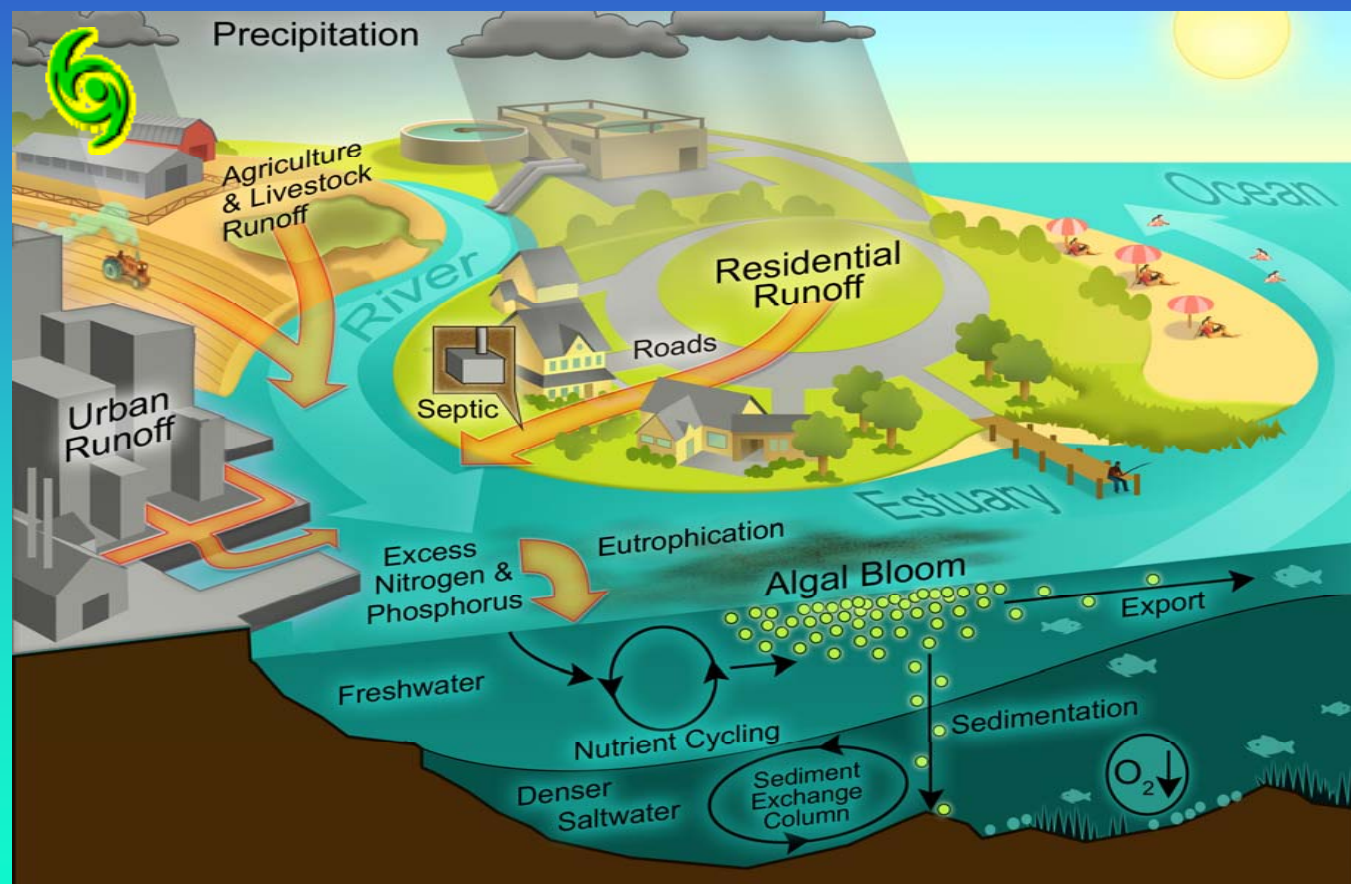


US EPA ARCHIVE DOCUMENT

Connections Between Public Health and Ecosystems Services in Estuarine and Coastal Systems

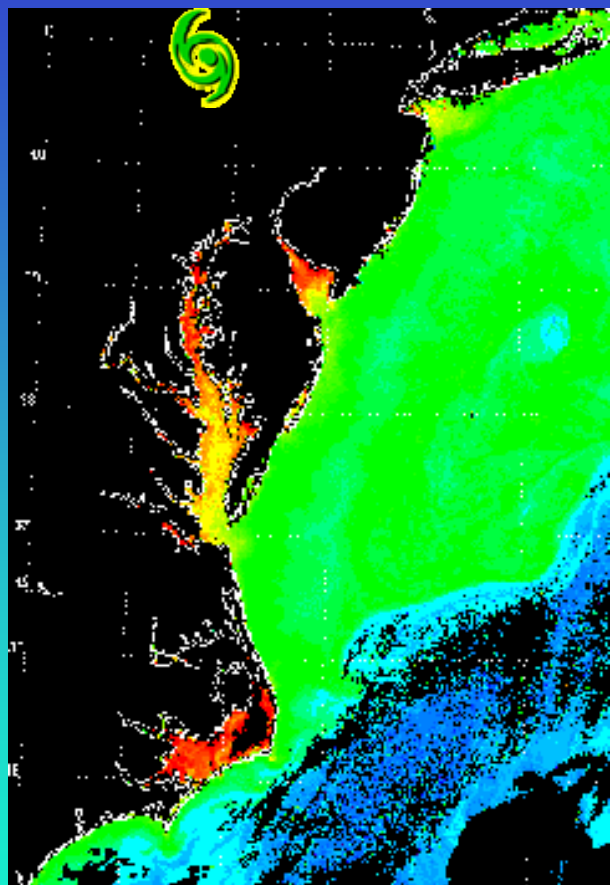
Hans Paerl & Colleagues, UNC-CH Instit. Marine Sciences
and collaborating institutions www.marine.unc.edu/Paerllab



The connection between humans, climate & ecosystem services

Human activities → nutrient/pollutant loading → eutrophication → hypoxia → WQ/habitat decline

- Estuaries major fisheries habitat, residences, recreation tourism; \$3.5 b annually for Pamlico Sound System
- Drains coastal plains experiencing agricultural, urban & industrial expansion
- N and P loads increased > 50% for PS
- Pathogen loads increased, linked to development
- Highly susceptible to eutrophication
- Site of increased Atlantic TS/Hurricane activity



Why the concern about hurricanes and tropical storms?

Large Hydrologic perturbations

(lots of water, quickly, and persistent flooding in low-lying areas)

↑ **Nutrient, sediment & contaminant (pathogen) inputs**

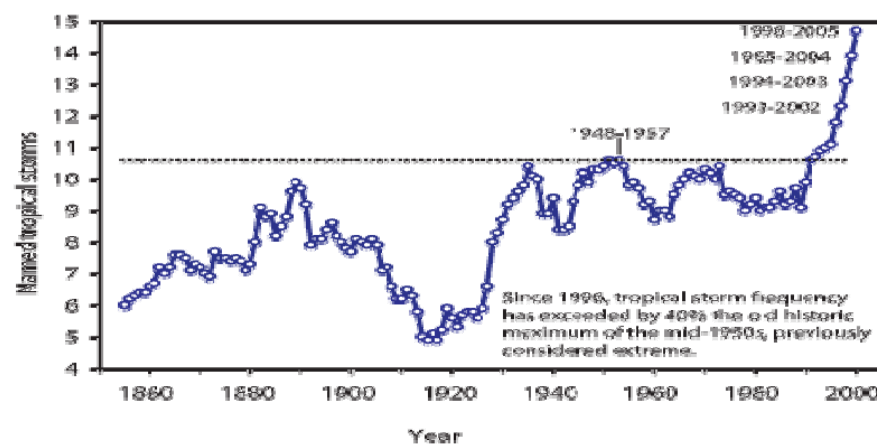
Biotic alterations (water quality, habitat, fisheries impacts)

Huge Economic/Health Impacts: ~\$3.2 billion from Floyd

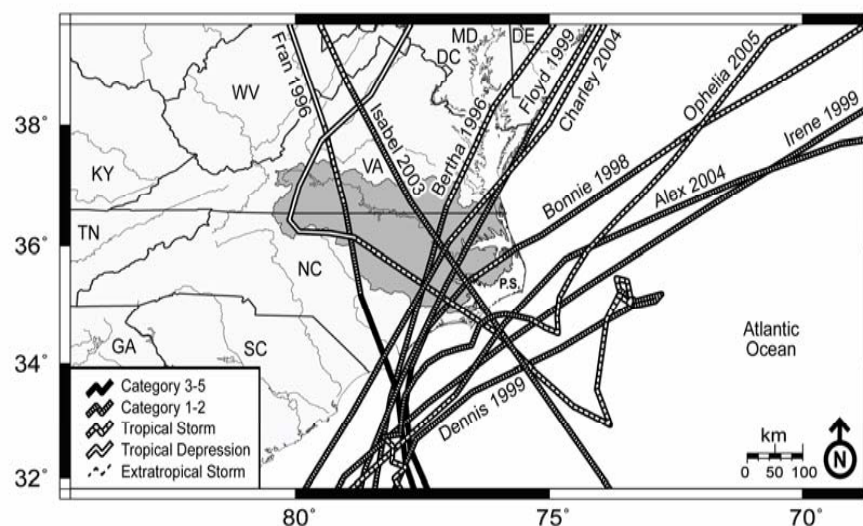
Hurricane Frequencies and Intensities are Increasing!!!

North Atlantic Tropical Storms

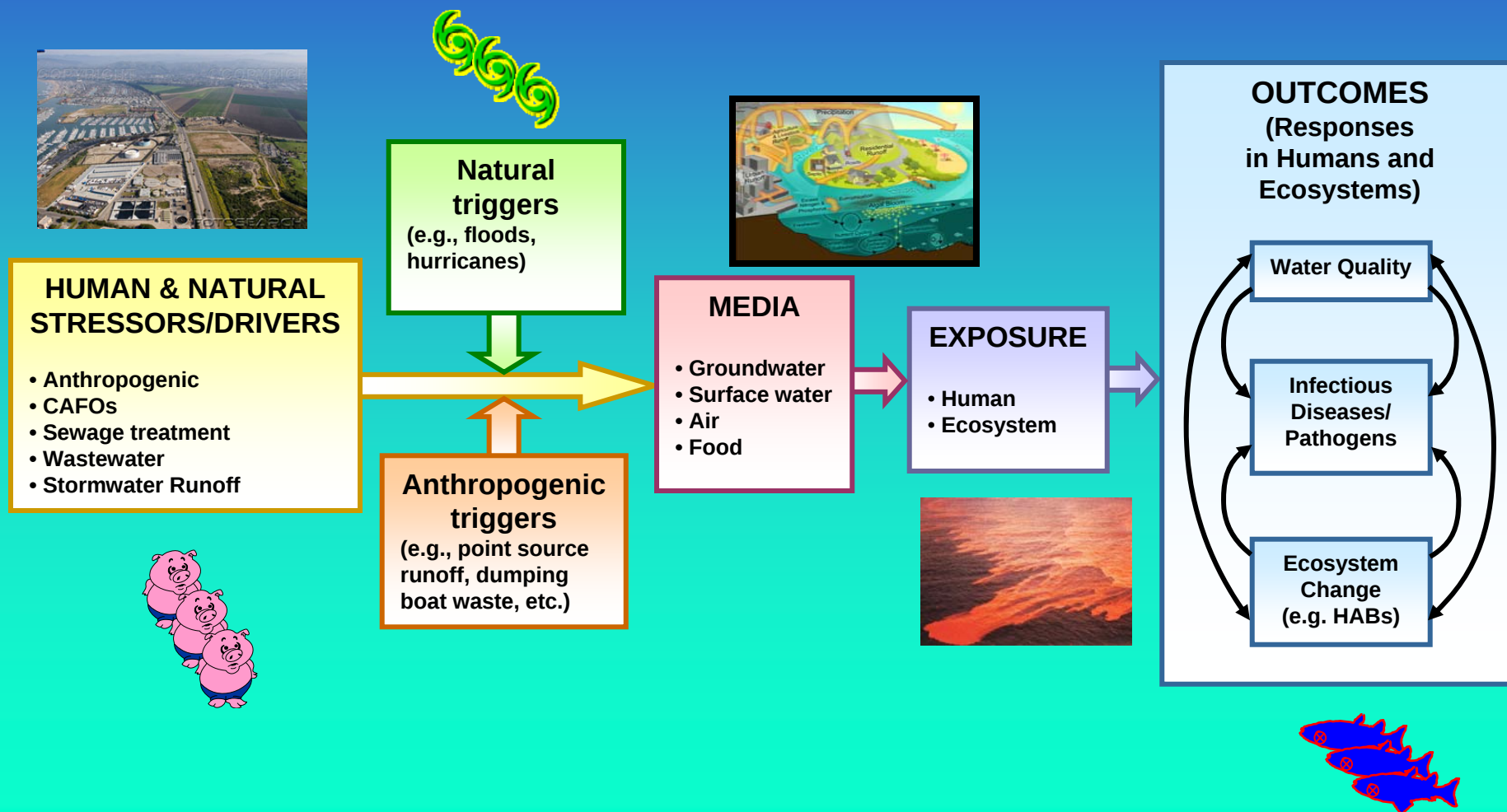
10-year running average



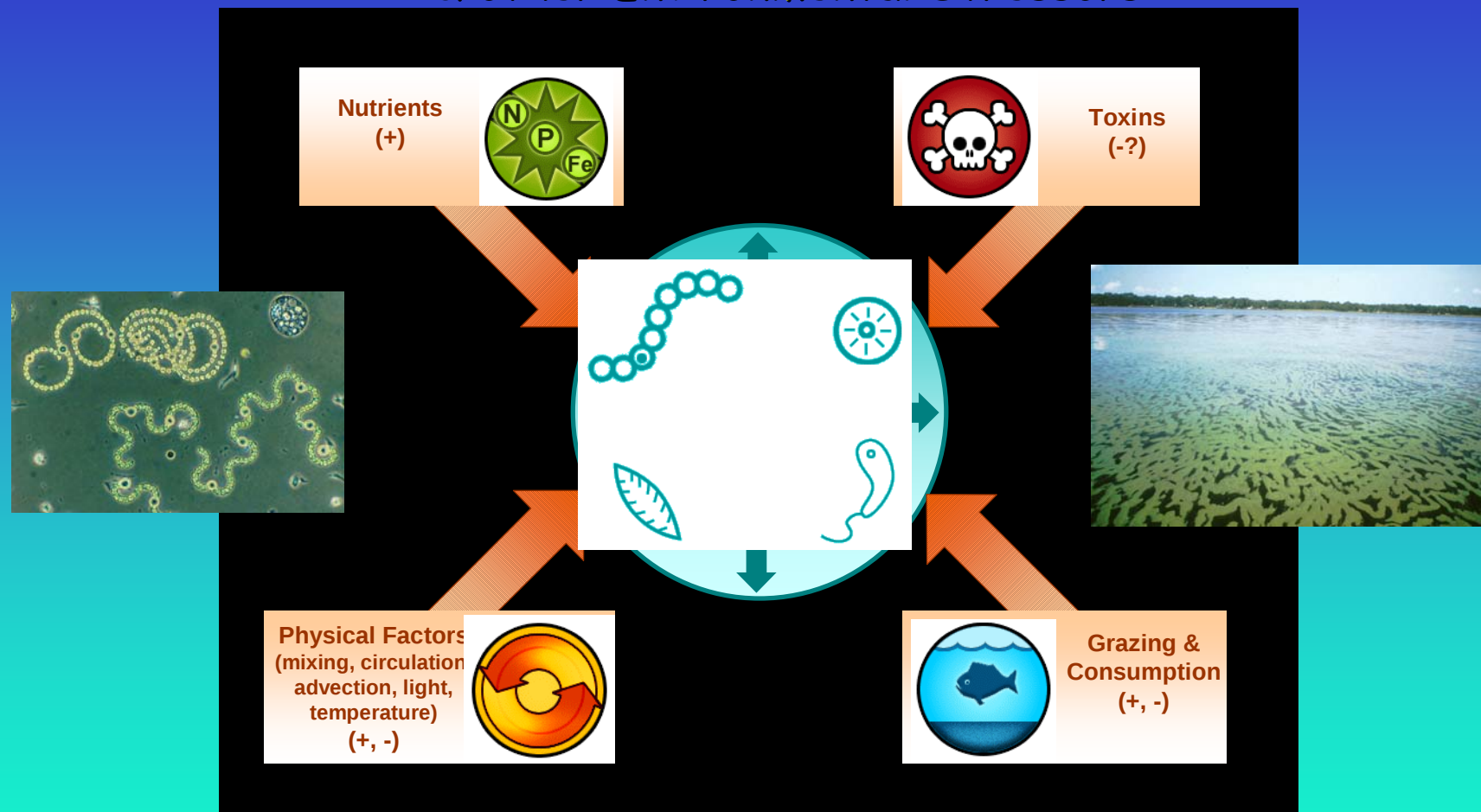
Data Source: National Hurricane Center



Conceptual Working Model for the System Response, Combining Biogeochemical, Ecological and Human Health Factors



Microbes as Indicators of Nutrient & other Environmental Stressors

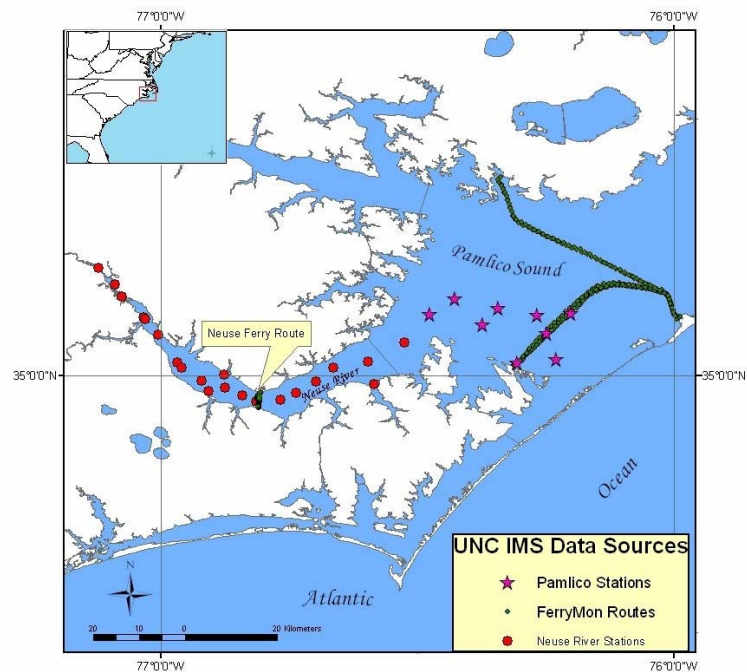
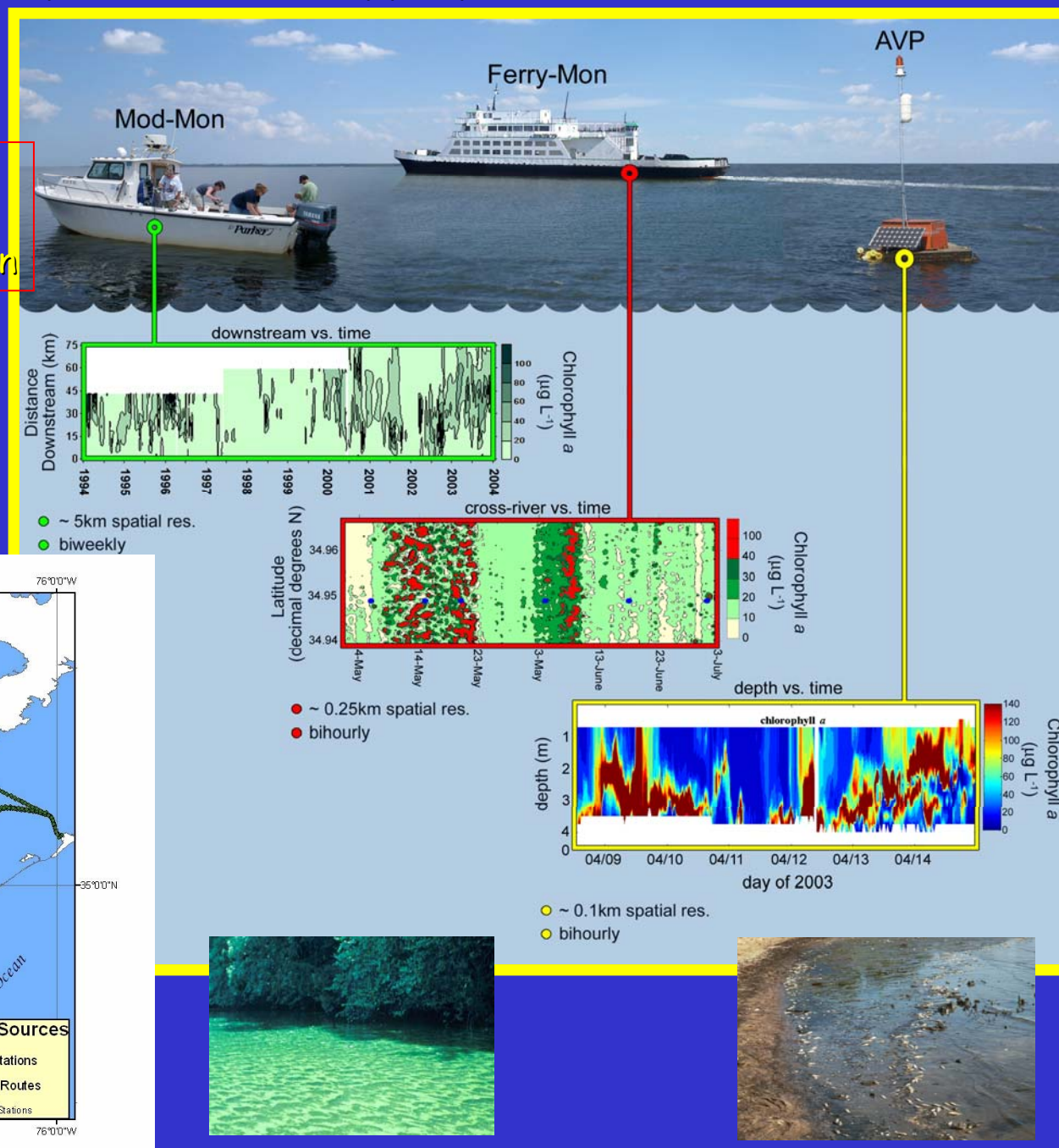


- Sensitive, meaningful indicators of physical-chemical change
- Determine productivity, nutrient cycling, water quality, use and health
 - Can be sensed and characterized by a variety techniques over a wide range of scales (cellular → global)

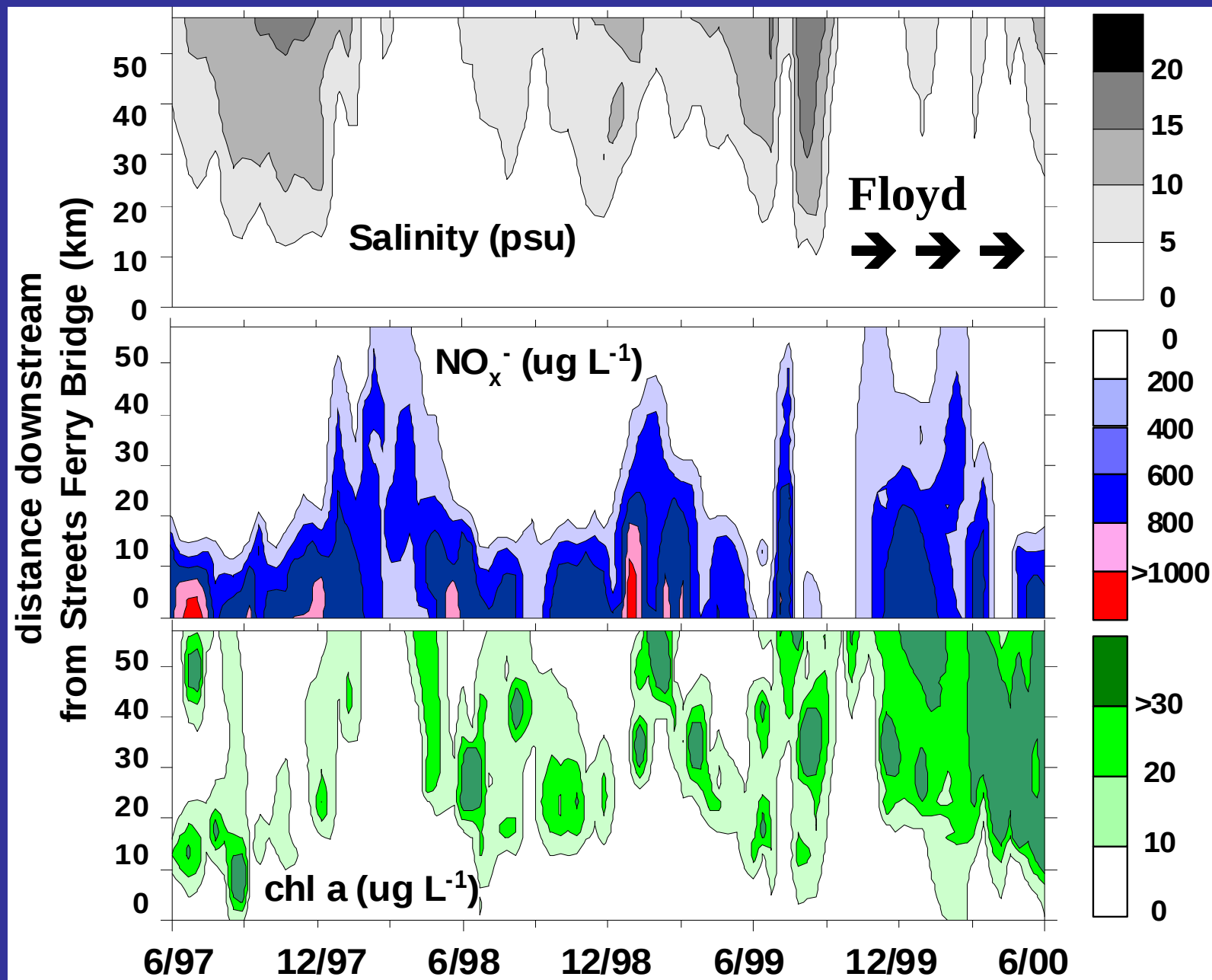
Assessing Impacts on the appropriate scales

www.ferrymon.org

www.unc.edu/ims/neuse/modmon



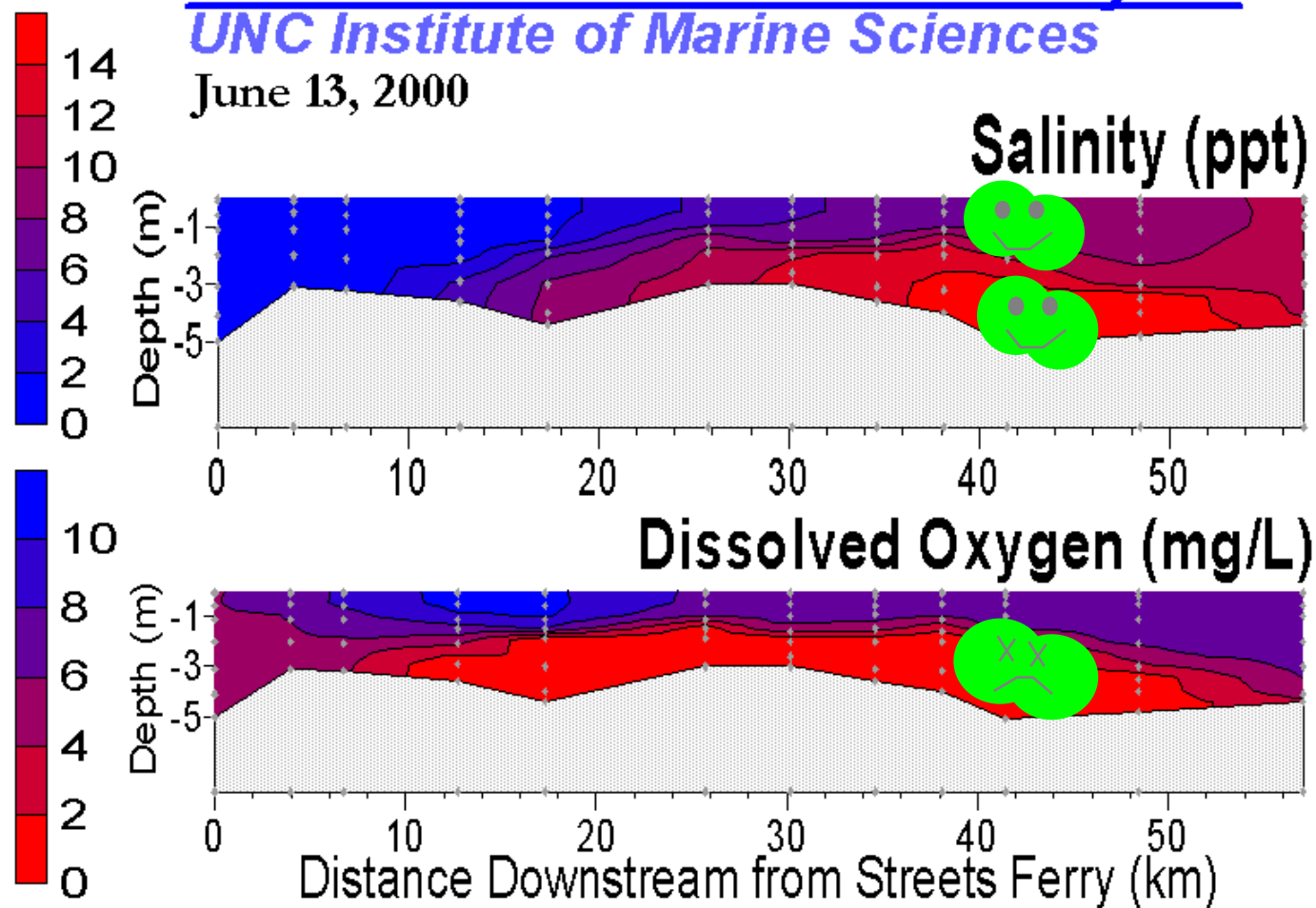
Using space-time intensive monitoring to examine the effects of seasonal vs episodic (hurricane) **N** loading on algal production (**Chl a**) in the Neuse R. Estuary



The "connection" to Hypoxia

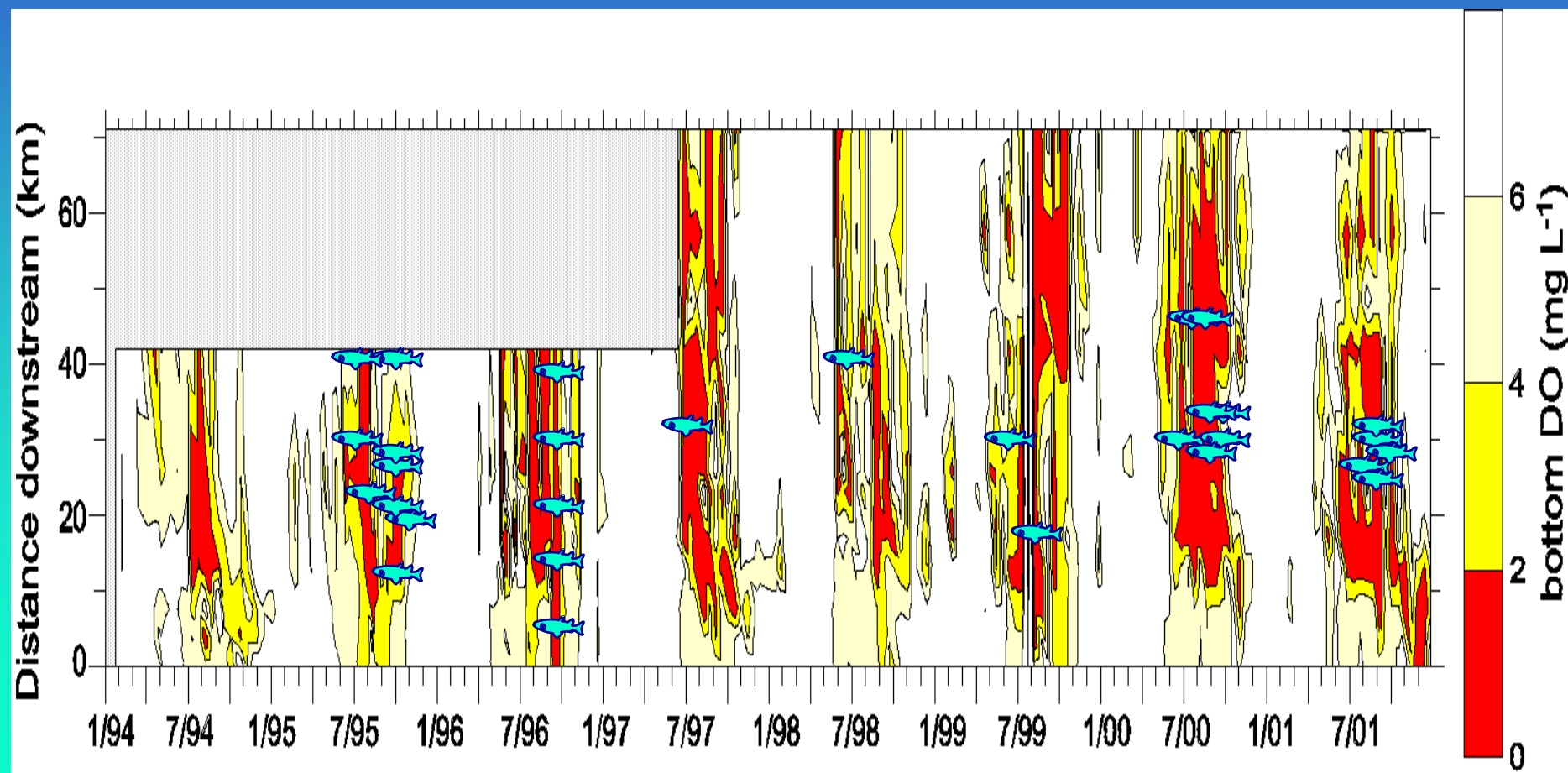
Neuse River MODMON Project UNC Institute of Marine Sciences

June 13, 2000



Linking Hypoxia and Fish kills in the Neuse River Estuary 1994-2001

Using the ModMon Project
(www.marine.unc.edu/neuse/modmon)



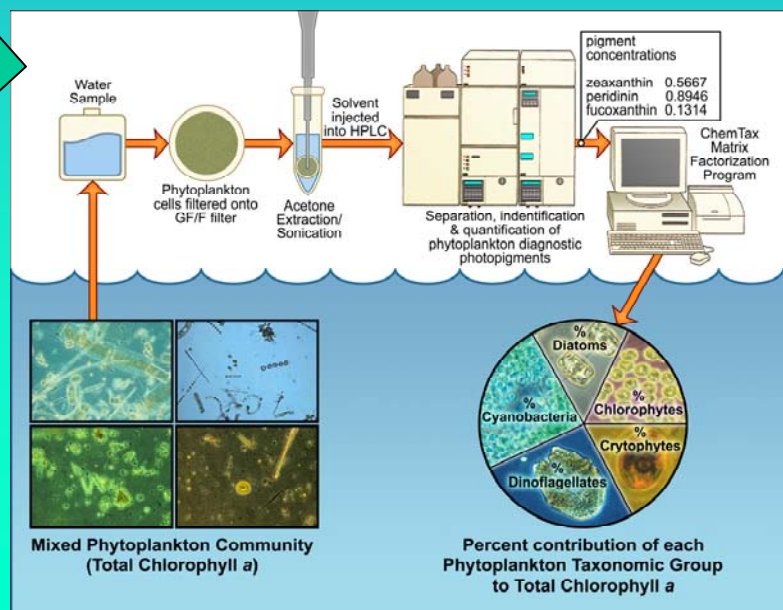
Fish kill data base:

<http://www.esb.enr.state.nc.us:80/Fishkill/fishkillmain.htm>

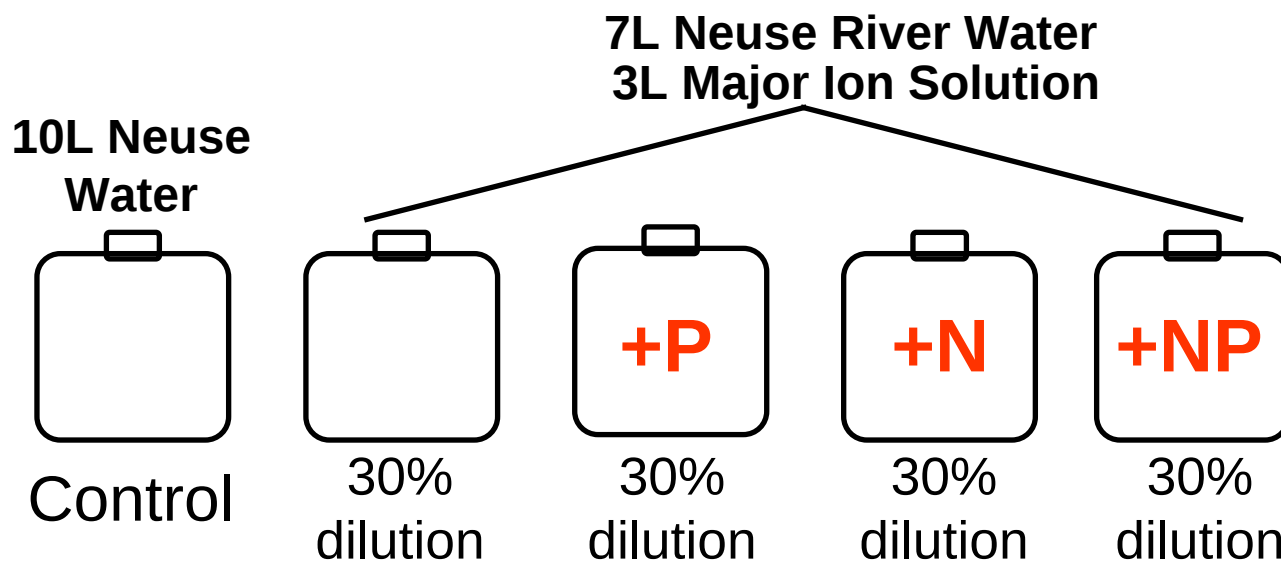
Need: Reduce Estuarine Primary Production (Chl *a*) by Establishing an N Input Threshold (TMDL)

Scientific Consensus/Recommendation:
30% N Input Reduction (based on 1990-1995 loads)

Proof: Using photopigments to assess algal growth response to N reductions (i.e. mandated 30% N input reduction = TMDL)

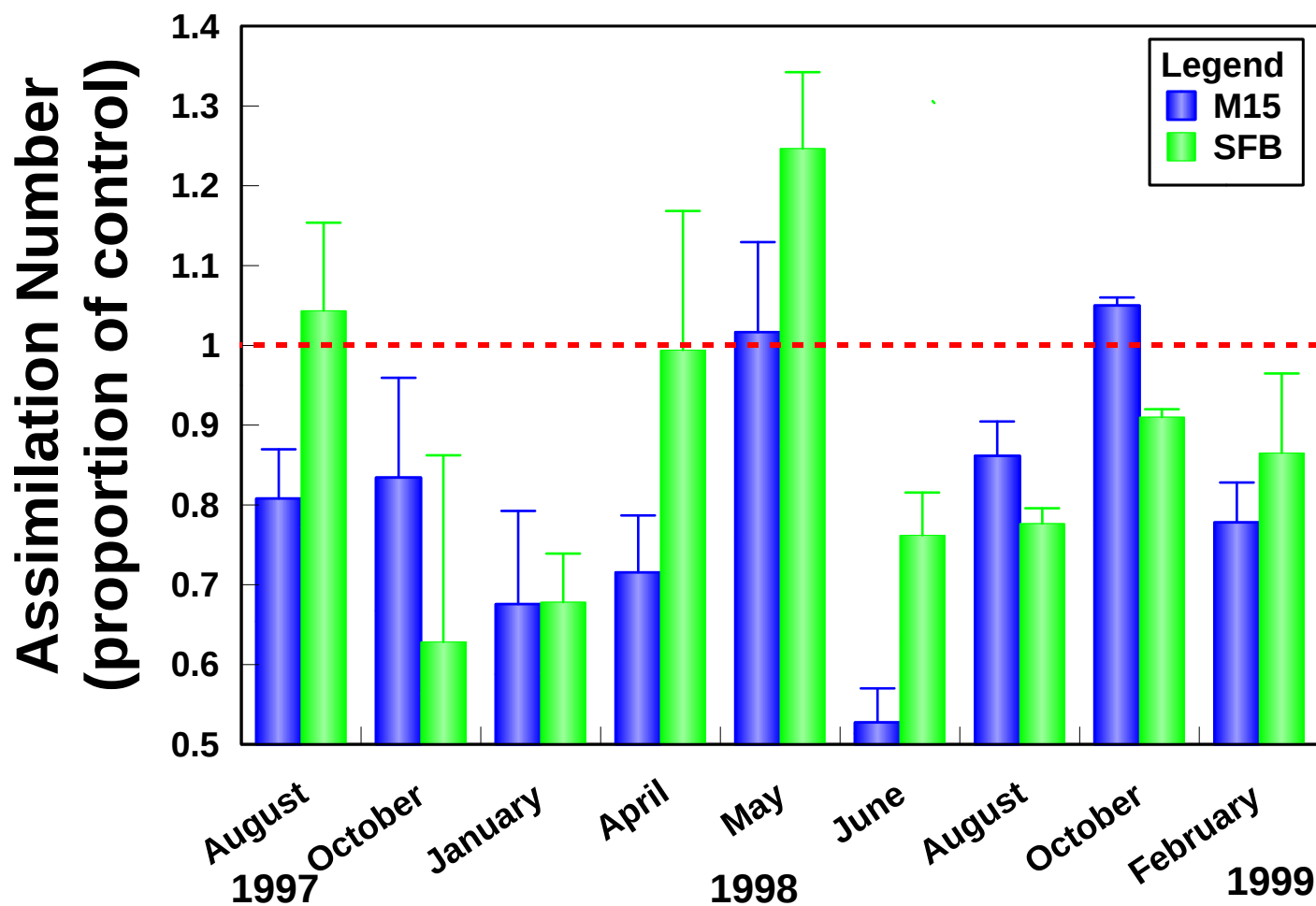


Asking the **Phytoplankton**: Dilution Bioassays



Response Indicators:
Chl *a*, primary productivity

Seasonal Effect of 30% Reduction in N Concentration 84 Hour Incubation

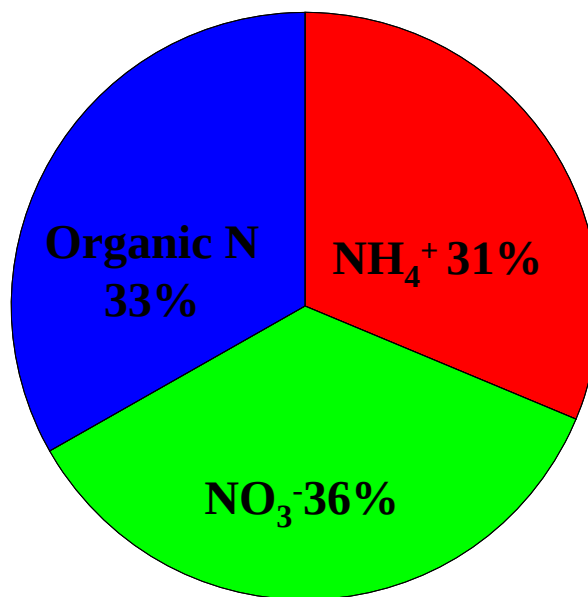


Piehler et al. 2001

However, when considering reductions.....
"New" N comes in different "flavors"

Why care?? Ecological/Health impacts of specific
forms of N enrichment?

Neuse R. N Loading 1997-00

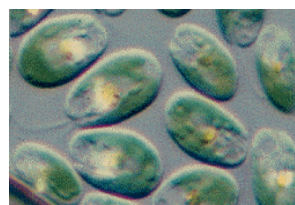


Nitrate vs Ammonium effects on algal production & composition



All phytos

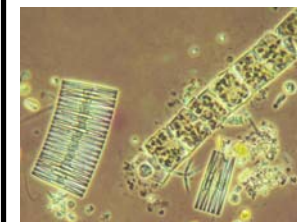
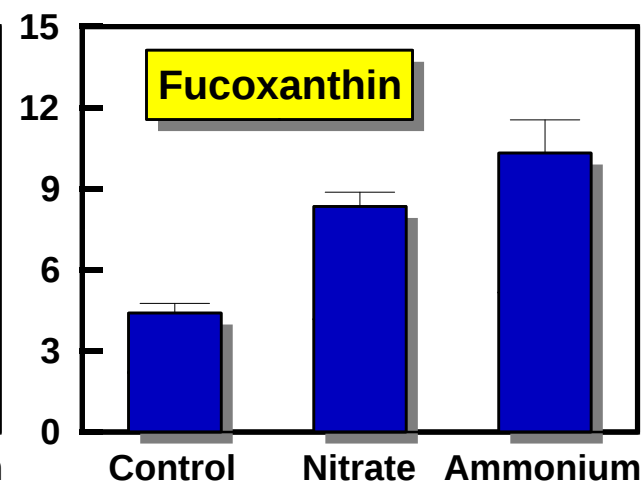
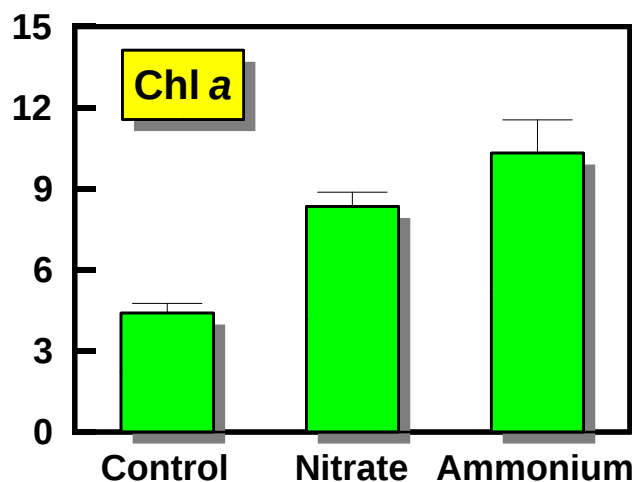
Concentration
(mg m⁻³)



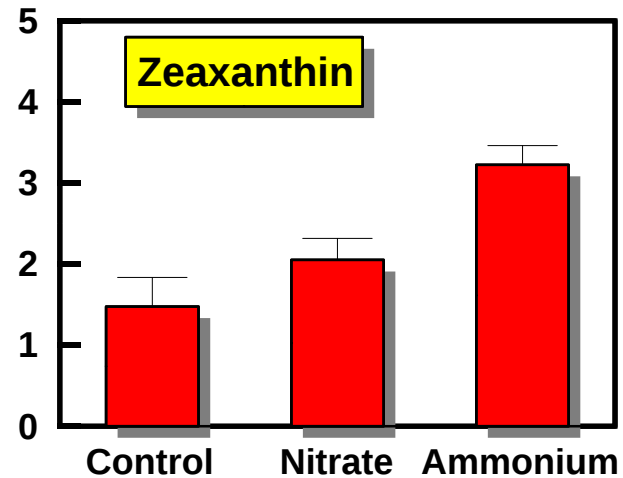
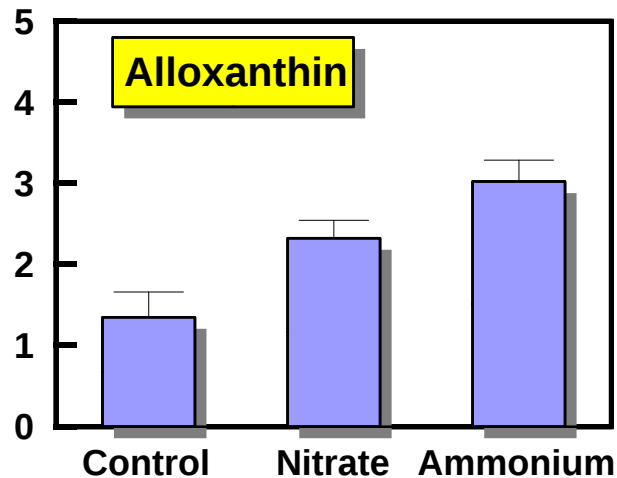
cryptophytes

Bogue Sound Bioassay

August, 1996



diatoms



cyanobacteria

Treatment

Pinckney et al. 1999

Cyanobacterial Harmful Blooms (CHABs): The link to human and climatic alteration of aquatic environments

Urban, agricultural and industrial expansion

Increasing nutrient (Nitrogen & Phosphorus) inputs

Water use and hydrologic modification play key roles

Climate (change) plays an interactive role
Blooms are intensifying and spreading



Why are we concerned about CHABs?

- Toxic to zooplankton, fish, shellfish, domestic animals and humans
 - Cause hypoxia and anoxia, leading to fish kills
 - Odor and taste problems
- Aesthetic problems, loss of recreational and fishing value of waters, worldwide



Should you let your kids or pets play in this?

BAD IDEA!

Algae are common in lakes and rivers. But at high concentrations a type called "blue-green" algae can make people and animals sick.

What to look for:

- Does the water look "fuzzy"?
- Does it smell swampy?

Blue-green algae can:

- irritate skin, eyes and nasal passages and make you sick.
- poison your pets or livestock — animals have died from it.

If you or your pets have come in contact with blue-green algae, wash thoroughly. Think you or animals are sick from it? Call a doctor or veterinarian immediately.

When in doubt, best keep out!

For more information see www.epa.gov/epaonline/bluegreenalgae, or call (800) 558-6000 or (202) 961-0800. This poster prepared by the Minnesota Invasive Species Group on Blue-Green Algae.



"Toxins" of Concern

Toxin

Anatoxin-a

Anatoxin-a(s)

Aplysiatoxins

BMAA β -N-methylamino-L-alanine Neurogenerative disease?

Cylindrospermopsins

Lyngbyatoxin-a

Microcystins

Nodularin

Saxitoxins

Effect

Nerve Synapse

Nerve Synapse

skin

Neurogenerative disease?

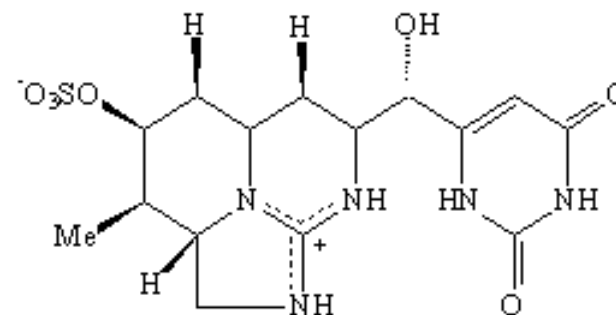
wide-spread tissue damage

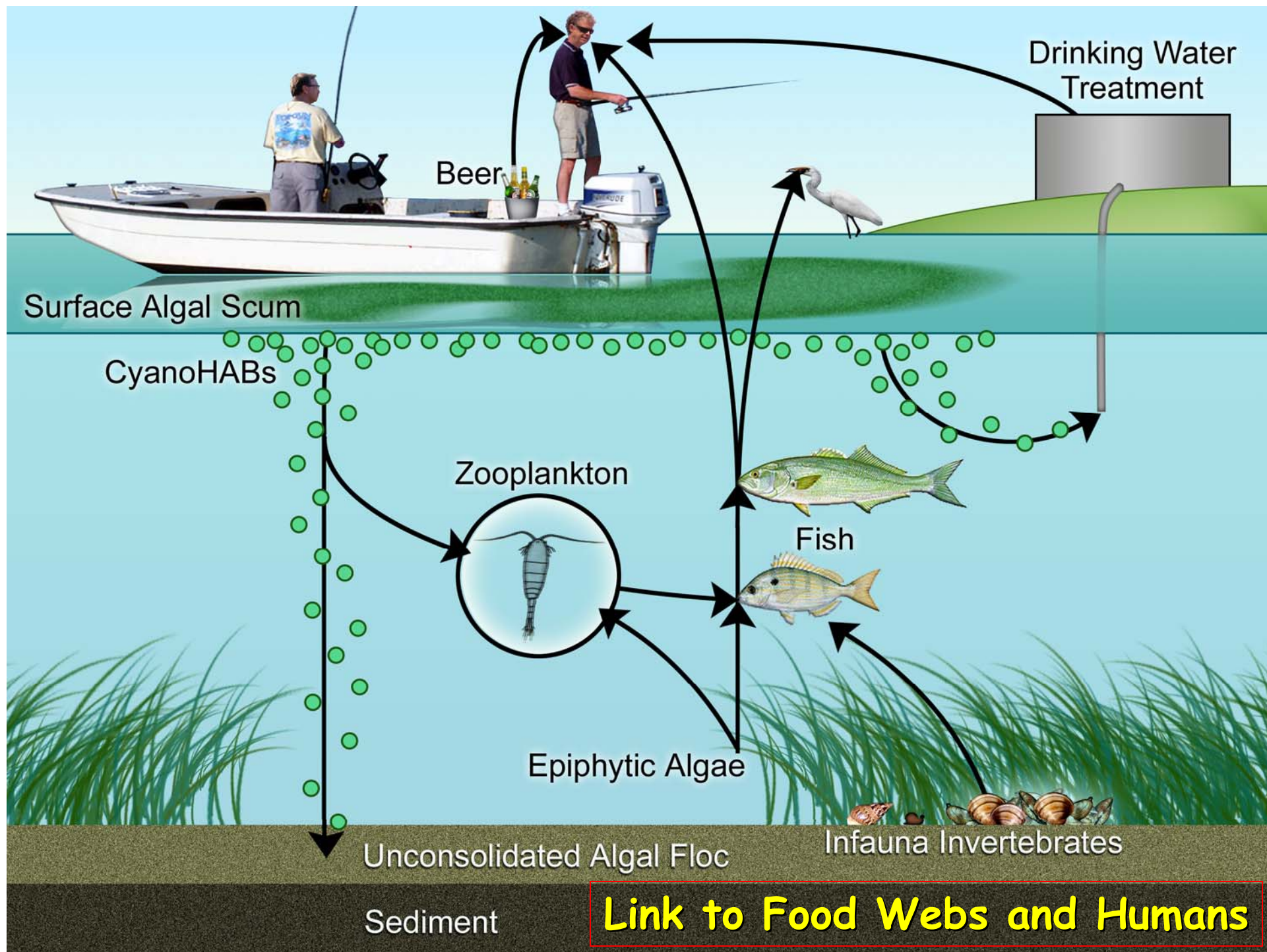
skin

Liver

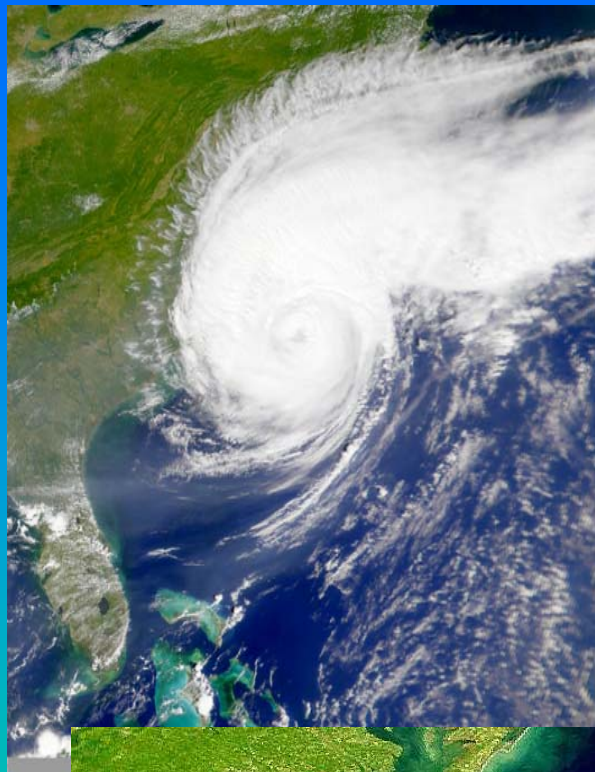
Liver

Nerve axons

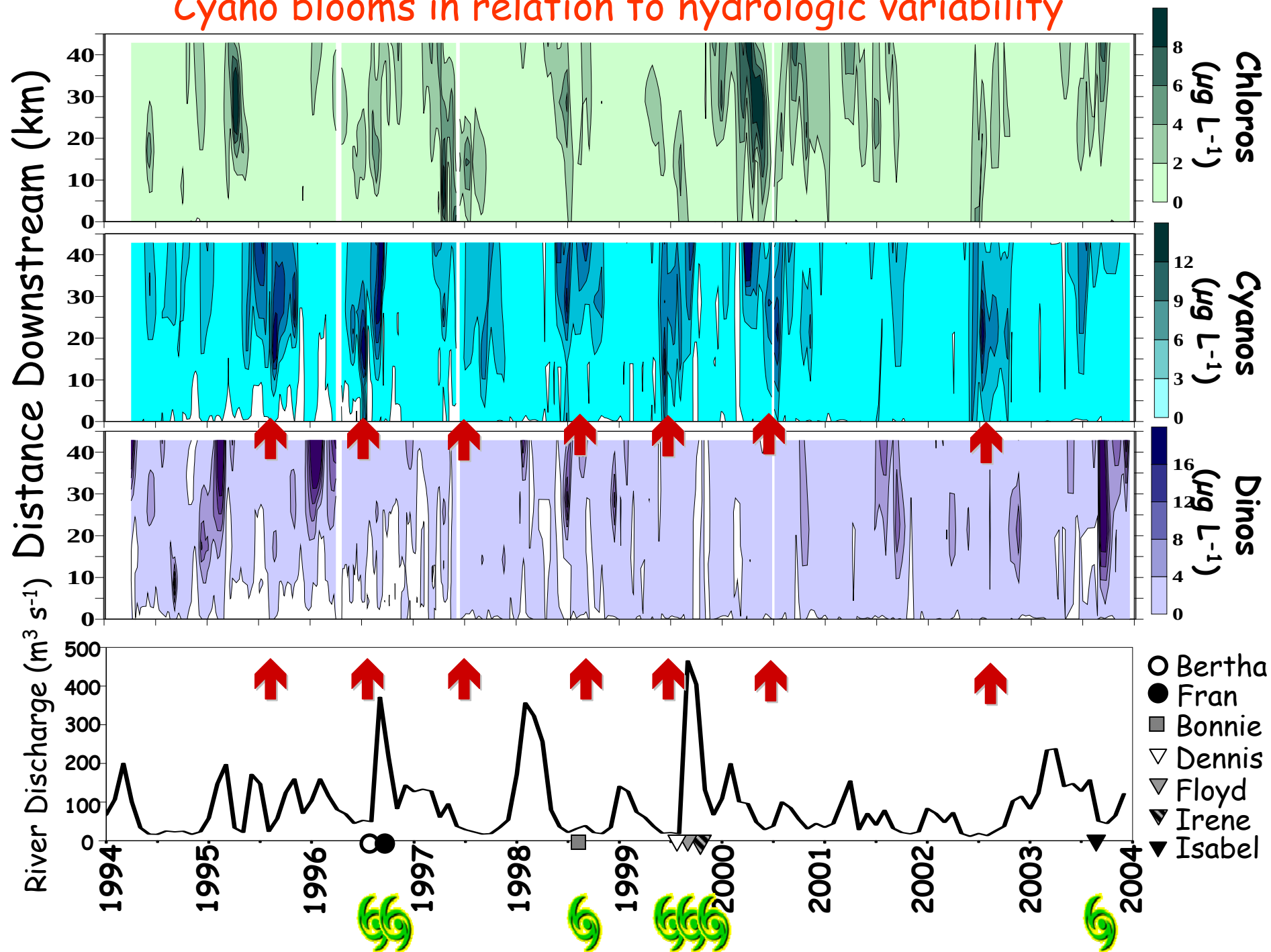




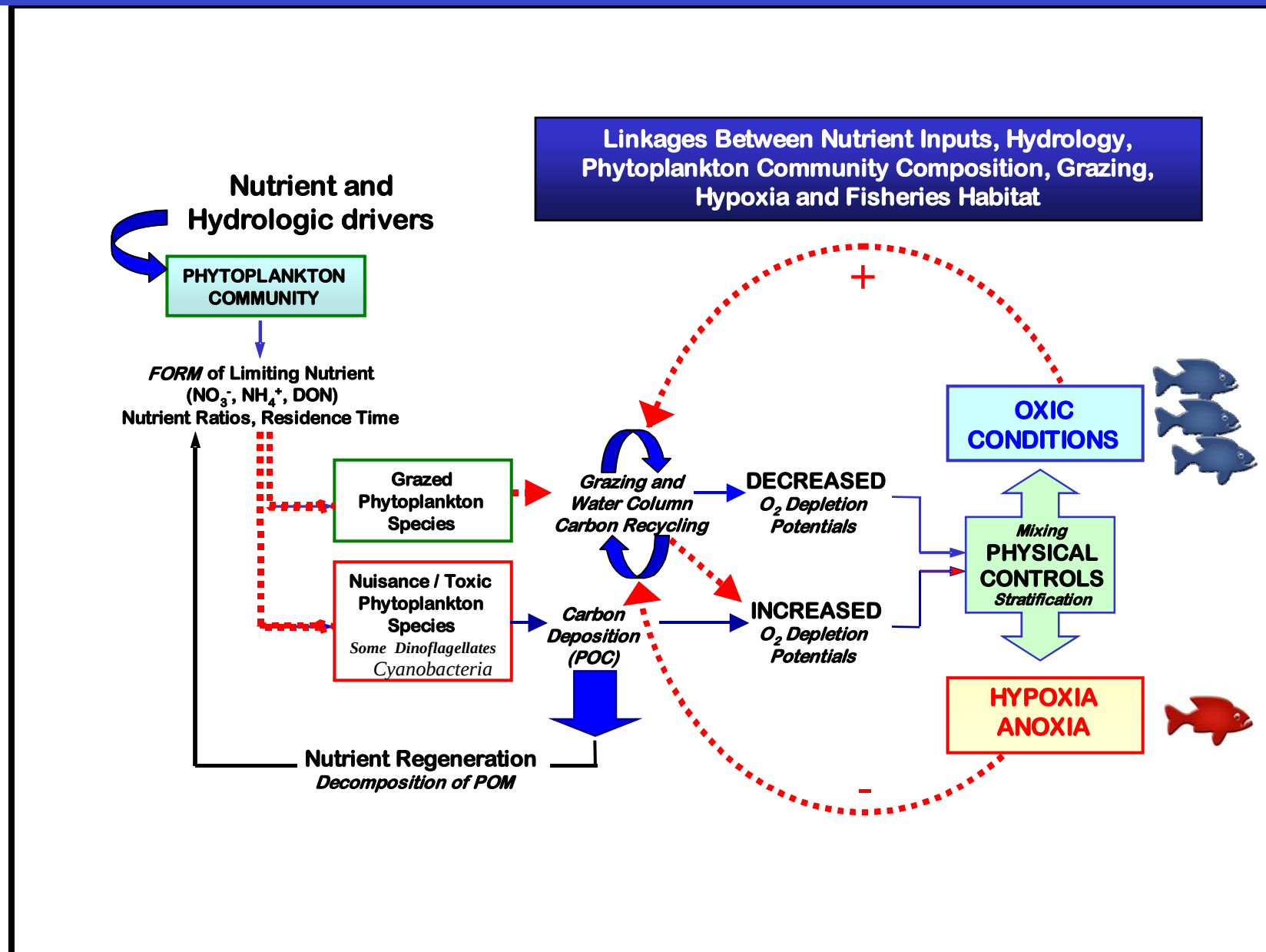
Cyanos and extreme climatic (hydrologic) events



Cyano blooms in relation to hydrologic variability



Ecosystem Service (Fisheries yield) Ramifications



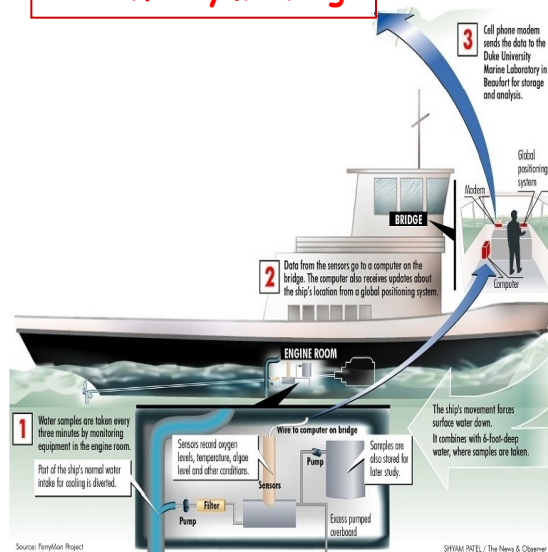
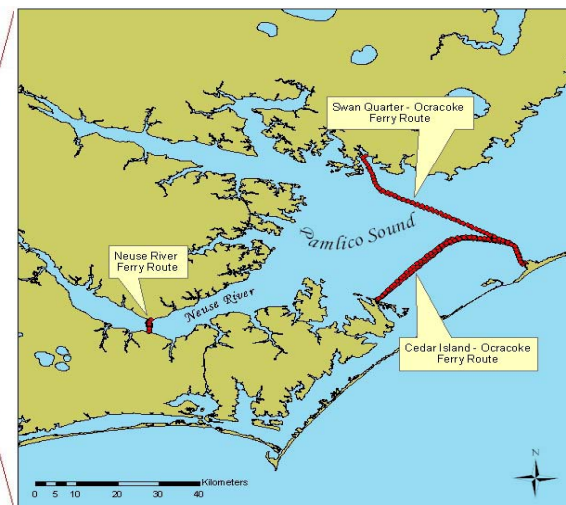
**Capturing
"events"**
**Using Ferries
as a platform
for indicators**
www.ferrymon.org



Raw Data Sent via Modem to
Duke/UNC-IMS Marine Labs

Raw Data Stored at IMS

Raw Data Text Files QA/QC'ed
QA/QC'ed Data added to
Microsoft Access Database



Ferry Bridge Equipt

Date/Time

DGPS Latitude / Longitude

Data Modem / Data Logger



ISCO discrete sampler

in-vivo Chla

Diagnostic Pigments

Nutrients

E. Coli / viruses

Date/Time

YSI sonde

in-situ Chla

Salinity

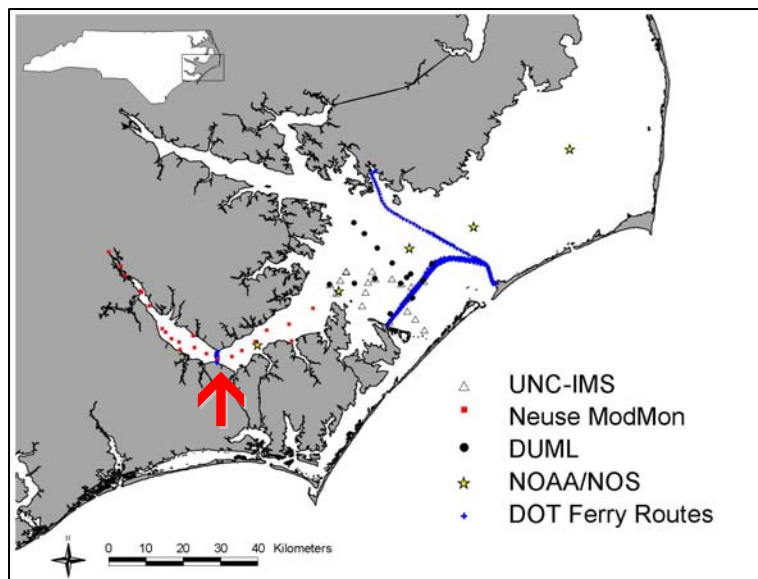
Temperature

Turbidity

pH, DO

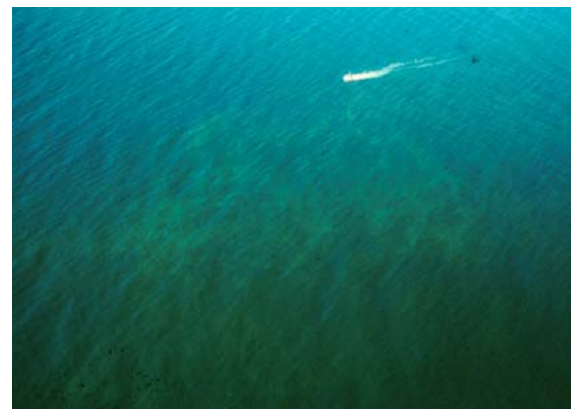
Date/Time



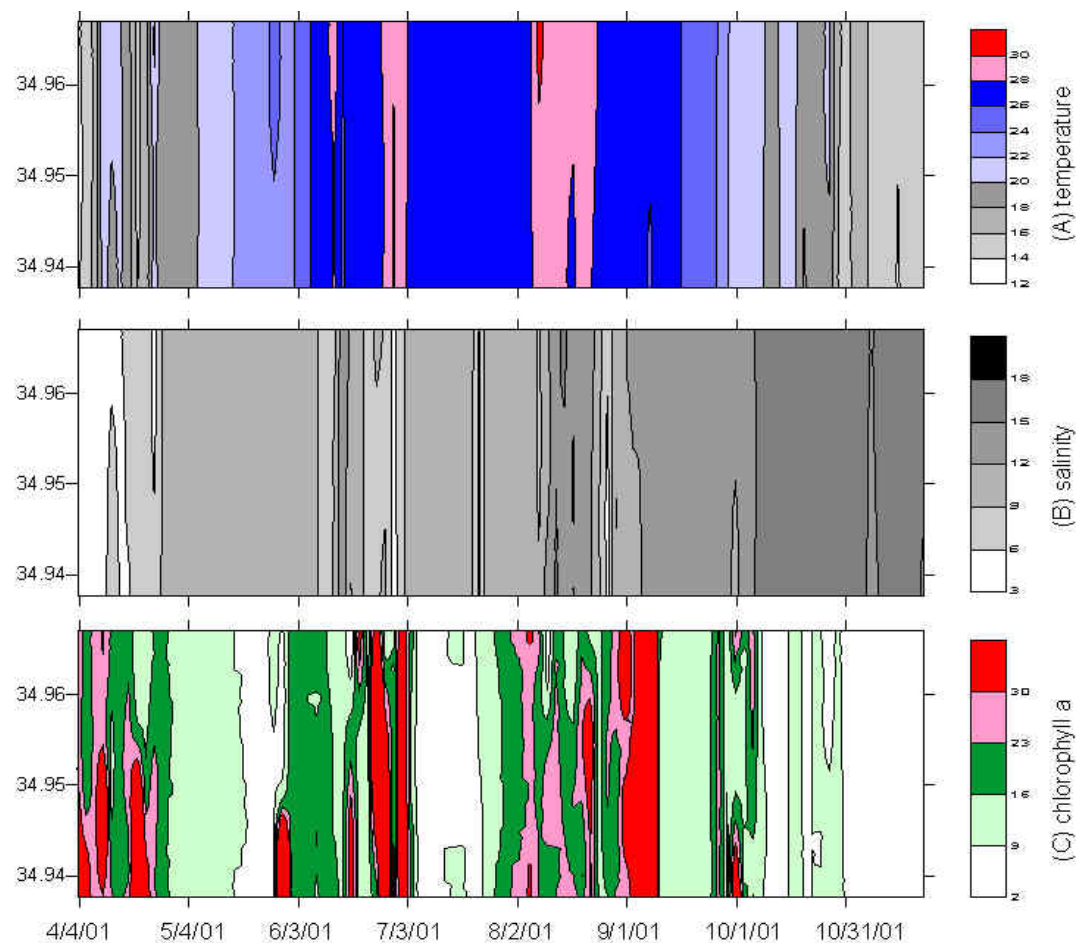


Quantifying Chl *a* & Detecting Algal Blooms

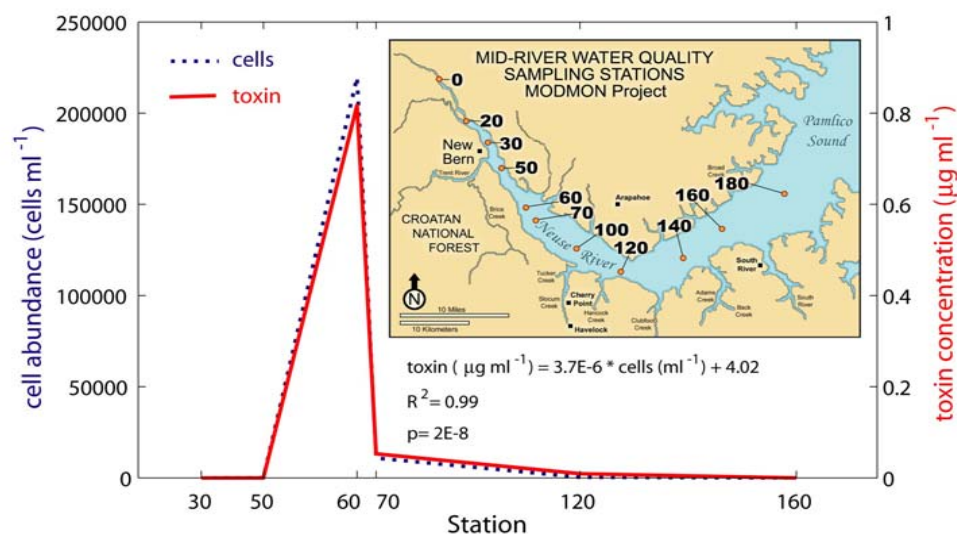
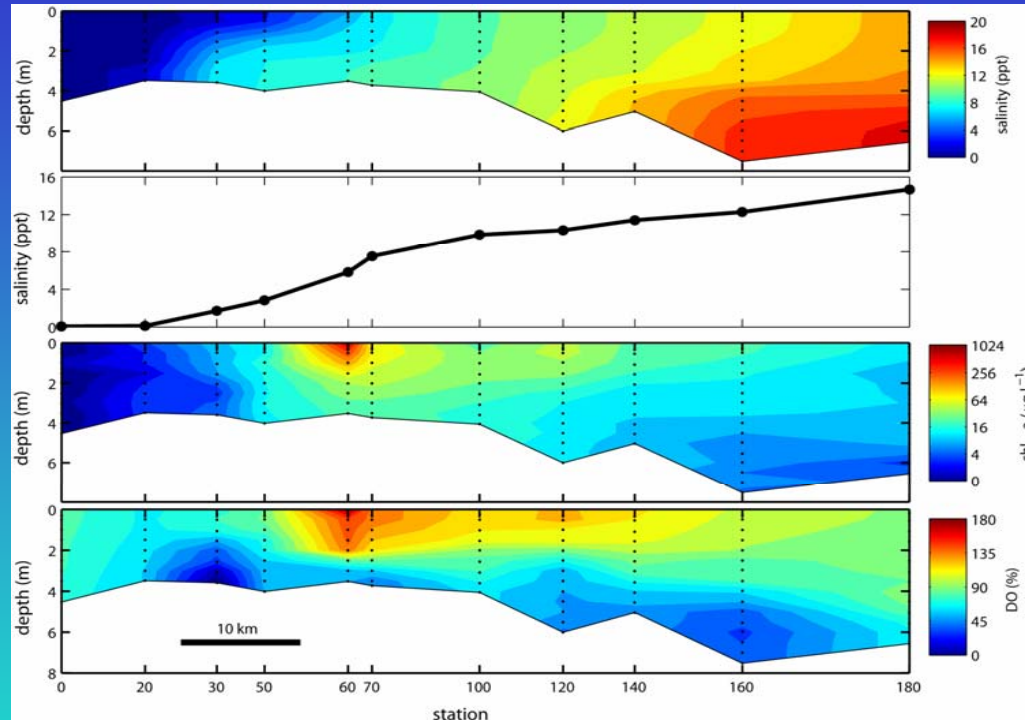
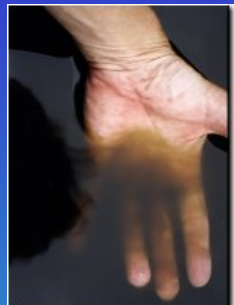
Cherry Branch-Minnesott Ferry



latitude (CB to MB)



The "perfect storm": Tropical Storm Ernesto (Oct. 2006) setting up a toxic *Karlodinium* bloom in the Neuse River Estuary

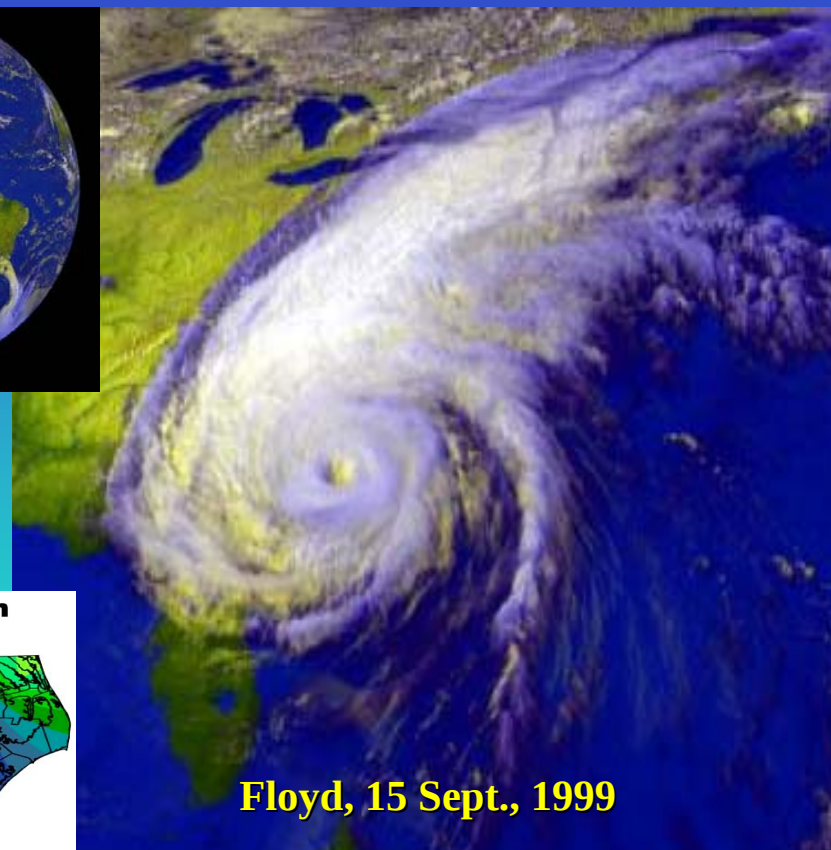
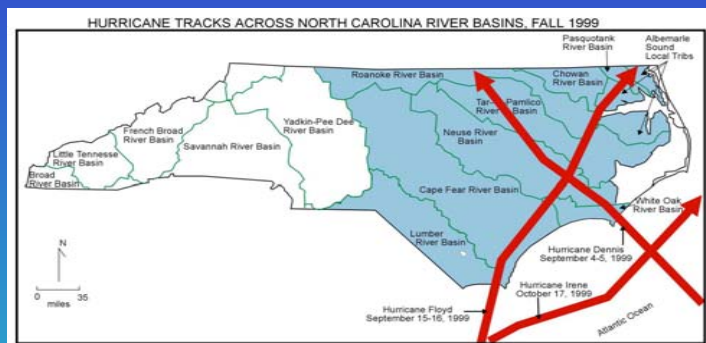


FerryMon & ModMon

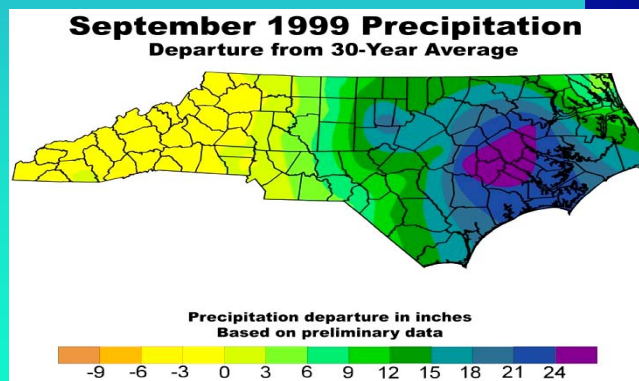
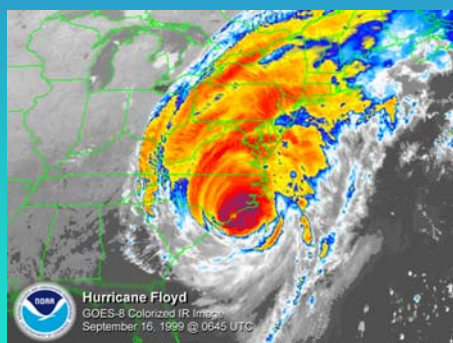
- Close interval and intensive spatial and temporal coverage clarifies causes and effects, and helps develop models that can *forecast* these episodes

Hall et al. submitted

The Hurricanes of 1999: What Happened?



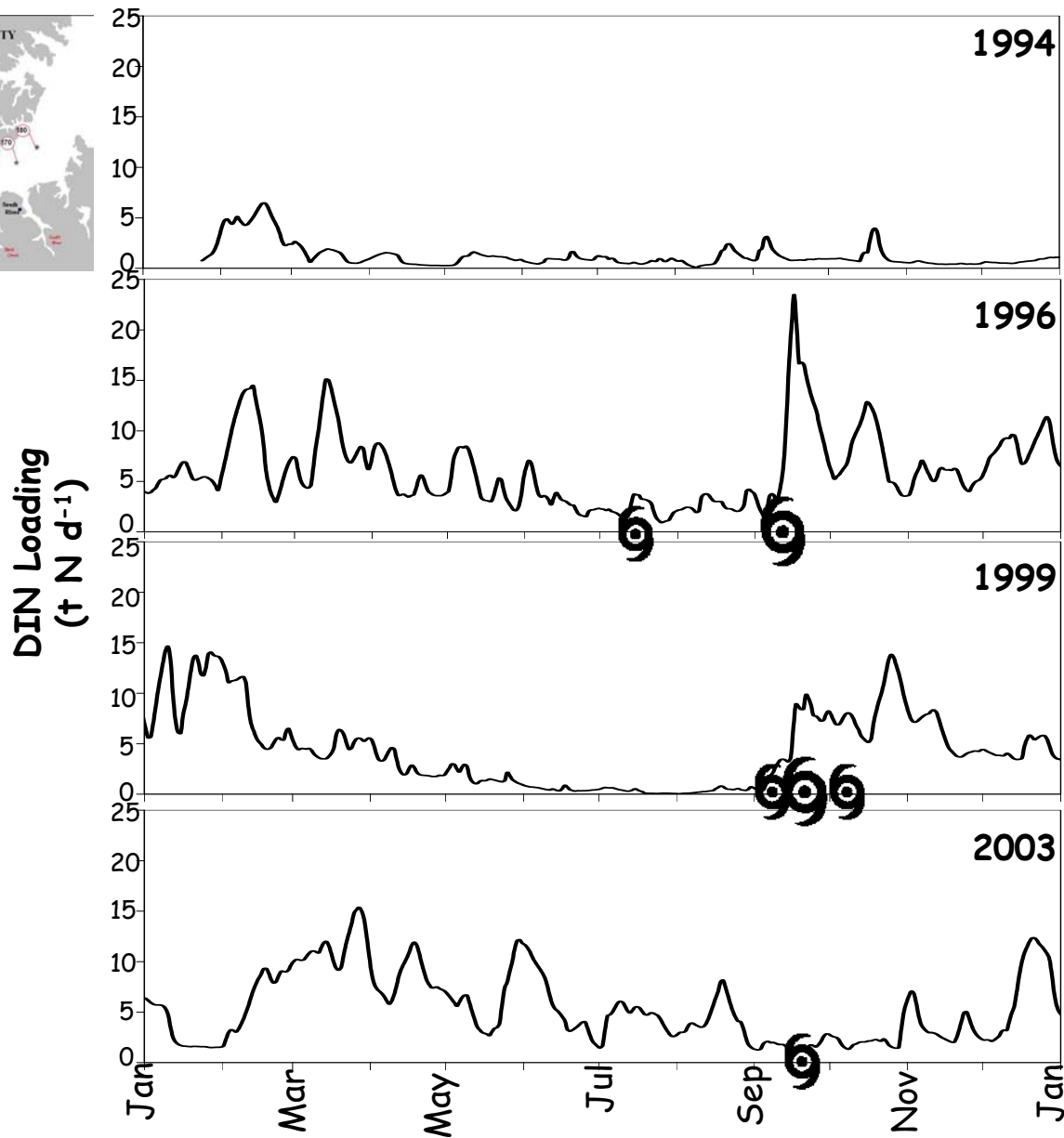
Floyd, 15 Sept., 1999



- 3 SS-scale 3 hurricanes (Dennis, Floyd & Irene) within 6 weeks
- Record rainfalls in Pamlico Sound Basin.
- 50-500 year floods in PS watershed
- PS Received annual water and N loads in about 1.5 months



Nitrogen Loading to the Neuse R. Estuary, NC



Drought year

Bertha
Fran

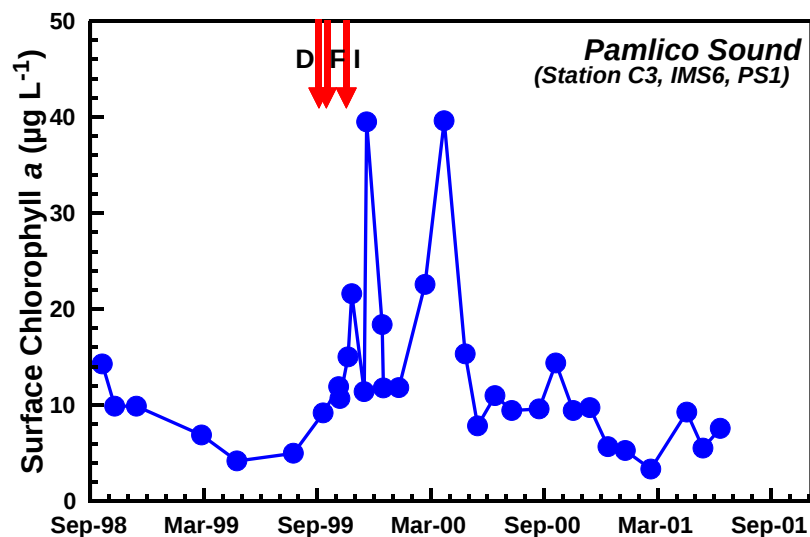
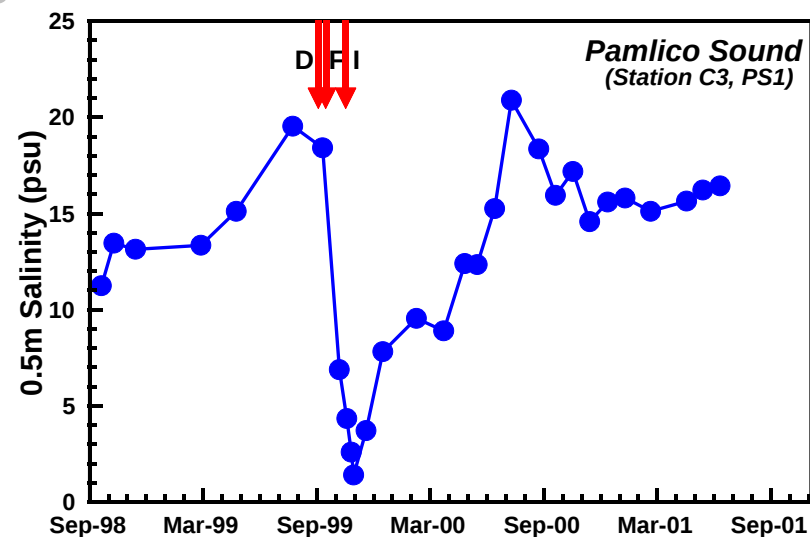
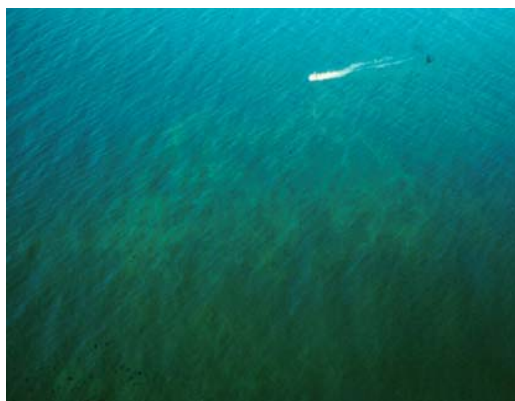
Dennis
Floyd
Irene

Isabel

Paerl et al. 2005;
2006

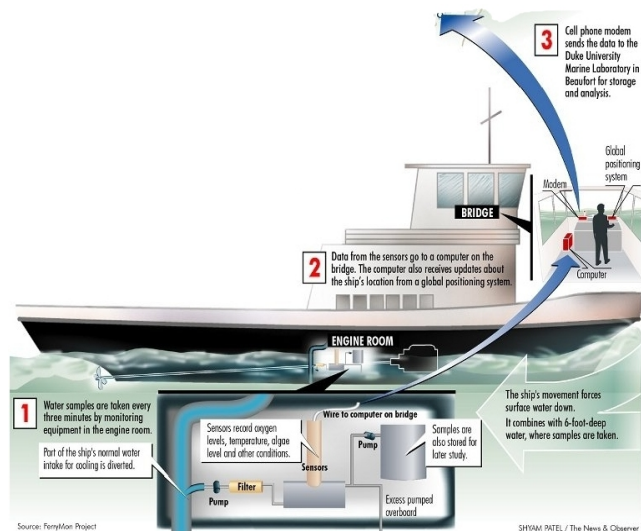
Hurricanes, combined with human activities can have huge impacts

Salinity and Chlorophyll *a* responses to the floodwaters in Pamlico Sound



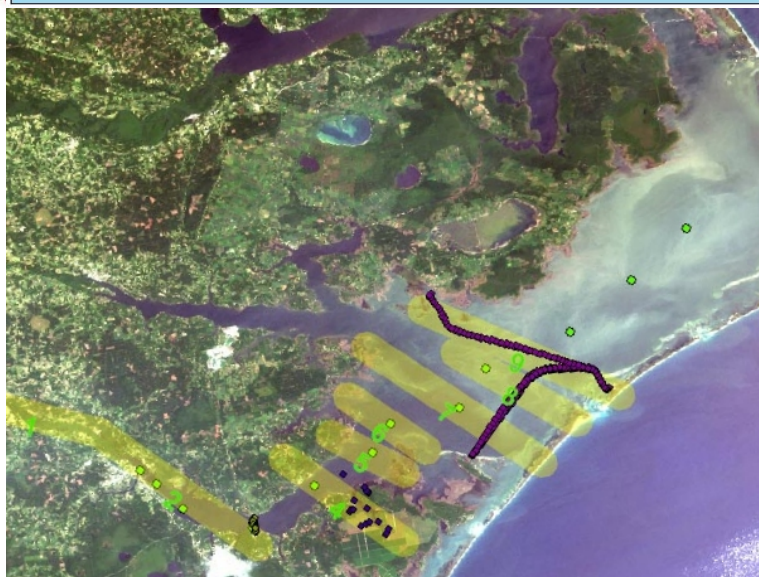
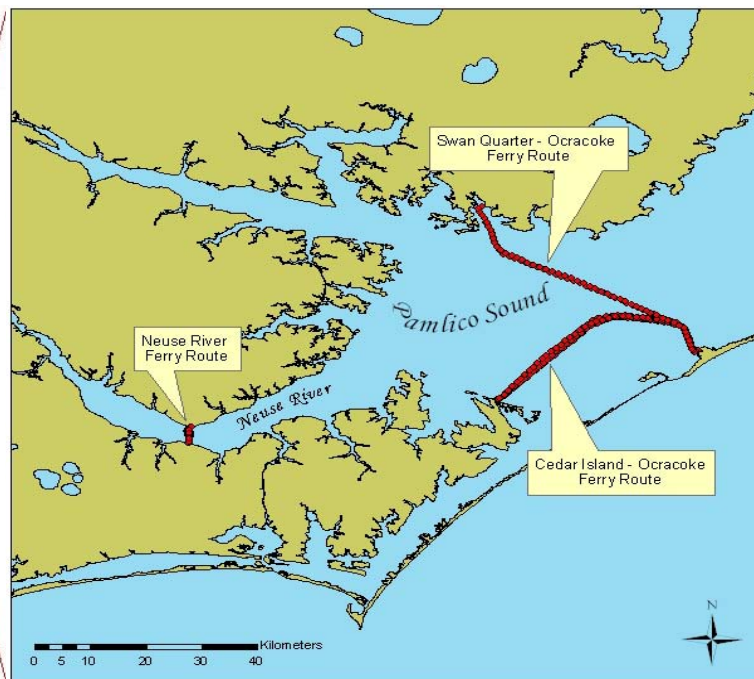


Neuse-Pamlico Estuarine
Routes: www.ferrymon.org



NASA / EPA Modified U2 Aircraft,
Beaver LiDAR & SeaWiFS

Scaling up by coupling FerryMon to Remote Sensing

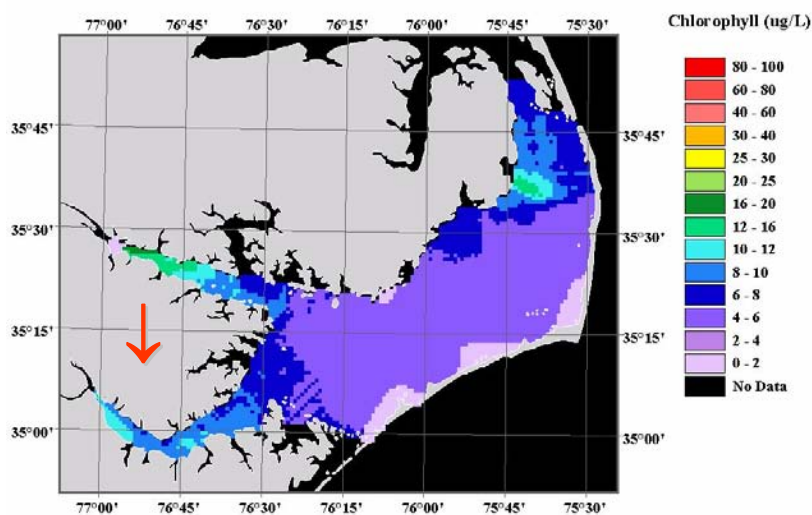


Parameters

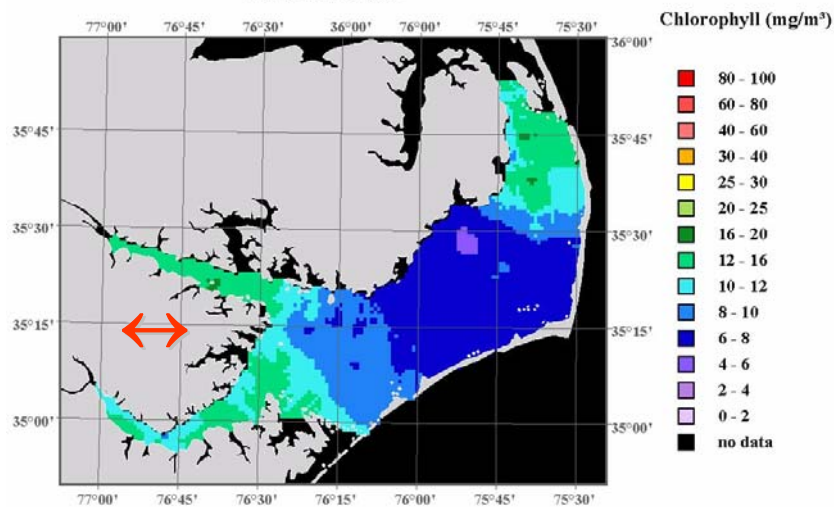
Temp.
Salinity
D.O.
pH
Turbidity
Chl a
Diagnostic pigments
Nutrients

SeaWiFS: Freshwater Discharge effects on algal production (Chl *a*)

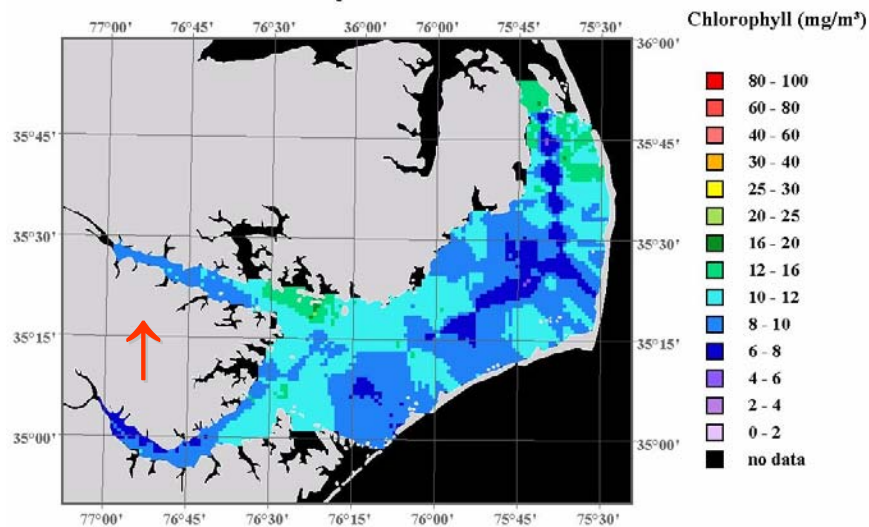
Pamlico Sound Remote Sensing Chlorophyll
15 May 2002



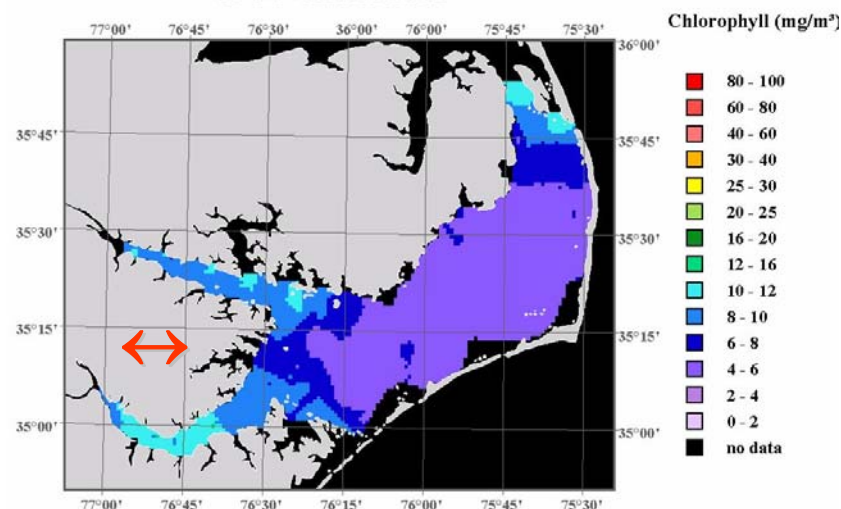
Pamlico Sound Remotely Sensed Chlorophyll
16 June 2002



Pamlico Sound Remotely Sensed Chlorophyll
17 July 2002

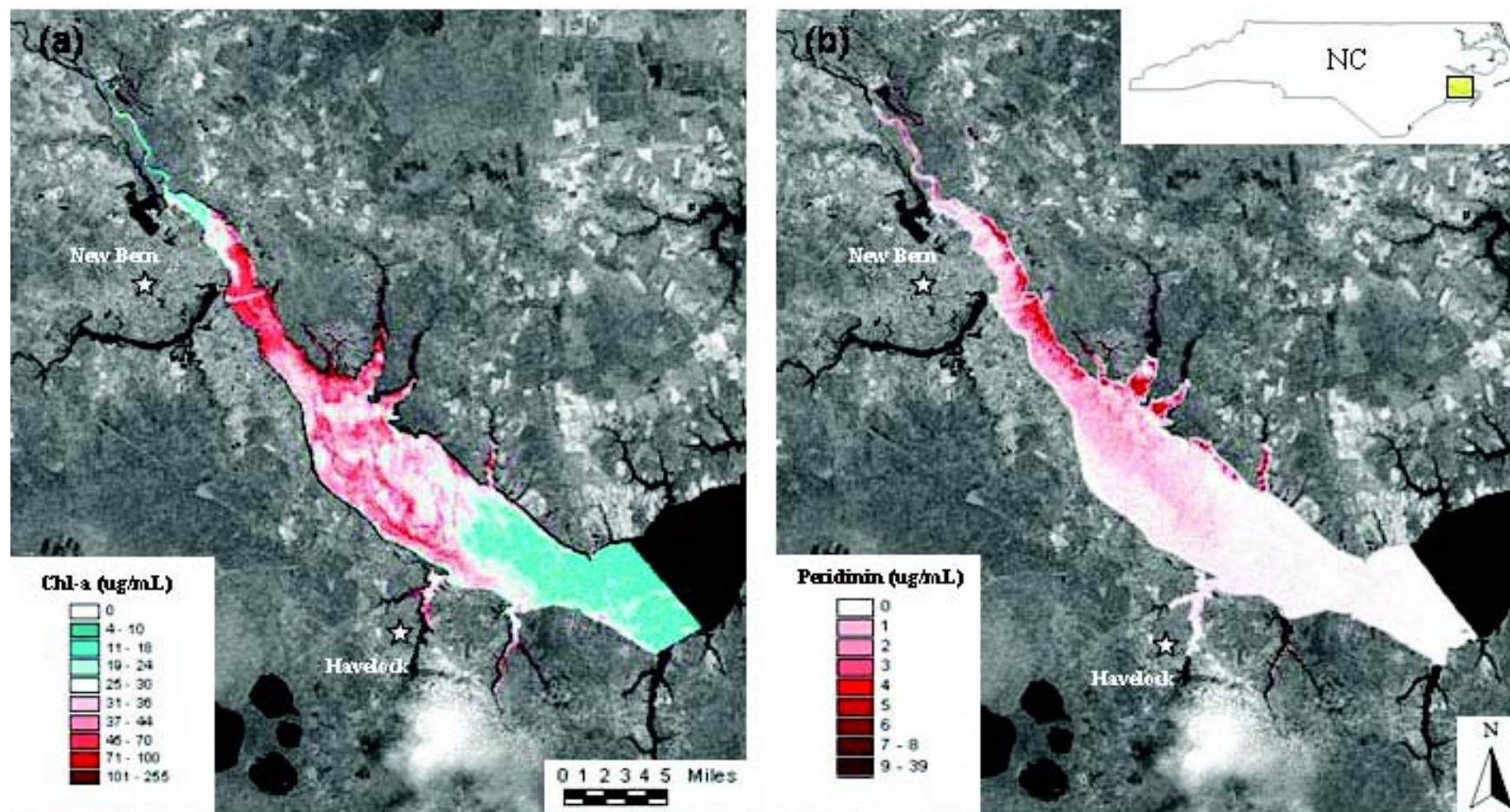


Pamlico Sound Remotely Sensed Chlorophyll
08 November 2002



Flow: high↑, low↓, moderate↔

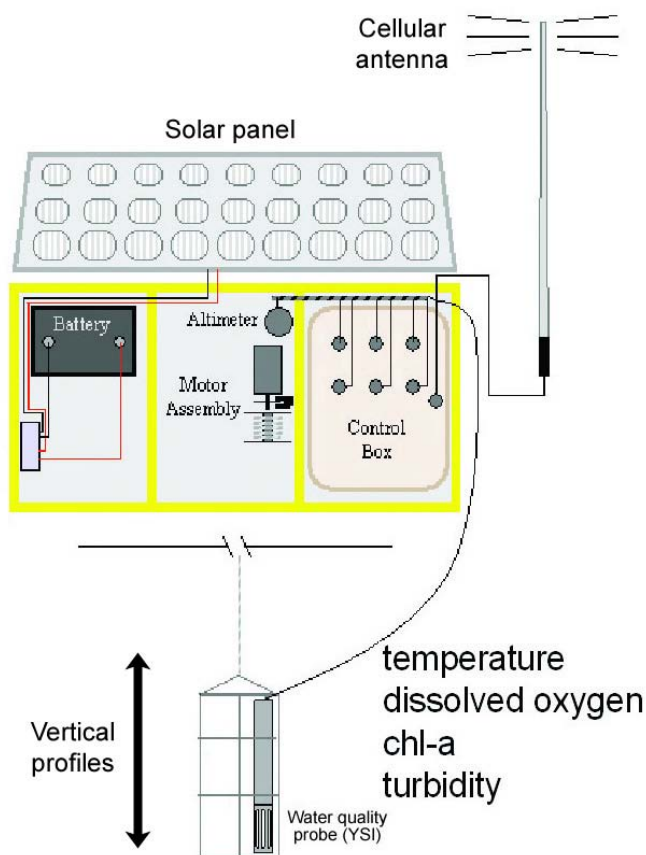
Diagnostic Pigment Indicators to Calibrate Remote Sensing



Estimated **Chlorophyll-a** and **Peridinin** concentrations in the Neuse River Estuary 15 May 2002 as determined with AVIRIS and ACE Eagles data. (Lunetta 2006 submitted)

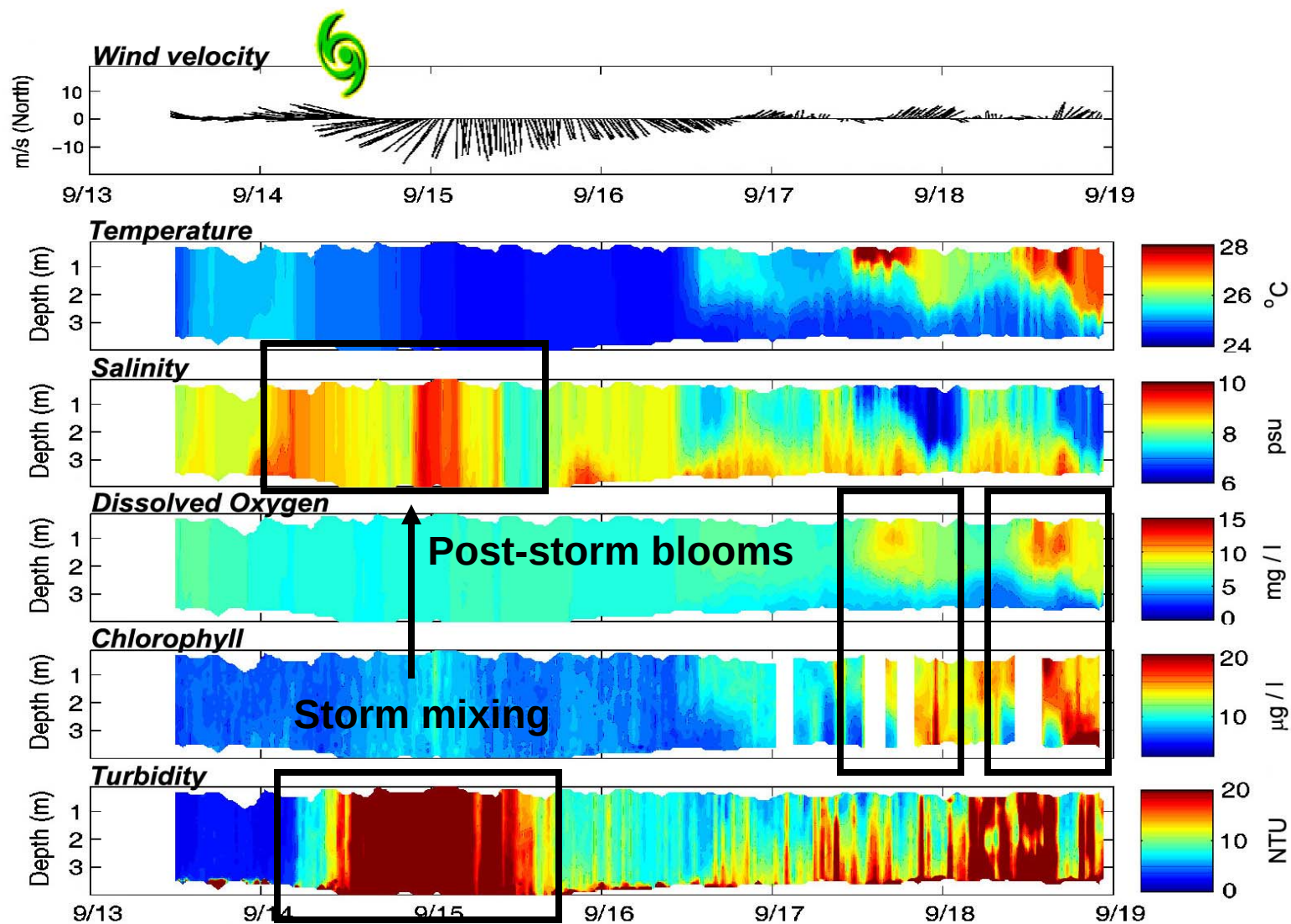
Users: EPA-RTP, NASA, NC DENR-DWQ

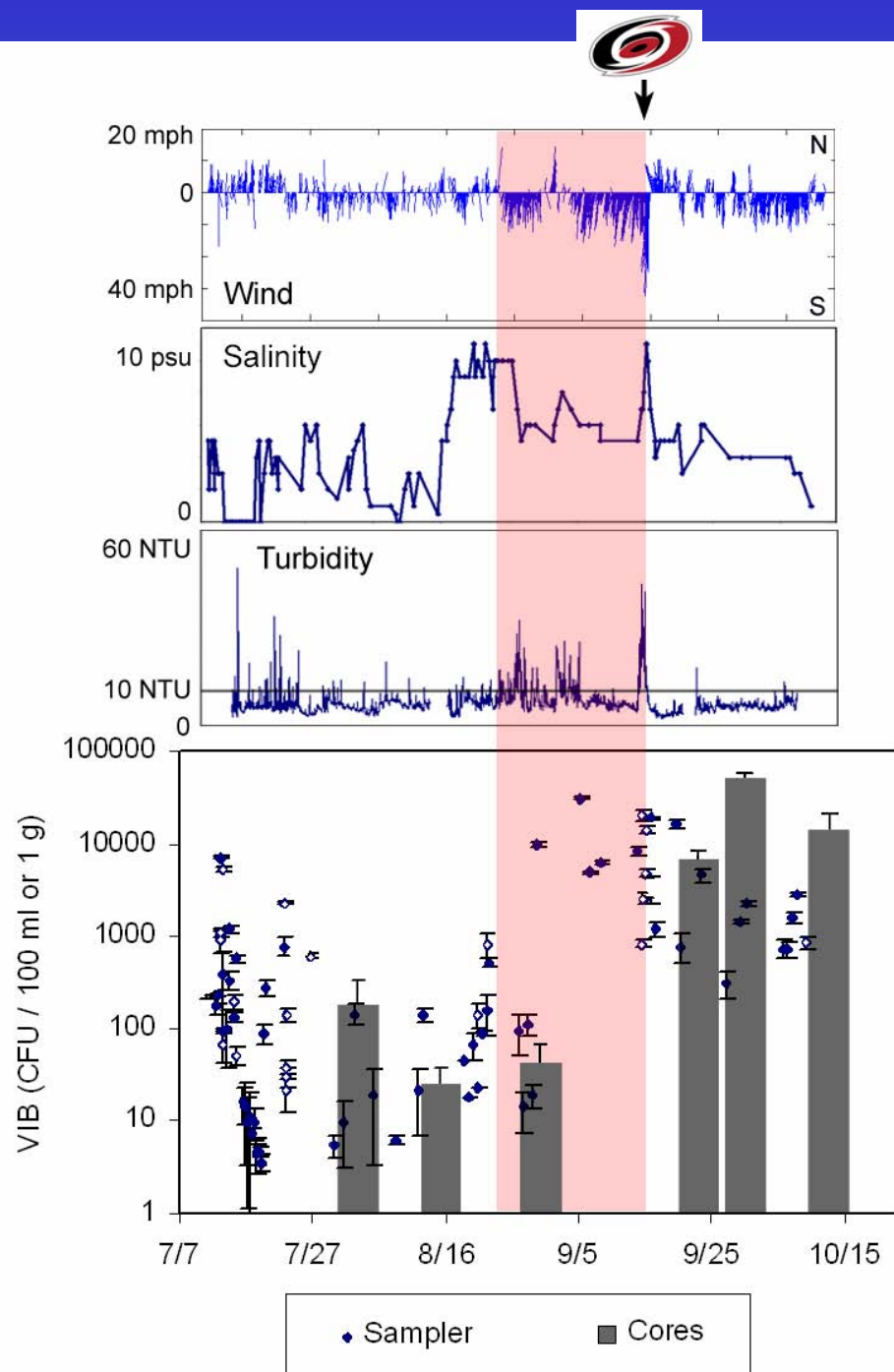
Observational Platforms Autonomous Vertical Profiler (AVP)



- Monitors water quality using profiling instrument
- Instruments:
 - Water quality sonde
- Sampling schedule:
 - Profiles every 30 min
 - Vertical resolution of 10 cm

Short-term Impacts of Hurricane Ophelia, Sept. 2005





Ophelia Impacts on *Vibrio*

- Large increase in water column concentrations during storm period
- Sediment increases following storm (deposition) and high levels persist through the winter

Storm Impacts on Potential Pathogens in Estuaries

Estuarine and coastal environments are susceptible to a variety of changes driven by tropical storms and hurricanes. The 2005 Atlantic hurricane season impressed upon the public the devastating impacts of storms on coastal populations and the possible social and public health costs. Storm surges and subsequent flooding have the potential to redistribute water and associated contaminants, including a wide range of chemicals and microorganisms. While this impact is difficult to observe through monitoring during larger storms, smaller storms provide

opportunities to observe the mechanisms responsible for contaminant and microbial transport.

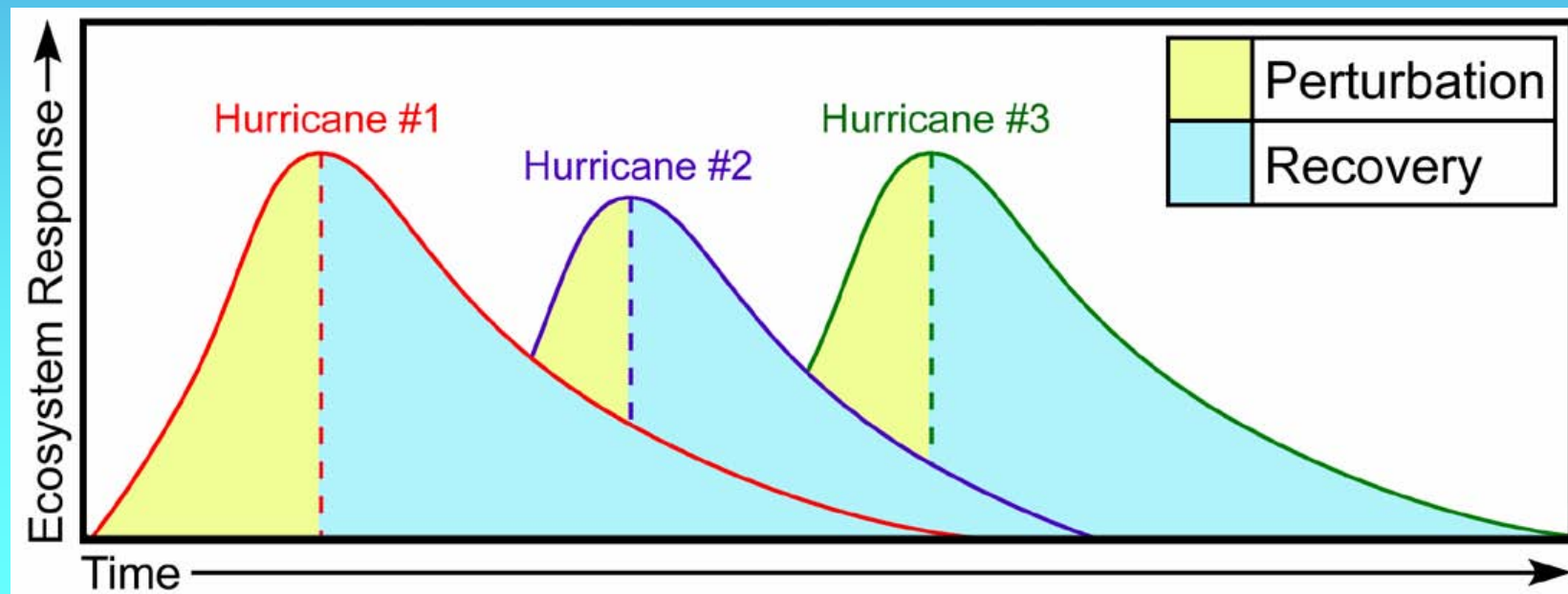
The approach and passage of category 1 Hurricane Ophelia resulted in a 3-week period of sustained winds that greatly perturbed the estuaries in eastern North Carolina (Figure 1). In particular, the Neuse River Estuary (NRE) experienced a significant storm surge and wind mixing, followed by large stormwater runoff input from storm-related rainfall. These forces dramatically changed the distribution of salt water in the estuary, thereby affecting the growth of microbial populations in the water column. The microbial dynamics of species of the

By J. S. FRIES, R. T. NOBLE, G. M. KELLY, AND J. L. HSIEH

Increased frequency of Atlantic hurricanes over the next 10-40 years? Goldenberg et al., 2001, Webster et al. 2005

Increase in "extremeness" and scales of storm events? Emanuel 2005

Multi-annual ecological effects and recovery?



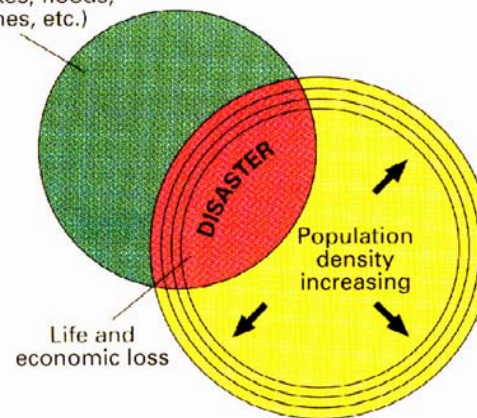


Long-Term Human Health & Management Issues

- Nutrient-Pathogen loadings are largely anthropogenic, and complicated by Hurricanes/floods. These are natural events exacerbated by human development in coastal watersheds
- Hurricanes are individualistic in terms of hydrologic, nutrient and other pollutant impacts.
- Water-quality, habitat & health impacts are highly variable.
- Understanding water-quality human health impacts requires appropriate indicators spatial and temporal "scaling up"
- Adaptive management is needed in response to climatic change (e.g. droughts, hurricane frequency) & sea level rise

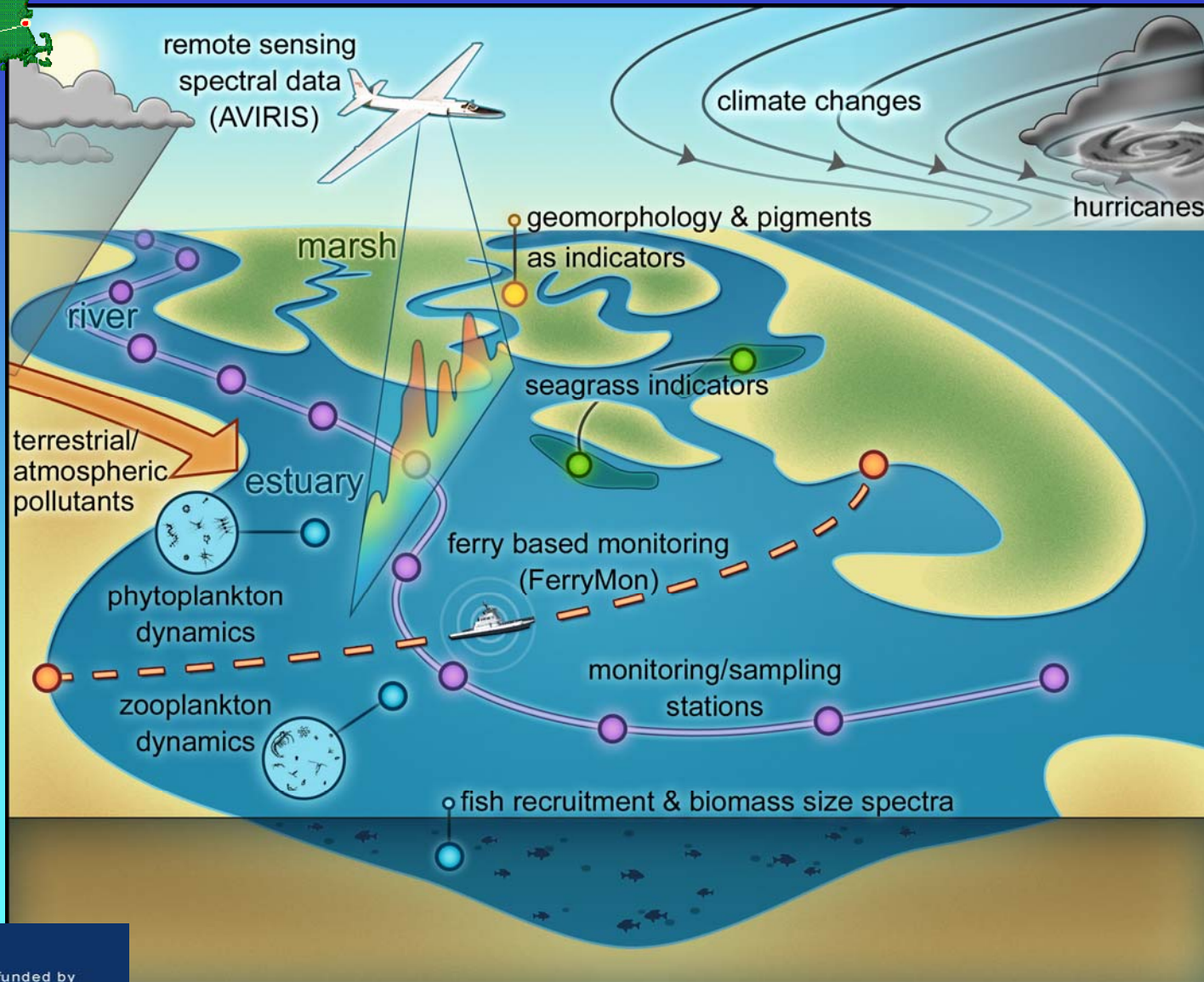


Natural events
earthquakes, floods,
hurricanes, etc.)





Coastal Indicators as Management Tools: www.aceinc.org



Special Thanks to:

Jerad Bales
Nathan Hall
Larry Harding
Alan Joyner
Ben Peierls
Karen Rossignol
Tony Whipple
Pam Wyrick & crew



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U.S. EPA - Science To Achieve
Results (STAR) Program

Grant # 82667701

& NSF, NC-DENR, NASA, USDA, NC Sea Grant, WRRI



Epidemiology

David Weber – UNC-CH
Hillel Koren- EPA – RTP
and CEP

Ecology & Biogeochemistry

Hans Paerl – UNC-IMS
Rachel Noble – UNC-IMS



Modeling

Richard Luetlich – UNC-IMS
James Bowen - UNC-C
Greg Characklis – UNC-CH
John Paul – EPA-RTP

CAROLINA
Environmental Program

Ecology of Human Pathogens and Disease

Risk Assessment

Doug Crawford-Brown - CEP
John Paul – EPA-RTP



Public Health

David Weber – UNC-CH
Hillel Koren – EPA-RTP
and CEP



Marine Science

Hans Paerl – UNC-IMS
Rachel Noble – UNC-IMS
John Paul – EPA-RTP



Assessing Human and Climatic Impacts on Coastal Ecosystem Condition and Services Using Microbial Indicators

- Integration of microbial ecology, pathogen, epidemiology, and modeling approaches to link eutrophication to ecosystem and human health
 - Extreme/Episodic events (hurricanes, floods)
 - Chronic, persistent forces (development, climate change)

Approaches and Indicators (only a few examples discussed here)

- Apply microbial diagnostic (molecular/biochemical) indicators to determine water quality, ecosystem condition, health and safety for consumers (HABS, pathogens)
- Microbial indicators should be useful for mechanistic probabilistic models
- Deploy Indicators in Monitoring Programs and on Platforms
- Couple Indicators to Remote Sensing
- Combine new technologies, sensing to support development of models relevant to ecosystem and human health

Where are they a problem?

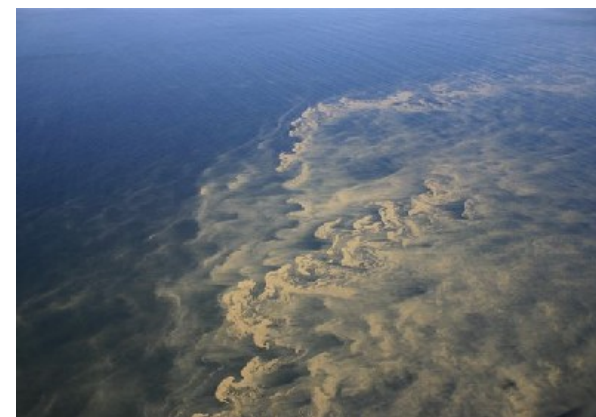
- **Freshwater Ecosystems**
(lakes, reservoirs, streams, rivers)



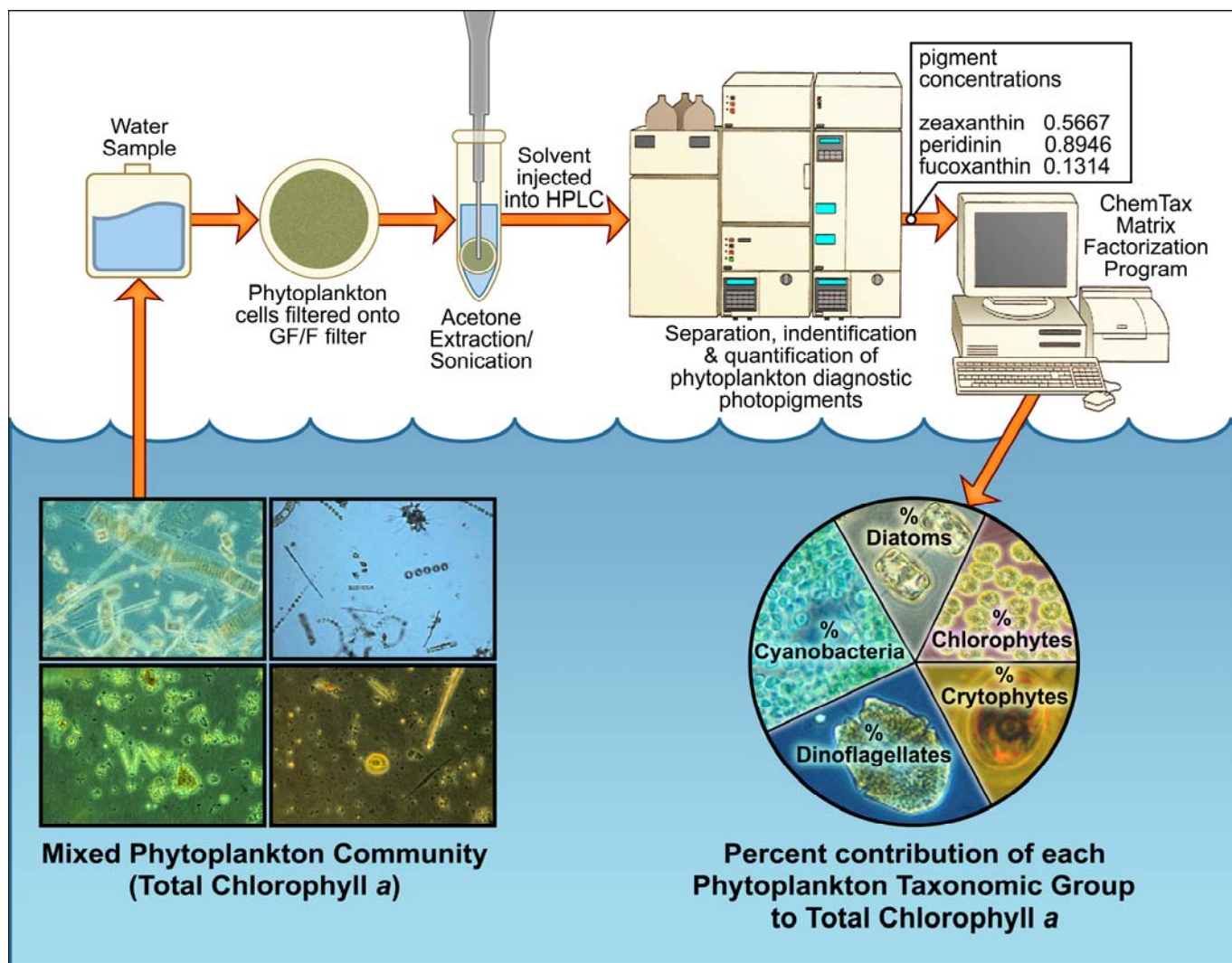
- **Estuaries**



- **Coastal waters & seas**



Looking into the "green box": Algal taxonomic group responses to various N sources using HPLC-ChemTax Analysis



Bacterial contaminants

- Measure contaminants contributed to system, focus on fecal contaminants
- Bacteria: *Enterococcus*, *E. coli*
- Measure native bacteria, potential pathogens: *Vibrio* sp., including *Vibrio vulnificus* and *Vibrio parahaemolyticus*
- Understand relationships of microbes to nutrients, particles, and storms/hydrology for model development
- Delve into mechanisms of attachment of microbes to phytoplankton
- Conduct research during storm and baseline conditions to create mechanistic models of fate and transport