Using A Satellite to Help Us Evaluate the Impacts of Oyster Restoration: A Perspective From Above

A NESDIS/NMFS Collaboration & Contribution to the Choptank HFA Water Column Habitat Study

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Satellite Turbidity at Selected Stations over Time


Creek influenced
2010 – 2013
Small increase in turbidity
2013 – 2016
Decrease in turbidity (few steep drops)

Main stem influenced
2010 - 2013
Decrease in turbidity
2013 – 2016
Small decrease or no change
Mean Oyster Biomass* by Area from Oyster Annual Fall Survey (AFS) over Time

Biomass Estimates using a *modified formula by NOAA (Fall 2009 – Fall 2016)
Does oyster restoration improve water clarity?

Public interest in socioeconomic value of oyster restoration

- Use satellite total suspended matter concentration (TSM) as an indicator of water clarity (250m resolution)
- Compare with MD DNR Annual Fall Survey oyster biomass
- Compare with VIMS aerial overflight SAV coverage
  - SAV has increased substantially in the region over this time period
- Comparisons over 8 years: 2009-2016
Total Suspended Matter (TSM) from Satellite

➢ Sediment concentration (mg/L) in surface water (top 1m)
➢ TSM algorithm specifically developed by NOAA for Chesapeake Bay (Ondrusek et al., 2012)
➢ Once daily observation (from a single satellite)
  ➢ Clouds cause missing data
➢ Provides spatial overview
  ➢ Detect spatial patterns
➢ Monitor change over time
➢ 250 m spatial resolution
➢ Data from NASA’s Aqua satellite, MODIS instrument
“13 Trib” Study Design

• Management Type:
  public, sanctuary,
  sanctuary with restoration

• High vs Low Oyster Biomass

• High vs Low SAV Cover

• Presumed similarities in regional precipitation

• Similarities in watershed sizes (Middle Choptank and Nanticoke exceptions)

14 Tributaries originally identified (Breton Bay excluded for too little data)
TSM Over Time:
TSM annual trend for each satellite grid cell, 2009-2017

Slope (mg/L / year)

Decreasing TSM slope in Choptank and Tangier Sound
TSM Over Time:
TSM annual trend for each satellite grid cell, 2009-2017

Slope

-0.531677 mg/L / year

Single grid cell annual trend at AFS sample location (blue circle) on Change Bar oyster restoration site. Perimeter grid cells have a high amount of variability. Spatial aggregations of grid cells with consistently high slopes might suggest real TSM decrease.
TSM Over Time:
TSM annual trend for each satellite grid cell, 2009-2017

Slope Standard Error (SE) - measure of how well points fit on TSM/yr line

Decreasing TSM slope in Harris and Broad Creeks with small slope SE implies confidence in TSM decrease. Decreasing TSM slope in Fishing Bay with large slope SE -- TSM decrease not reliable.
Individual Temporal Trend Plots
(2009-2016, stronger relationships)
IndividualTemporal Trend Plots
(2009-2016, relationships are unclear)
TSM and Oyster Biomass Relative to Oyster Fishery Management Regime

Pairwise comparison (Tukey): different letters have different mean values (alpha = 0.05)
Is there a relationship between TSM and Oyster Biomass?

- Simple regression: $TSM = \log_{10} \text{biomass}$
  - 13 Trib sites (blue)
    - Slope = -0.49, $p < 0.0001$
    - $n=601$
    - $r^2 = 0.04$ (4% of TSM variation is explained by oyster biomass)
  - Non-trib sites (red)
    - Slope = -0.17, $p < 0.0024$
    - $n=1468$
    - $r^2 = 0.0006$ (0.06% of TSM variation explained by oyster biomass)

- ANCOVA: the two slope parameters are significantly different ($p=0.0052$)
Is there a relationship between TSM and SAV coverage?

- **13 Trib sites (blue)**

- Simple regression: $TSM = \log \% SAV$ coverage
  - Slope = -0.39, $p < 0.0001$
  - $n=570$
  - $r^2 = 0.05$ (5% of TSM variation is explained by SAV coverage)
What Other Factors contribute to TSM variability?

General Linear Model (GLM) analysis:
Evaluate TSM against Time, Location, Oyster Biomass, SAV

Sum of Squares statistics (SS)

**Type III SS:** Considers all independent variables together
- When all variables are in the model TSM varies significantly only with Location (Zones_13) and Year (p values < 0.05)
What Other Factors contribute to TSM variability: Location

Single Term GLM: Location Only

R² – Location (Zones_13) explains 51% of the variation in TSM
Data Summary by location “13 Tribs”

Lowest TSM values:
Harris Creek, Tred Avon River, Choptank River, Broad Creek, & Big Anamessex River
Summary

• Satellites are a good method of observing large-scale spatial and temporal patterns in water clarity

• Recent Oyster Biomass and SAV trends are improving over time (AFS & VIMS survey)

• Temporal TSM trend suggests a water quality improvement in Harris and Broad Creeks, and some parts of Tangier Sound, but no cause is implied

• TSM values are significantly higher on Public areas than Restored Sanctuary Management Areas. Inverse relationship for oyster biomass

• TSM decreases significantly with increased Oyster Biomass and increased SAV

• Oyster Biomass explains 4% of TSM variability; SAV explains 5% of TSM variability; unknown Location effects explain 51% of TSM variability
Next Steps?

• Examine additional location effects: land use, precipitation, basin morphology, wind vs. water depth, bay circulation patterns

• Explore using oyster abundance datasets other than AFS that are increasingly becoming available from Sanctuary and Restoration monitoring efforts
  • AFS may not do a great job of quantifying oyster biomass (length converted to biomass may introduce error)

• Revisit the TSM/oyster relationship in a few years when restored reefs are mature and restoration is complete
Backup Slides
Question: What is the relationship between Oyster Biomass and TSM for Study Sites?

- Removed oyster biomass values that = 0
- TSM declines significantly with Biomass (oyster)
- Slope = -0.499
- Biomass explains ~4% of the variability in TSM (r^2)
- Slope parameters (-0.413,-0.499) and r^2 (0.054, 0.039) are similar for the SAV and Biomass models respectively
- Removed oyster biomass values that = 0
- SAV increases significantly with Biomass (oyster)
- Slope = +0.35
- Biomass explains 6% of the variability in SAV
Question: If Management type is significant, and we’re managing for oysters, does relationship between TSM and oyster biomass vary by management type?

- ANCOVA Results: A significant relationship exists between TSM and biomass but it is not affected by management regimen.
Data Distribution by Area—“13 Tribs”

Distribution of TSM by 13 Tributary Sites

Lowest TSM values: Big Anamesssex, Broad Creek, Choptank River, Harris Creek, and Tred Avon River
Satellite TSM Seasonal Averages, 2009-2015

Spring

Summer

Fall

Winter

Total Suspended Matter (mg/L)
Decreasing TSM slope in Harris and Broad Creek with small slope SE and high R^2 suggests a water quality improvement but with no cause implied. Some areas of Tangier Sound also show this (but not Fishing Bay).
How a satellite instrument measures the earth surface

- Emitted radiation
- Solar reflected radiation
- Atmo-spheric correction

Particles in the Water:
- plankton
- sediment
- organic matter
- debris

- Heat energy
- Radiation at discrete visible and infrared wavelengths
Algorithm Description

Ondrusek et al., 2012, Remote Sensing of Environment

Satellite red band (645 nm)

Water-leaving radiance

TSM vs nLw 645

Simultaneous in-water data collection

In-water TSM samples
Satellite TSM Accuracy

Chesapeake Bay Program in-water TSM samples were spatially & temporally matched to satellite TSM values at single pixels, Bay-wide for one year: 2009
(Ondrusek et al., 2012, Remote Sensing of Environment)

![Graph showing Satellite TSM vs Measured TSM](image)

- **Bias (mg/L):** -1.82443
- **RMSE (mg/L):** 6.93795
- **Mean Rel Diff:** -4.2%
- **Mean Rel Abs Diff:** 36%
- **N:** 241

TSM values <20 mg/L are more accurate than values >20 mg/L