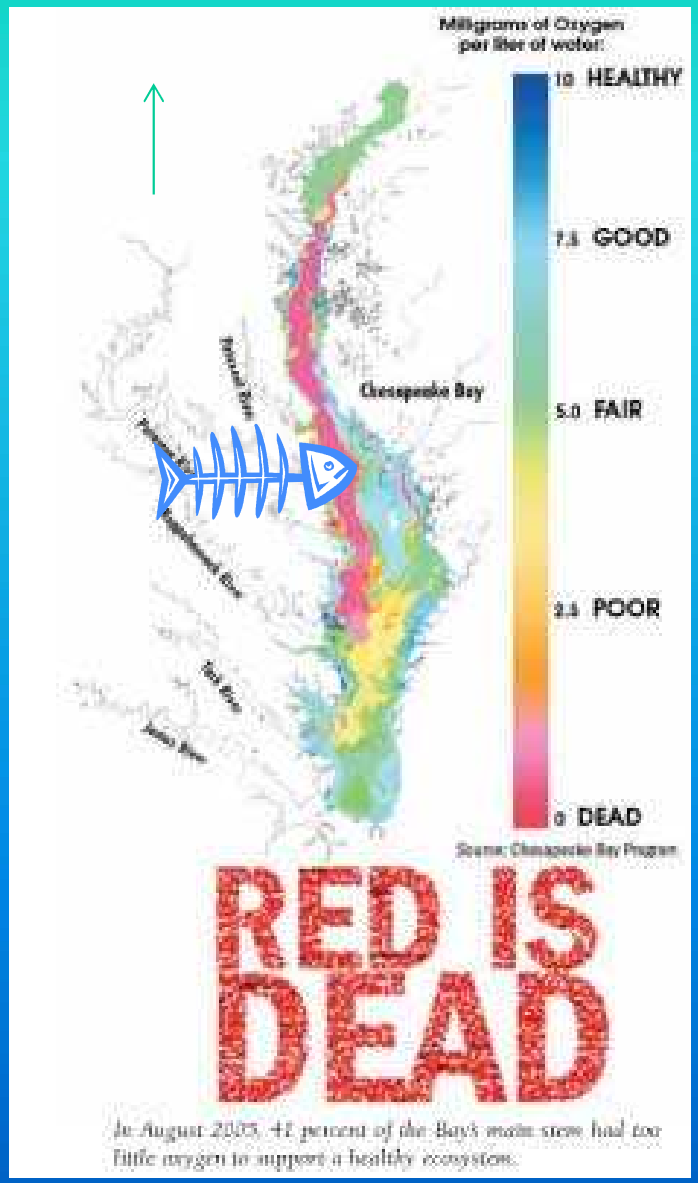
Compromised



Case I. Fish kill diagnosis

- Details of water quality dynamics preceding events for understanding of multiple stressor conditions
  - *High plankton biomass, high respiration demand, toxic algae, hypoxic to anoxic conditions, sublethal & lethal karlotoxin concentrations and compromised gill tissue*
- Leverage high time density data to direct and target further levels of investigation

Case II. Fish Kill. Potomac River, MD



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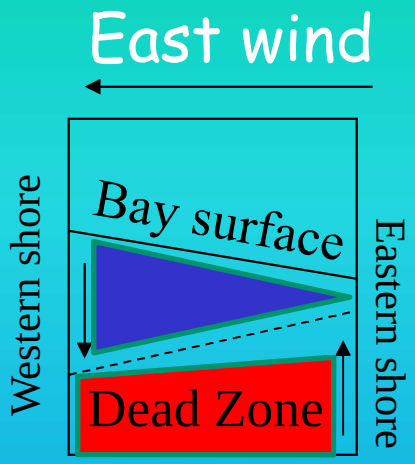
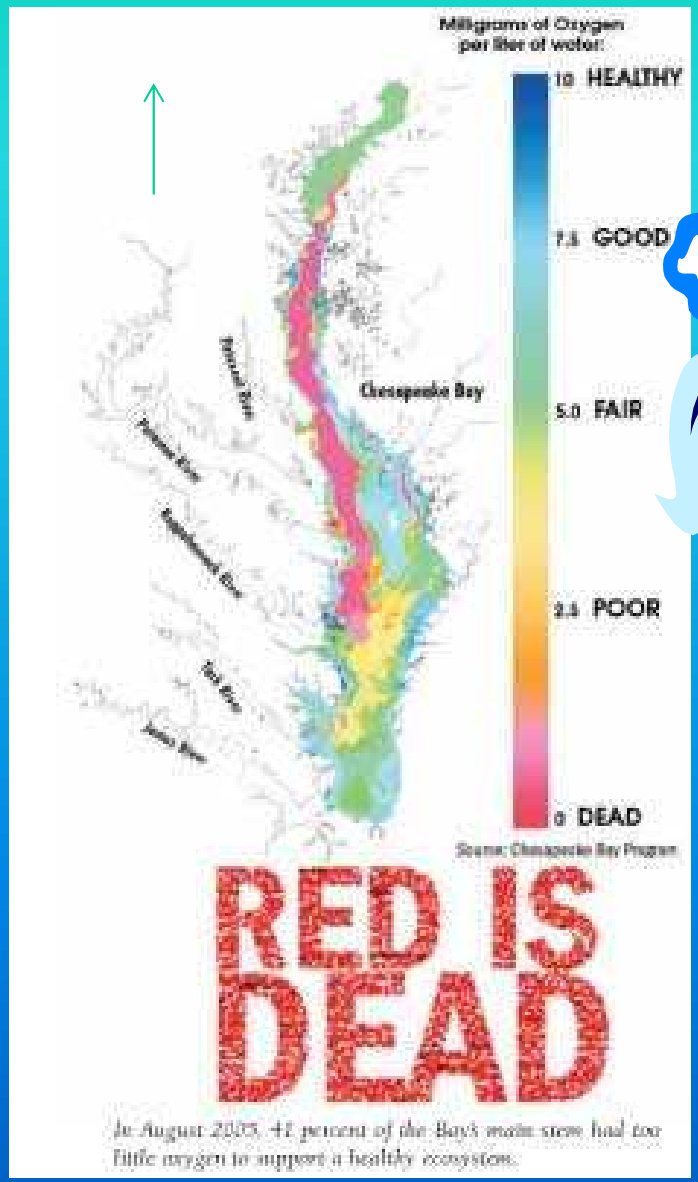
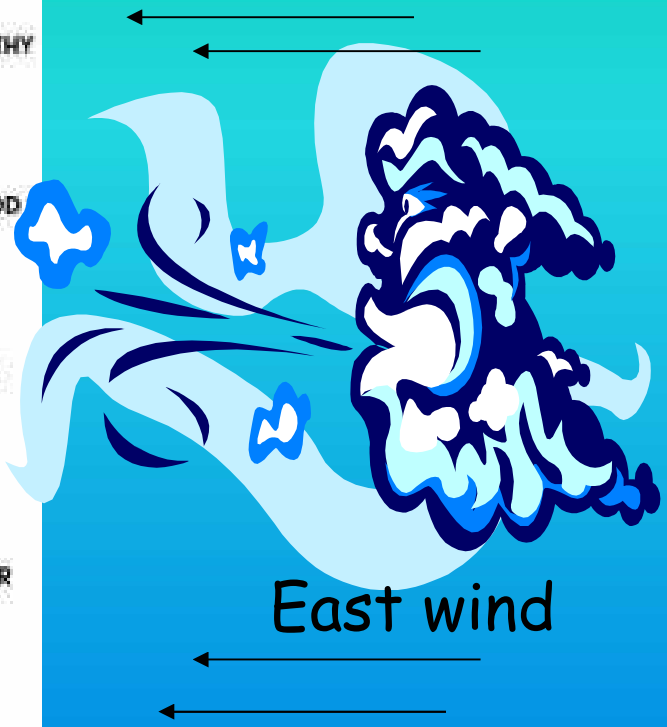


Climate influences
Bay water quality
and Living Resources:

Seiching effects.





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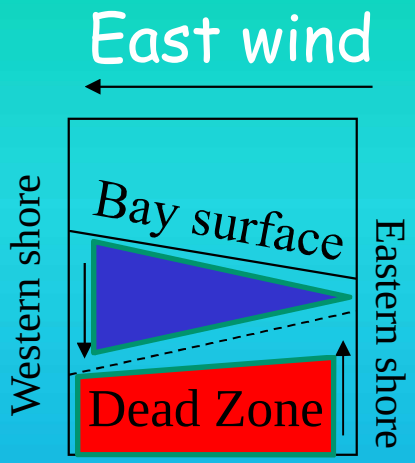

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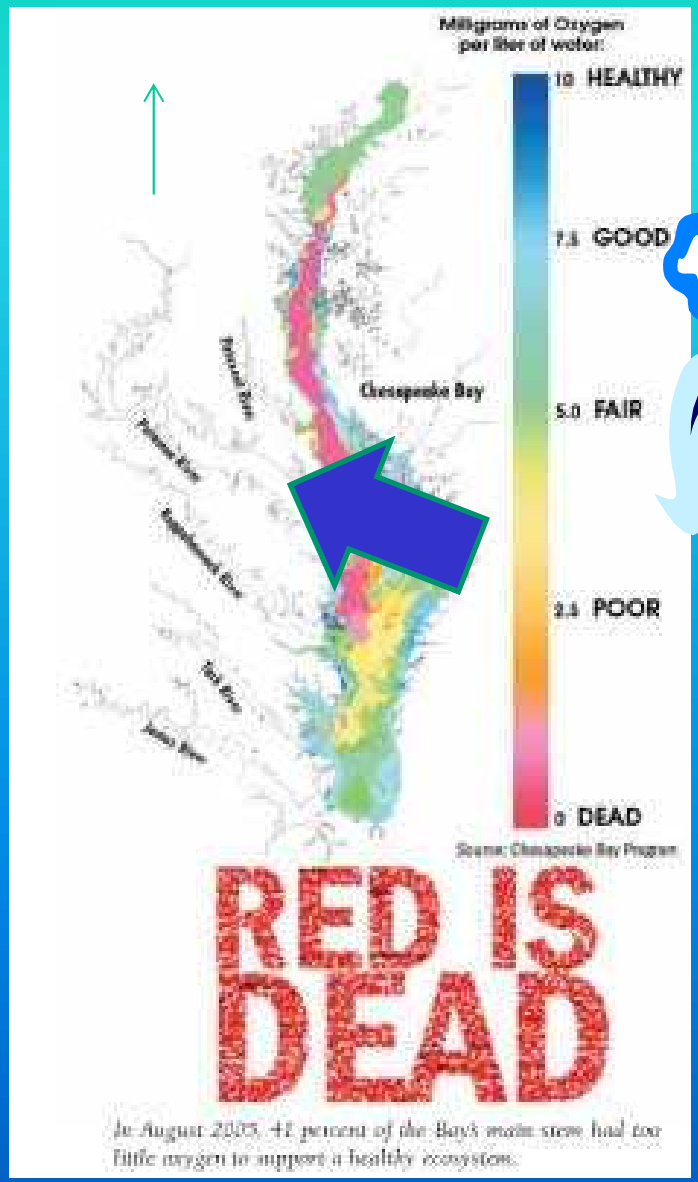

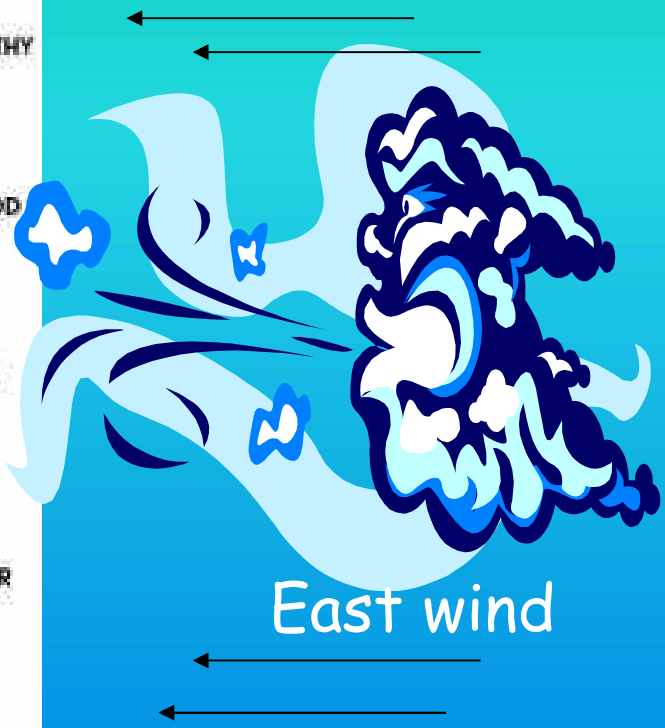

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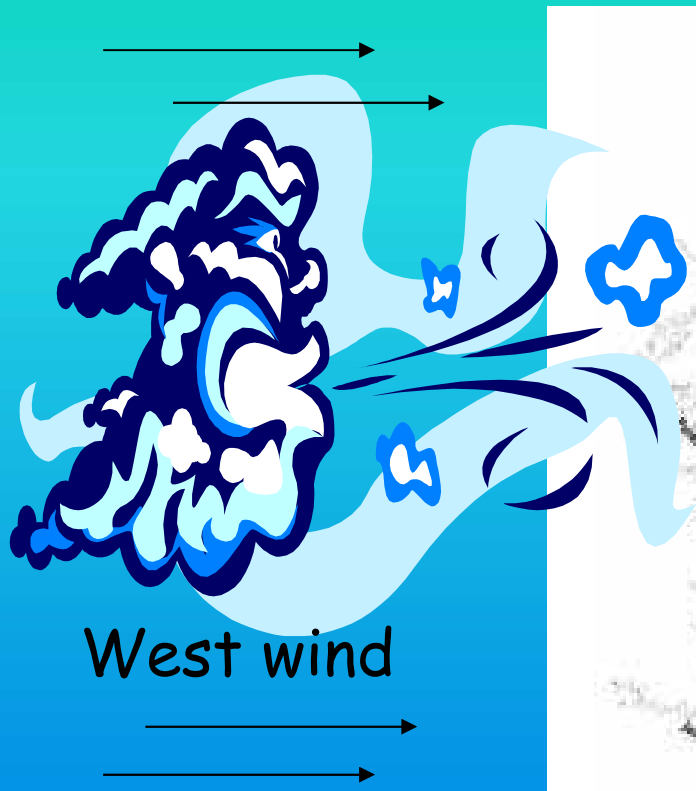
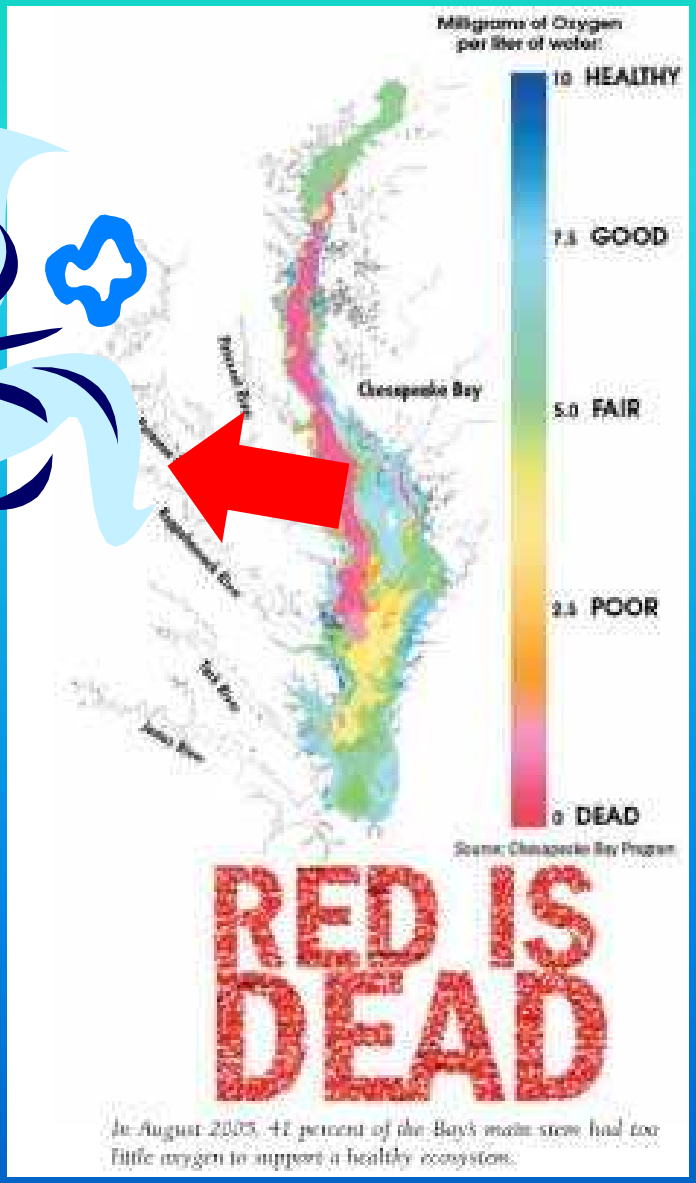
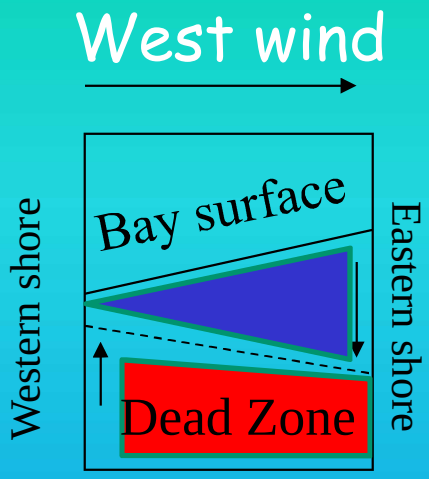
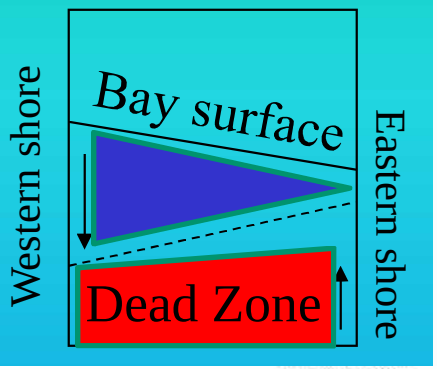




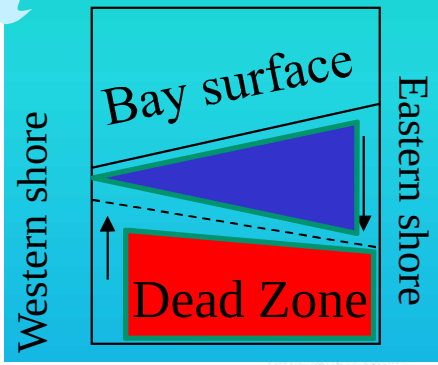


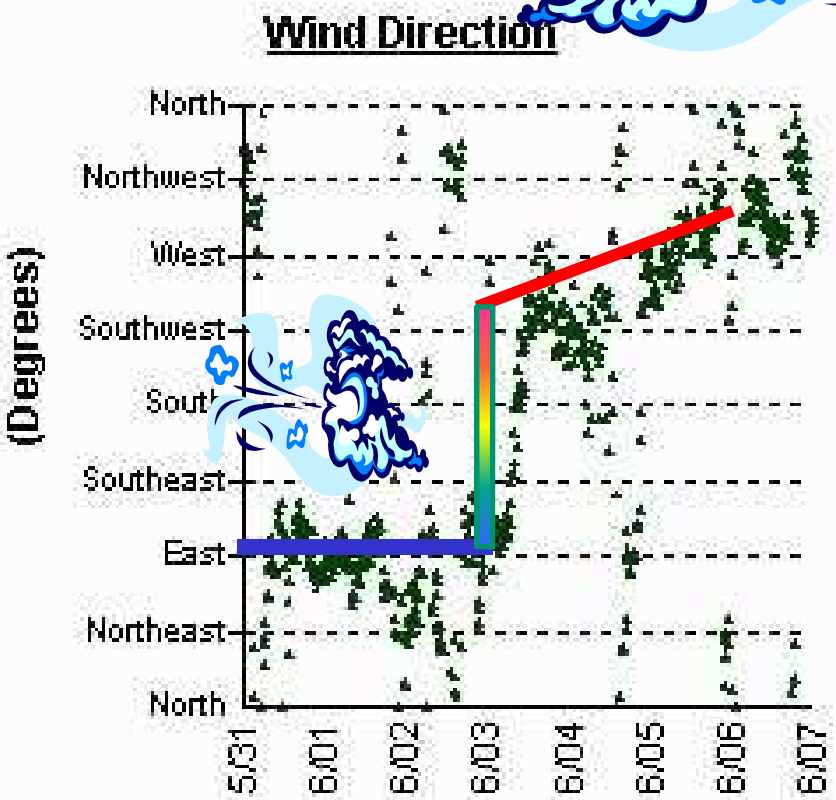
Case II. Fish Kill. Potomac River, MD

East wind

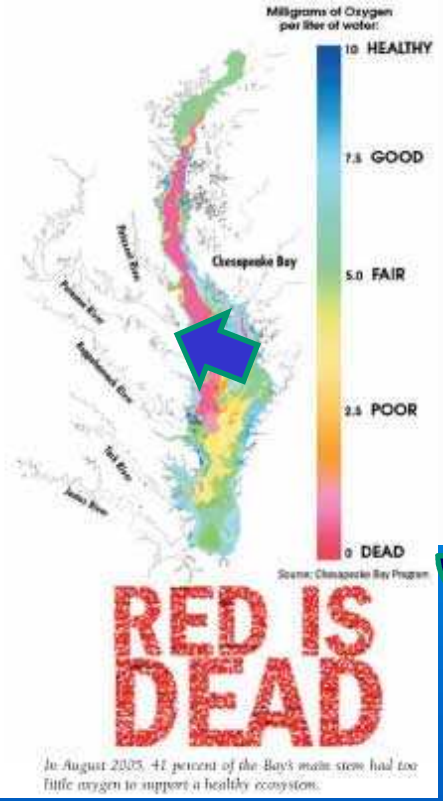


West wind





2006



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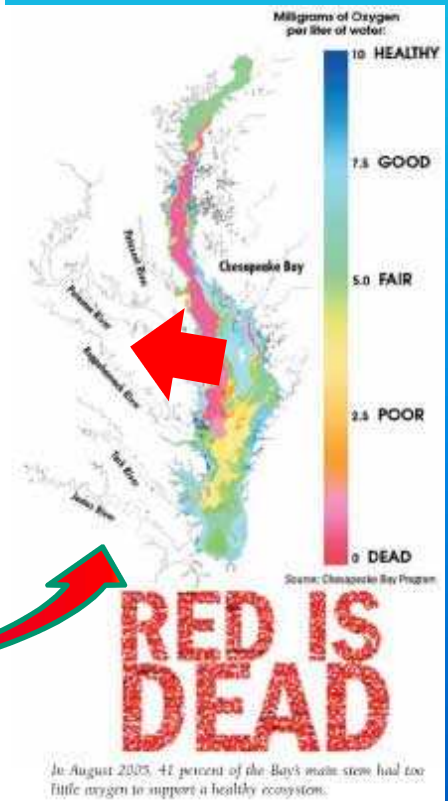


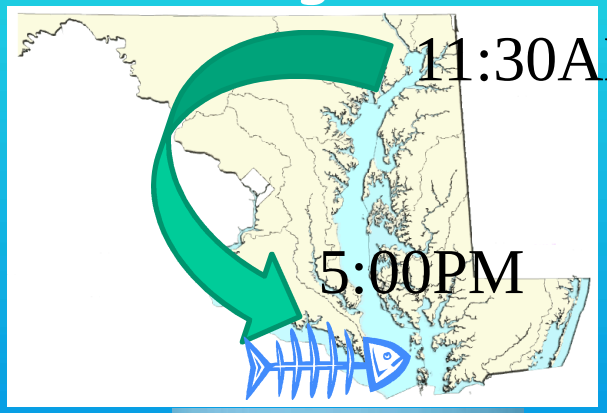
June 2006 Fish kill investigation time line

June 4th
Citizen observes dead fish

June 4th
sleeps on it…zzz

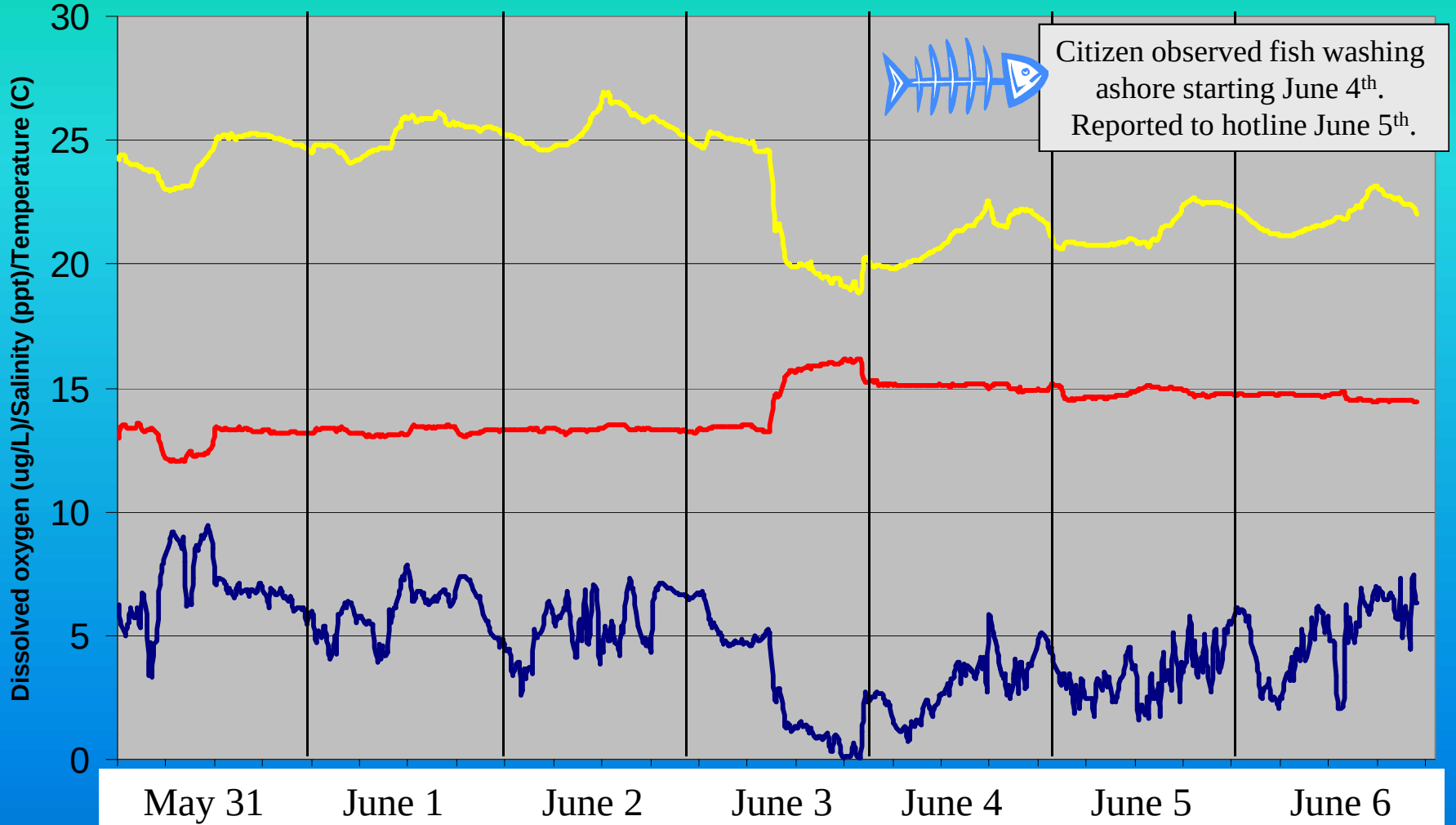
Morning June 5th
Oh yeh! Call MDE

June 5th State hotline calls field investigation team



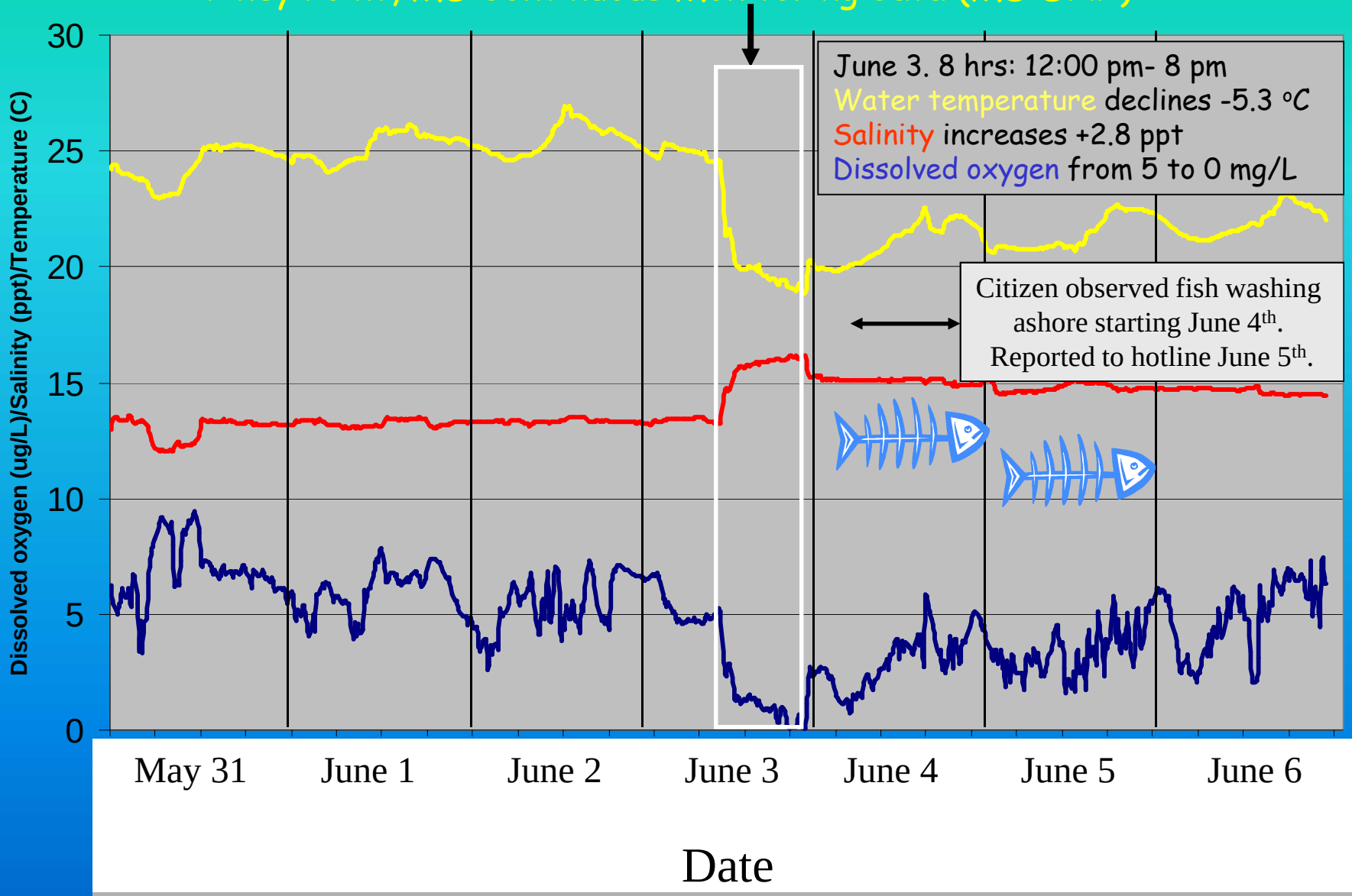
June 5th, 5pm
Data collection:
D.O. 5.2 mg/l, SAL=15
Temp=23 oC
Hmmmm…

June 5, 2006. Thousands of fish dead in lower Potomac River



Dissolved oxygen (mg O_2/L), Salinity (ppt) and Water Temperature (oC) May 31-June 6, 2006.

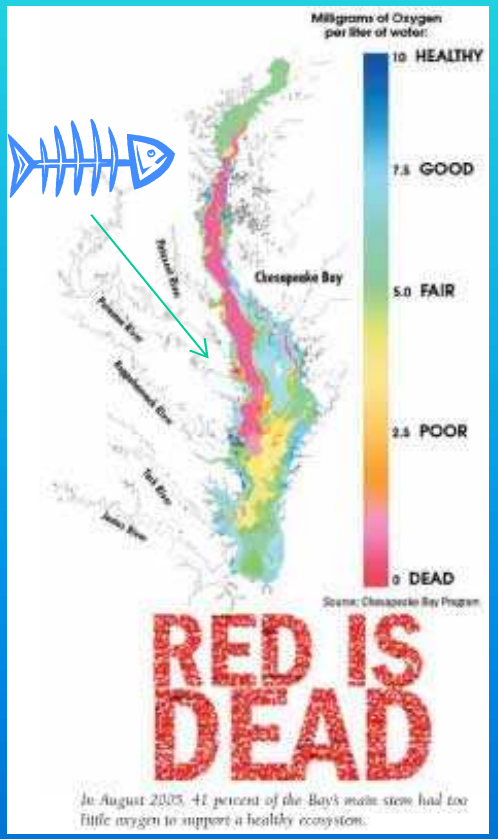
June 5, 2006. Thousands of fish found dead on lower Potomac River, MD.
Piney Point, MD Continuous Monitoring data (MD DNR)



Dissolved oxygen (mg O_2/L), Salinity (ppt) and Water Temperature (oC)
May 31-June 6, 2006.

Further sleuthing…

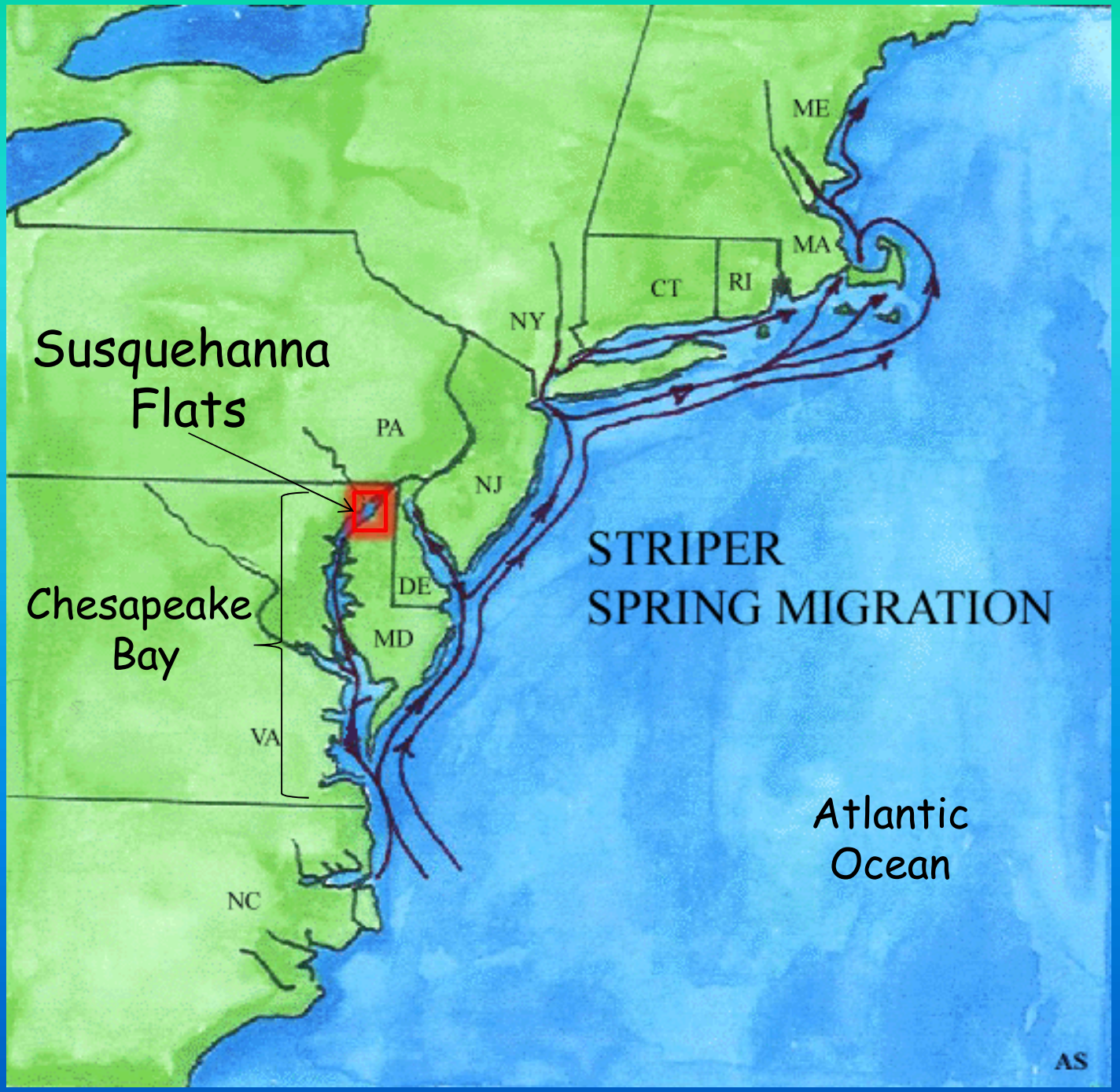
- Active Pound nets in the area
- Fish outside of nets apparently found refuge
- Waterman reported: Fish inside net died, discarded



Case II. Fish kill diagnosis

- Weather front passage
- Evidence for a Seiching event
  - Anoxic bottom water of the lower river and Bay entered shallow water habitat
- Pound net: Fish entrapment had no ability to seek refuge
- Plankton population and toxin evaluations indicated low probability of HAB contributions to the events.
- Dead fish were discarded = fish kill

II. Realtime Fisheries Management Decision Support


ME
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Susquehanna
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SPRING MIGRATION
Atlantic
Ocean
AS

2008

MARYLAND DEPARTMENT OF NATURAL RESOURCES

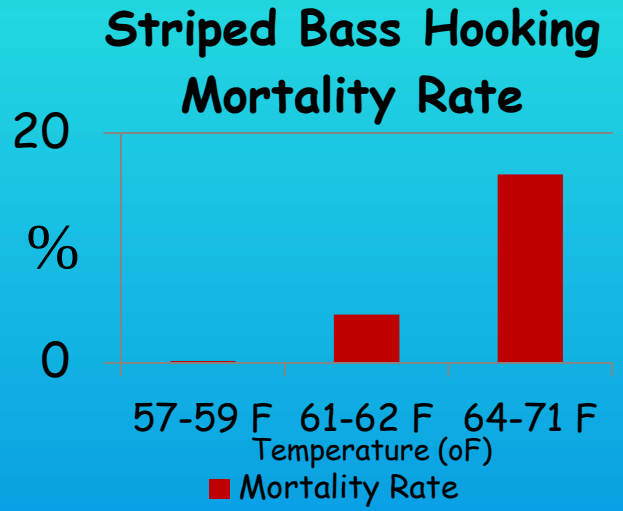
DNR Extends Susquehanna Flats Striped Bass Catch & Release Season

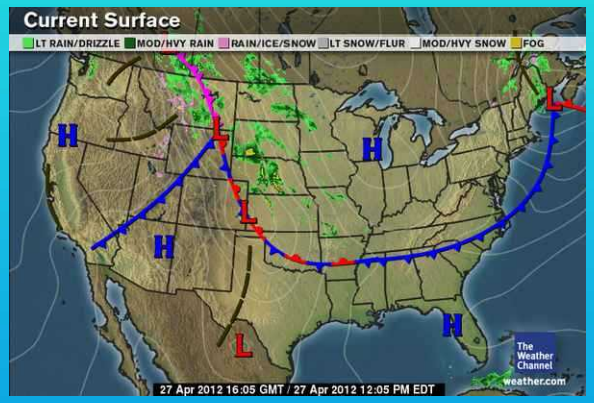
ANNAPOLIS, Md. — The Maryland Department of Natural Resources (DNR) Fisheries Service will extend the Susquehanna Flats catch and release fishery for striped bass by one week. The fishery, originally scheduled to close on May 3, will remain open until midnight on Friday, May 9.

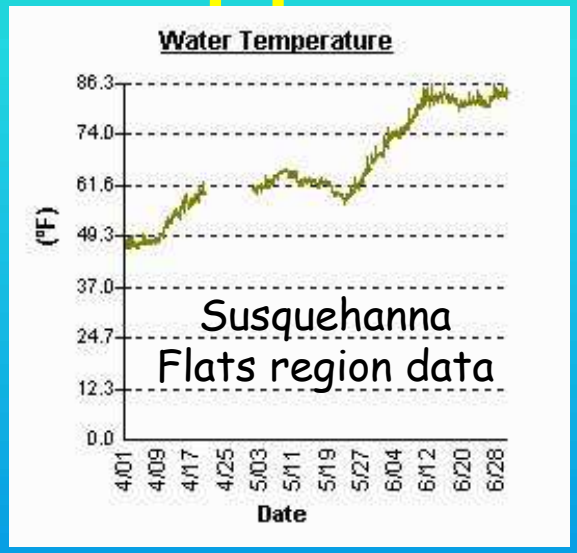
Cold water combined with the forecast of an extended cool weather period will keep water temperatures in an acceptable range for catch and release fishing for striped bass. Maryland anglers and visitors to the top of the Chesapeake Bay will enjoy another week of catch and release fishing for stripers in the unique shallow water expanse that is the Susquehanna Flats

"The experience of responsible catch and release fishing can not be overstated," said Fisheries Service Director Tom O'Connell. "We hope that this extended season will allow Maryland's anglers a longer opportunity to enjoy our world-class fishing opportunities under ideal weather conditions."

Integrated Realtime Fisheries Management Decision Support

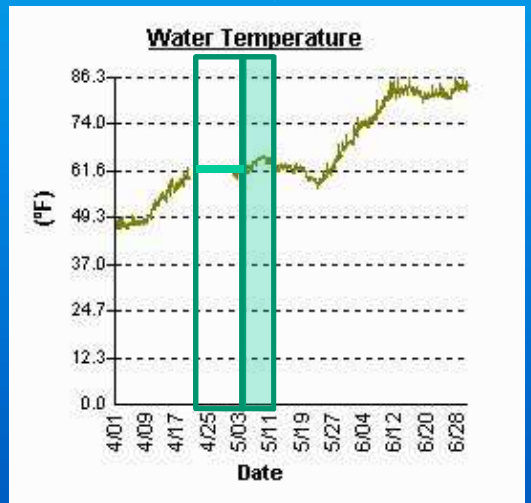






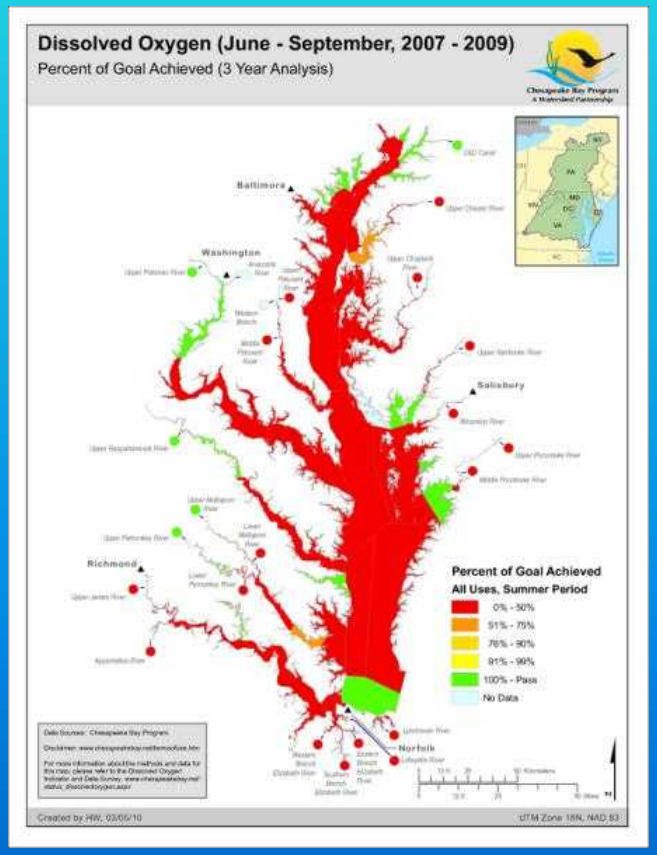
Fishery Science + Weather Forecasting + Realtime WQ Monitoring =

Management Decision to Extend the Trophy Fishing Season by 1 week.



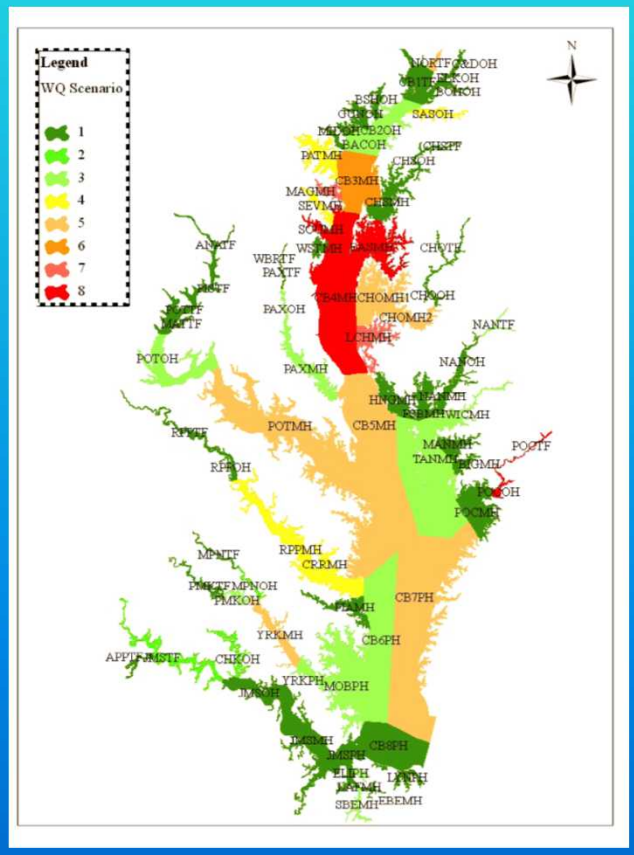
Result: Extended trophy season opportunities yield a happy fishing community ☺

III. Tracking Ecosystem Recovery



BMPs

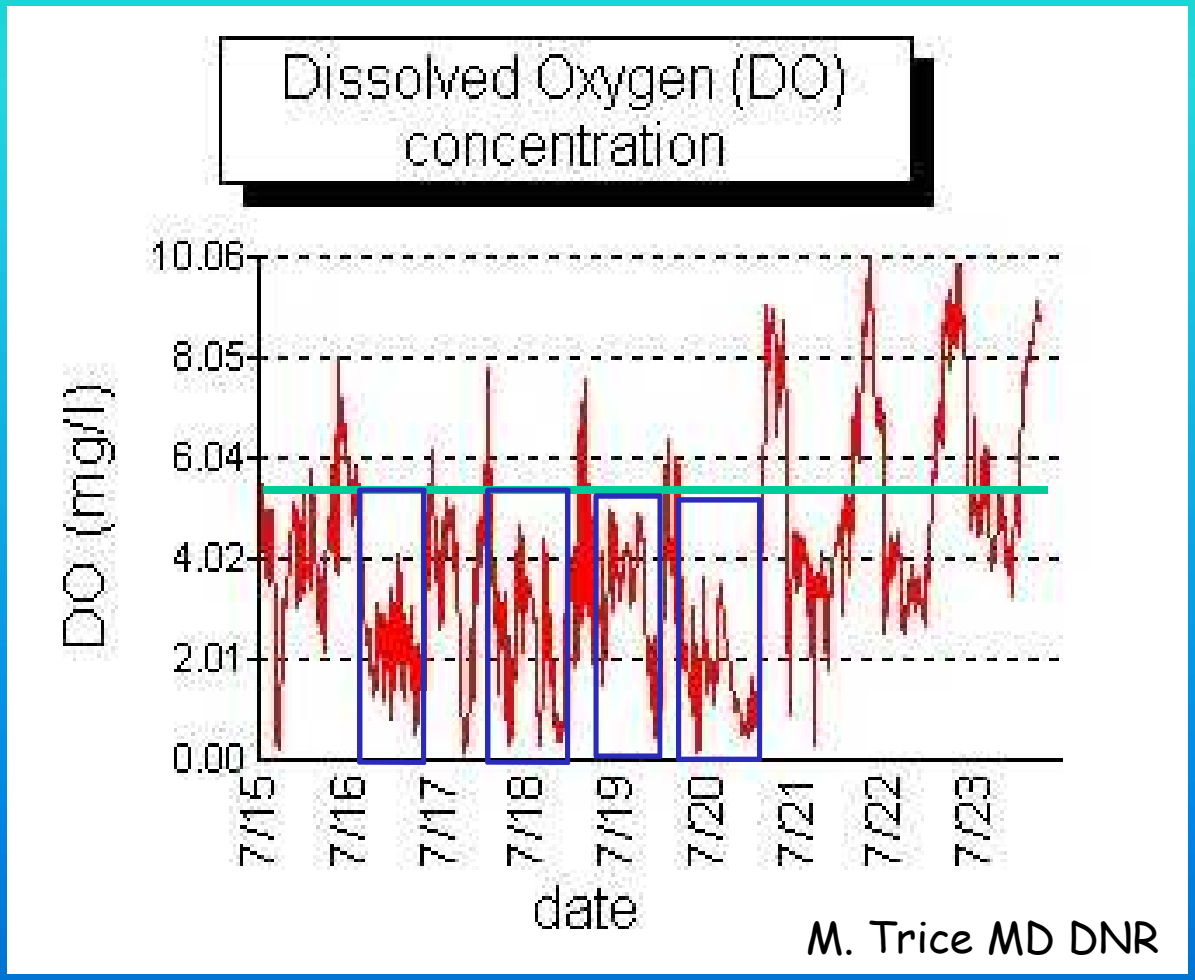
"Pollution Diet"



Present Status

Future Recovery Status Projections

Do we have a way to track degradation and recovery that bridges multiple monitoring scales in time?



Testing:
Examining durations below critical thresholds

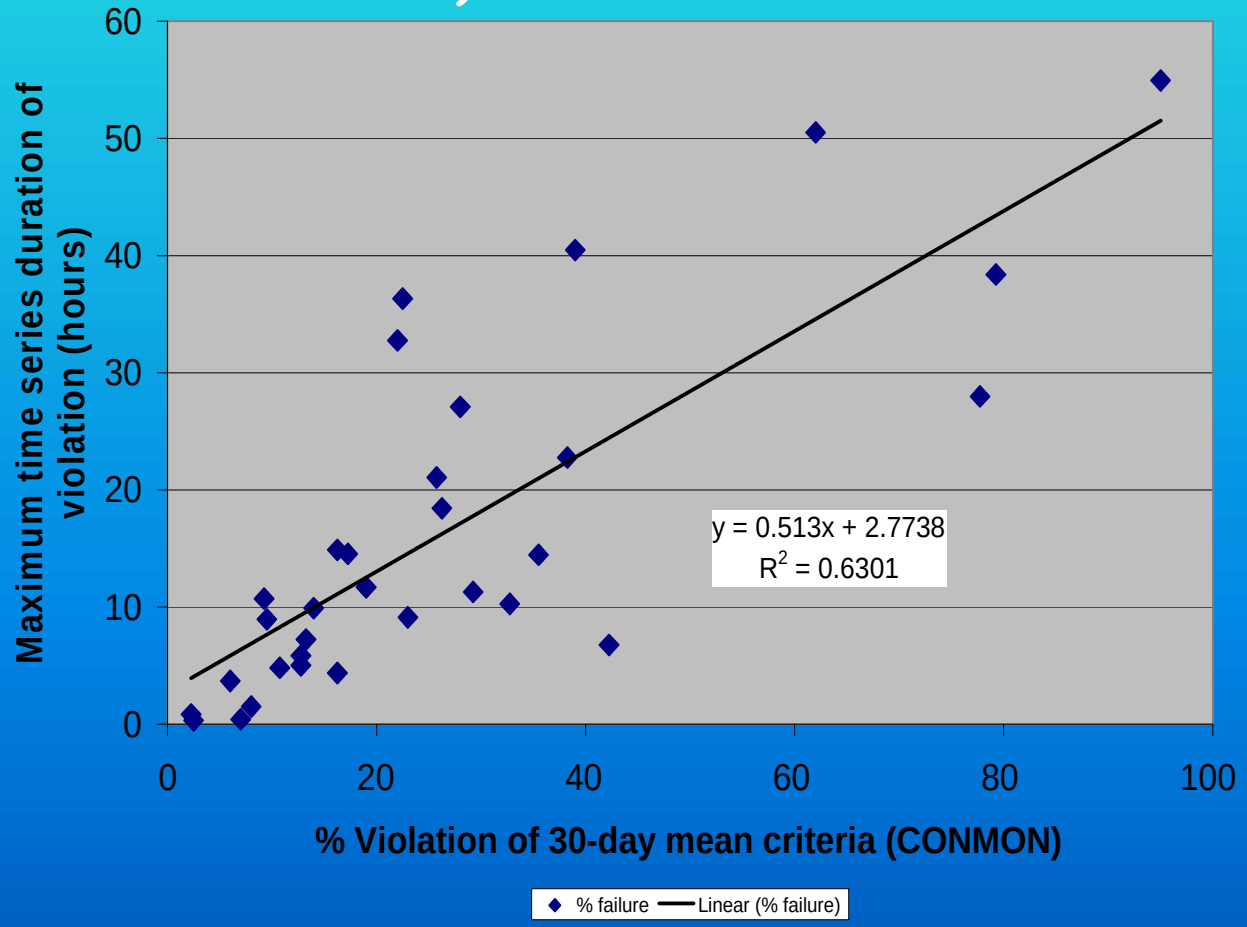
Biological Significance of Duration below D.O. threshold?

- Walt Boynton puts it this way…
- Assuming 6 breaths per minute, if you have to hold your breath once each minute (10 seconds) of the day, it might be uncomfortable but you survive.
- Now, compare that to holding your breath for 240 minutes continuously…

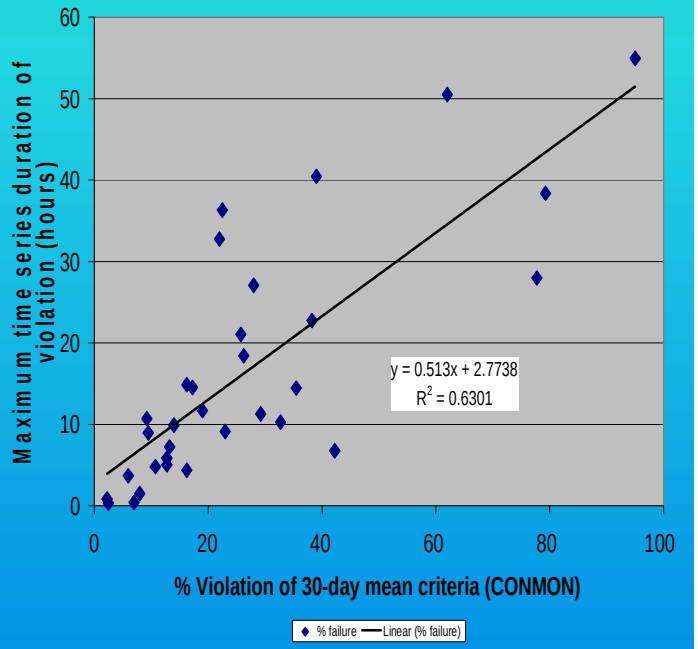
How does realtime dissolved oxygen data behave?

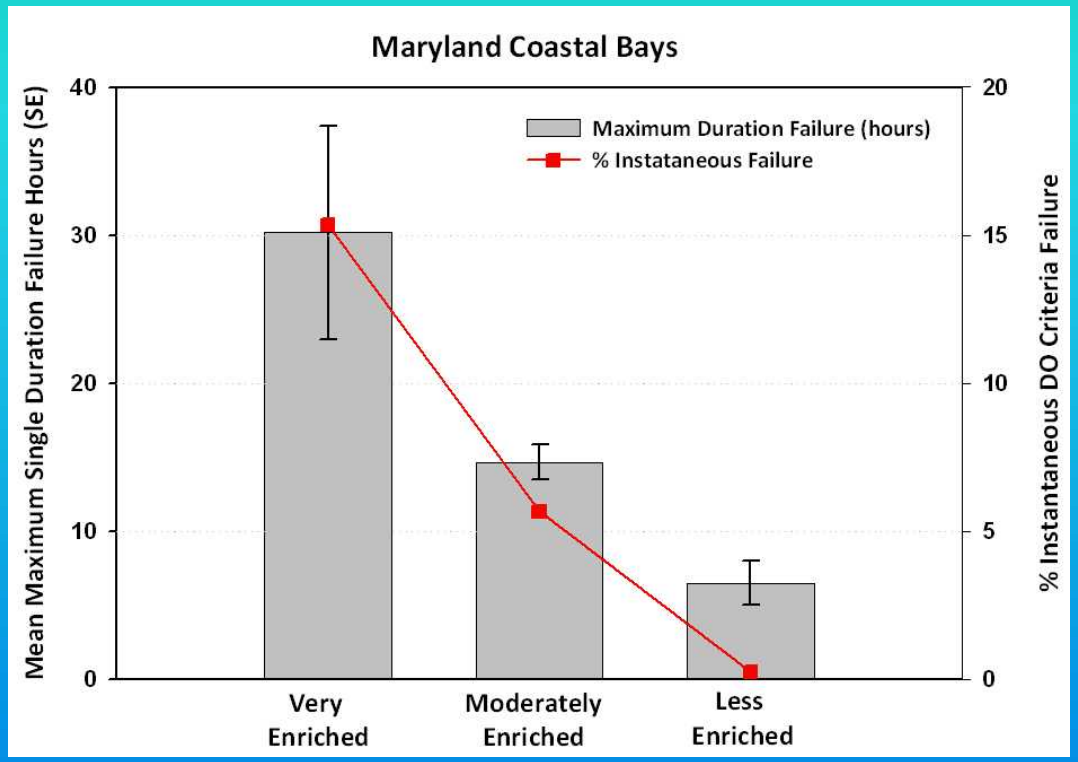
ECOSYSTEM RECOVERY INDICATOR DEVELOPMENT

Insight: An increase in the violation rate of a single water quality criteria relates to an increase in the maximum continuous duration (hours) below that criteria. (E.g over a complete summer season).



ECOSYSTEM RECOVERY INDICATOR DEVELOPMENT





Bailey and Boynton CERF 2011

Result:

Maximum continuous duration (hours) of failure relates to a nutrient enrichment gradient.

Data support further indicator development.

IV. Reducing Measurement Uncertainty

Data Collection

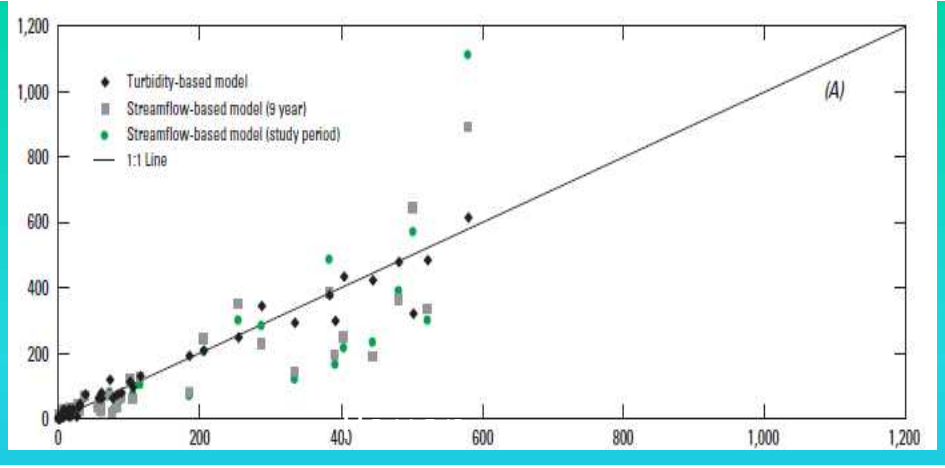
- Continuous water-quality monitoring
  - Water Temperature
  - Specific Conductance
  - pH
  - Turbidity
- Sediment and Nutrient Sampling
  - Scheduled Monthly
  - Storm Events

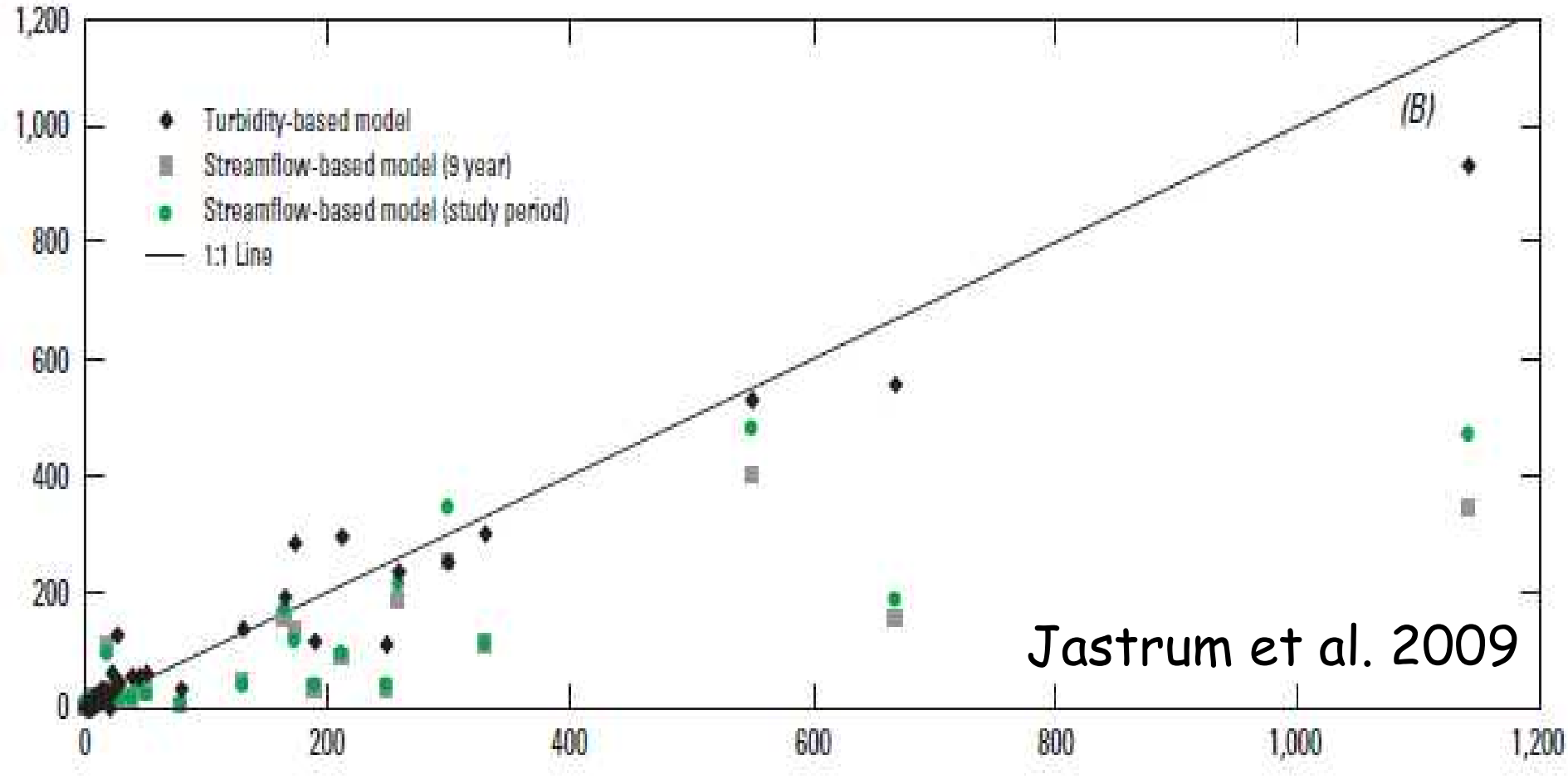
Reducing measurement uncertainty:

- Streamflow has been used as a surrogate to estimate fluvial sediment transport for over a half century (Campbell and Bauder, 1940).
- Improved streamflow-based models (ESTIMATOR) have traditionally been used to estimate sediment and nutrient loadings to the Bay.
  - Variability in relation between streamflow and constituent concentrations leads to large uncertainty terms.
- Turbidity has been recognized as an effective sediment surrogate for decades (Walling, 1977).

- Recent technological advances have enabled the *in-situ* measurement of turbidity at high temporal resolution.
- CBP funded a study of the effectiveness of turbidity-based SSC estimation in Bay tributaries.

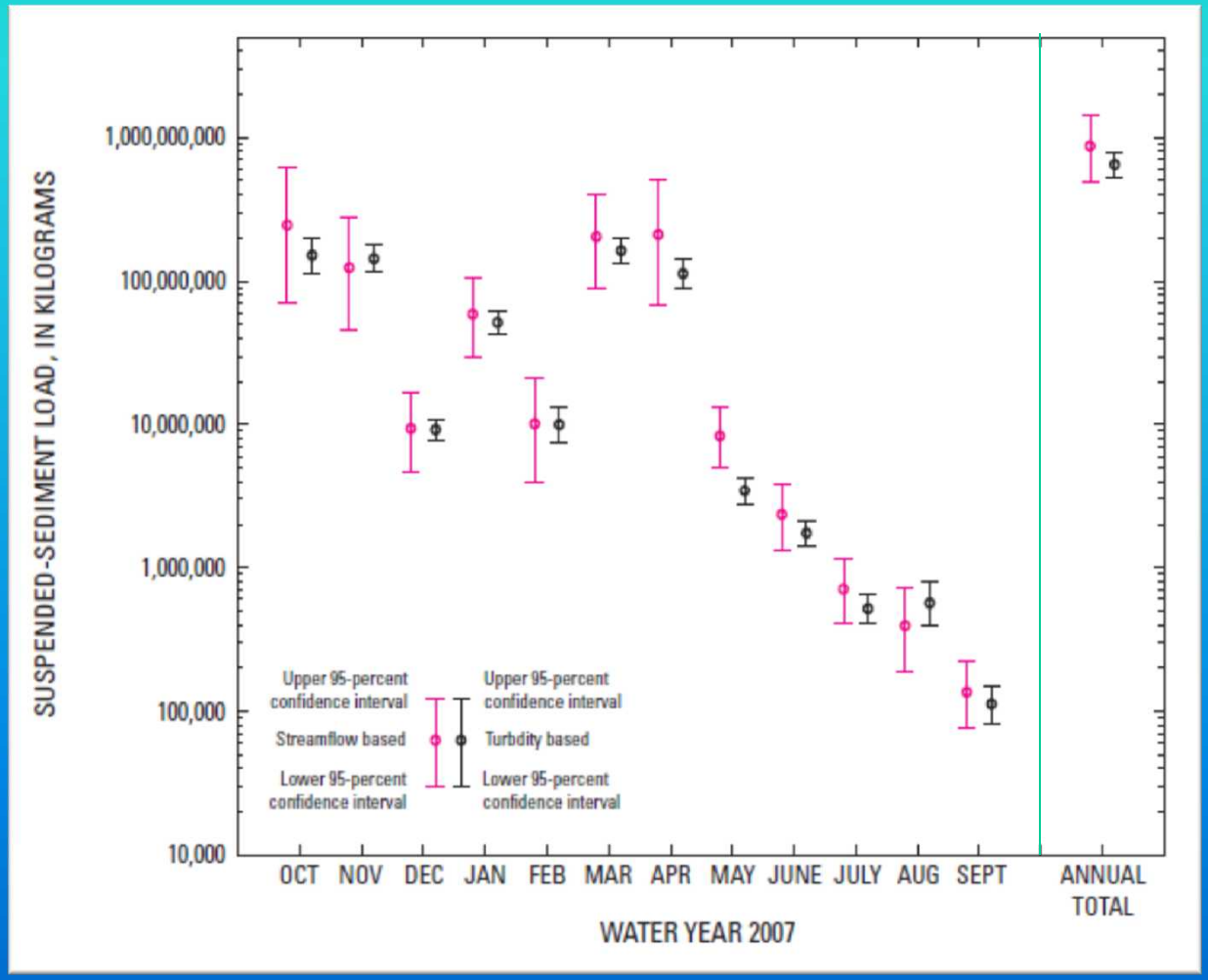
Observed vs. Estimated SSC with two models: Streamflow vs. Turbidity-based





Jastrum et al. 2009

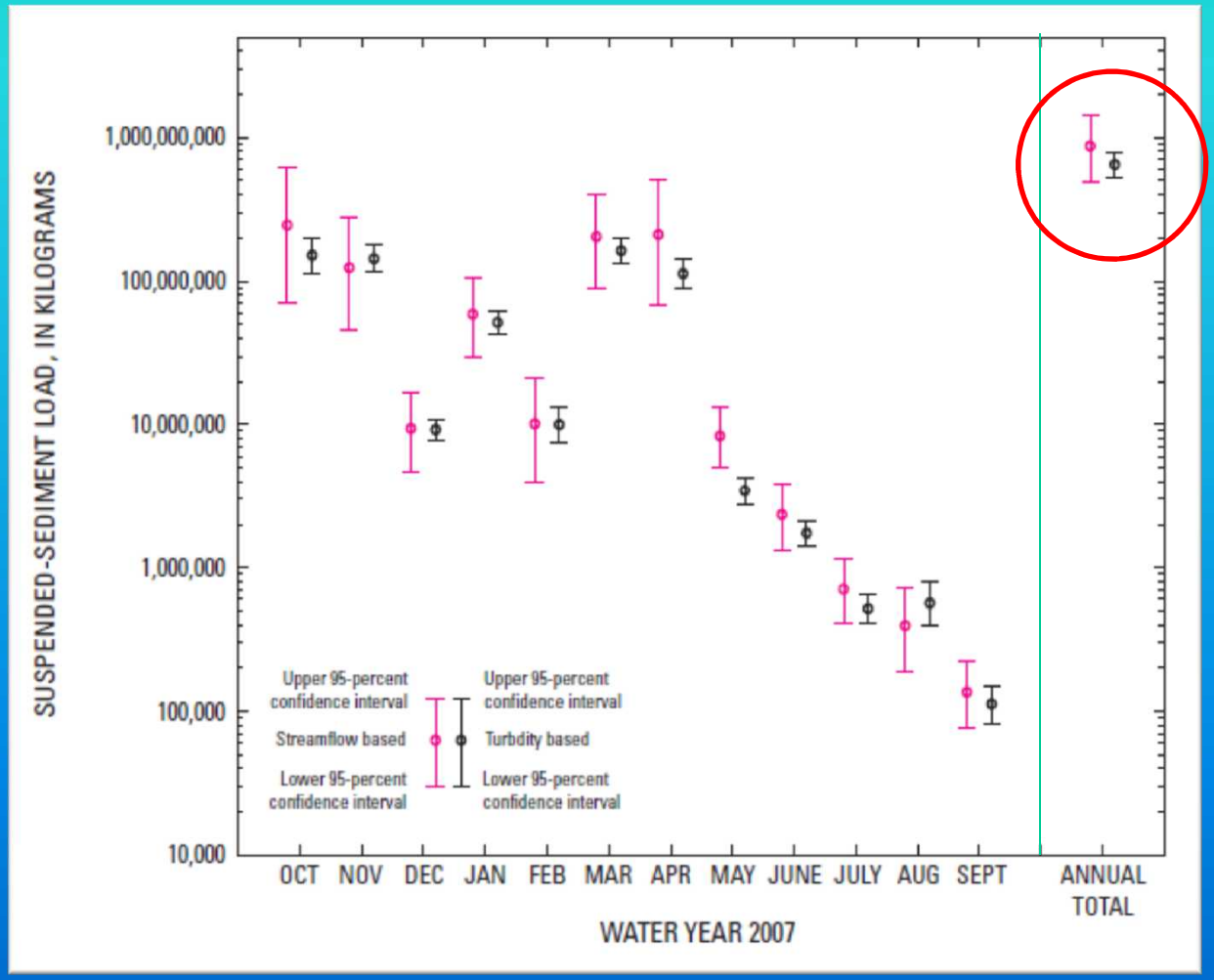
Realtime Measurements: Effect on Summed Loads over the Water Year



- Loads generated using LN transformed models in LOADEST
- Greatly reduced width of 95% confidence intervals.
- Critical improvement to enable change detection.
- Critical issues to management – time to detect response to management actions.

Jastrum et al. 2009

Realtime Measurements: Effect on Summed Loads over the Water Year



- Loads generated using LN transformed models in LOADEST
- Greatly reduced width of 95% confidence intervals.
- Critical improvement to enable change detection.
- Critical issues to management – time to detect response to management actions.

Jastrum et al. 2009

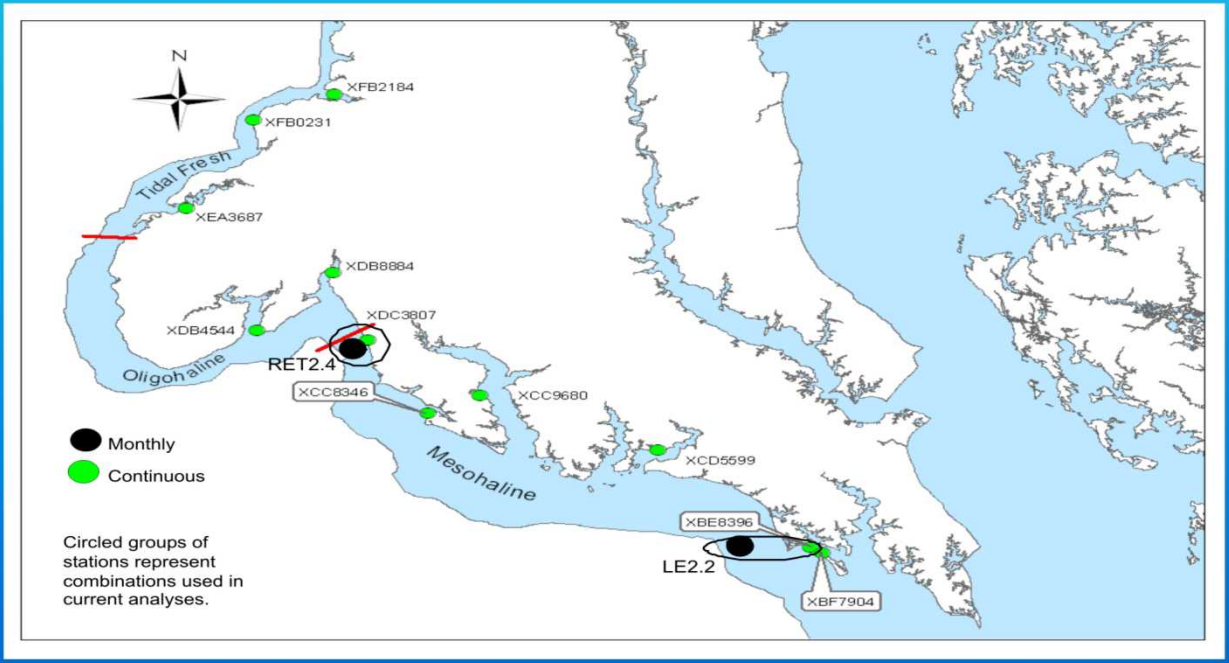
Reduced Measurement Uncertainty Management Impacts and Feedbacks

Results

Critical improvement to enable change detection. Critical issues to management – time to detect response to management actions decreases with lower .

Significant focusing of budgeting considerations among jurisdictions.

V. Short Duration Water Quality Criteria Assumption Tests



Multiple, Simultaneously Applied Water Quality Criteria

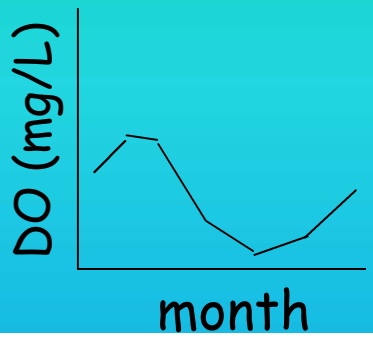
- Chesapeake Bay: The open water fish and shellfish designated use and the accompanying dissolved oxygen criteria will fully protect the biological communities inhabiting shallow water habitats.

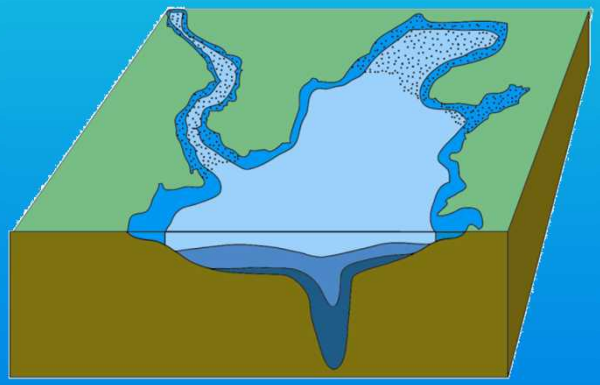
Designated Use	Dissolved oxygen Criteria Concentration/Duration		Temporal Application
Open water fish and shellfish use	30-day mean	≥ 5.5 mg/L Salinity: (0-0.5ppt)	Year-round
		≥ 5 mg/L Salinity: >0.5ppt	
	7-day mean	≥ 4 mg/L	
	Instantaneous min ≥ 3.2 mg/L		

USEPA 2003

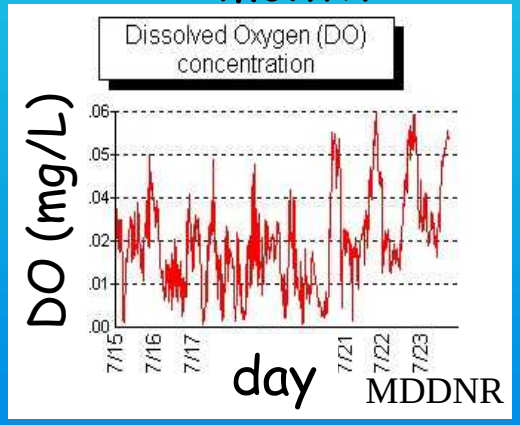
Evolution of the Chesapeake Bay Program long-term water quality monitoring program

Historical:
Fixed station
Biweekly/
monthly
1984-present

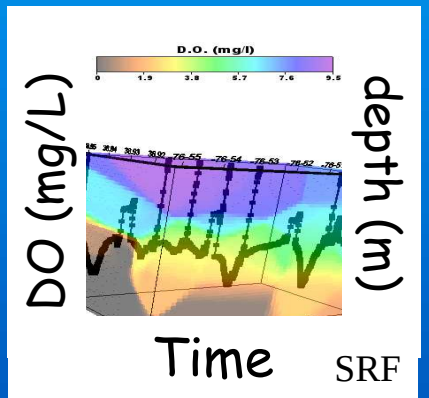




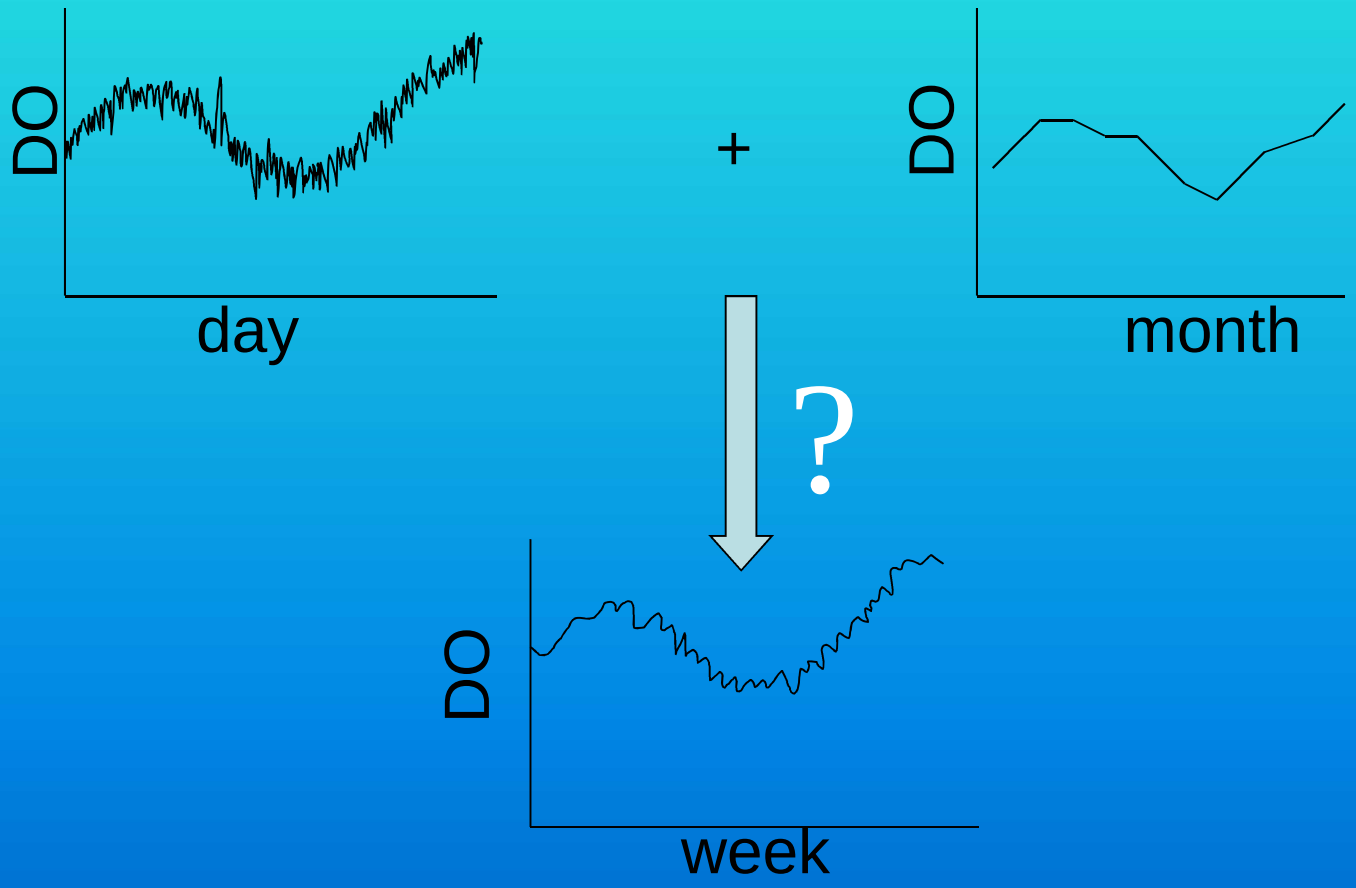
Fixed site
Nearshore
Realtime
2004-present



Fixed site
offshore
Realtime
profilers
2007-present



• Question: Is there any way to combine the information we get with high frequency (e.g. every 15 mins) in one location with low frequency data (e.g. biweekly to monthly) in another location?



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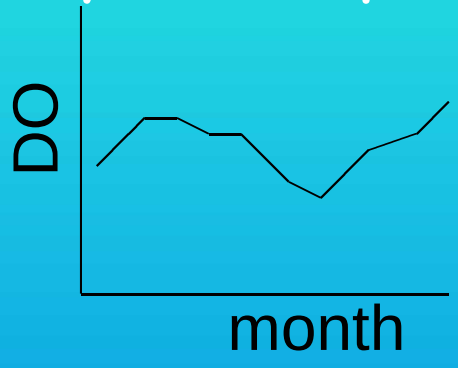
• Is there any way to combine the information we get with high frequency (e.g. every 15 mins) in one location with low frequency data (e.g. biweekly to monthly) in another location? YES

Nerchall (1994) Spectral Analysis, Perry (2011) Spectral Casting

+

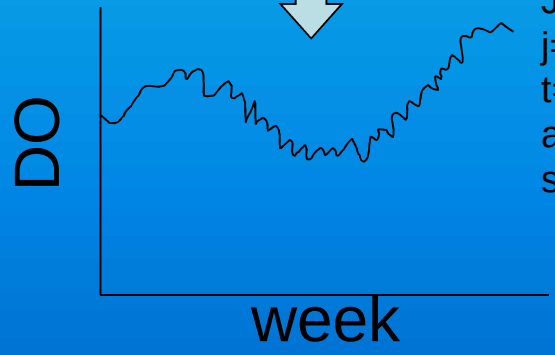


$$y_{st} = \text{intercept}_{st} + \sum_{j=1}^{J} a_j \cos(2\pi jt) + b_j \sin(2\pi jt)$$

J=(total no. of weeks) ÷ 2
j= fourier frequency
t= time (in weeks)
a,b= regression coefficients (selected using stepwise ordinary least squares)

$$y_{lt} = \text{intercept}_{lt} + \sum_{j=1}^{J} a_j \cos(2\pi jt) + b_j \sin(2\pi jt)$$

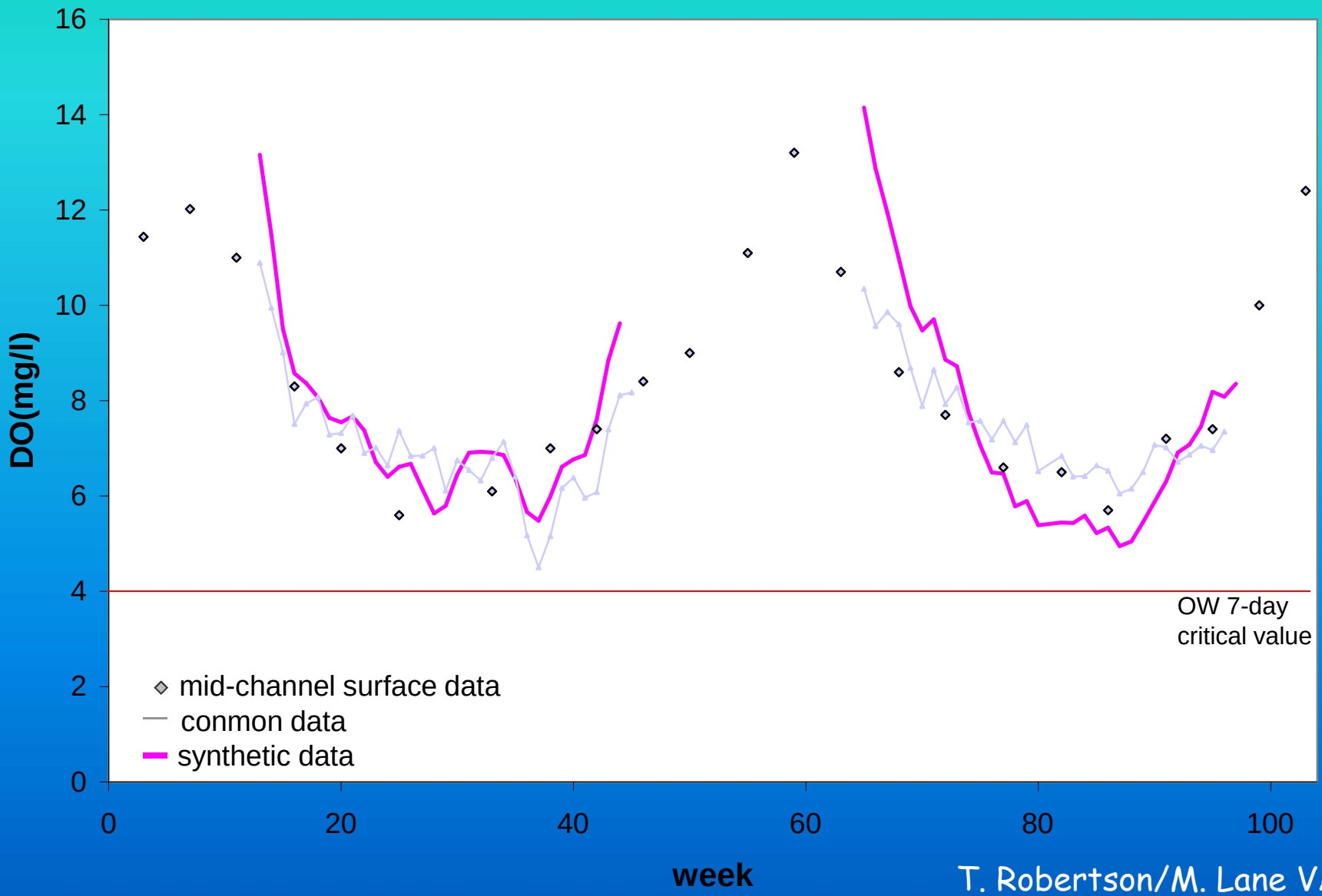
J=(total no. of months) ÷ 2
j= fourier frequency
t= time (in months)
a,b= regression coefficients (selected using stepwise ordinary least squares)



$$y_{lt+st} = \text{intercept}_{lt} + \sum_{j=1}^{J} a^{lt}_j \cos(2\pi jt) + b^{lt}_j \sin(2\pi jt) + \sum_{j=1}^{J} a^{st}_j \cos(2\pi jt) + b^{st}_j \sin(2\pi jt)$$

The Synthetic Dataset - A combination of long-term and short-term models

$$y_{lt+st} = \text{intercept}_{lt} + \Sigma\, a^{lt}_j \cos(2\pi jt) + b^{lt}_j \sin(2\pi jt) + \Sigma\, a^{st}_j \cos(2\pi jt) + b^{st}_j \sin(2\pi jt)$$



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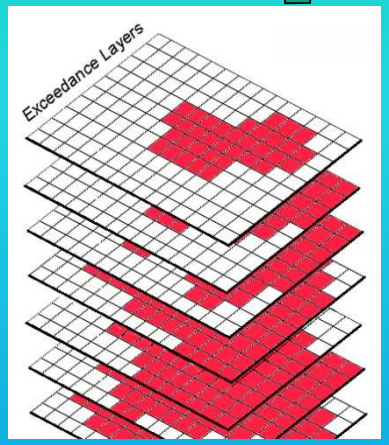
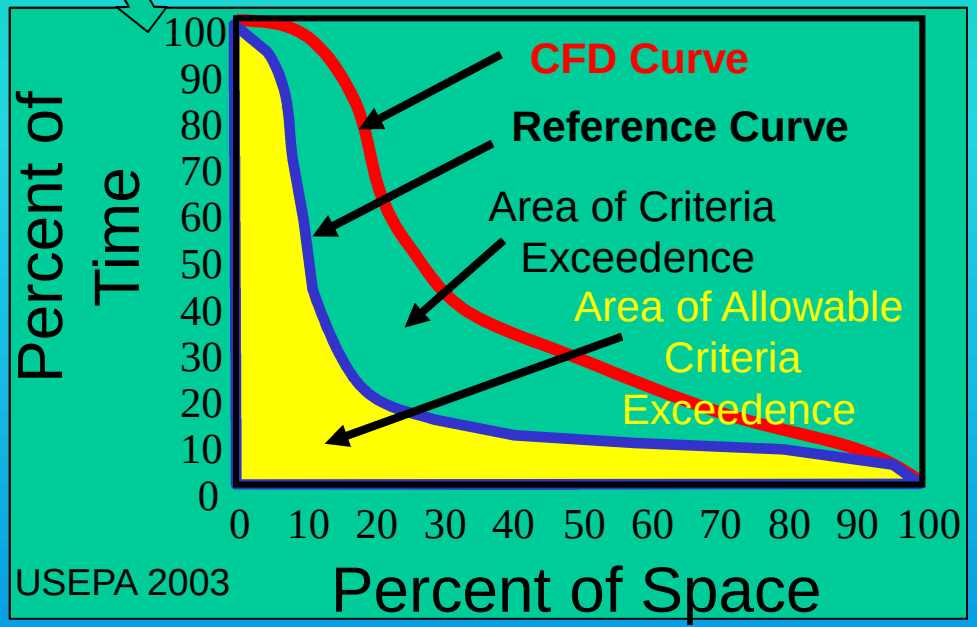
Water Quality Criteria Assessment



"Monitoring" (Synthetic) Data

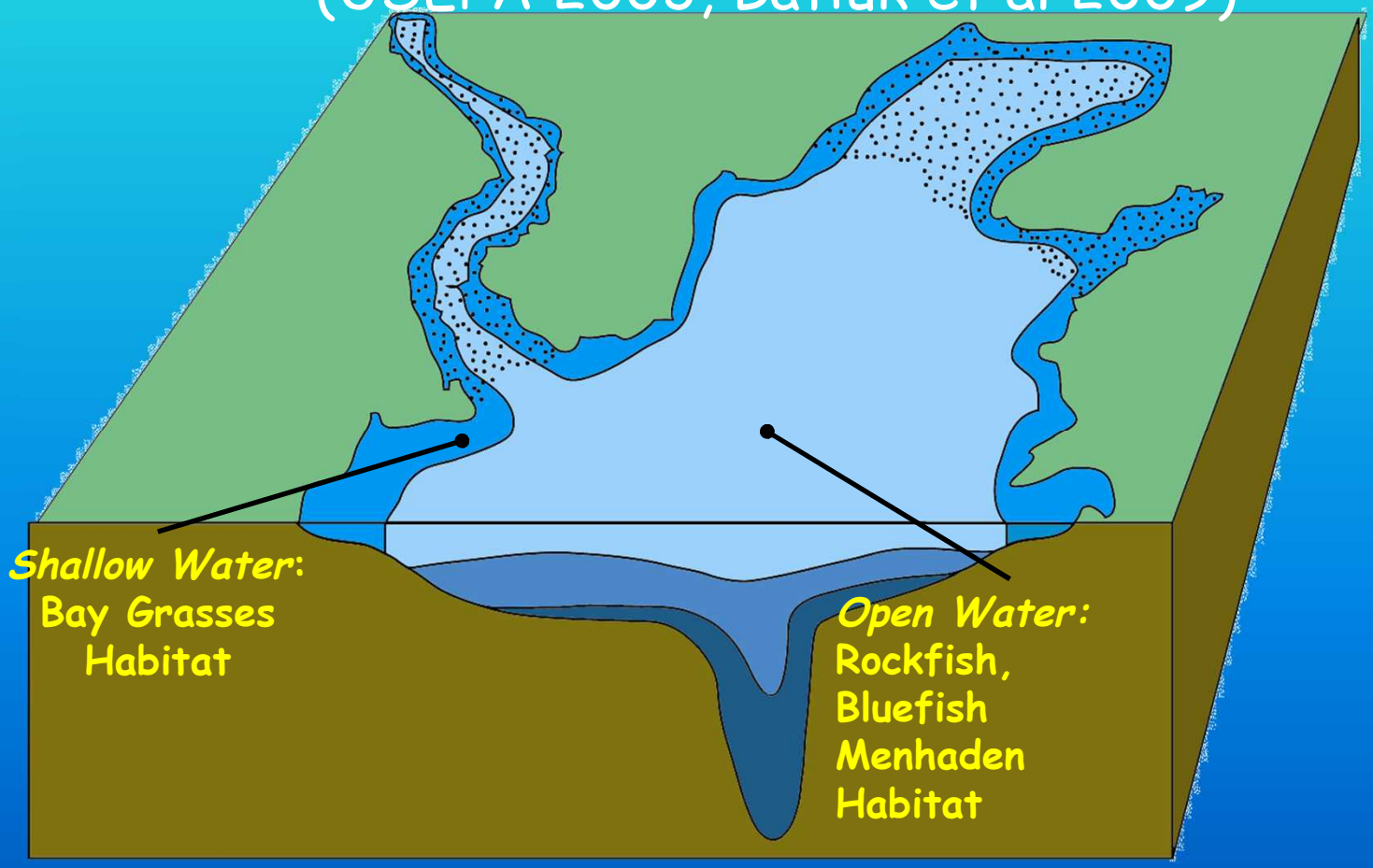


Result:

Proof of concept for the application of spectral casting in assessing short time scale water quality criteria in a regulatory framework

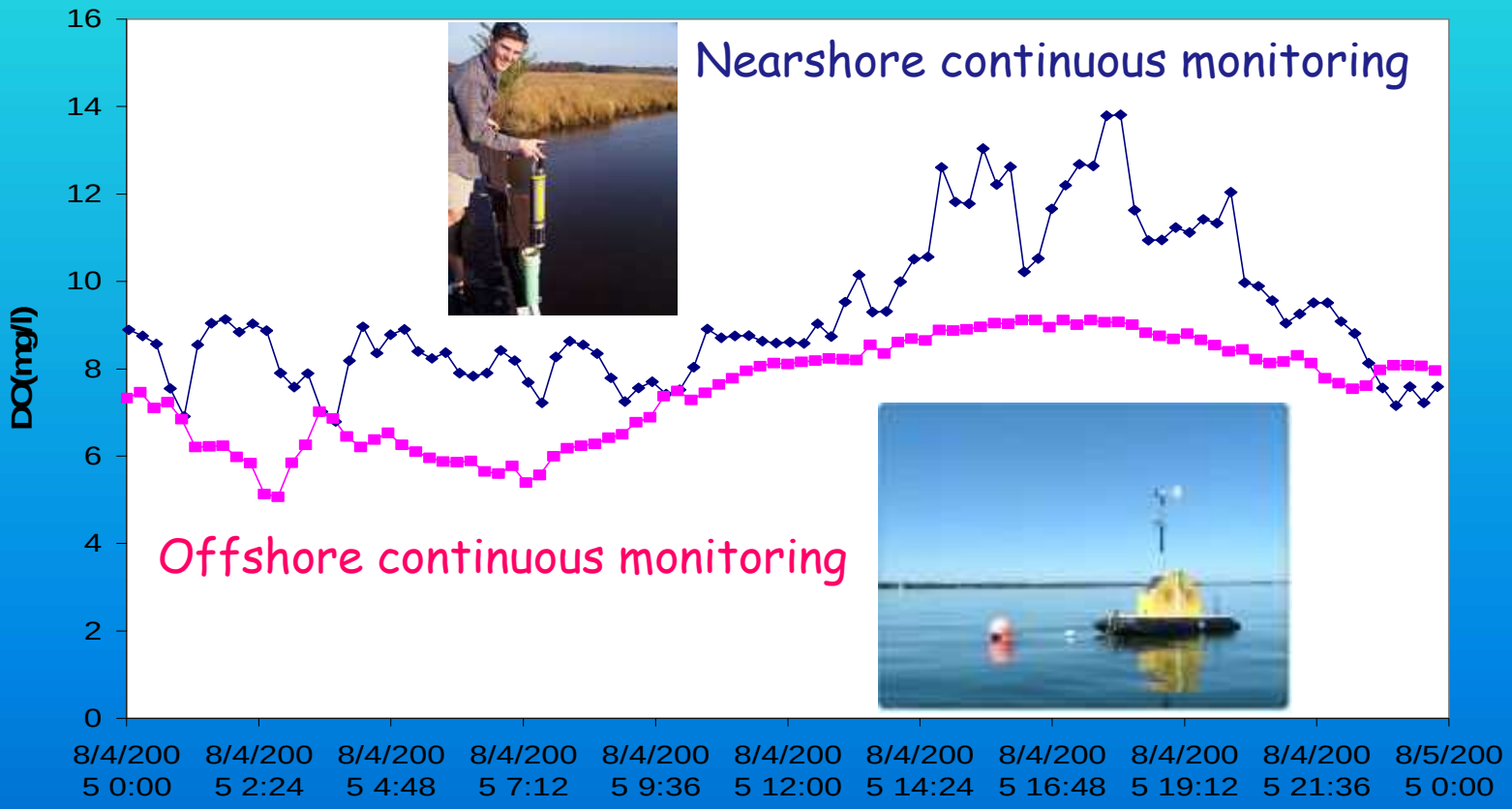
VI. Discovery

Hypothesis testing about habitat behavior:
Assumption: Shallow water dissolved oxygen dynamics are comparable to surface water dissolved oxygen offshore (USEPA 2003, Batiuk et al 2009)



VI. Discovery

Shallow water vs. Open water DO behavior at long scales of time were similar but at small scales of time showed significant differences in behavior



T. Robertson/M. Lane VADEQ, C. Buchanan ICPRB, W. Boynton UMCES, M. Trice MDDNR

In closing…

Mine your data

Exercise your data

Interrogate your data

Explore your data

Continue to Demonstrate and Illustrate the Applications and Value of ConMon