Monitoring Strategy for the Albemarle-Pamlico Estuarine System- Estuarine Monitoring: Water and Surficial Sediments

APNEP Water Resources Monitoring & Assessment Team

Remote Sensing Opportunities for APNEP Monitoring

Darryl Keith, PhD
Research Oceanographer
USEPA/ORD/CEMM/ACESD
Narragansett, RI 02882

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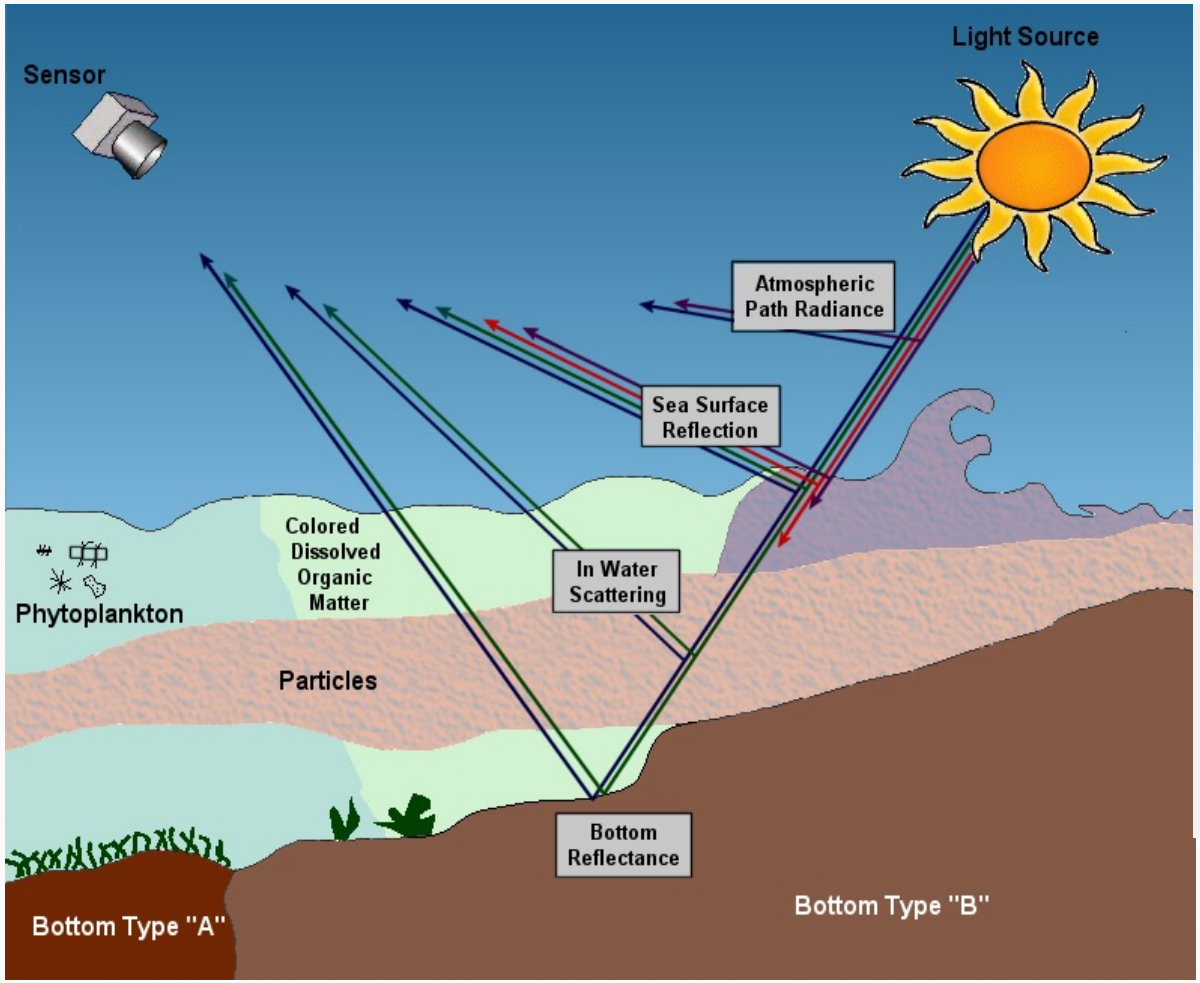
Optical components and pathways of radiance and reflectance in coastal waters



Multiple light paths

- ***Scattering due to:***
  - atmosphere
  - aerosols
  - water surface
  - suspended particles
  - bottom
- ***Absorption due to:***
  - atmosphere
  - aerosols
  - suspended particles
  - dissolved matter

What is ocean/estuary color?

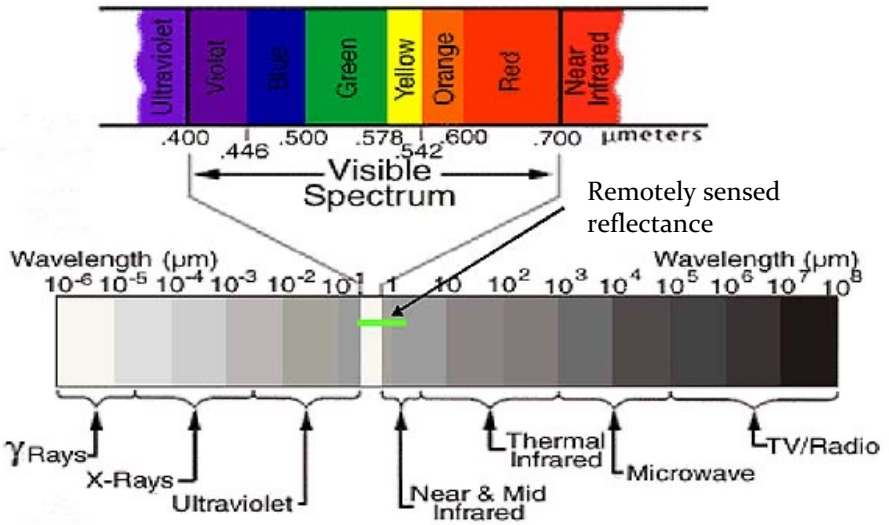


Figure 1. Electromagnetic spectrum and region of reflected light remote sensing.

Definition of Remotely Sensed Reflectance (R_{rs})

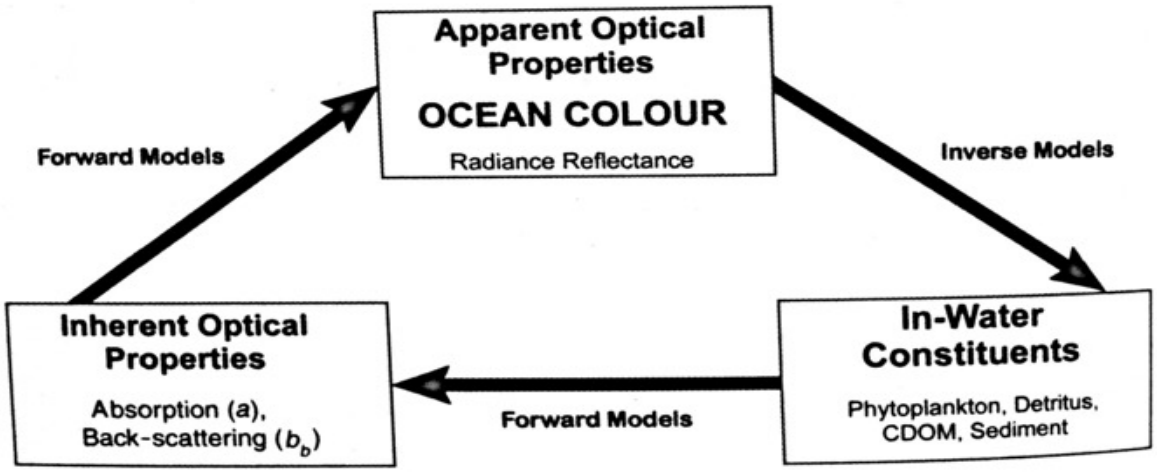
$$R_{rs}(0^+,\lambda) = L_w(0^+,\lambda)/\ E_s(0^+,\lambda)$$

R_{rs} = remotely sensed reflectance (1/sr)

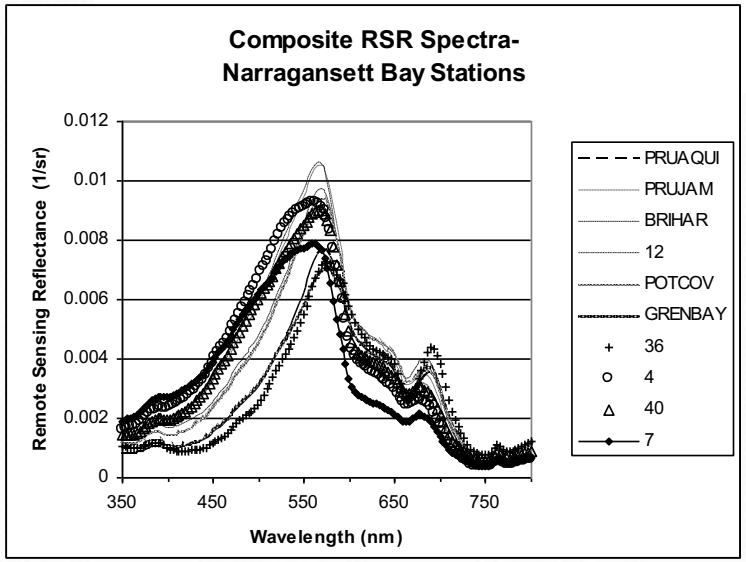
L_w (λ) = water leaving radiance measured above the air/water interface (W m^{-2} sr^{-1}),

E_s (λ) = downwelling irradiance measured above the air/water interface (W m^{-2} sr^{-1})

Interrelationship between optical properties and in-water constituents



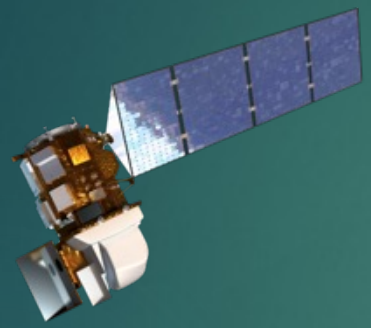
For example:



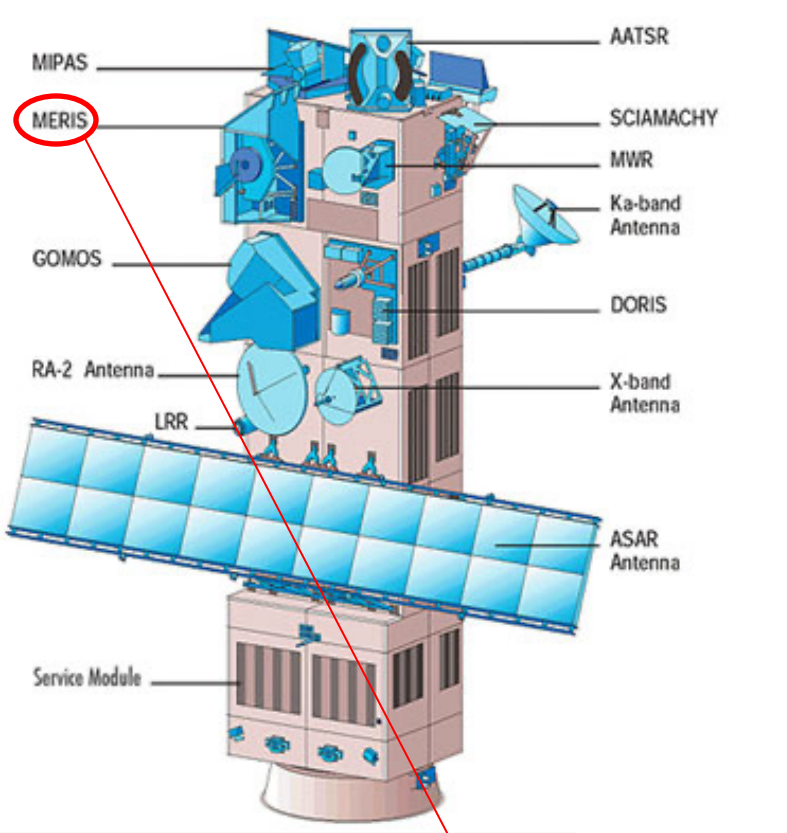
Empirical models

- *[Chl a]*
- *[TSS]*
- *CDOM*
- *salinity*

Space-based Optical Color Sensors

SENSOR (spatial resolution)		PLATFORM	AGENCY	Data Distribution Policy	Data Access	Cost to User
OLI 30 m		Landsat 8/9 (2013–present)	USGS/NASA	Products distributed online from USGS EarthExplorer website	Registration required	No cost
OLCI 10 m		Sentinel A/B (2015-present)	European Space Agency	Products are distributed online from the Copernicus Data Hub	Registration required	No cost

ESA ENVISAT platform



MERIS = Medium Resolution Imaging Spectrometer

3. Monitoring Needs and Recommendations

3.2. Needs and Recommendations: Phytoplankton

3.2.1. Phytoplankton Metric: Chlorophyll *a* Concentration

3.2.2. Phytoplankton Metric: Extent and Frequency of Algal Blooms

(See slide presentation)

Satellite Remote Sensing of Chlorophyll *a* in Support of Nutrient Management in the Neuse and Tar-Pamlico River estuaries

Darryl J. Keith, Research Oceanographer
EPA/ORD/CEMM/Atlantic Coastal Environmental Sciences Division

Introduction

- The North Carolina Environmental Management Commission (EMC) has adopted as a water quality standard that chlorophyll *a* concentration should not exceed 40 µg/L in sounds, estuaries and other slow-moving waters.

- Exceedances require the development of a Total Maximum Daily Limit (TMDL) for nutrients in that water body.

- Chlorophyll *a* was chosen as the endpoint to manage total nitrogen concentrations in the Phase I TMDL for the Neuse River

- TMDL compliance would be achieved if Chl *a* exceedances occurred in fewer than 10% of the samples collected in a specified area and time

(aka “10/40 criterion” or “Neuse Rules”)

Questions

- Can TMDL compliance and chlorophyll exceedances in the Neuse and Tar-Pamlico River estuaries be assessed at daily and annual time scales from MERIS imagery?

- Which summary statistic of chlorophyll *a* concentrations (sample mean, median, and 90th percentile values) is the most useful for determining TMDL violations and to support environmental compliance monitoring?

Methods

- Used the MERIS Chl *a* product derived from atmospherically-corrected, full resolution (300 X 300 m pixel size) images (n= 206) of the Neuse and Tar-Pamlico River estuaries to determine the number of pixels exceeding 40 µg/L from January 2006 to December 2009.

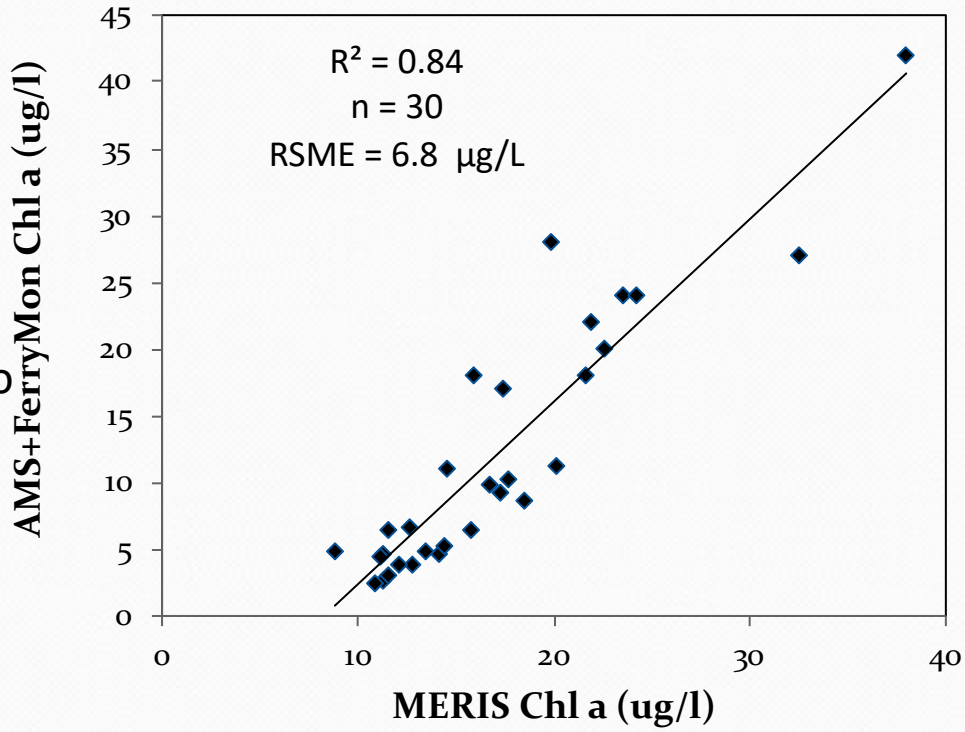
  ** MERIS images were acquired from the European Space Agency (ESA) by Ross Lunetta of the EPA National Exposure Research Laboratory (NERL) Landscape Characterization Branch (LCB) in 2009.*

Calibrating MERIS derived chlorophyll values to the Neuse River Estuary

- FerryMon monitoring program from crossings (n = 19) during 2006 – 2009 of the Neuse River Bend and Lower Neuse River Estuary segments (Cedar Island/Orcacoke, Cherry Branch/Minnesott) and in Pamlico Sound (Swan Quarter/Orcacoke)

- NC DWQ Ambient Monitoring System (AMS) Chl *a* data collected along the Lower Neuse River Estuary segment (n= 11) from 2008- 2009.

- The *in situ* data were collected at dates and times concurrent with MERIS overflights.

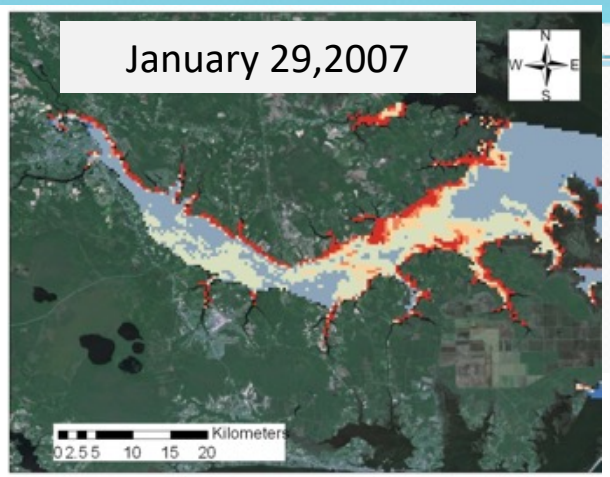


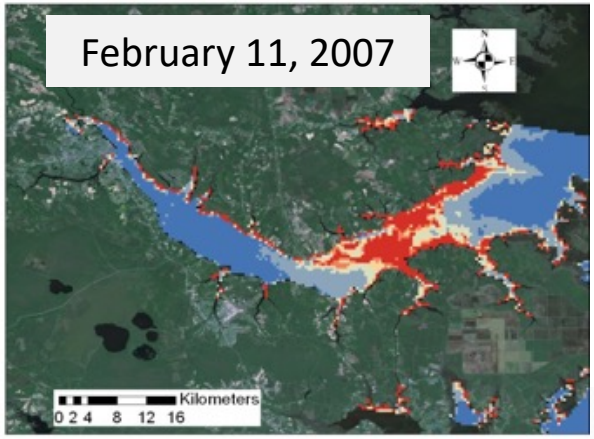
Chl *a* $_{ambient}$ = 1.3671 * (MERIS Chl *a* - 11.283)

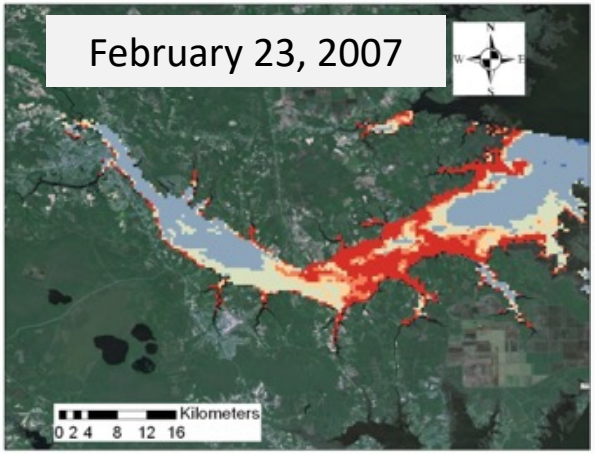
NCDENR

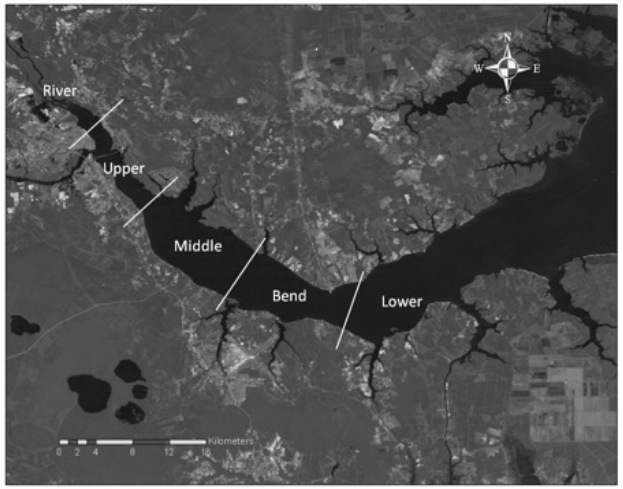
FerryMon

Time Series of a TMDL Violation - Neuse River Estuary: Winter -Spring 2007



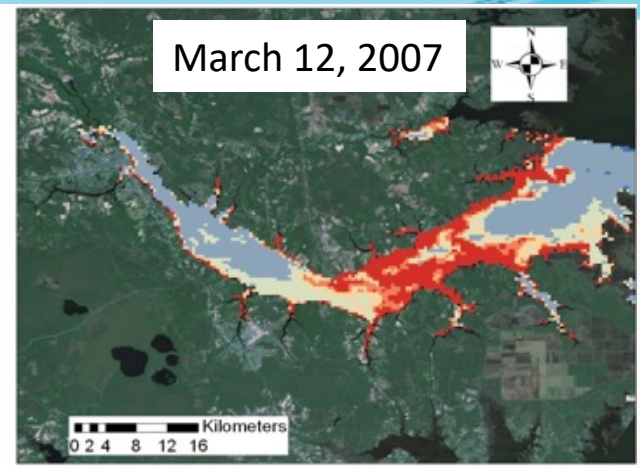


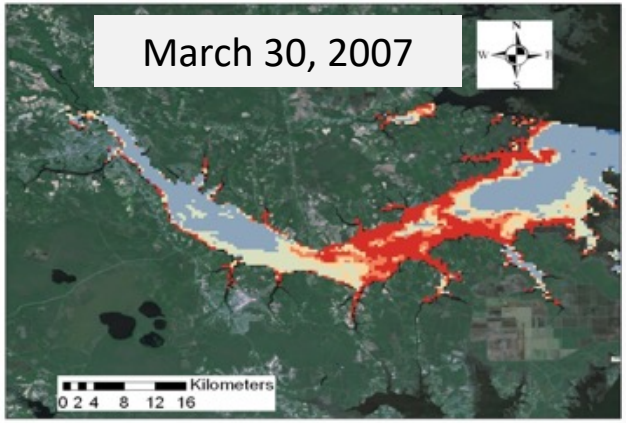


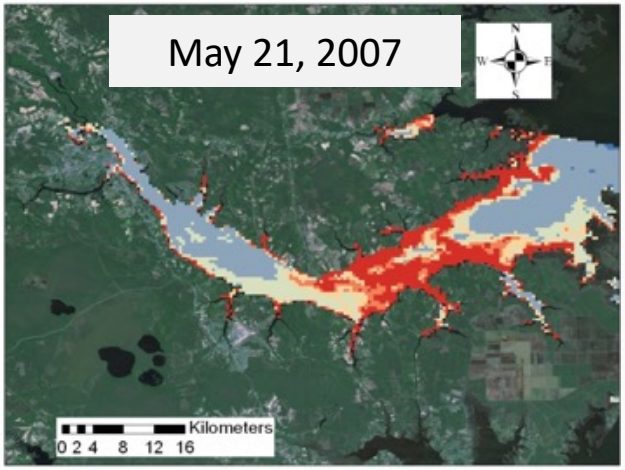


Chlorophyll a Concentration (ug/L)

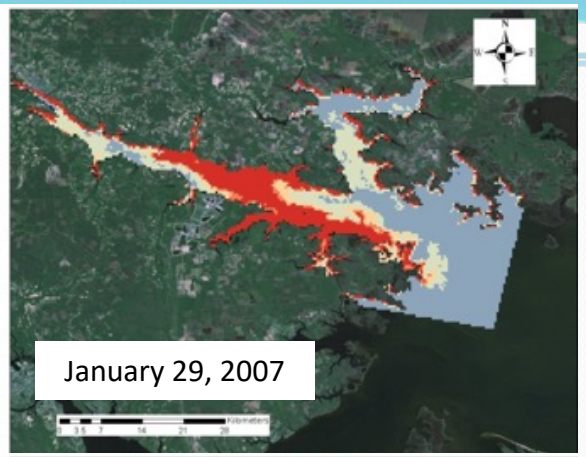
- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

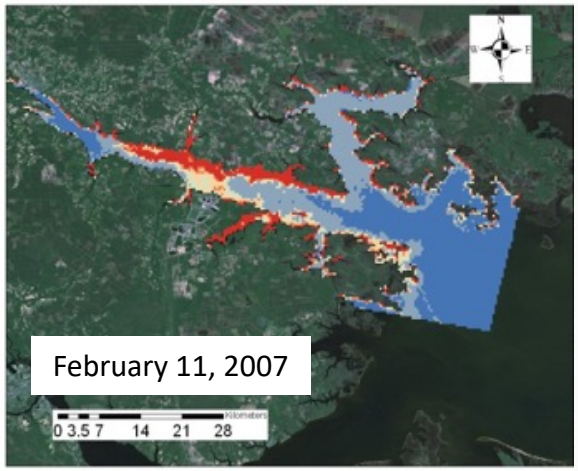


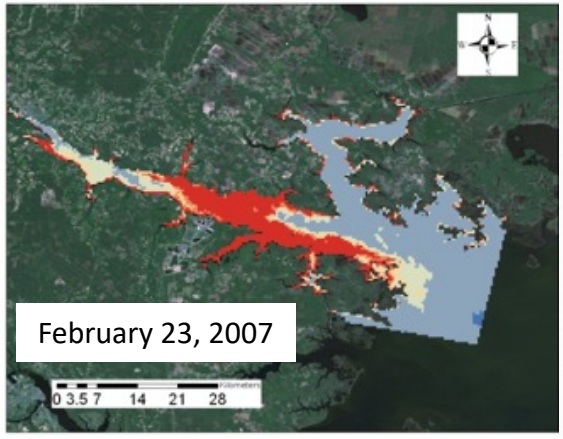


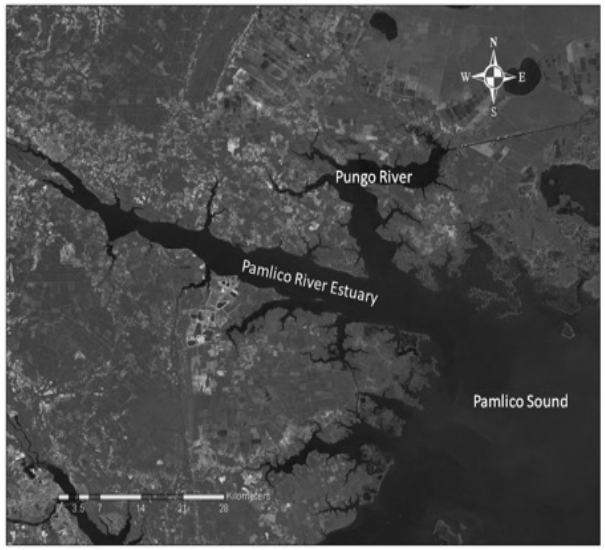


Time Series of a TMDL Violation Tar-Pamlico River Estuary: Winter – Spring 2007



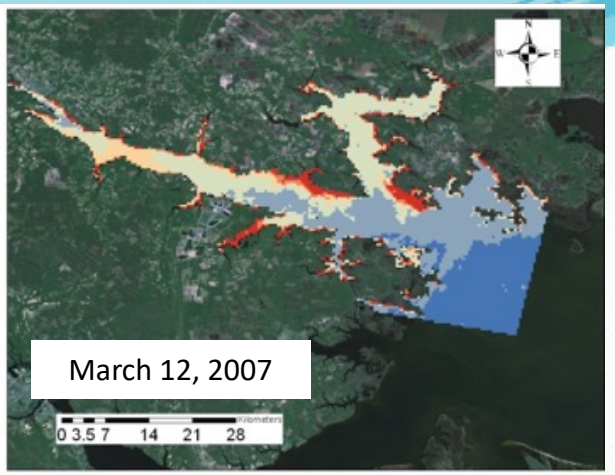


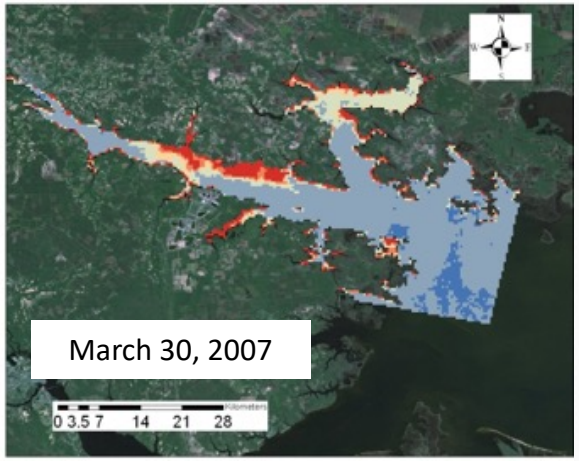


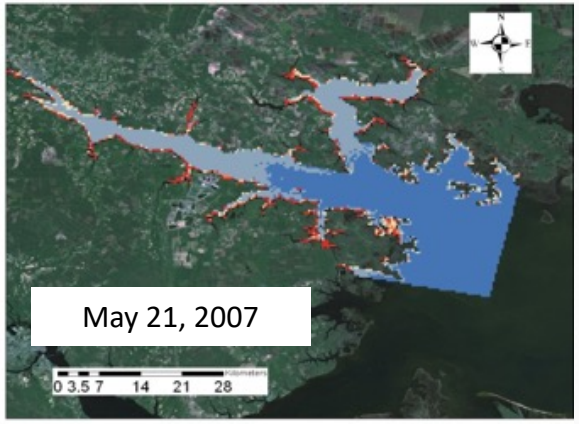


Chlorophyll a Concentration (ug/L)

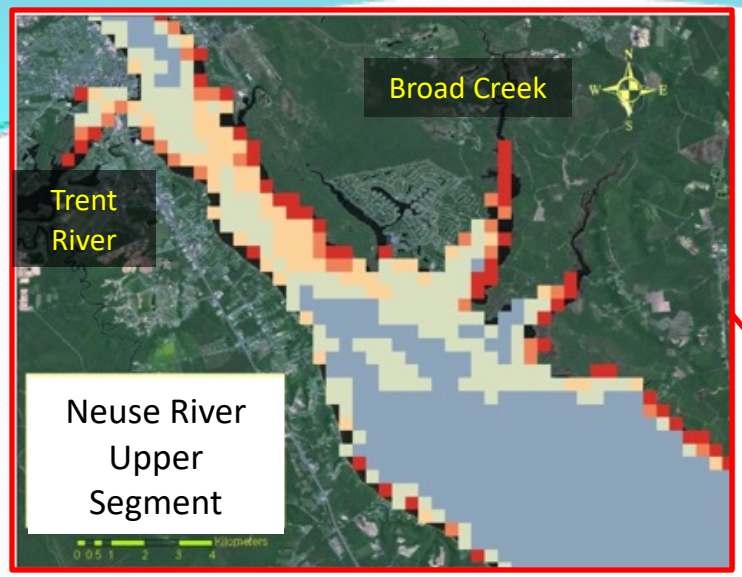
- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

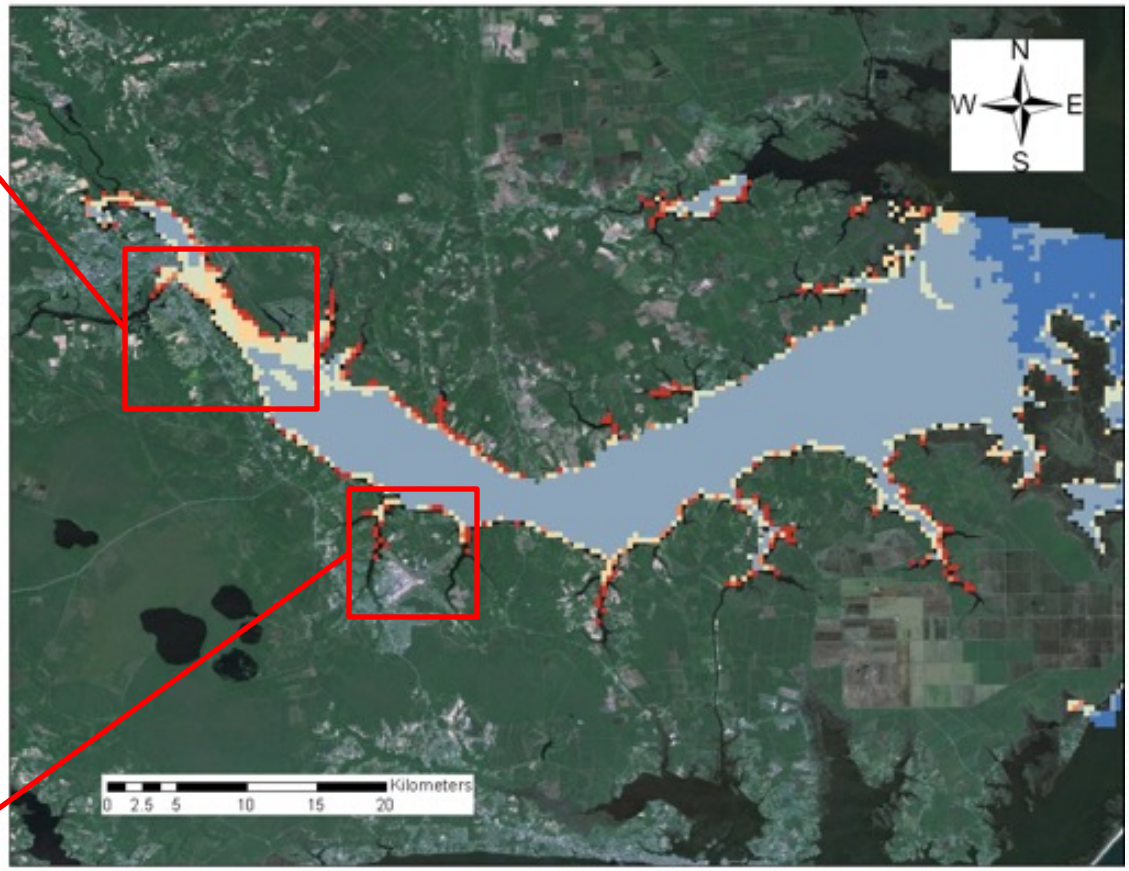


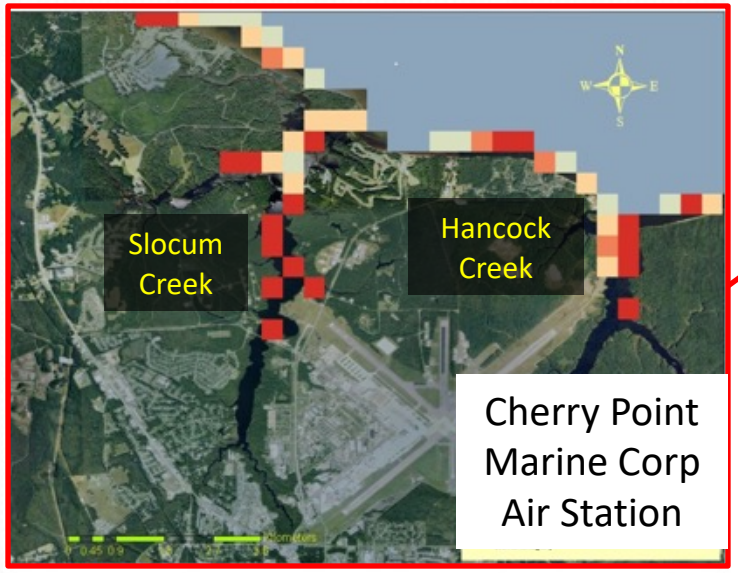




Neuse River
2006 Composite Image



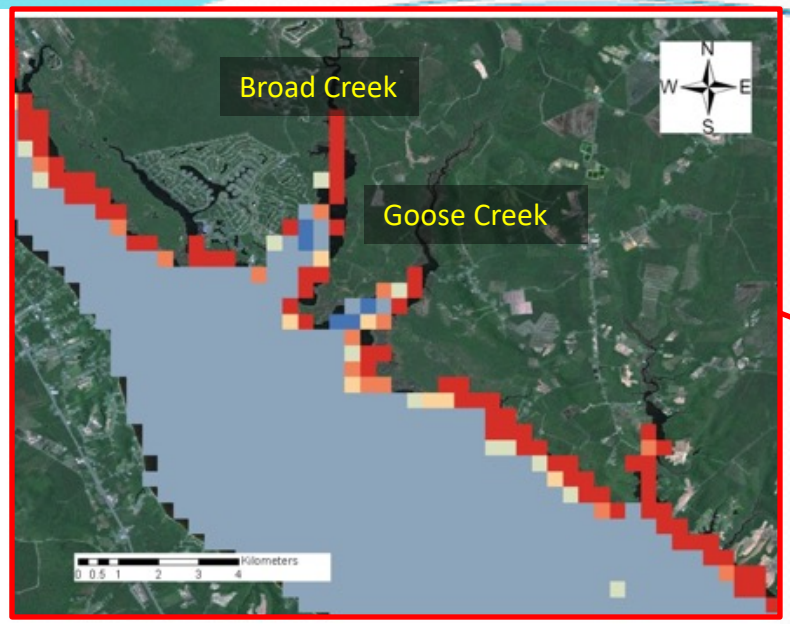


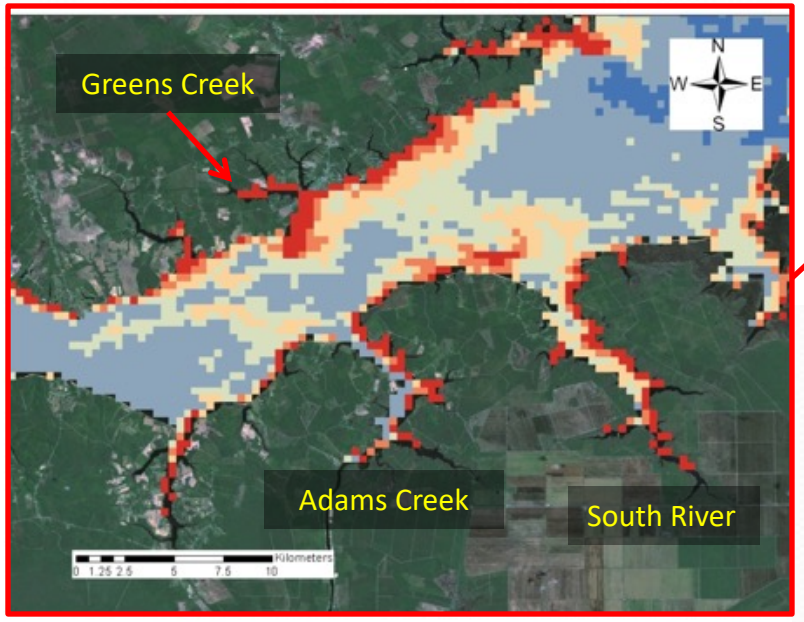


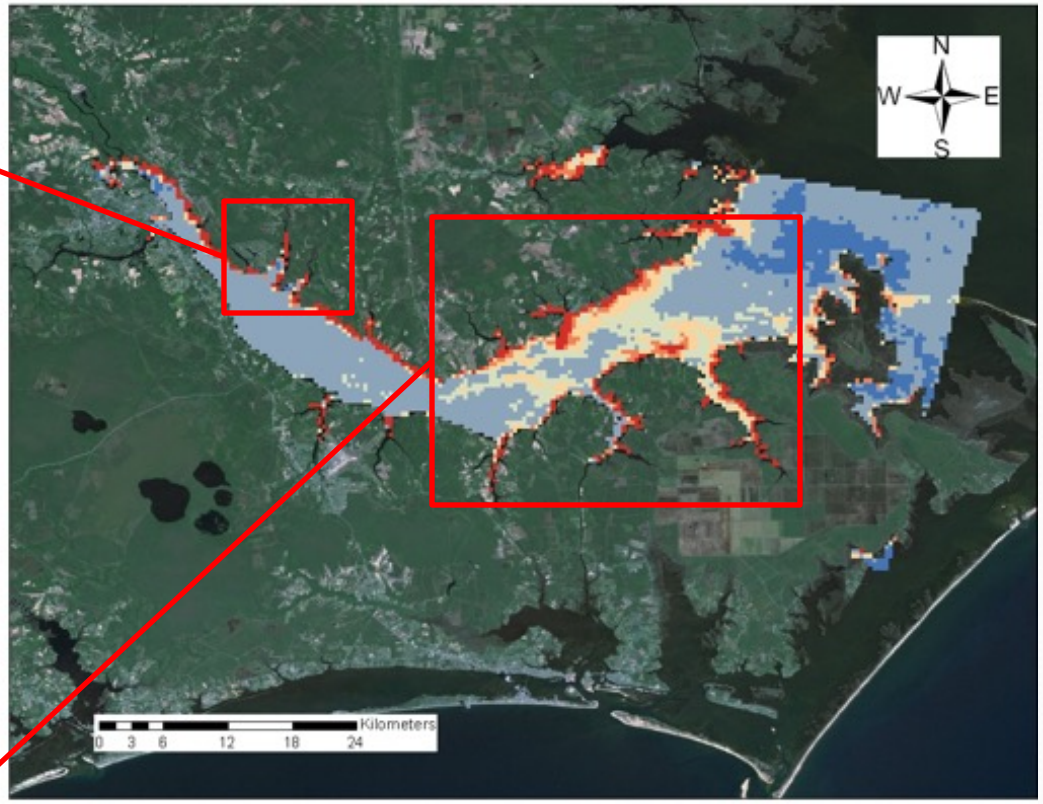
Chlorophyll a Concentration (ug/L)

- 6.9 - 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

Neuse River
2007 Chl *a* composite image



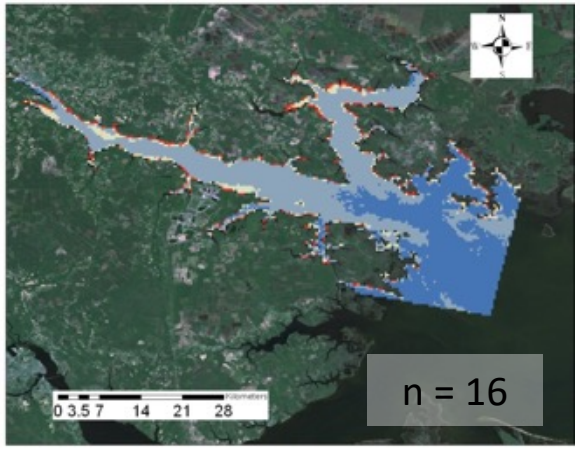




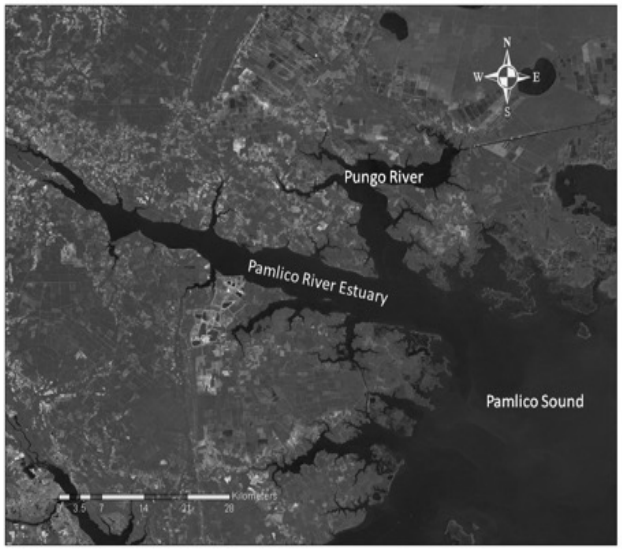
Chlorophyll a Concentration (ug/L)

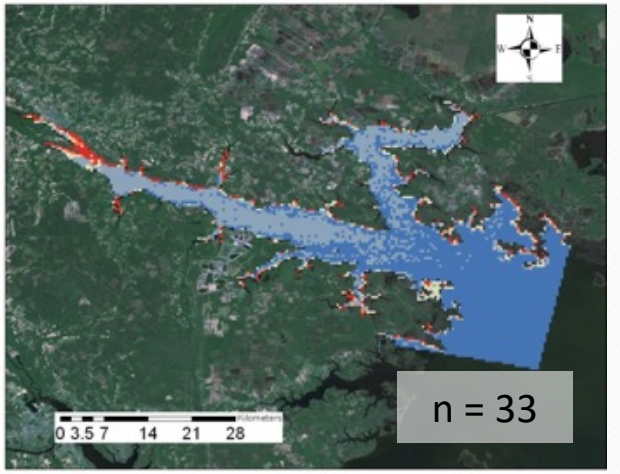
- 4.8 - 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

MERIS Chl a concentrations composited on an annual basis along the Tar-Pamlico River Estuary

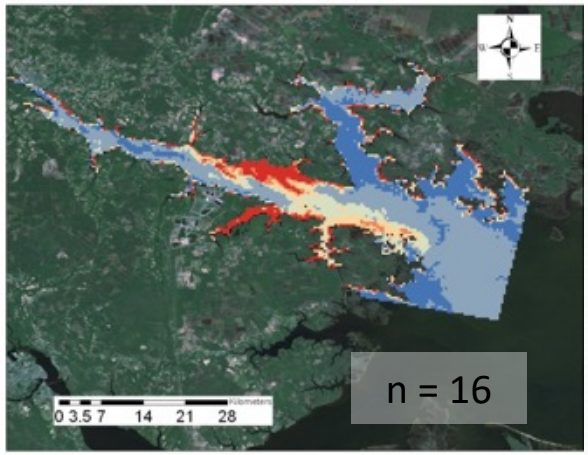


2006





2008



2007

Chlorophyll a Concentration (ug/L)

- < 10
- 10.1 - 20
- 20.1 - 30
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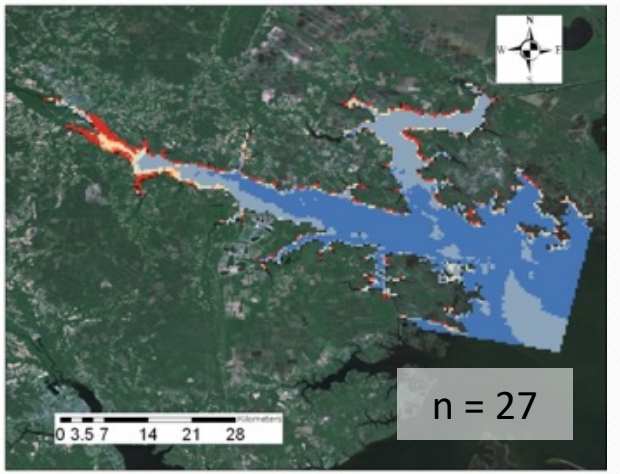
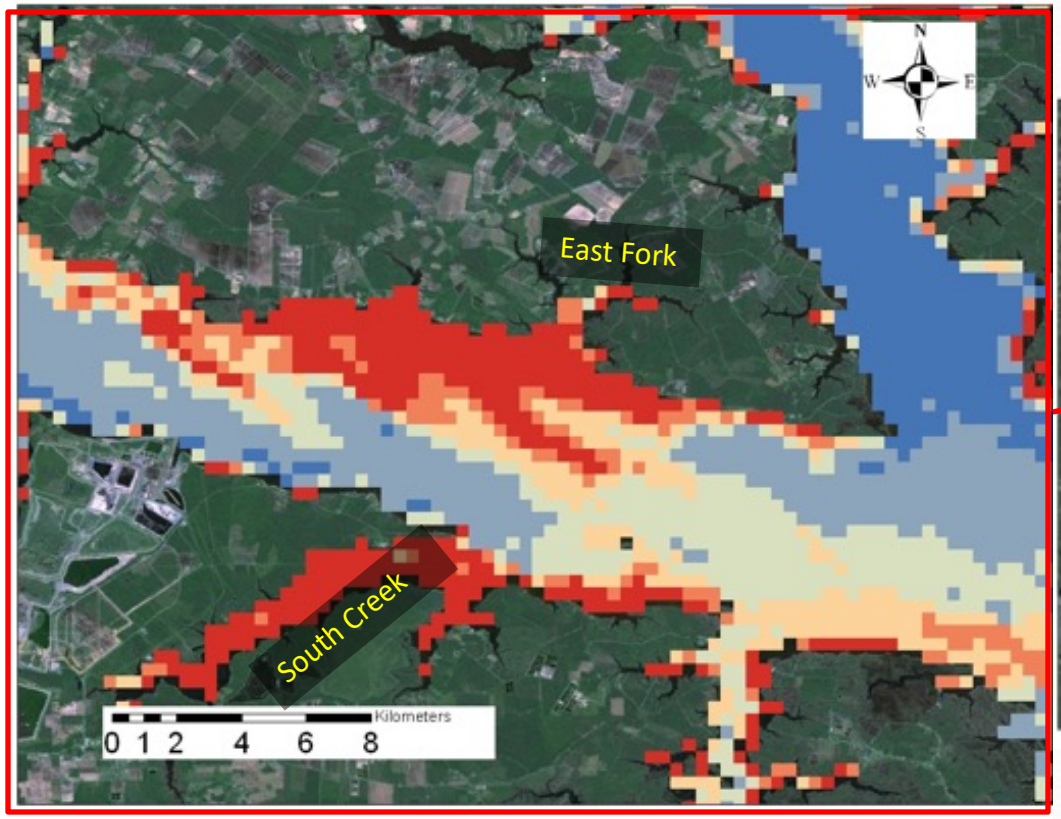
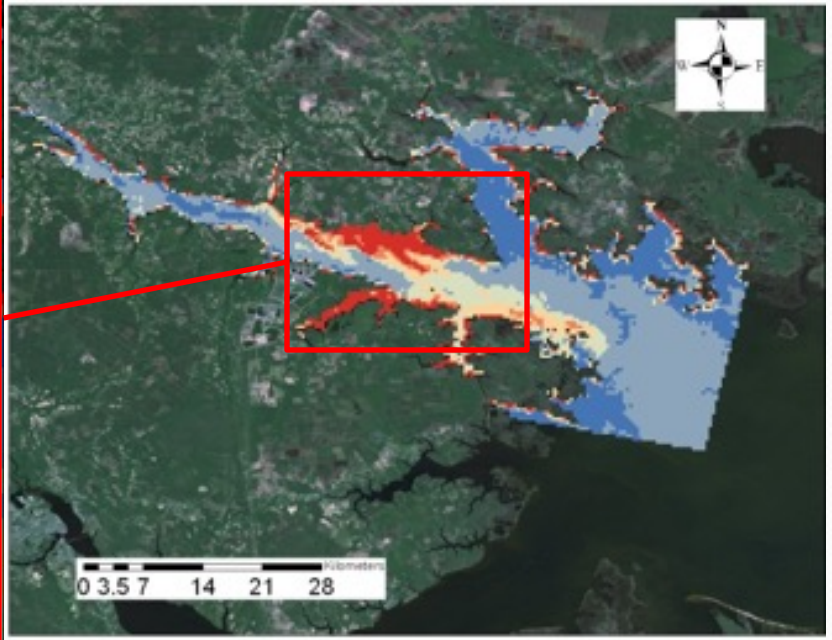
- 40.1 - 50
- 50.1 - > 60



2009

Tar-Pamlico River
2007 Chl *a* composite image

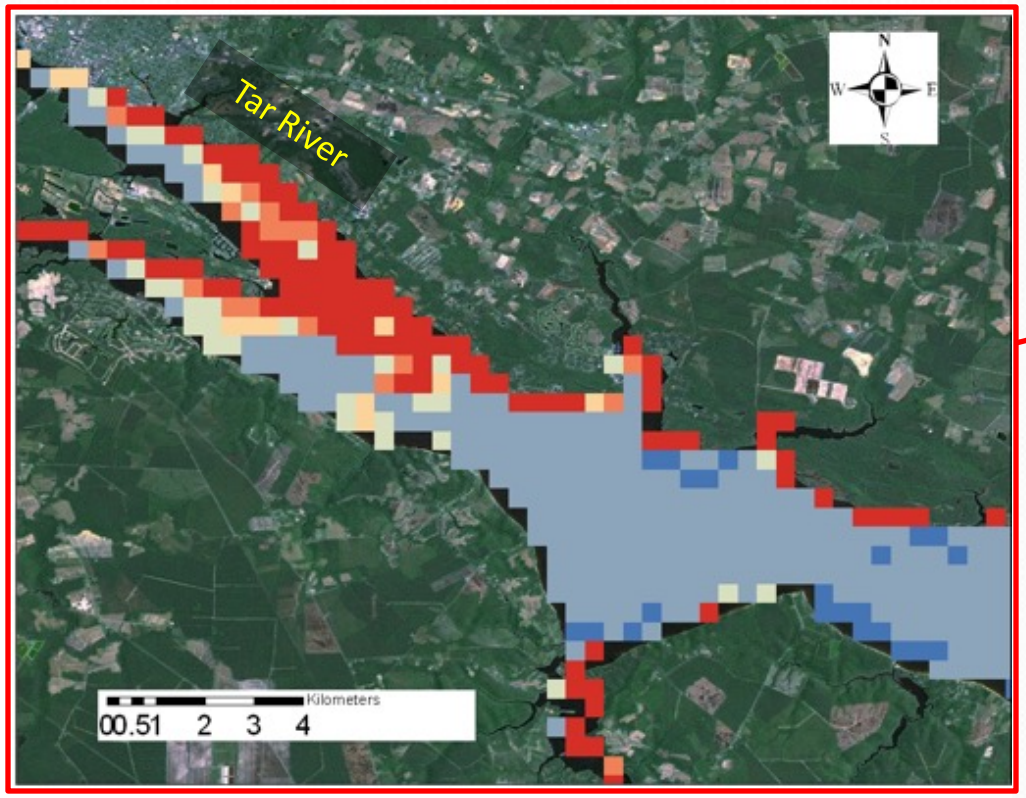


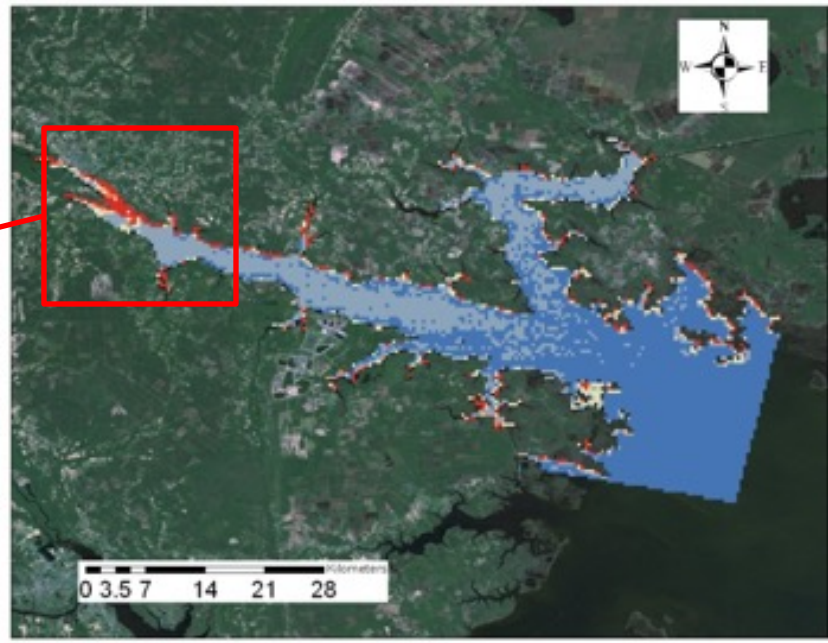


Chlorophyll a Concentration (ug/L)

- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

Tar-Pamlico
2008 Chl *a* composite image





Chlorophyll a Concentration (ug/L)

- < 10
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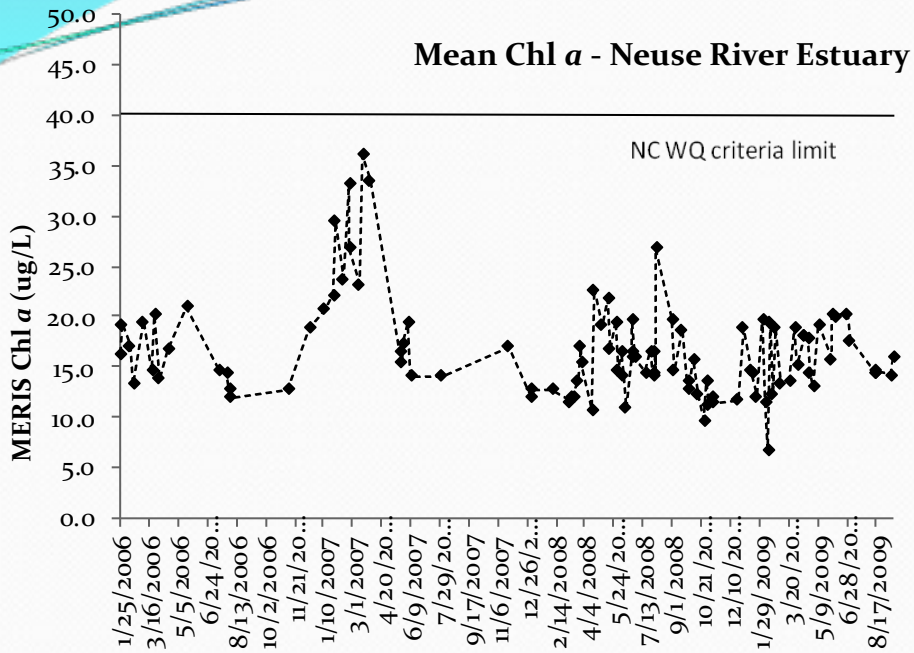
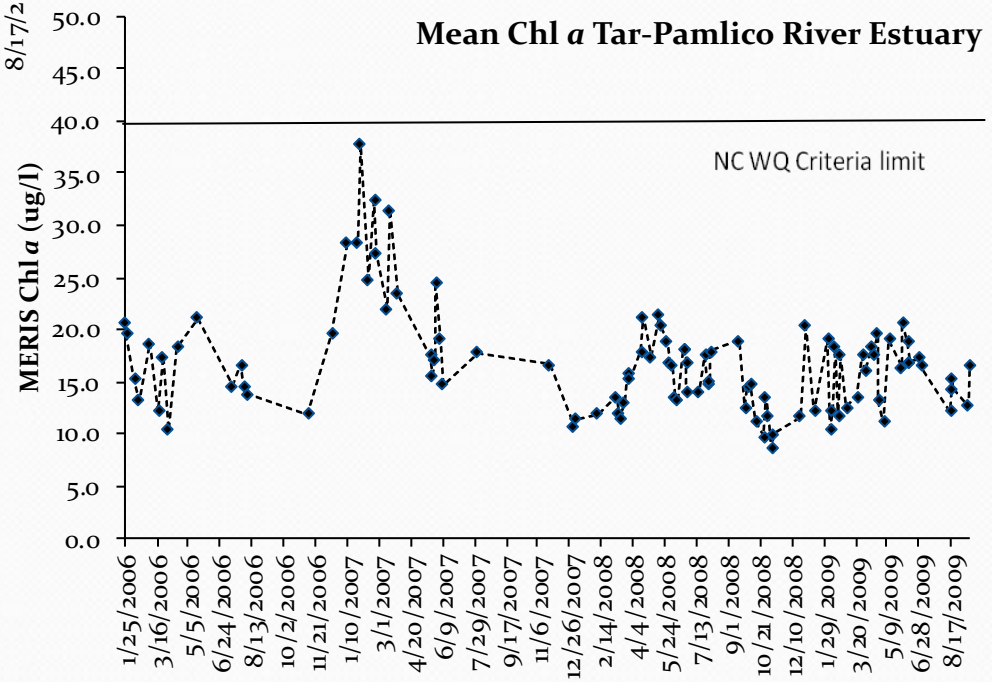
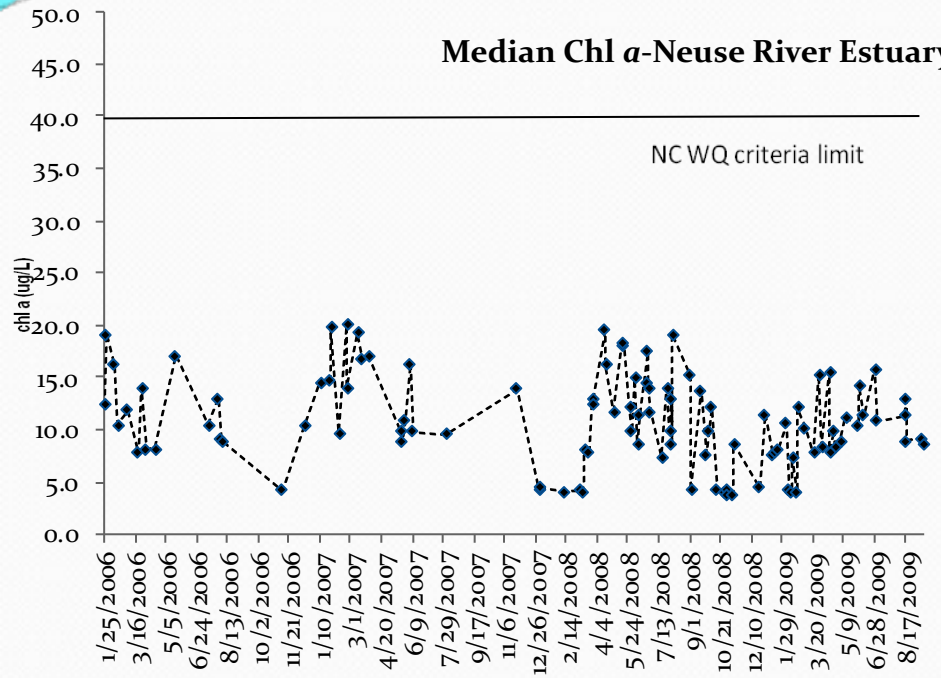
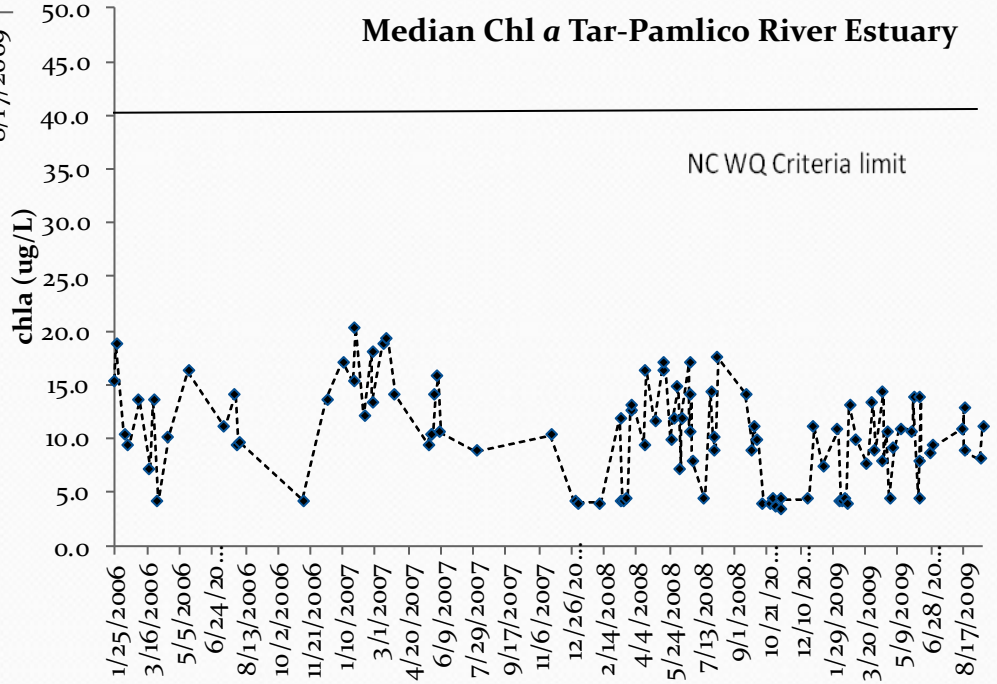
Mean chlorophyll *a* estimates: 2006 – 2009

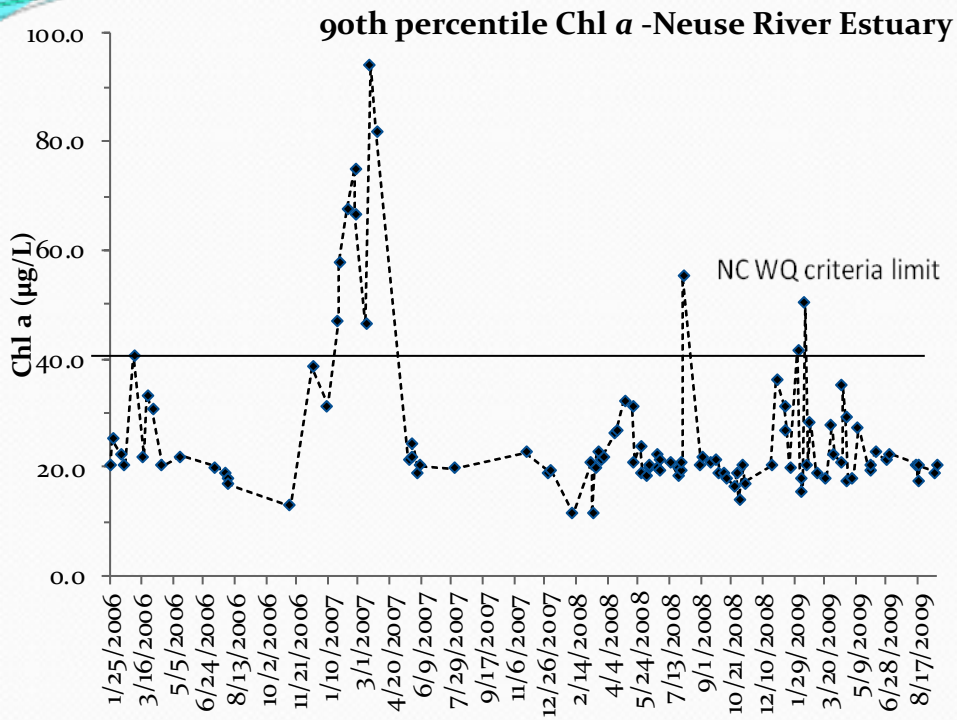




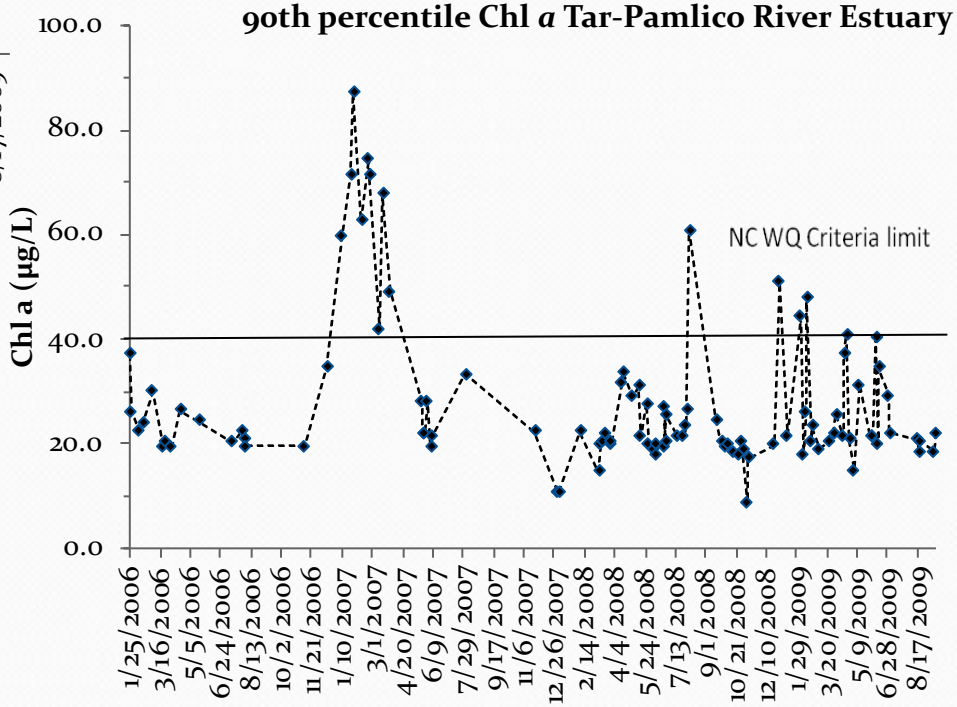
Median chlorophyll *a* estimates: 2006 – 2009







90th percentile chlorophyll *a* estimates: 2006 – 2009



3. Monitoring Needs and Recommendations

3.2. Needs and Recommendations: Phytoplankton

3.2.3. Phytoplankton Metric: Cyanobacteria Density

See Slide presentation

Satellite Assessment for Cyanobacteria: development of an early warning detection system

* *Project goals* are to:

(1) develop a standard and uniform approach for early identification of algal blooms that is useful and accessible to stakeholders of freshwater systems using the new set of satellites: Ocean Land Colour Instrument (OLCI) on Sentinel-3, Landsat-8 and applicable to future NASA missions;

(2) develop an information dissemination system for expedient public health advisory postings; and

(3) better understand the connections between health, economic, and environmental conditions to cyanobacteria and phytoplankton blooms.

•*Project Outcomes* are:

(1) assess and validate the performance of algorithms for MERIS, Sentinel-2, and Landsat-8 satellites using existing *in situ* data.

(2) formulate the framework for merging economic, ecological and human health research in developing threshold indicators that could be used to develop an aquatic and human health early warning system.

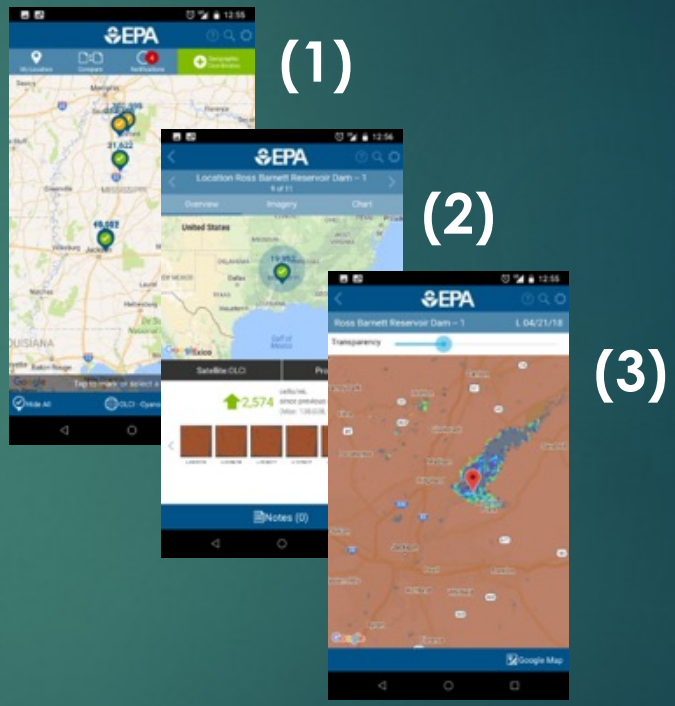
CyAN App

- Cyanobacteria estimates derived from European Sentinel-3 satellite
- Populate database that can be accessed by Android app.

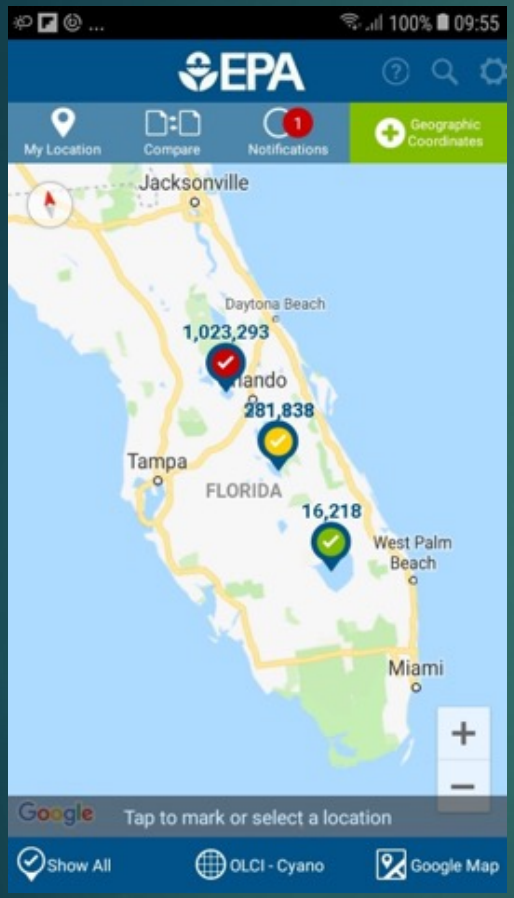
  (1) View available data

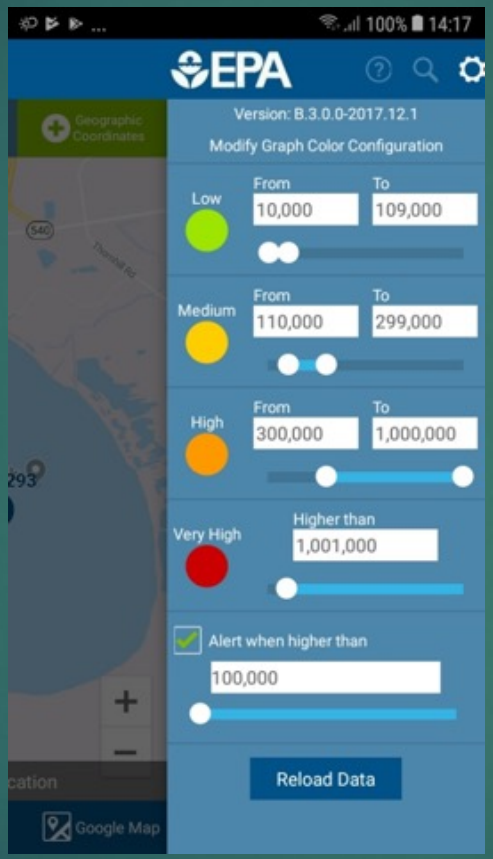
  (2) Zoom to targeted lake or reservoir (see stats on bloom)

  (3) View image of harmful algae bloom



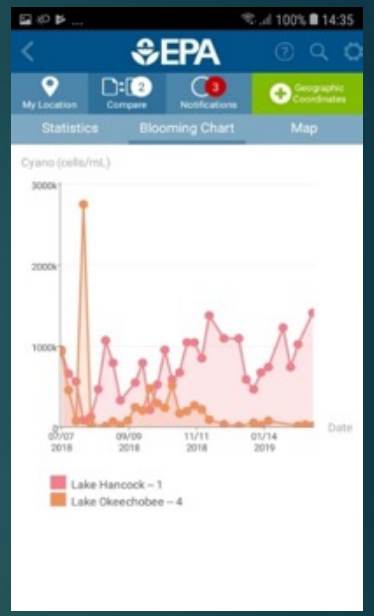
Comparisons with the App





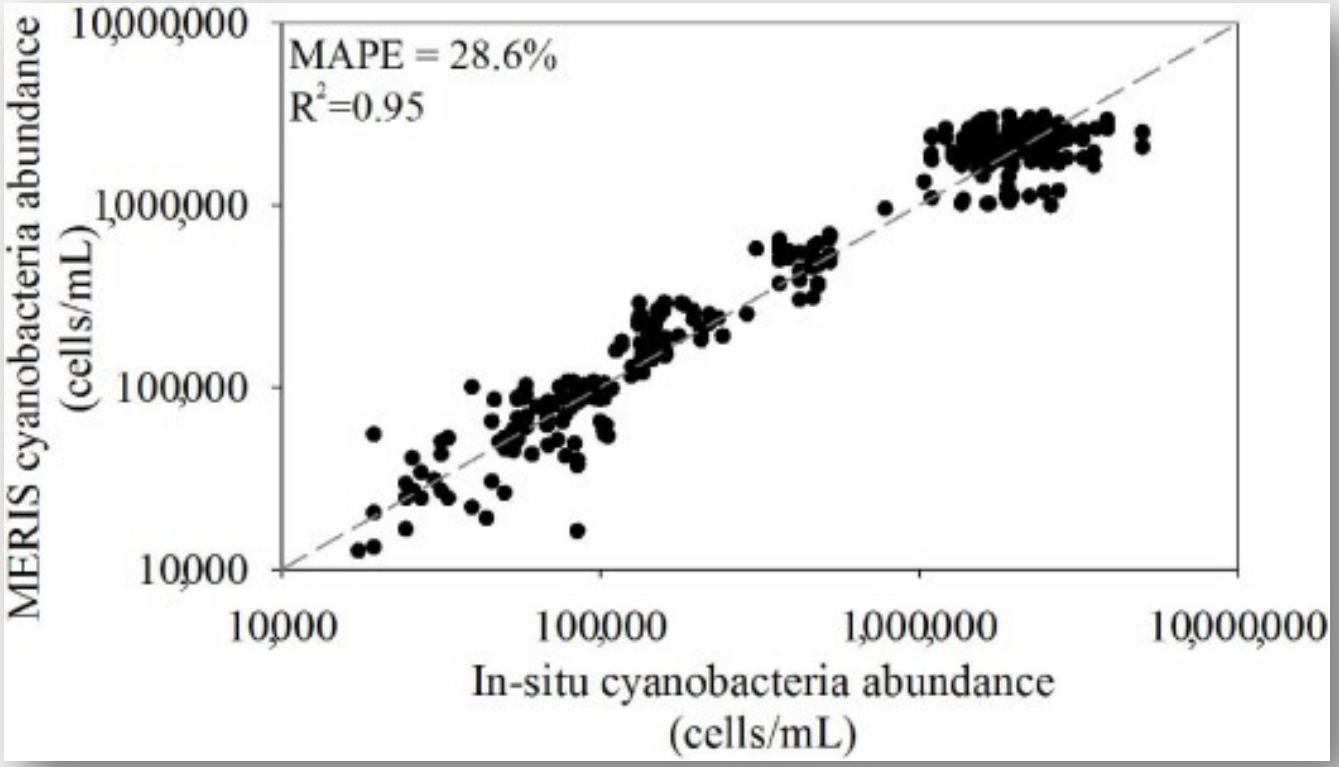
User threshold settings

More info: selected locations to compare



Time series: shows individual location cyano response through time

Initial Cyanobacteria Validation



Satellite Value

Bottle Samples

Satellite results represent what is seen in the field.

Clark et al. 2015. Ecological Indicators.
doi.org/10.1016/j.ecolind.2017.04.046

Lunetta et al. 2015. Remote Sensing of Environment.
doi.org/10.1016/j.rse.2014.06.008

3. Monitoring Needs and Recommendations

3.4.2. Water-Clarity Metric: Secchi Depth

$$K_d(\lambda) = (1+0.005\theta_0)a_t(\lambda) + 4.18[1-0.52exp(-10.8a_t)]b_b(\lambda)$$

(Kenworthy et al., 2014)

$K_d(\lambda)$ = spectral diffuse attenuation coefficient (m-1),
θ_0 = above-water solar angle of incidence (degrees),
$a_t(\lambda)$ = total absorption coefficient (m-1)
$b_b(\lambda)$ = backscattering coefficient (m-1)

Secchi Depth (Z_{SD}) can be derived from light attenuation (K_d) using the following relationship:

$$K_d(490) = 1.45/Z_{SD}$$ (Lee et al., 2018)

3.4.3. Water-Clarity Metric: Turbidity (TSS)

$$TSS\ (gm{-}3) = A\rho\ *\pi*R_{rs}\ (\lambda)/(1{-}\pi*R_{rs}/C\rho)$$

$R_{rs}(665)$ = Remote sensing reflectance at 665 nm
$C\rho = 17.28*10\text{-}2$
$A\rho = 355.85$
(Nechad et al., 2010)

3. Monitoring Needs and Recommendations

3.5.1. Physical-Chemical Metric: Water Temperature

Surface water temperatures can derived as a product from atmospherically corrected Landsat 8/9 satellite imagery. During this process, the ACOLITE atmospheric correction program calculates the at-sensor brightness temperature from the Landsat 8/9 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) instruments. The spatial resolution of these data will be 30 m

3.5.2. Physical-Chemical Metric: Estuarine Salinity

See Slide presentation

Temporal and Spatial Variation in Fish Nursery Areas of the Albemarle-Pamlico Sound, NC Estuarine System Derived from MERIS

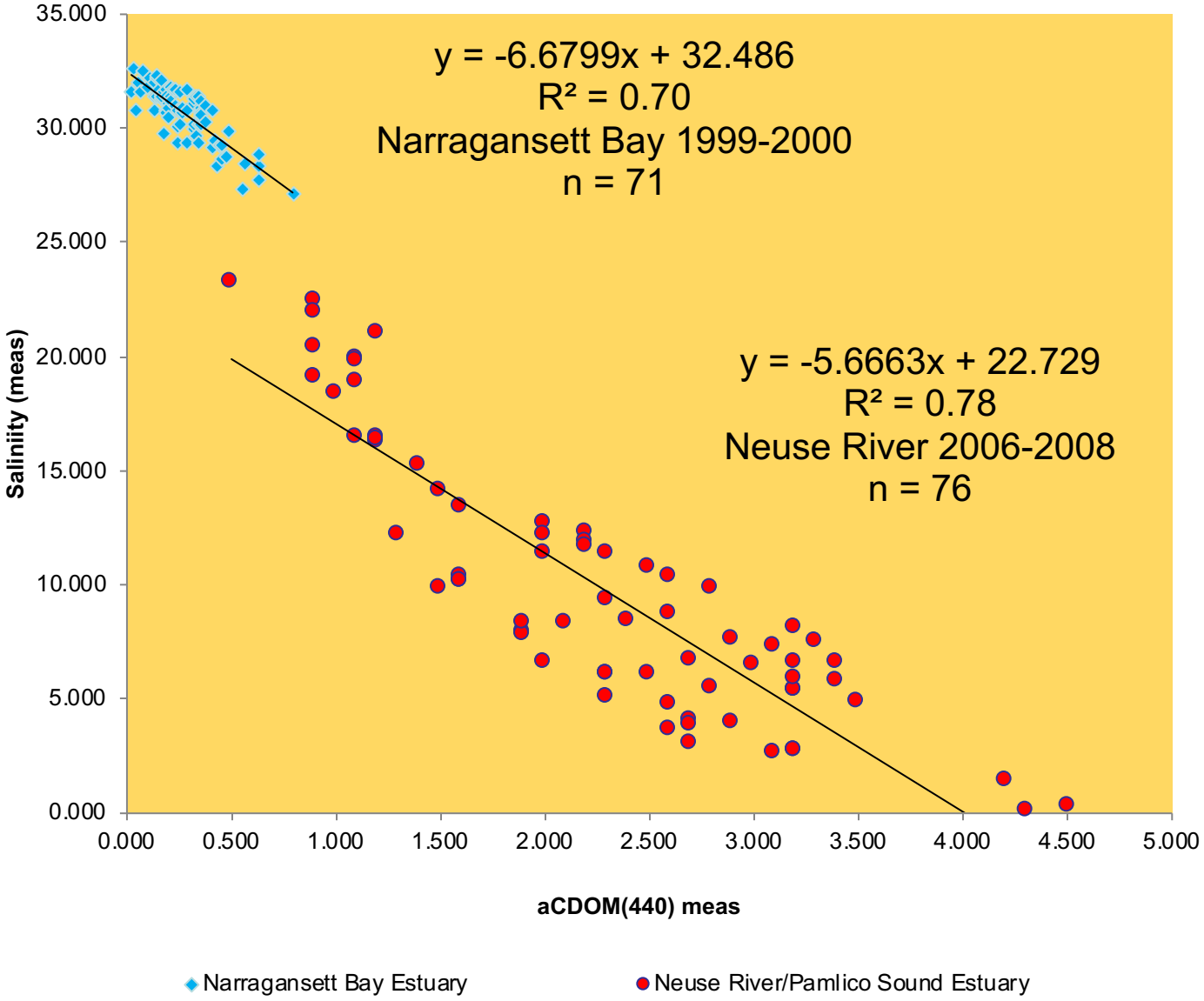
Darryl Keith
USEPA National Health and Environmental Effects Research Laboratory
Atlantic Ecology Division
Narragansett, RI

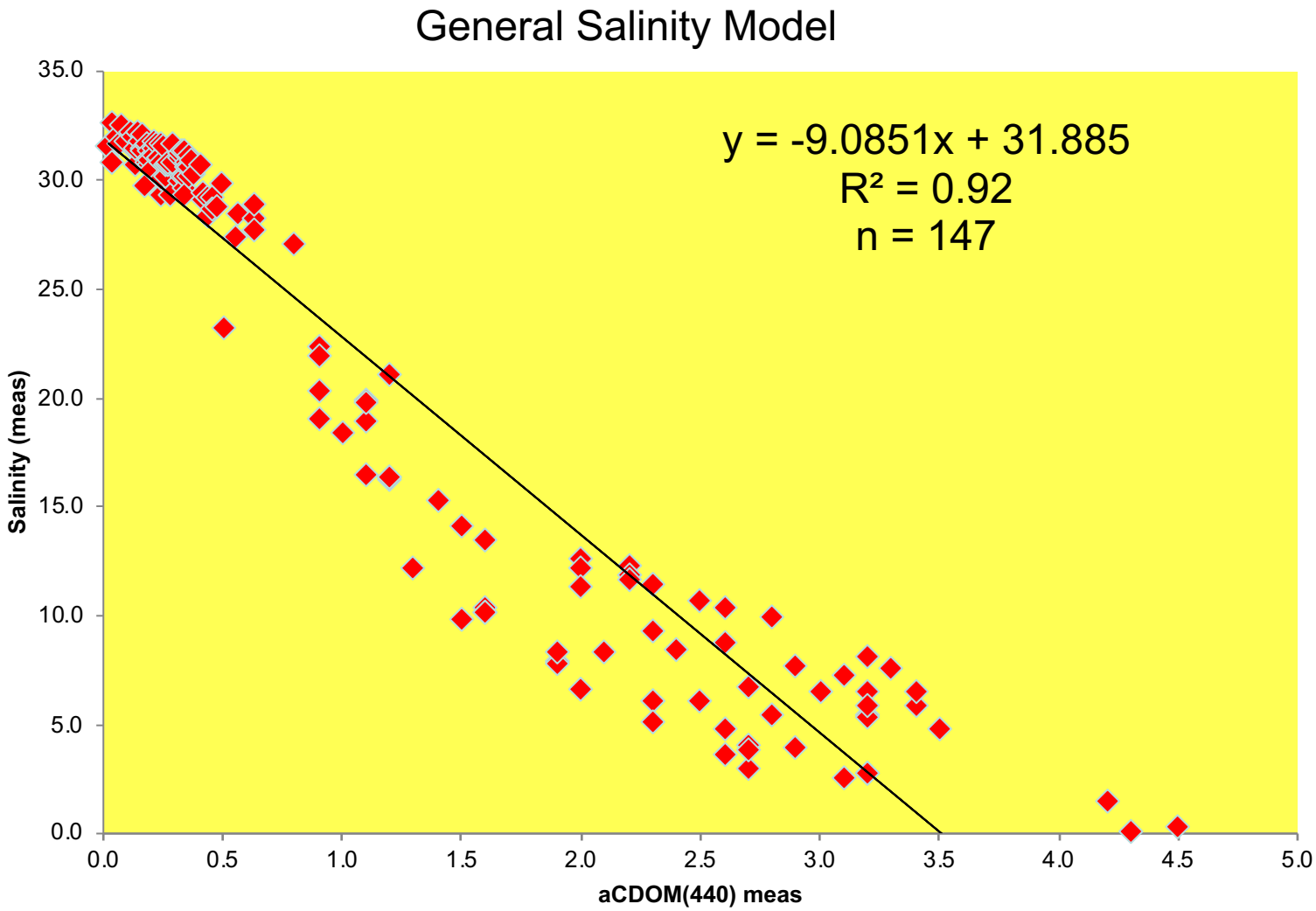
Ross Lunetta
USEPA National Exposure Research Laboratory
Environmental Science Division
Research Triangle Park, NC

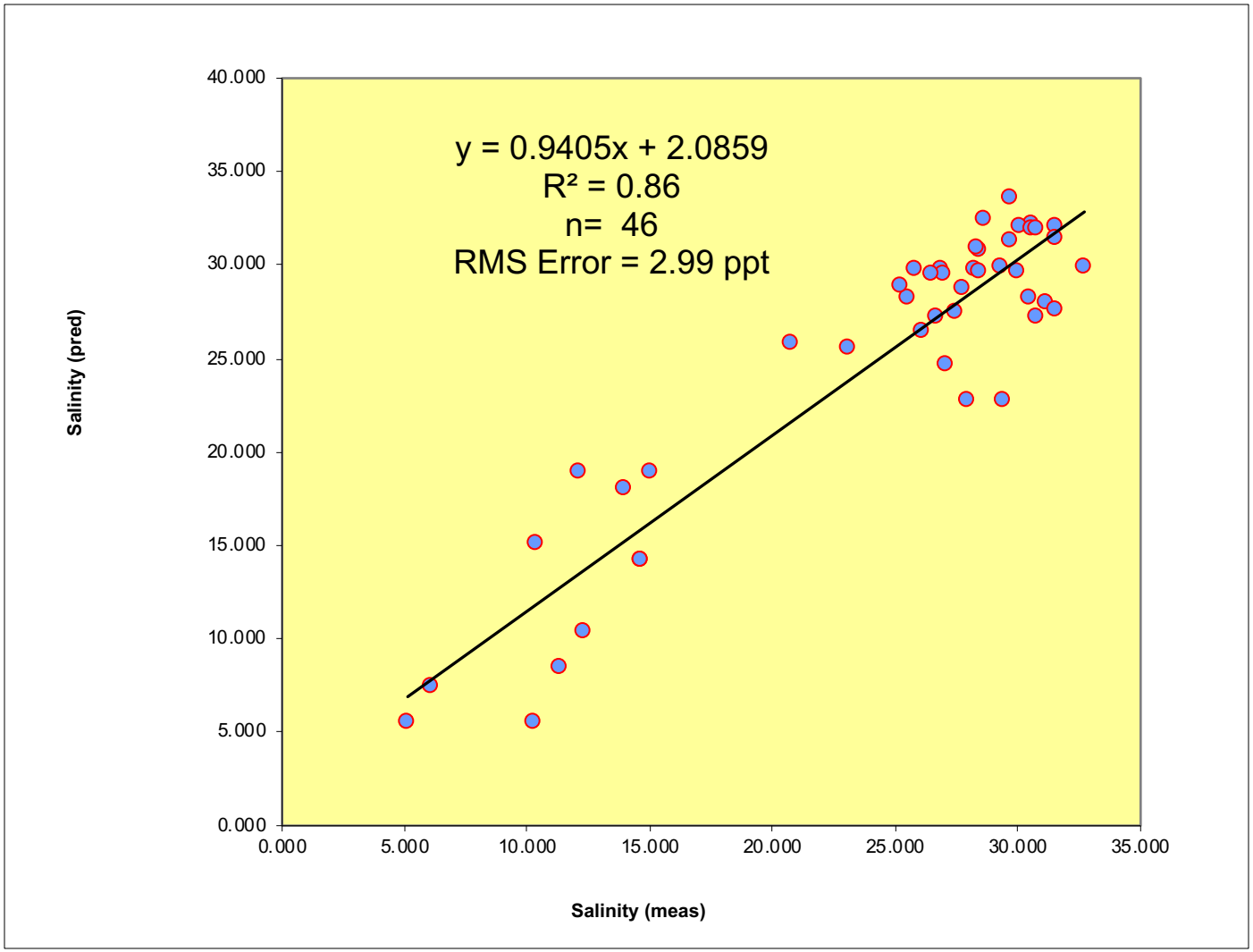
Anne Kuhn and Jeff Hollister
USEPA National Health and Environmental Effects Research Laboratory
Atlantic Ecology Division
Narragansett, RI

Research Objectives

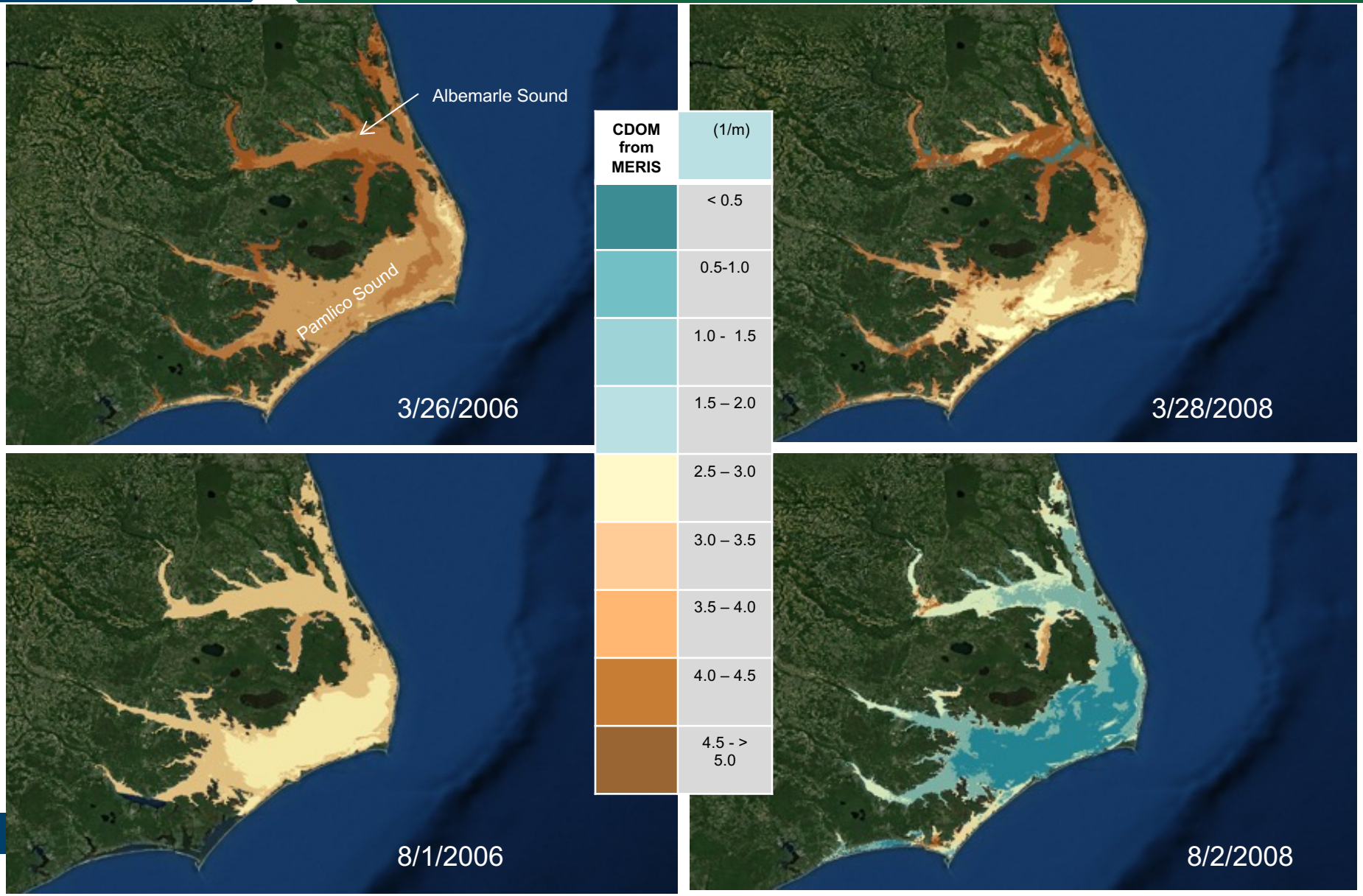
- Create a salinity algorithm for estuarine and coastal waters from the inverse relationship between measured CDOM absorption at 440 nm and salinity.
- Map the temporal and spatial distribution of salinity in Albemarle-Pamlico Sound system as derived from the ESA MERIS full resolution (300 m) CDOM (443 nm) data product.
- Using NC Marine Fisheries Commission (NCMFC) categories, map the spatial distribution of nursery areas from a MERIS August 2006 image.

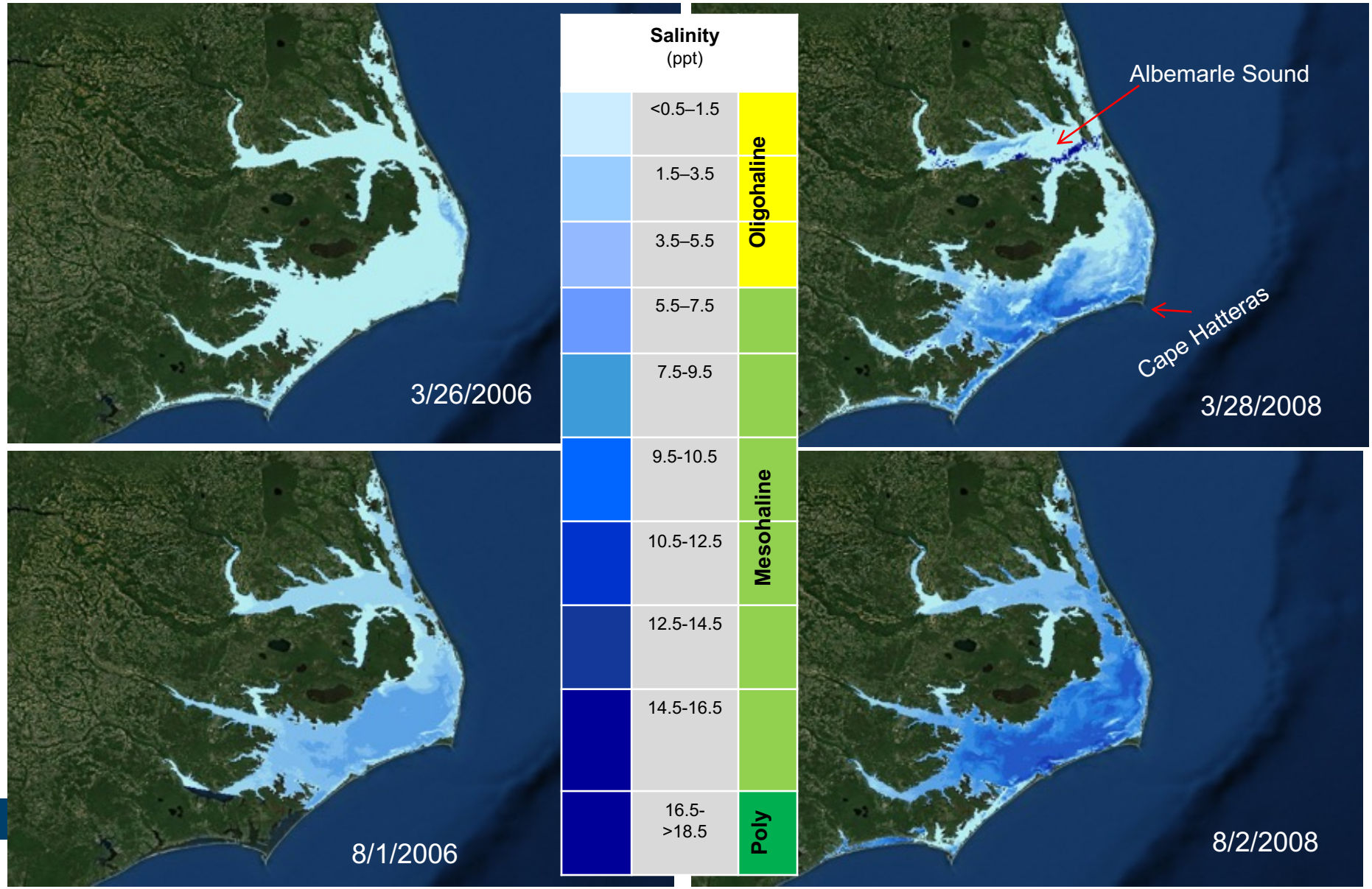

y = -6.6799x + 32.486
R² = 0.70
Narragansett Bay 1999-2000
n = 71
y = -5.6663x + 22.729
R² = 0.78
Neuse River 2006-2008
n = 76
Salinity (meas)
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
0.000
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
5.000
aCDOM(440) meas
Narragansett Bay Estuary
Neuse River/Pamlico Sound Estuary


General Salinity Model
y = -9.0851x + 31.885
R² = 0.92
n = 147
Salinity (meas)
aCDOM(440) meas
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


y = 0.9405x + 2.0859
R² = 0.86
n= 46
RMS Error = 2.99 ppt
Salinity (pred)
Salinity (meas)
0.000
5.000
10.000
15.000
20.000
25.000
30.000
35.000
40.000

ECOSYSTEMS SERVICES RESEARCH PROGRAM




Salinity
(ppt)
<0.5–1.5
1.5–3.5
3.5–5.5
5.5–7.5
7.5-9.5
9.5-10.5
10.5-12.5
12.5-14.5
14.5-16.5
16.5-
>18.5
Oligohaline
Mesohaline
Poly
Albemarle Sound
Cape Hatteras
3/26/2006
3/28/2008
8/1/2006
8/2/2008

Contact

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Darryl Keith
Research Oceanographer
Office of Research and Development
Center for Environmental Measurement and Modeling
Atlantic Coastal Environmental Sciences Division
keith.darryl@epa.gov

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CyAN@epa.gov