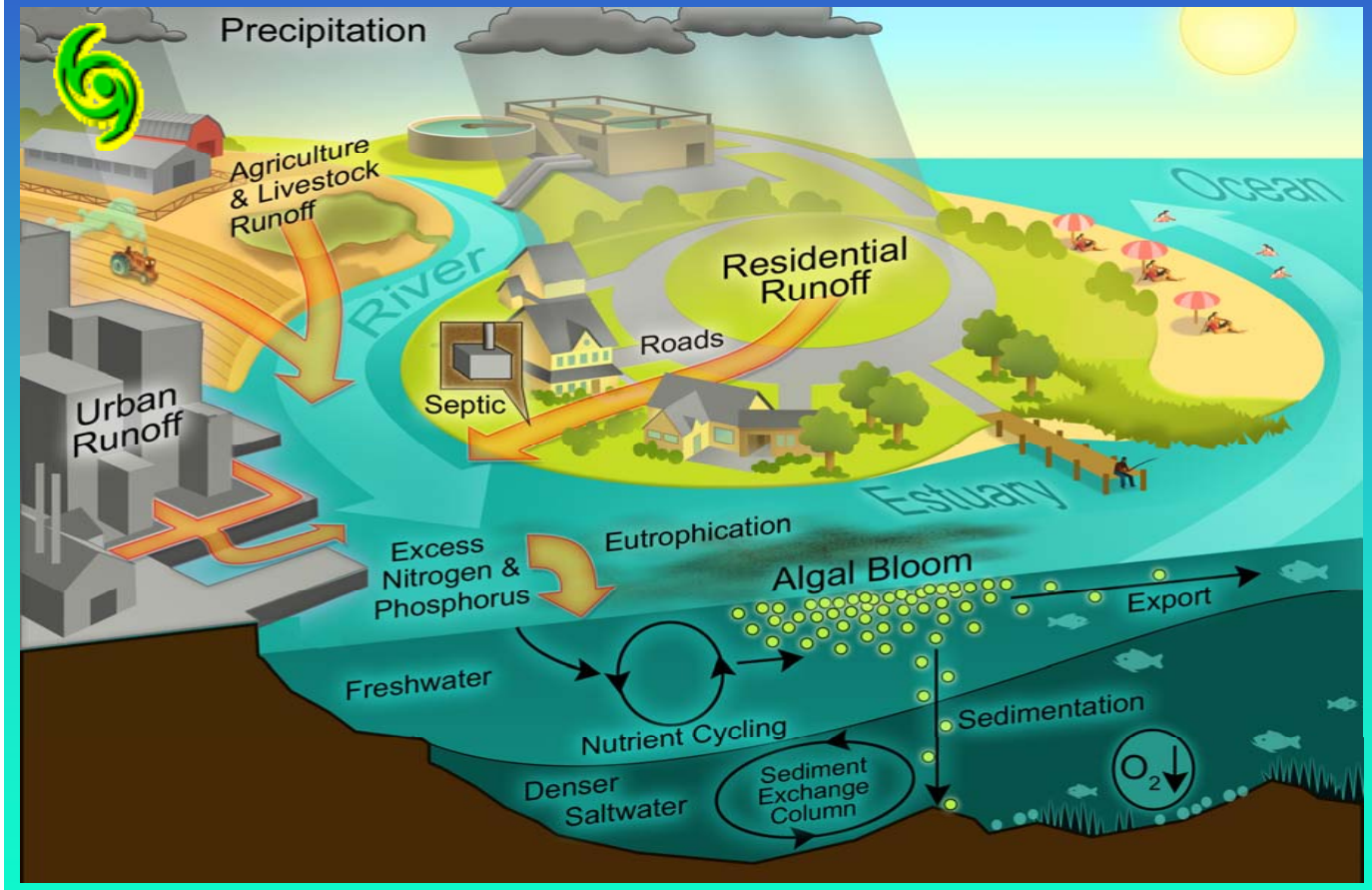
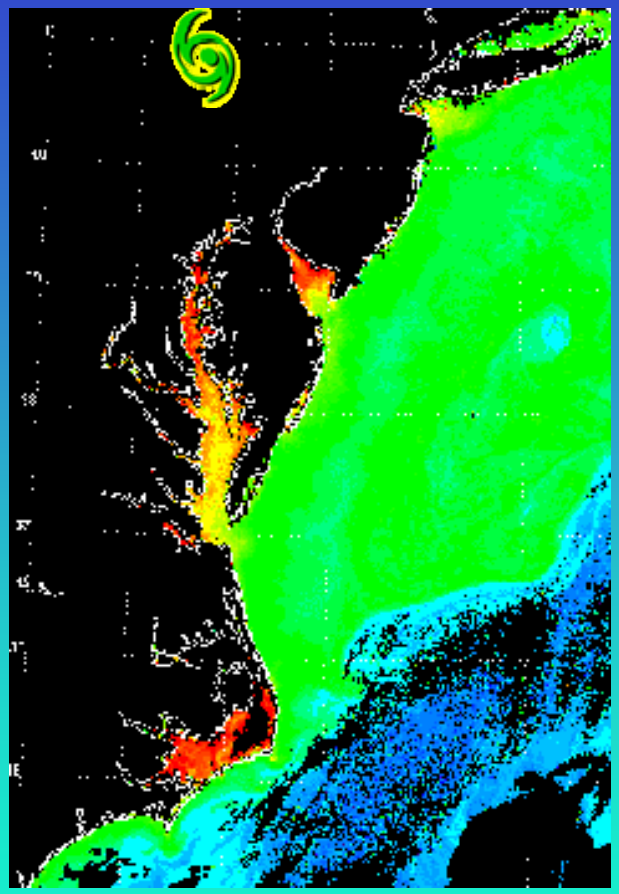
Connections Between Public Health and Ecosystems Services in Estuarine and Coastal Systems

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

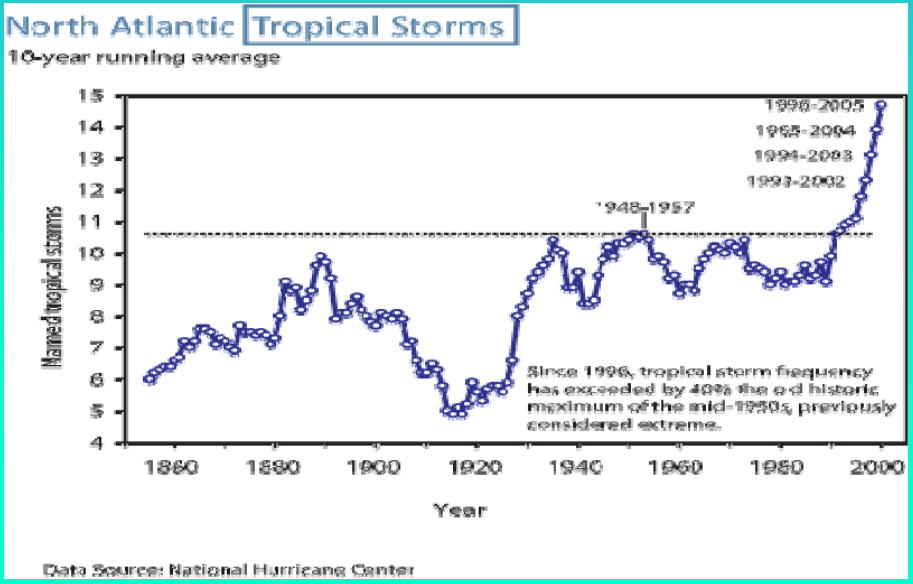
(lots of water, quickly, and persistent flooding in low-lying areas)

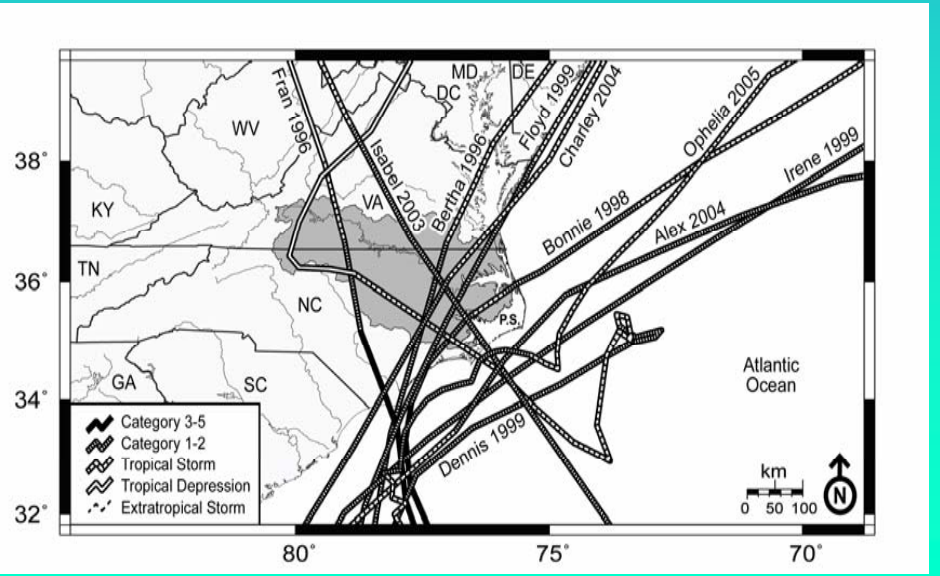
↑ Nutrient, sediment & contaminant (pathogen) inputs

Biotic alterations (water quality, habitat, fisheries impacts)

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

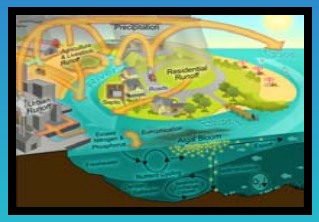
Hurricane Frequencies and Intensities are Increasing!!!





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

Natural triggers
(e.g., floods, hurricanes)



HUMAN & NATURAL STRESSORS/DRIVERS

- Anthropogenic
- CAFOs
- Sewage treatment
- Wastewater
- Stormwater Runoff

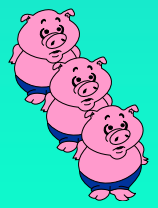
MEDIA

- Groundwater
- Surface water
- Air
- Food

EXPOSURE

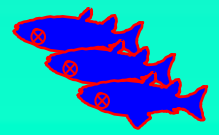
- Human
- Ecosystem

Anthropogenic triggers
(e.g., point source runoff, dumping boat waste, etc.)

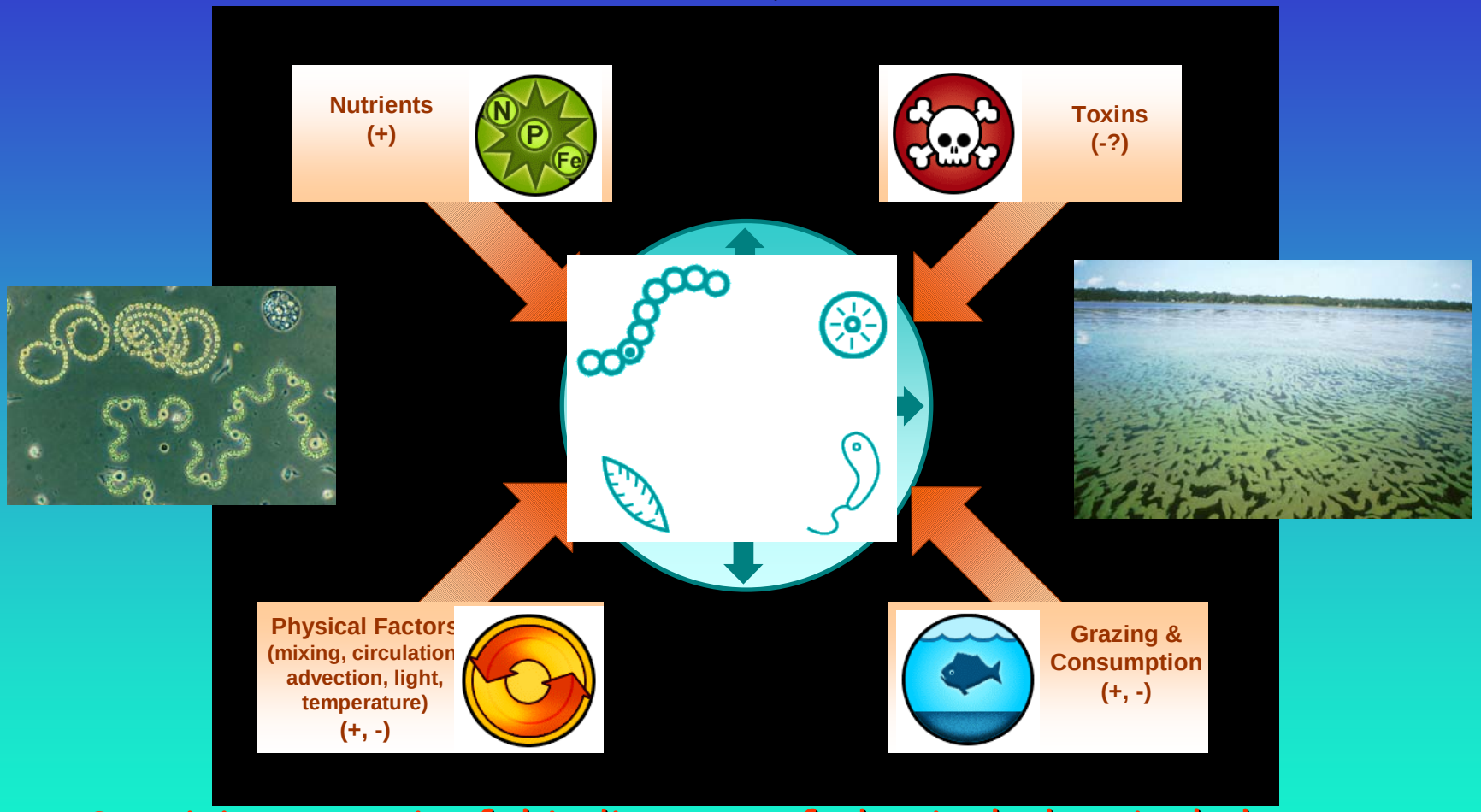


OUTCOMES
(Responses in Humans and Ecosystems)

- Water Quality
- Infectious Diseases/ Pathogens
- Ecosystem Change (e.g. HABs)



Microbes as Indicators of Nutrient & other Environmental Stressors

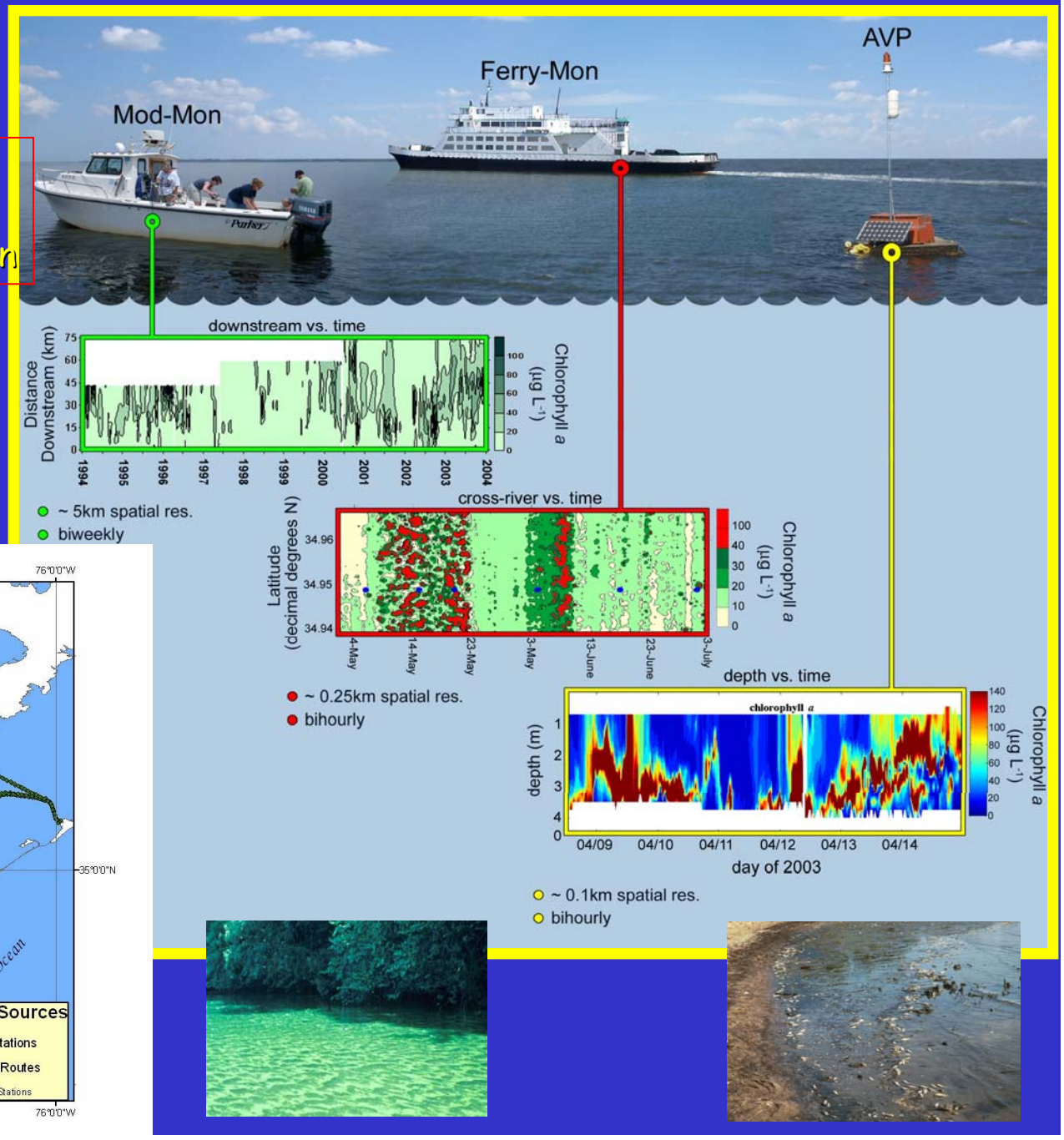


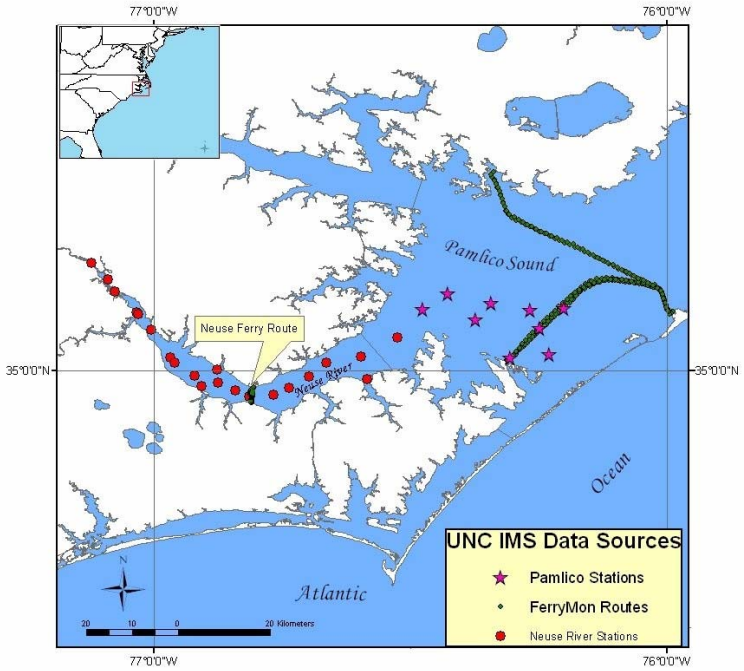
- Sensitive, meaningful indicators of physical-chemical change
- Determine productivity, nutrient cycling, water quality, use and health
- Can be sensed and characterized by a variety techniques over a wide range of scales (cellular → global)

Assessing Impacts on the appropriate scales

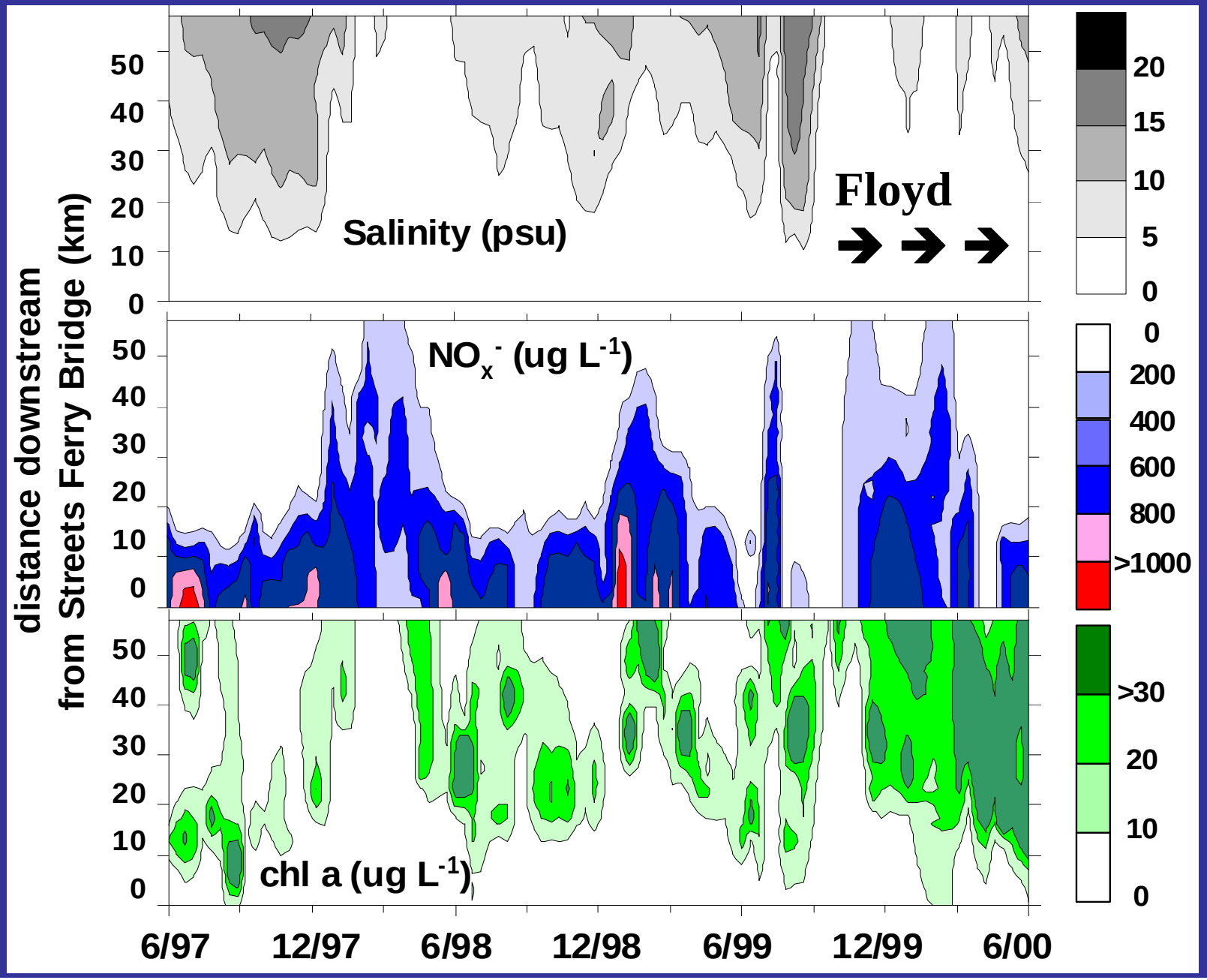
www.ferrymon.org

www.unc.edu/ims/neuse/modmon

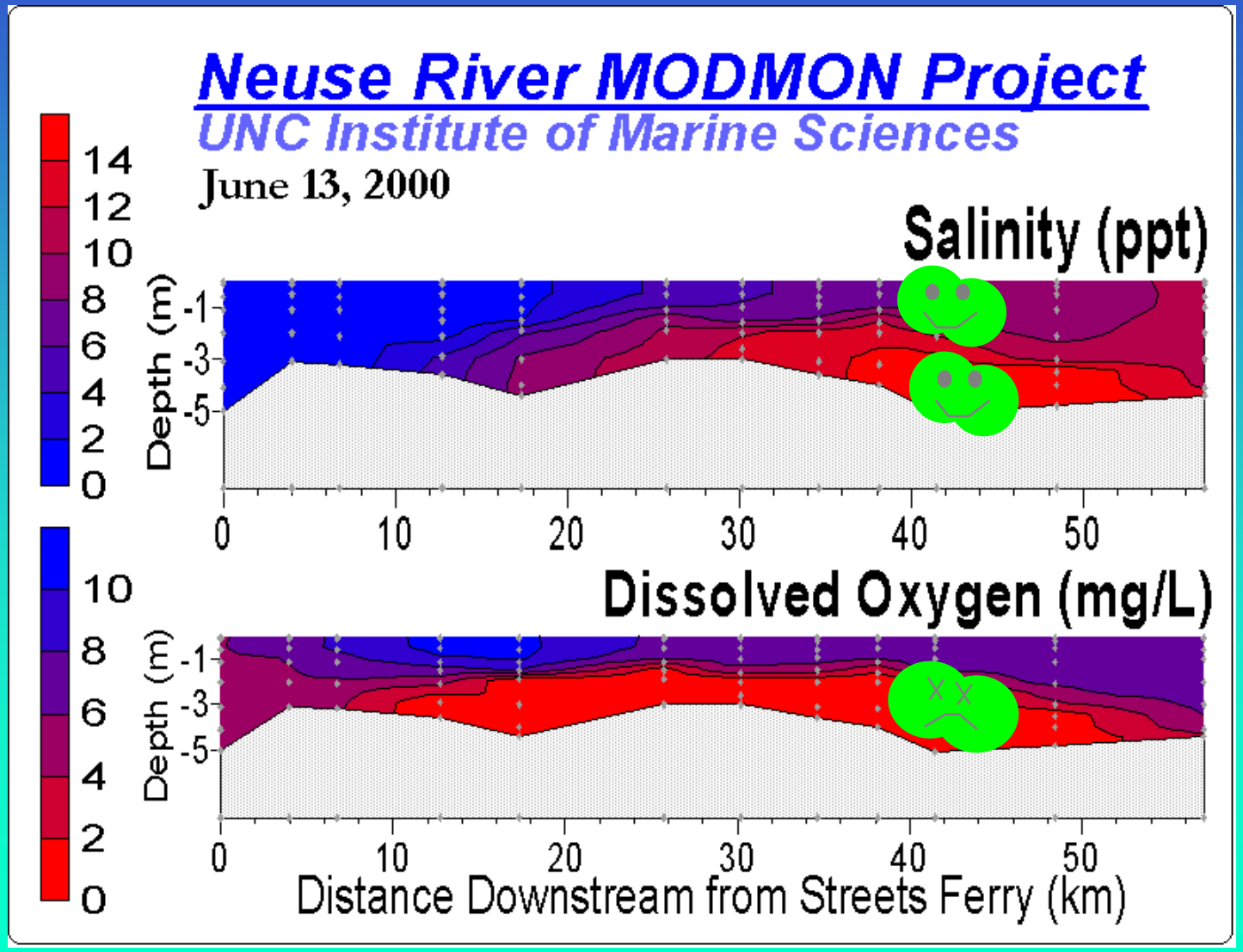




Using space-time intensive monitoring to examine the effects of seasonal vs episodic (hurricane) N loading on algal production (Chl a) in the Neuse R. Estuary

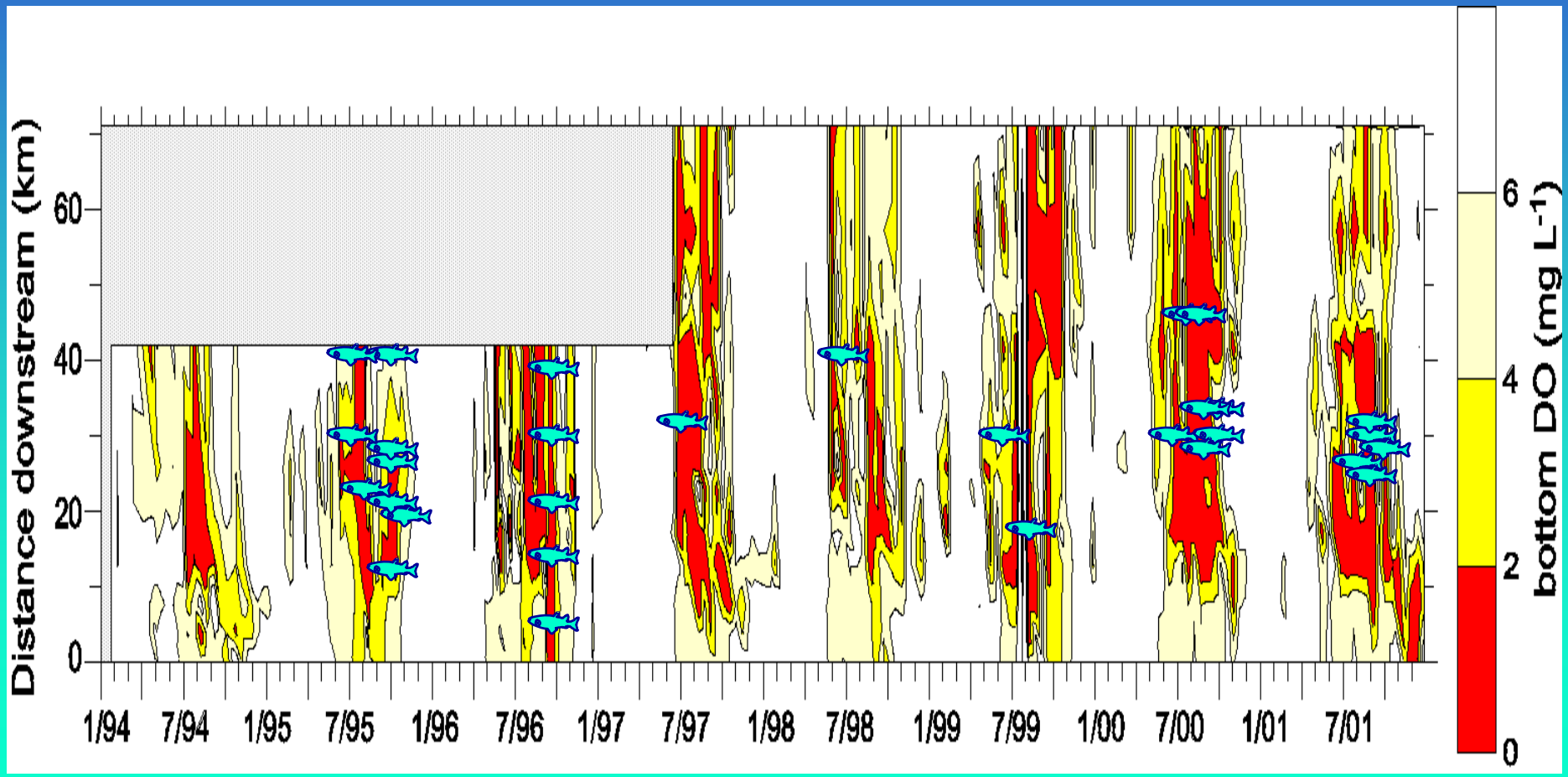


The "connection" to Hypoxia



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

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



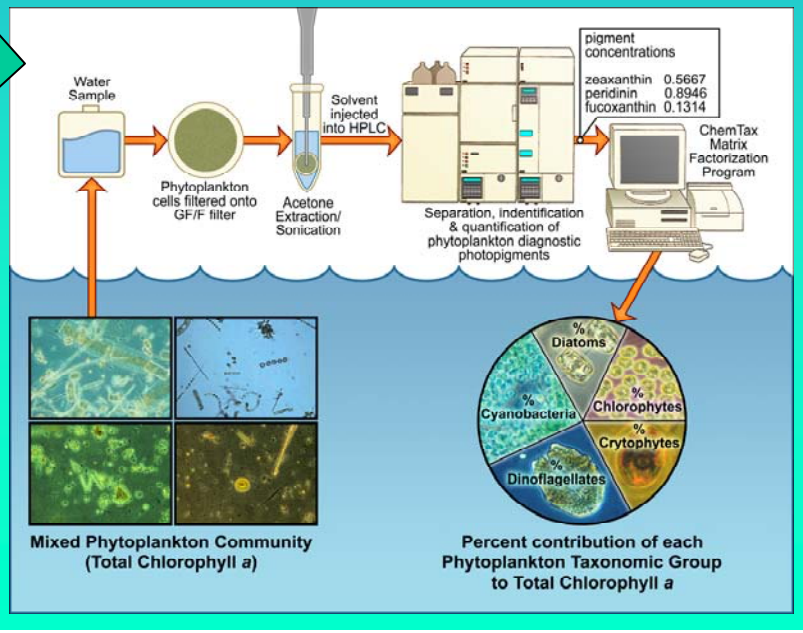
Fish kill data base:

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

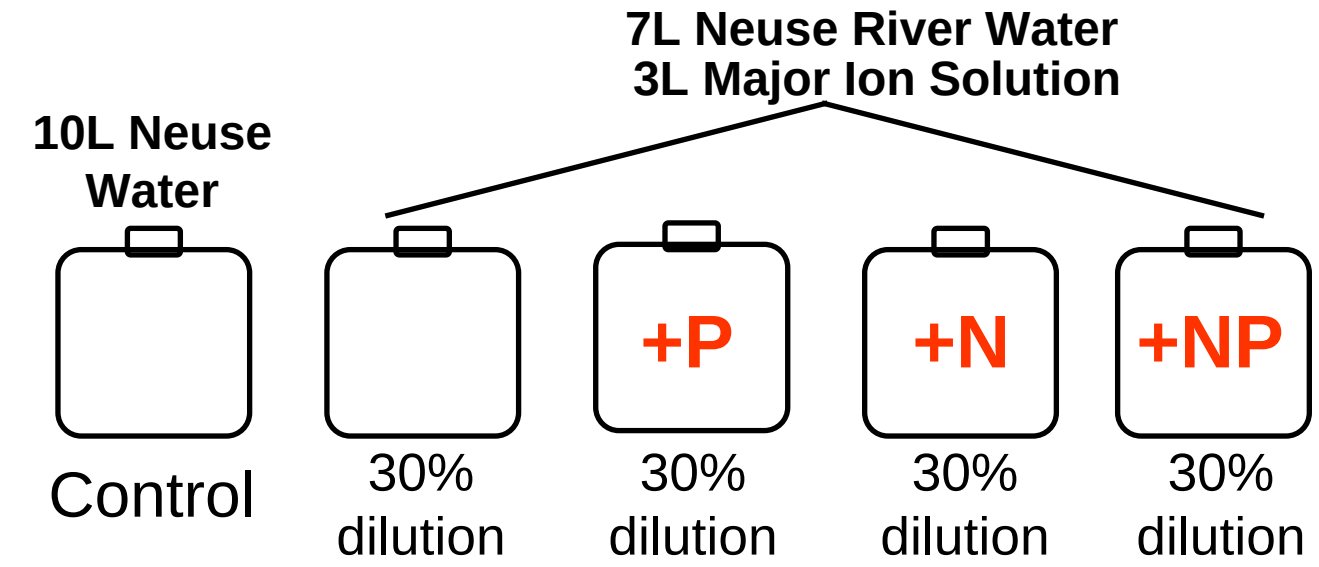
Need: Reduce Estuarine Primary Production (Chl *a*) by Establishing an N Input Threshold (TMDL)

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)



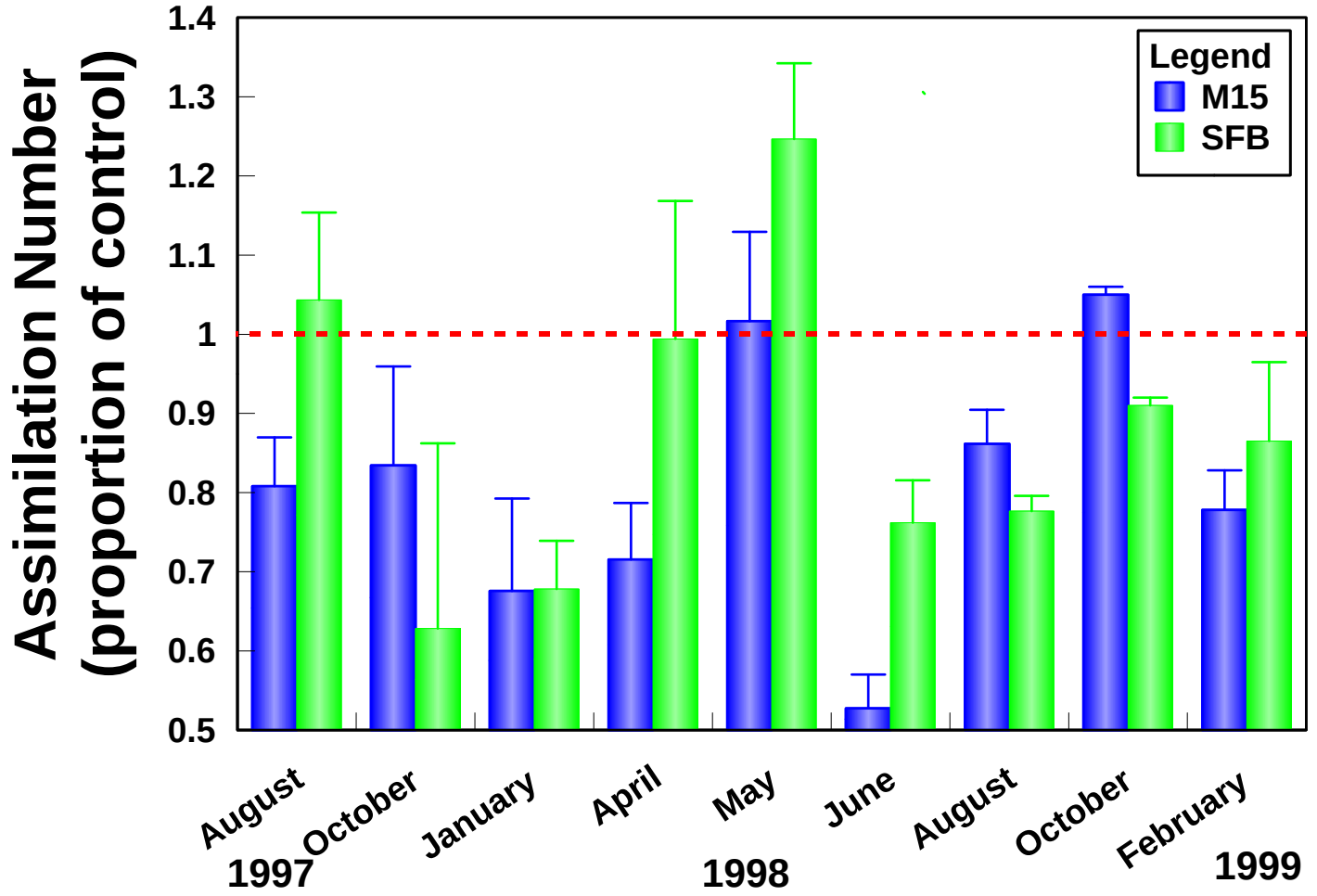
Asking the Phytoplankton: Dilution Bioassays



Response Indicators:

Chl *a*, primary productivity

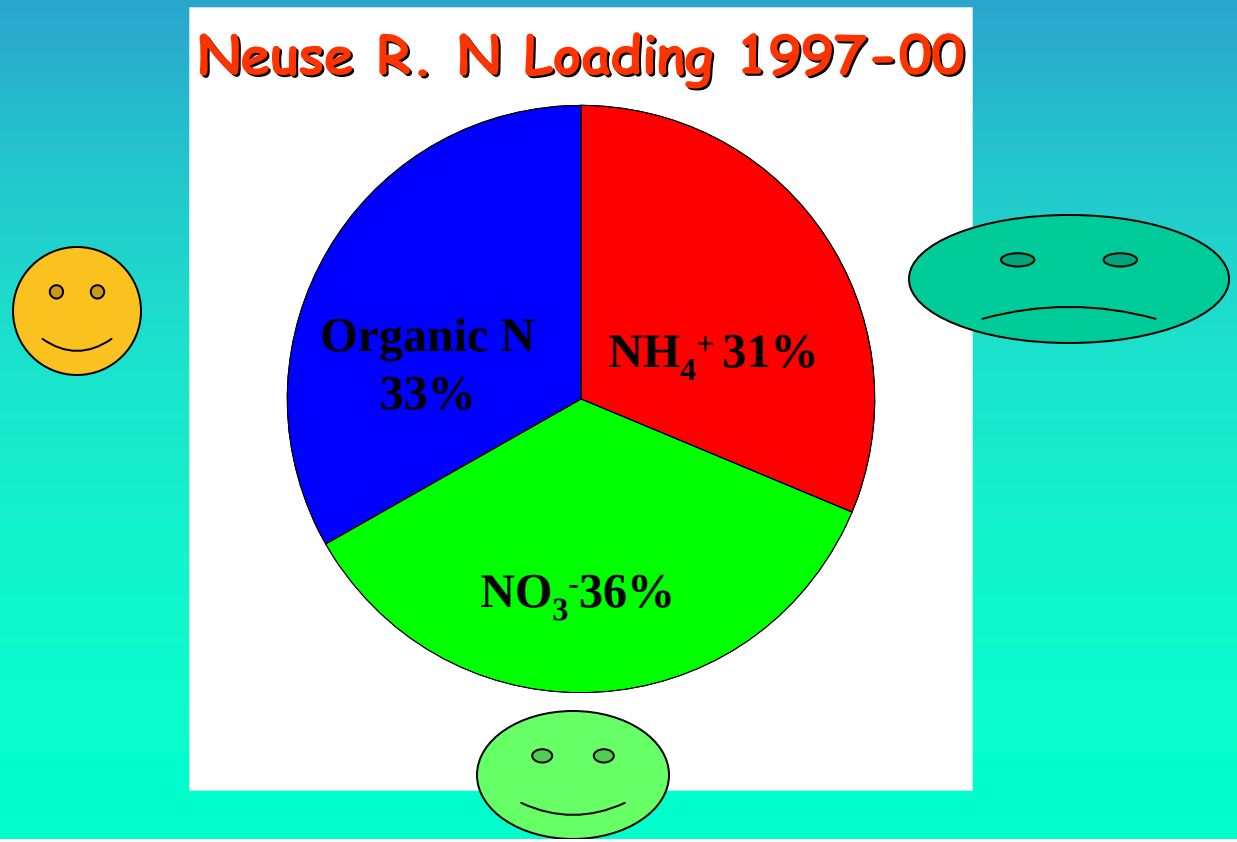
Seasonal Effect of 30% Reduction in N Concentration
84 Hour Incubation



Piehler et al. 2001

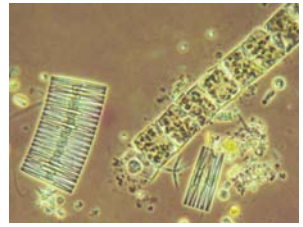
However, when considering reductions…….
"New" N comes in different "flavors"

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

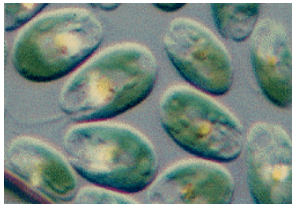


Nitrate vs Ammonium effects on algal production & composition

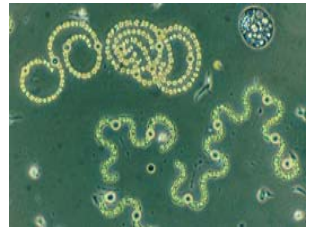
All phytos



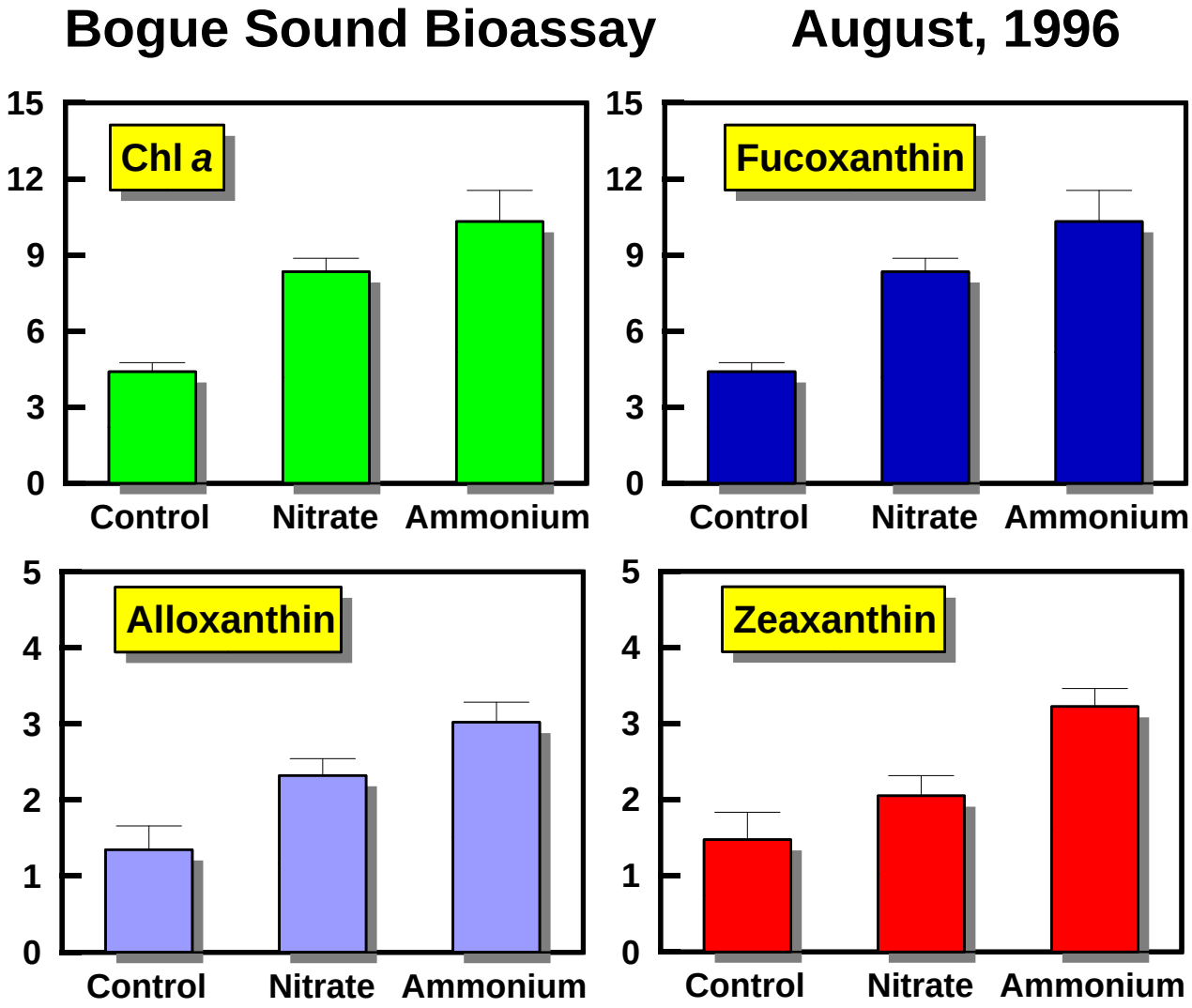
diatoms



cryptophytes



cyanobacteria



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

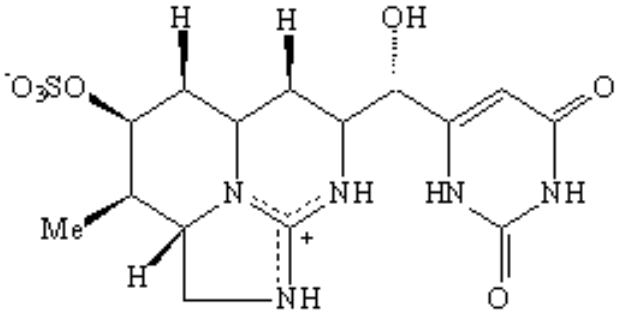
↙ ↓ ↘

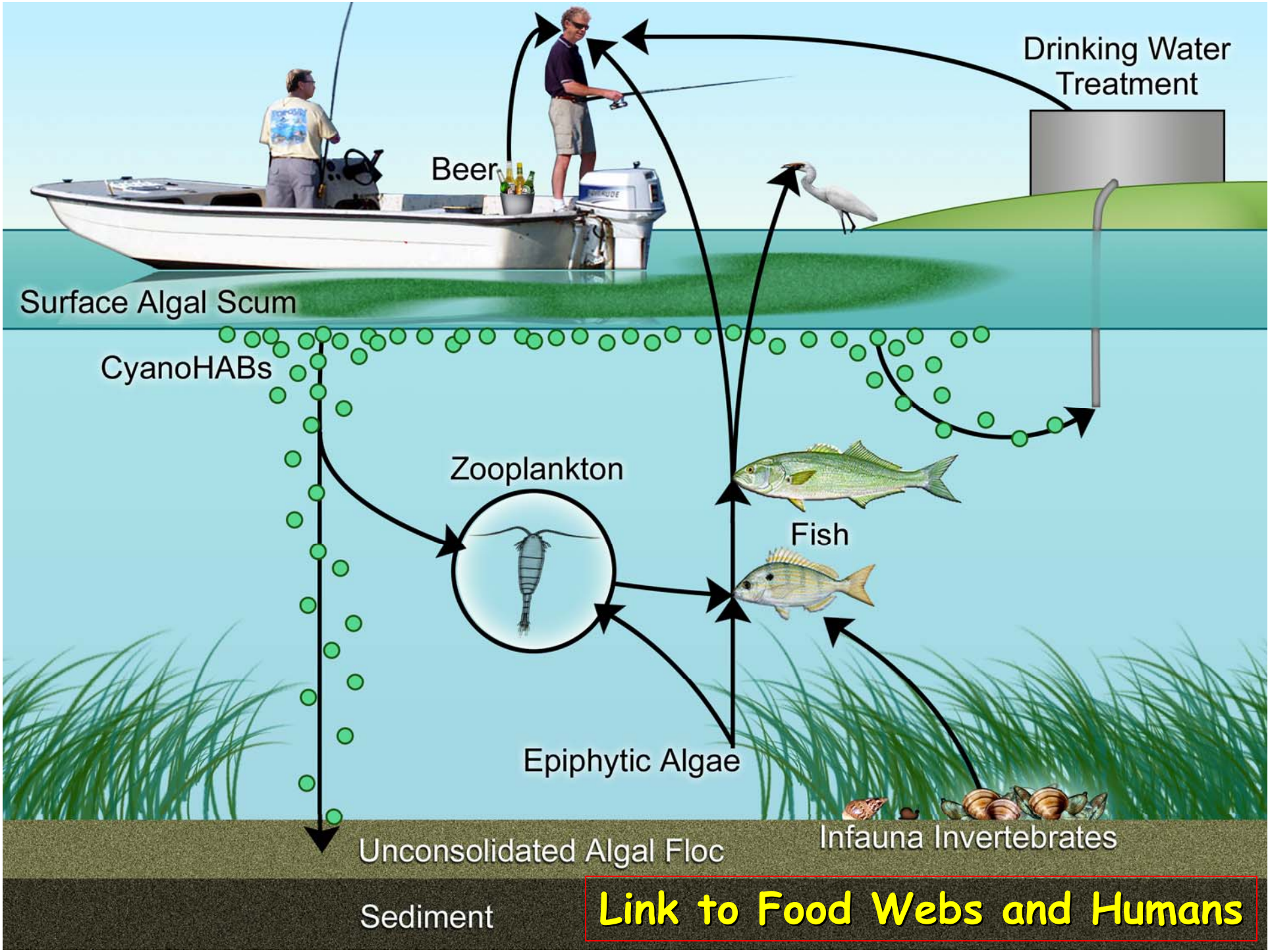
Why are we concerned about CHABs?

- 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

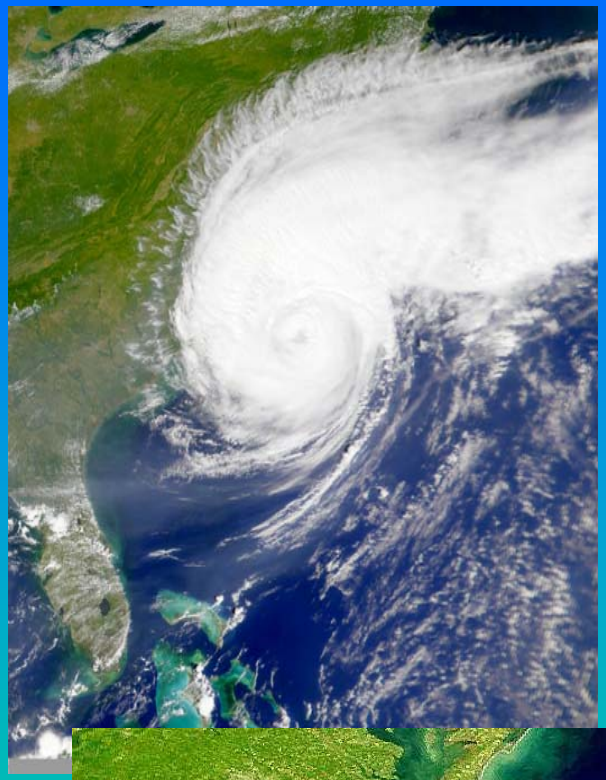
"Toxins" of Concern

Toxin	Effect
Anatoxin-a	Nerve Synapse
Anatoxin-a(s)	Nerve Synapse
Aplysiatoxins	skin
BMAA ß-N-methylamino-L-alanine	Neurogenerative disease?
Cylindrospermopsins	wide-spread tissue damage
Lyngbyatoxin-a	skin
Microcystins	Liver
Nodularin	Liver
Saxitoxins	Nerve axons

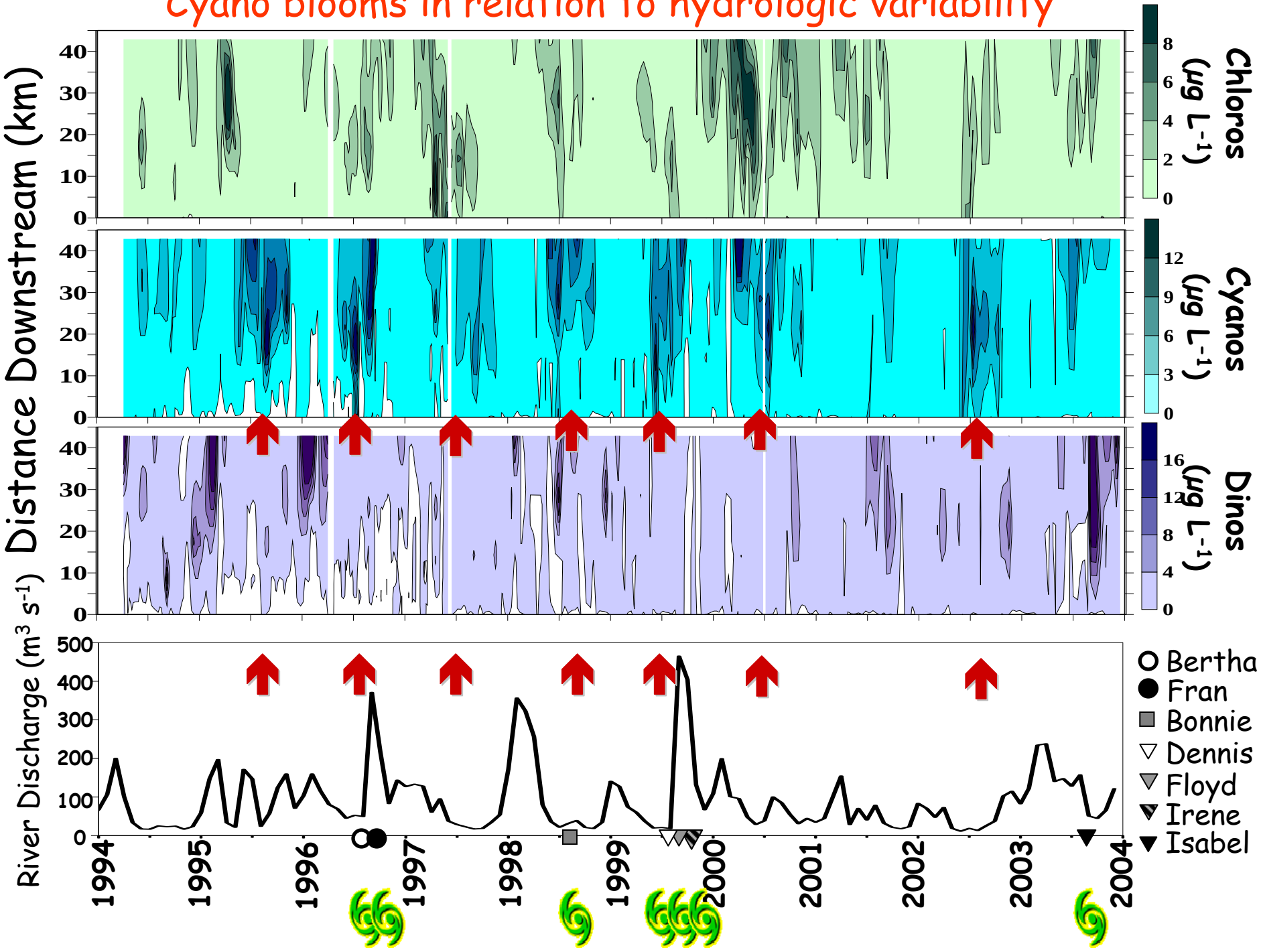



Drinking Water Treatment
Beer
Surface Algal Scum
CyanoHABs
Zooplankton
Fish
Epiphytic Algae
Infauna Invertebrates
Unconsolidated Algal Floc
Sediment
Link to Food Webs and Humans

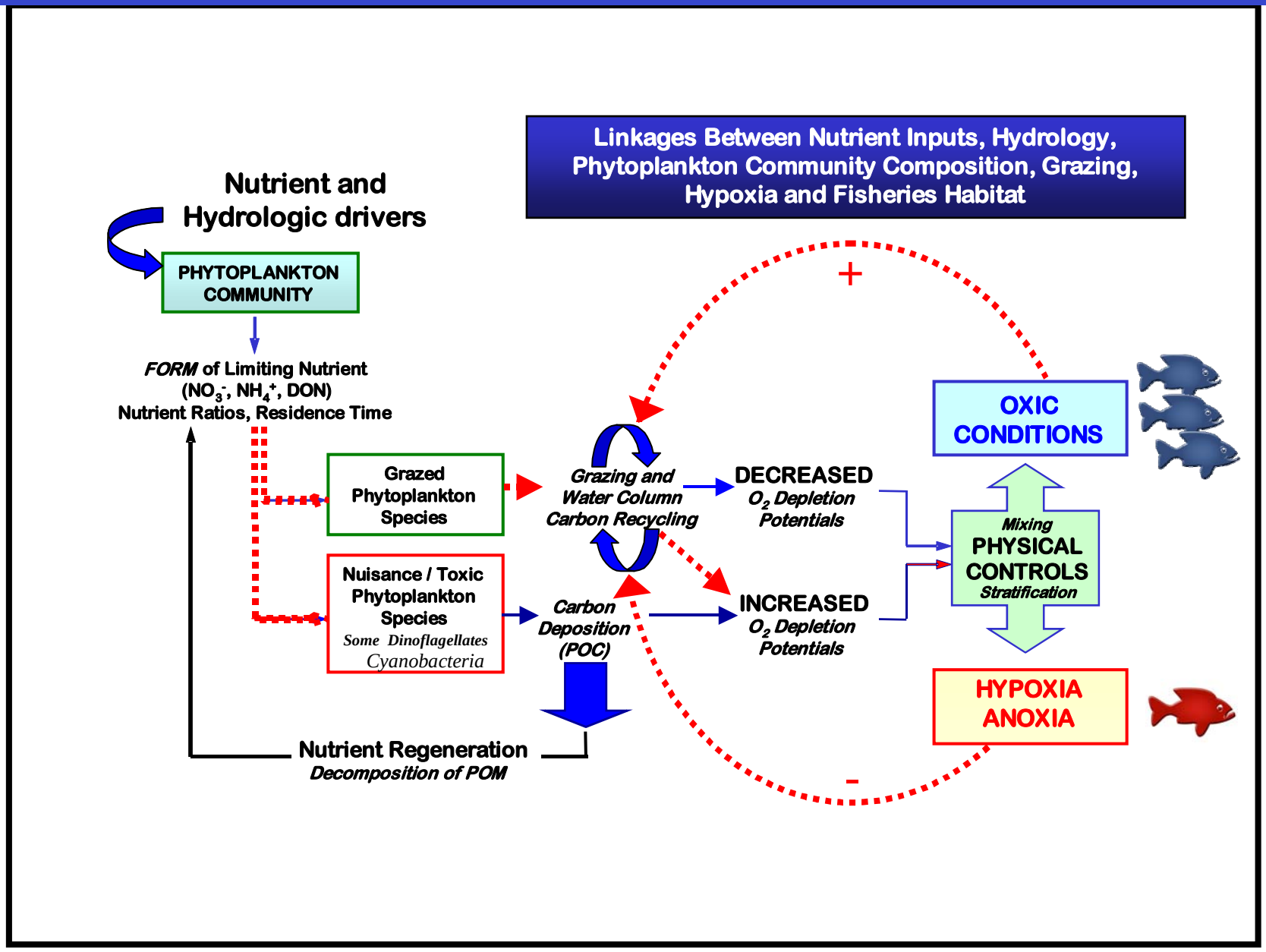
Cyanos and extreme climatic (hydrologic) events



Cyano blooms in relation to hydrologic variability

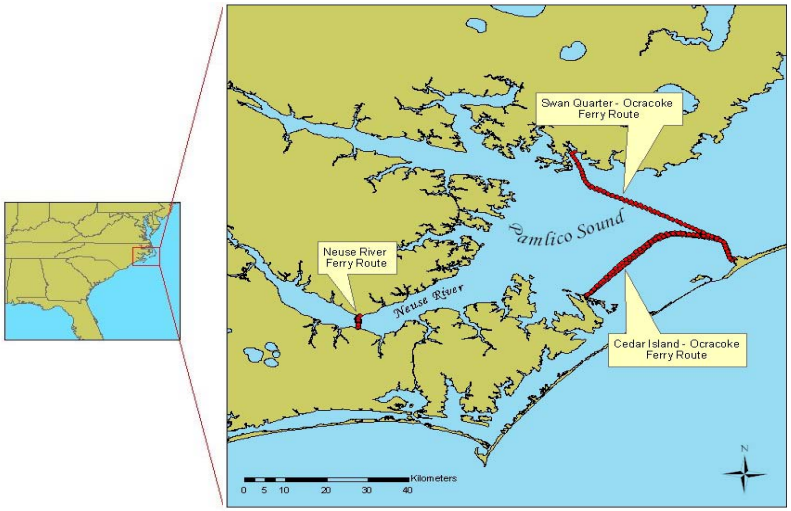


Ecosystem Service (Fisheries yield) Ramifications

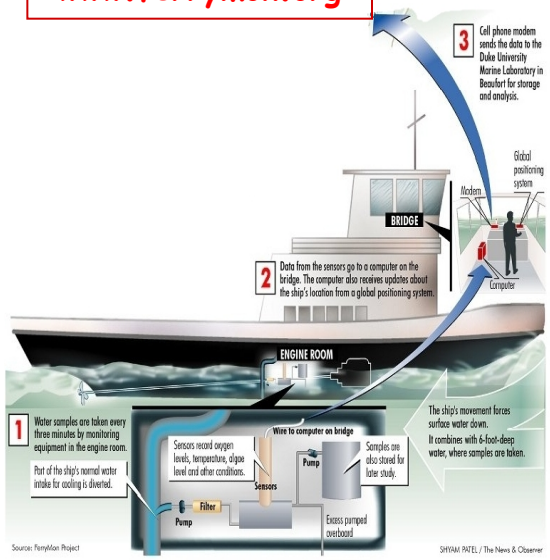


Capturing "events" Using Ferries as a platform for indicators

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



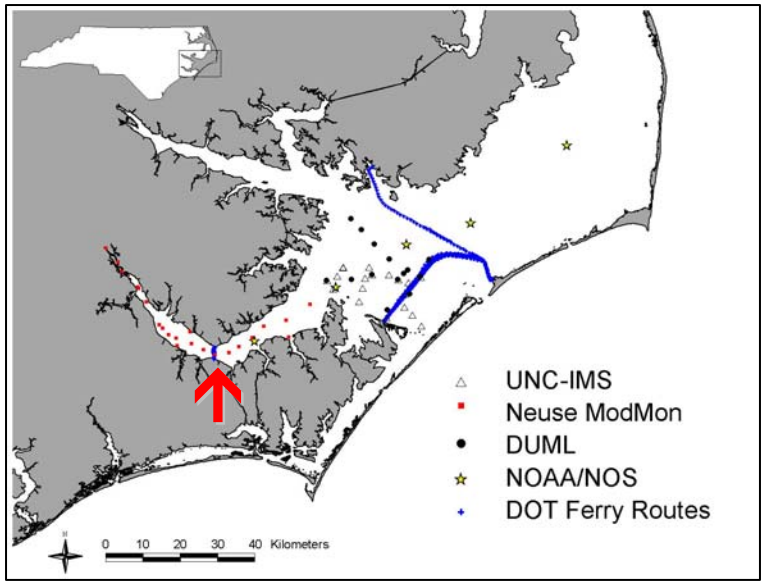
Ferry Bridge Equipt
Date/Time
DGPS Latitude / Longitude
Data Modem / Data Logger

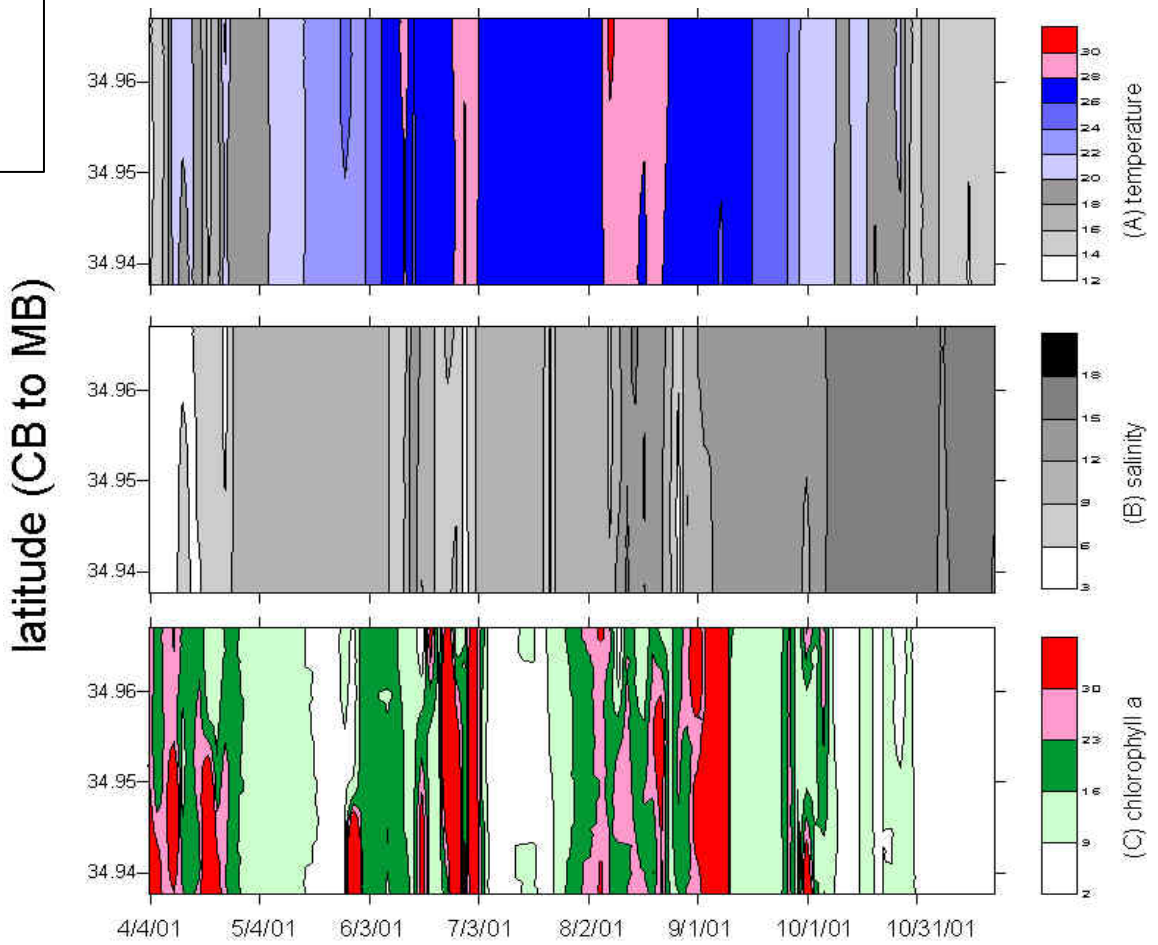
YSI sonde
in-situ Chla
Salinity
Temperature
Turbidity
pH, DO
Date/Time

ISCO discrete sampler
in-vivo Chla
Diagnostic Pigments
Nutrients
E. Coli / viruses
Date/Time

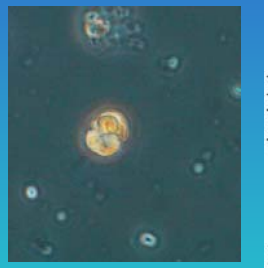
Quantifying Chl *a* & Detecting Algal Blooms

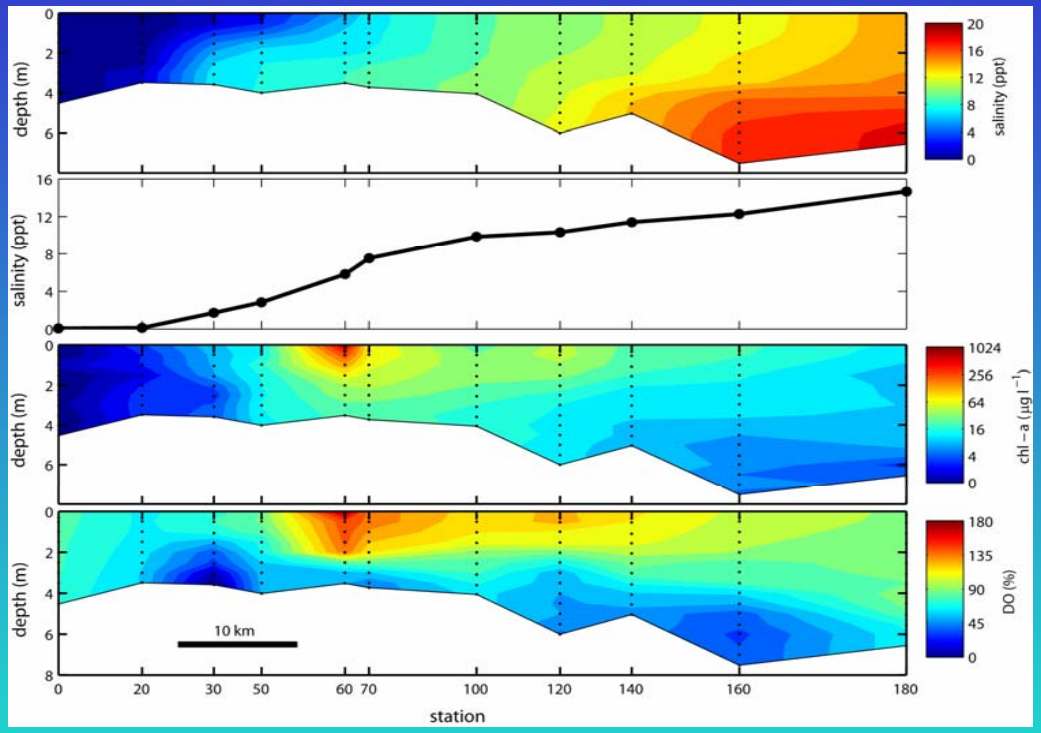
Cherry Branch-Minnesott Ferry

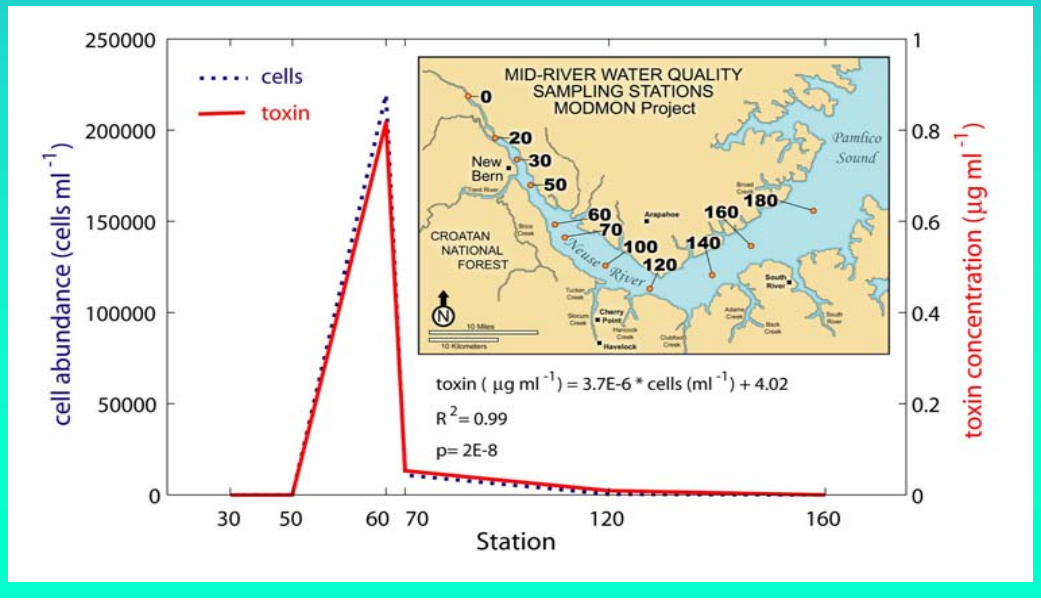




The "perfect storm": Tropical Storm Ernesto (Oct. 2006) setting up a toxic *Karlodinium* bloom in the Neuse River Estuary





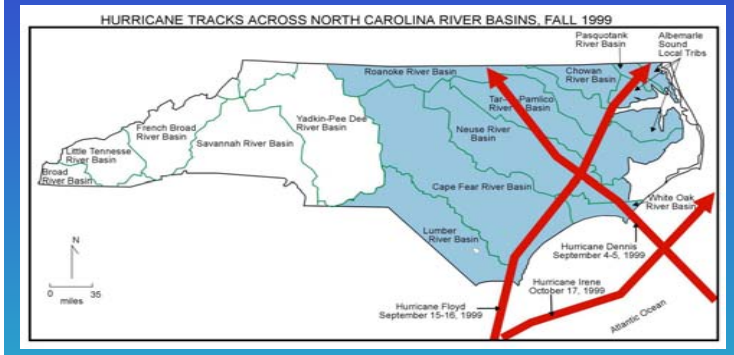


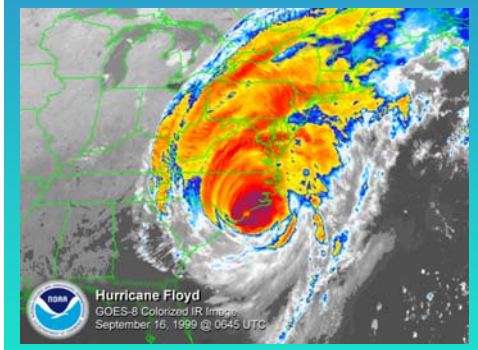
FerryMon & ModMon

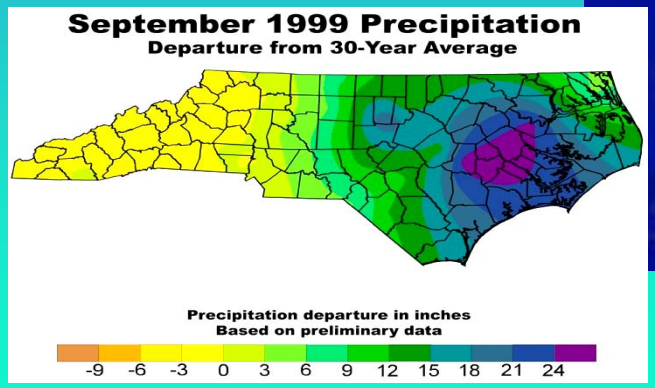
- Close interval and intensive spatial and temporal coverage clarifies causes and effects, and helps develop models that can *forecast* these episodes

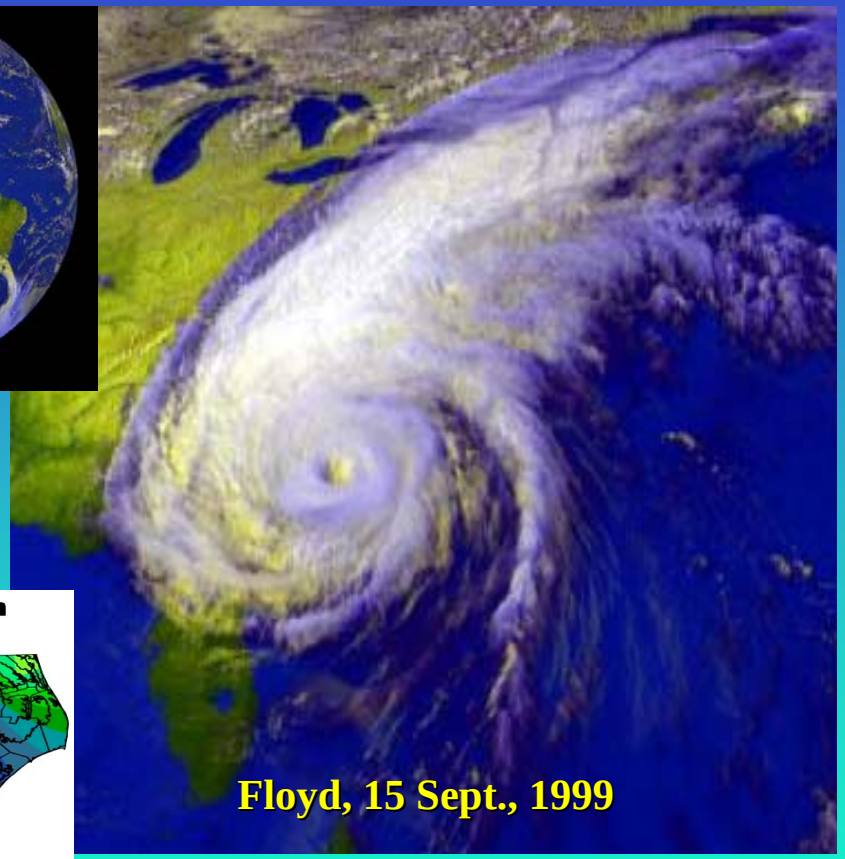
Hall et al. submitted

The Hurricanes of 1999: What Happened?



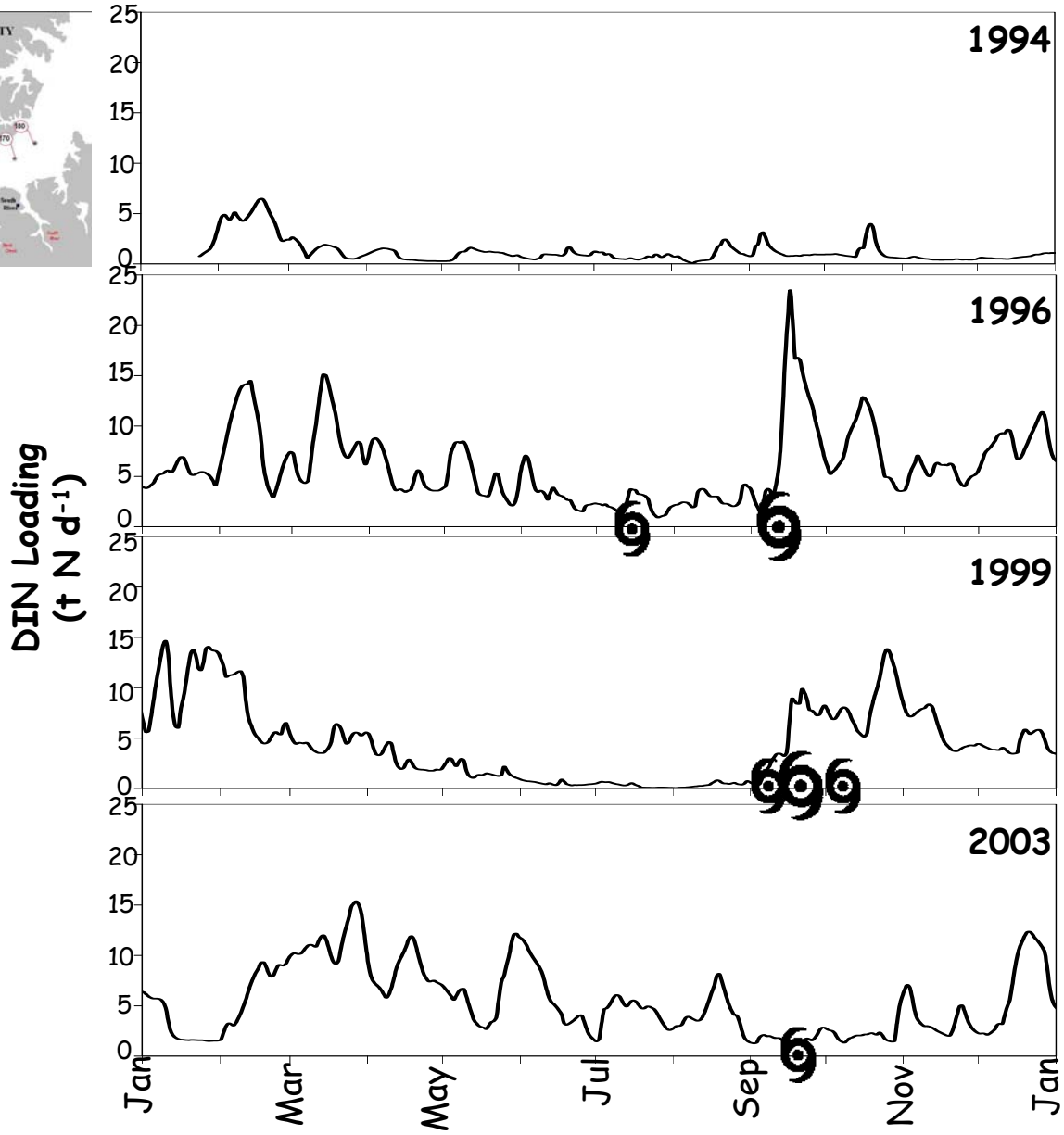






- 3 SS-scale 3 hurricanes (Dennis, Floyd & Irene) within 6 weeks
- Record rainfalls in Pamlico Sound Basin.
- 50-500 year floods in PS watershed
- PS Received annual water and N loads in about 1.5 months

Nitrogen Loading to the Neuse R. Estuary, NC



Drought year

Bertha
Fran

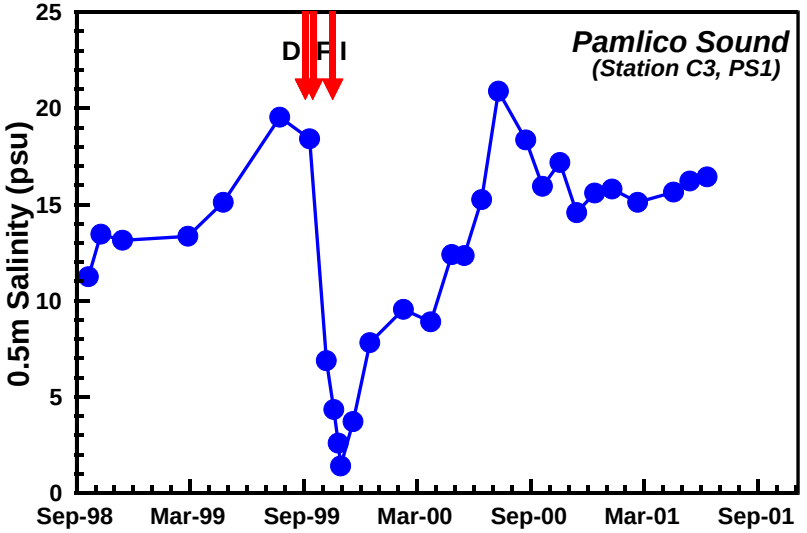
Dennis
Floyd
Irene

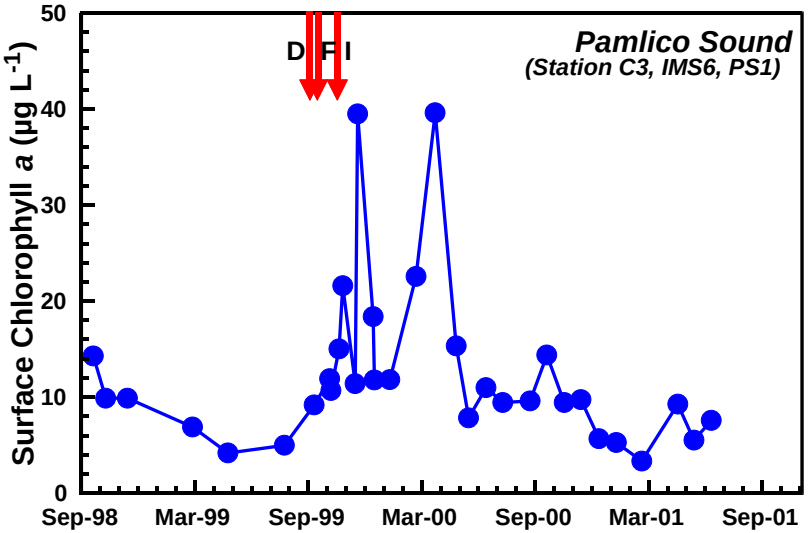
Isabel

Paerl et al. 2005; 2006

Hurricanes, combined with human activities can have huge impacts

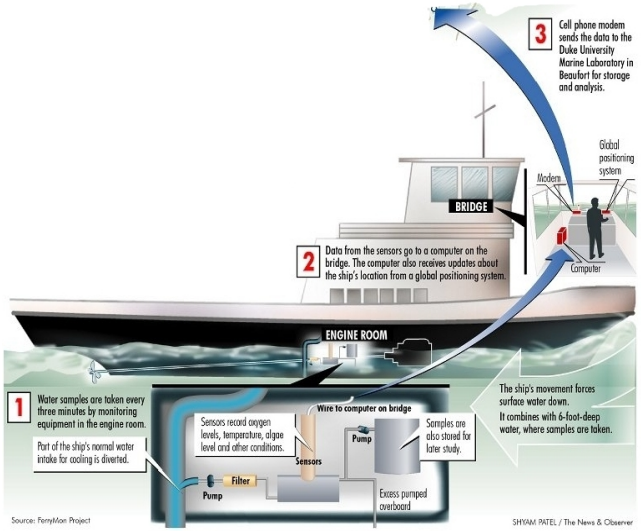
Salinity and Chlorophyll *a* responses to the floodwaters in Pamlico Sound



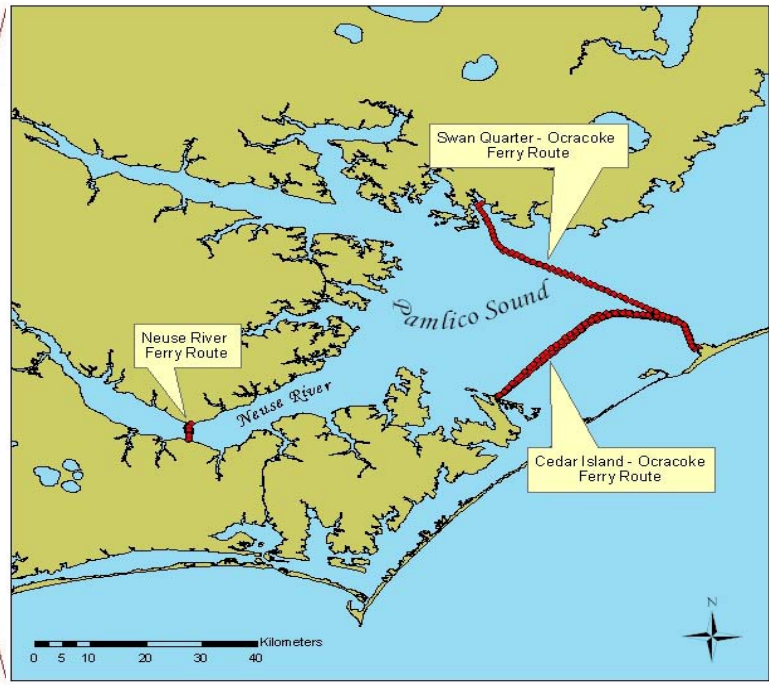


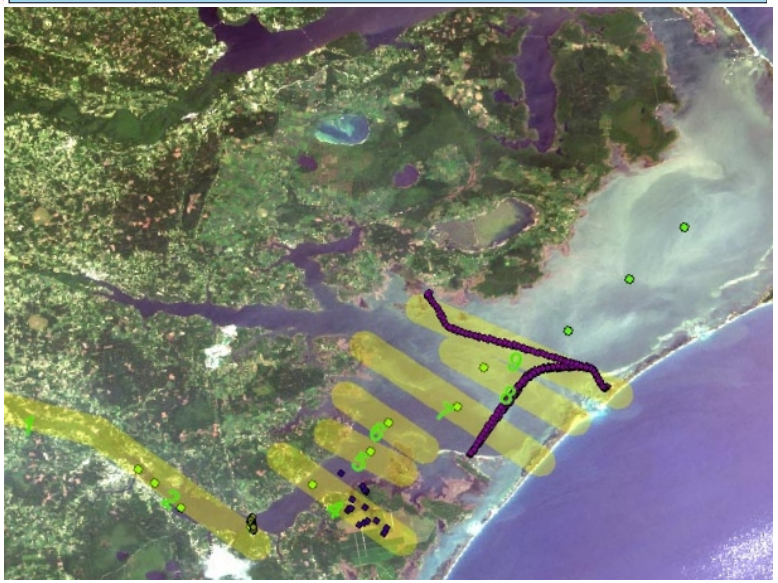
Scaling up by coupling FerryMon to Remote Sensing

Neuse-Pamlico Estuarine
Routes: www.ferrymon.org



NASA / EPA Modified U2 Aircraft,
Beaver LiDAR & SeaWiFS

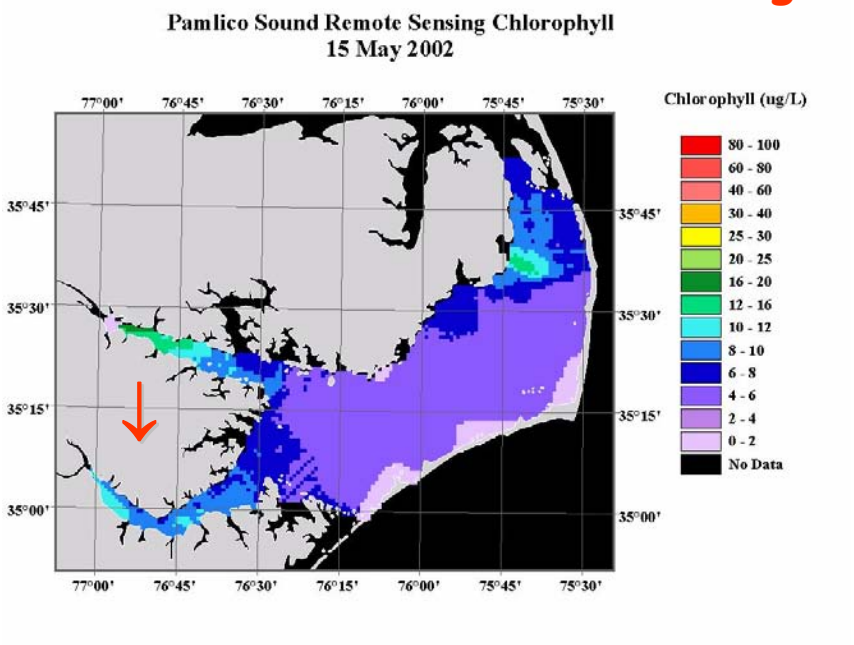


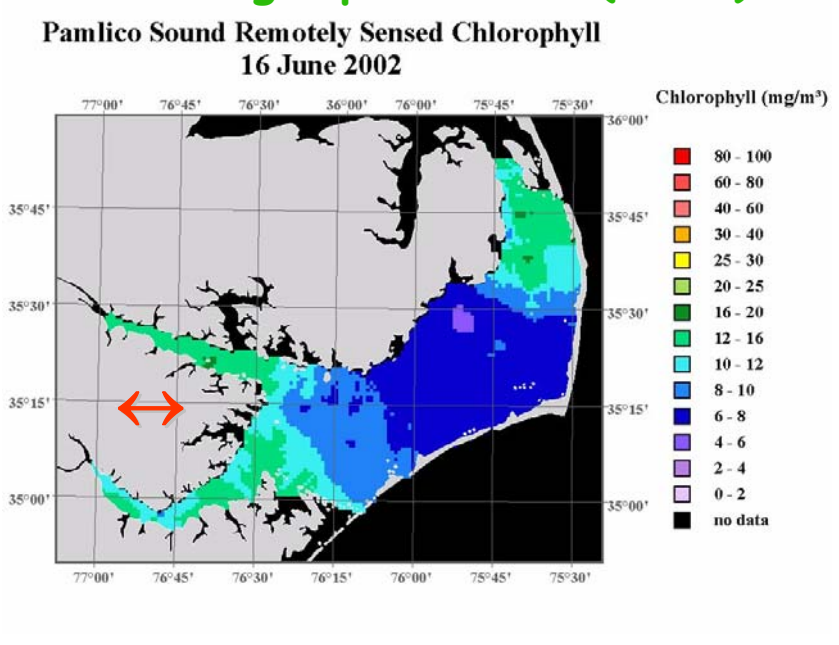


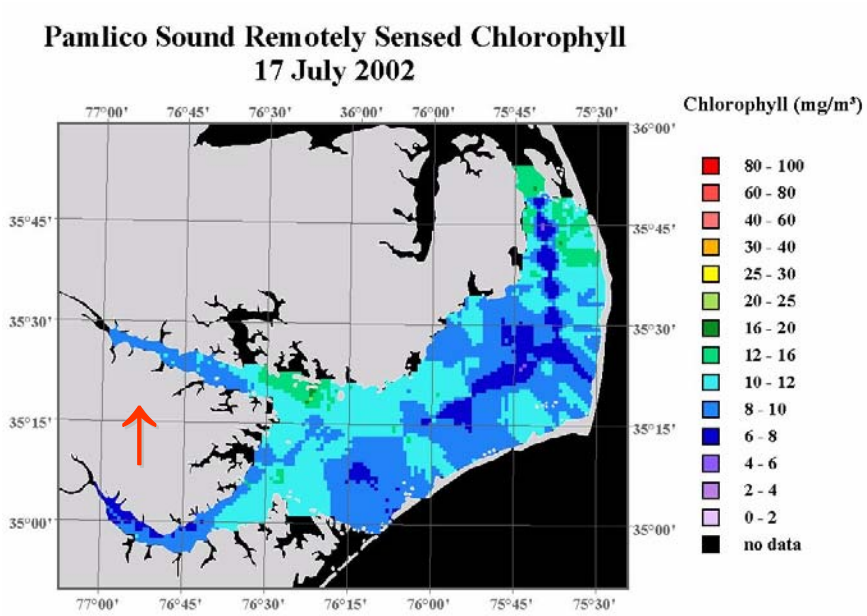
Parameters

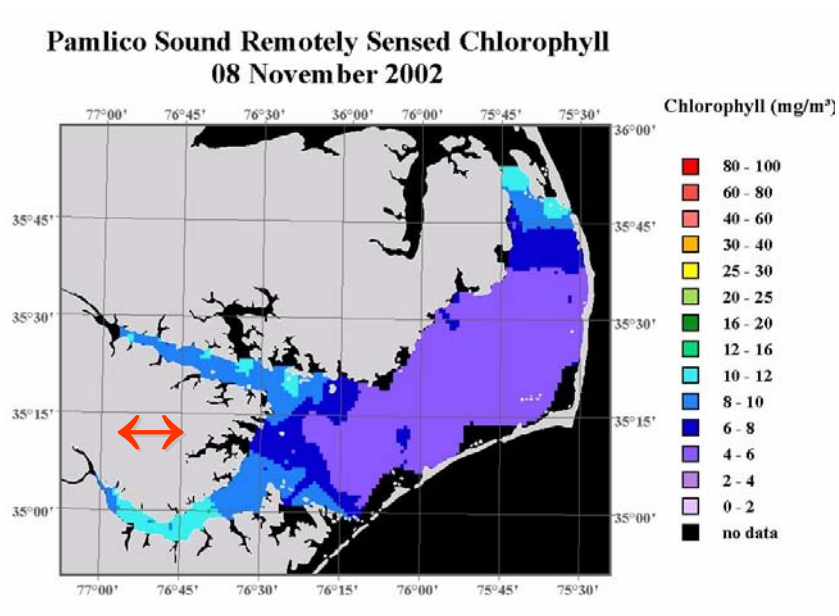
Temp.
Salinity
D.O.
pH
Turbidity
Chl a
Diagnostic pigments
Nutrients

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



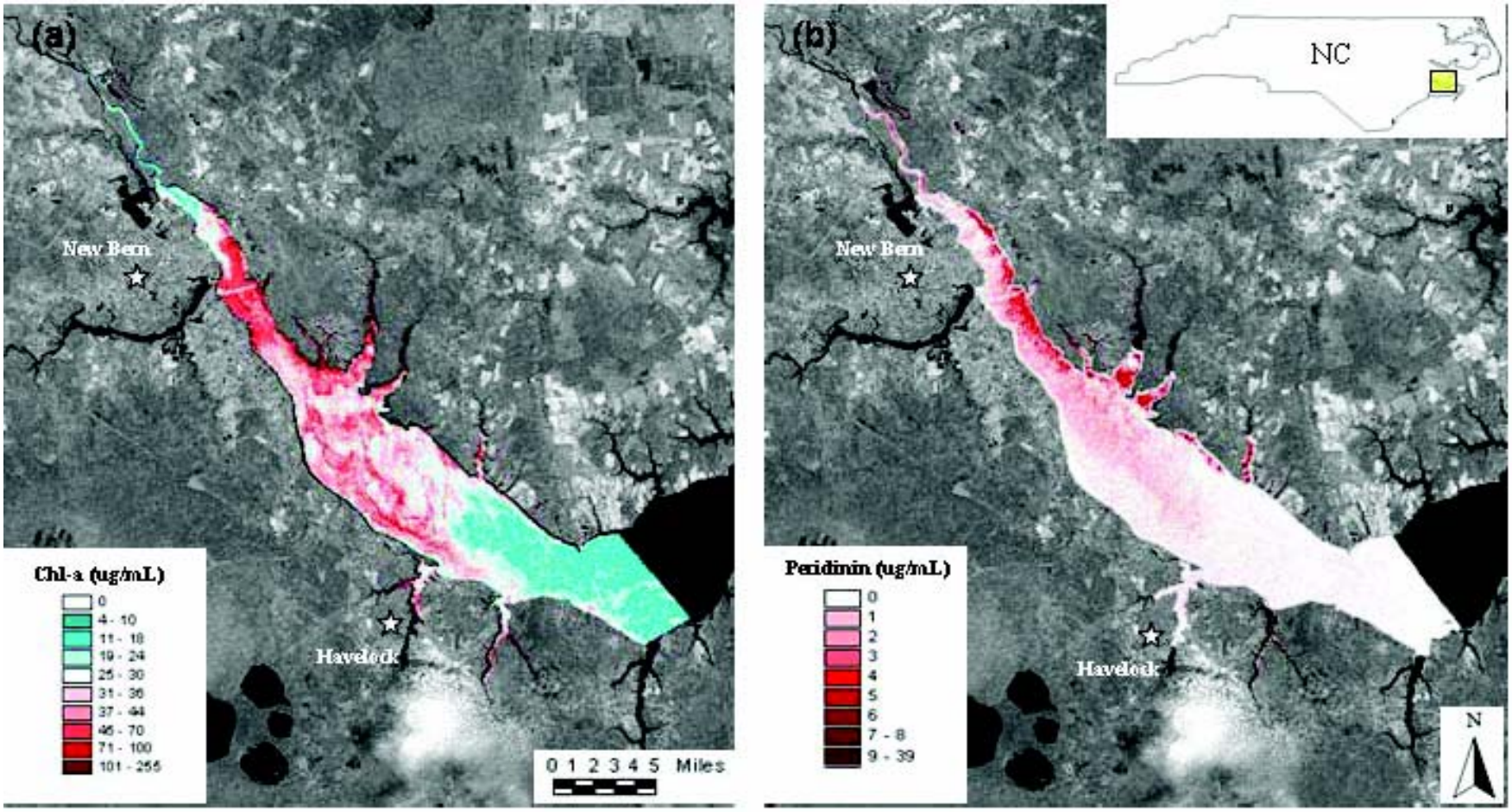






Flow: high↑, low↓, moderate↔

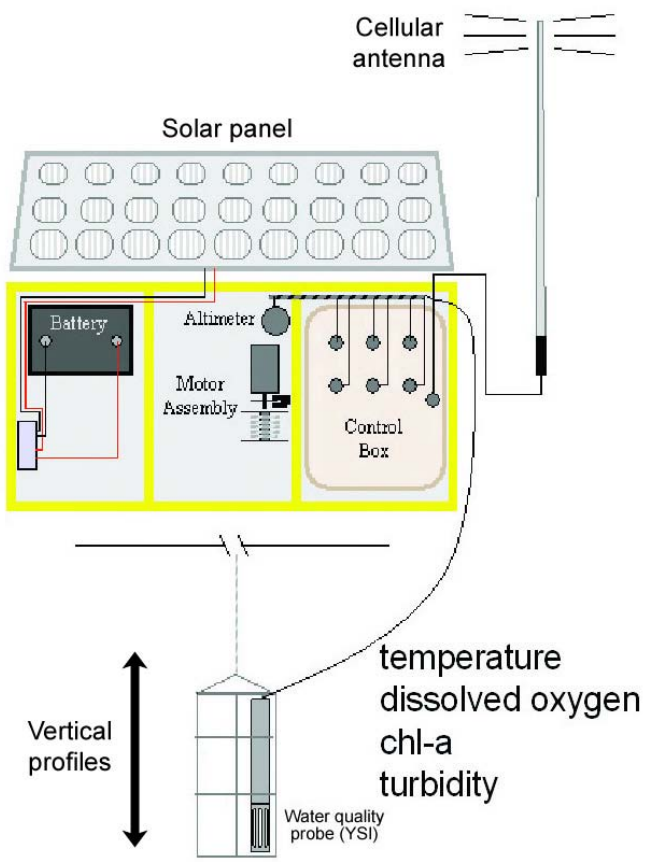
Diagnostic Pigment Indicators to Calibrate Remote Sensing



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)

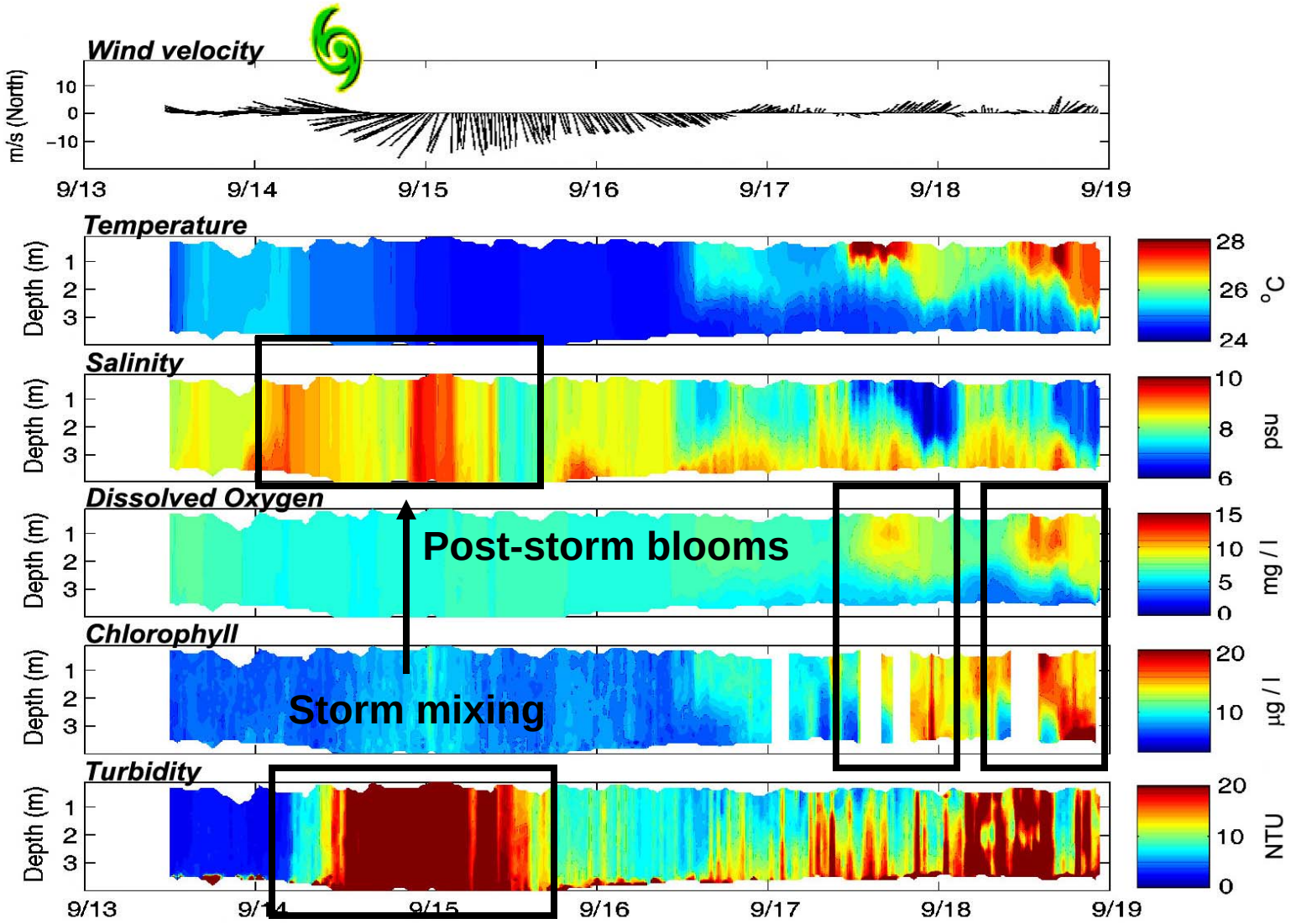
Users: EPA-RTP, NASA, NC DENR-DWQ

Observational Platforms
Autonomous Vertical Profiler (AVP)

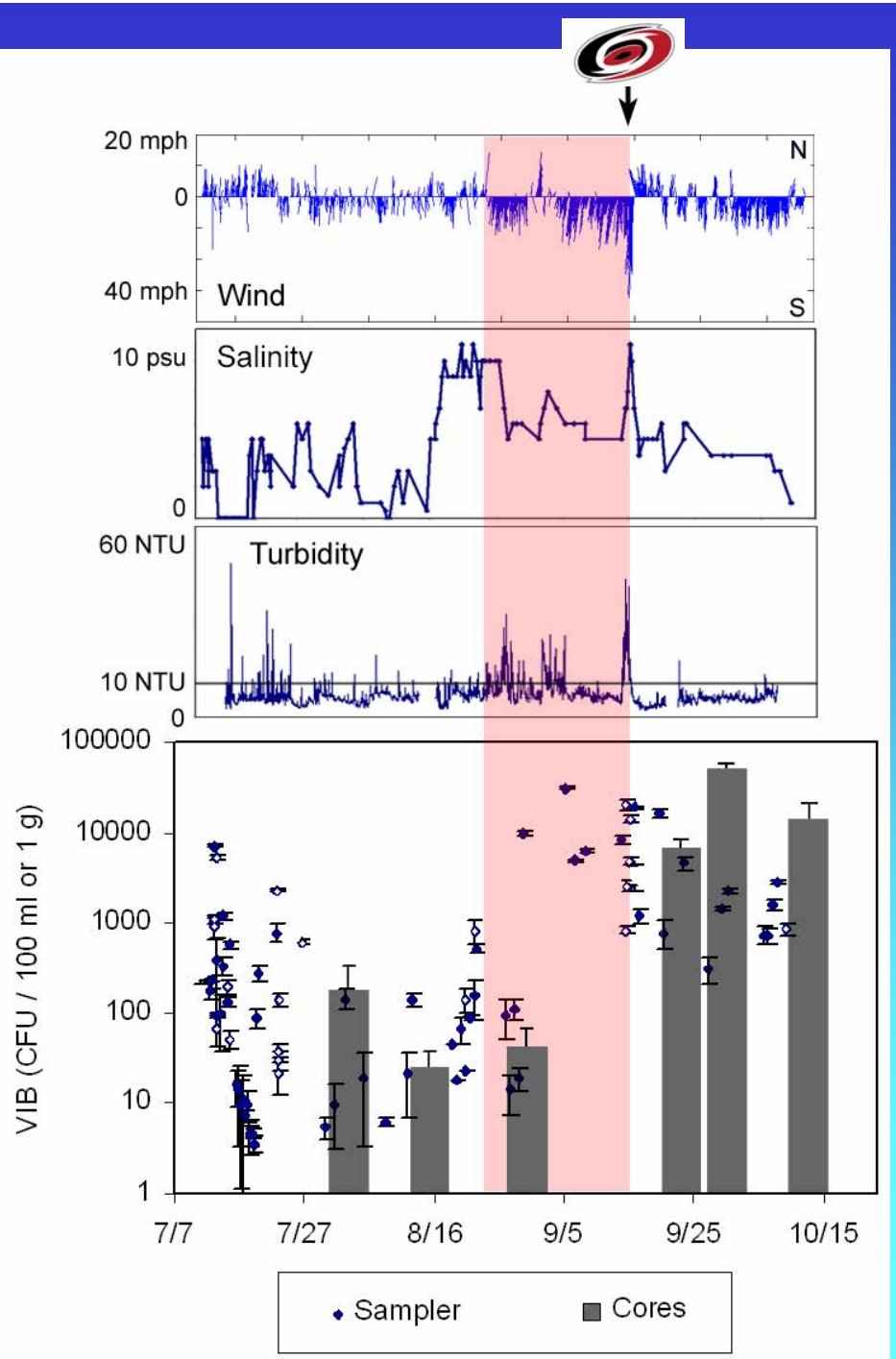


- Monitors water quality using profiling instrument
- Instruments:
  - Water quality sonde
- Sampling schedule:
  - Profiles every 30 min
  - Vertical resolution of 10 cm

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.

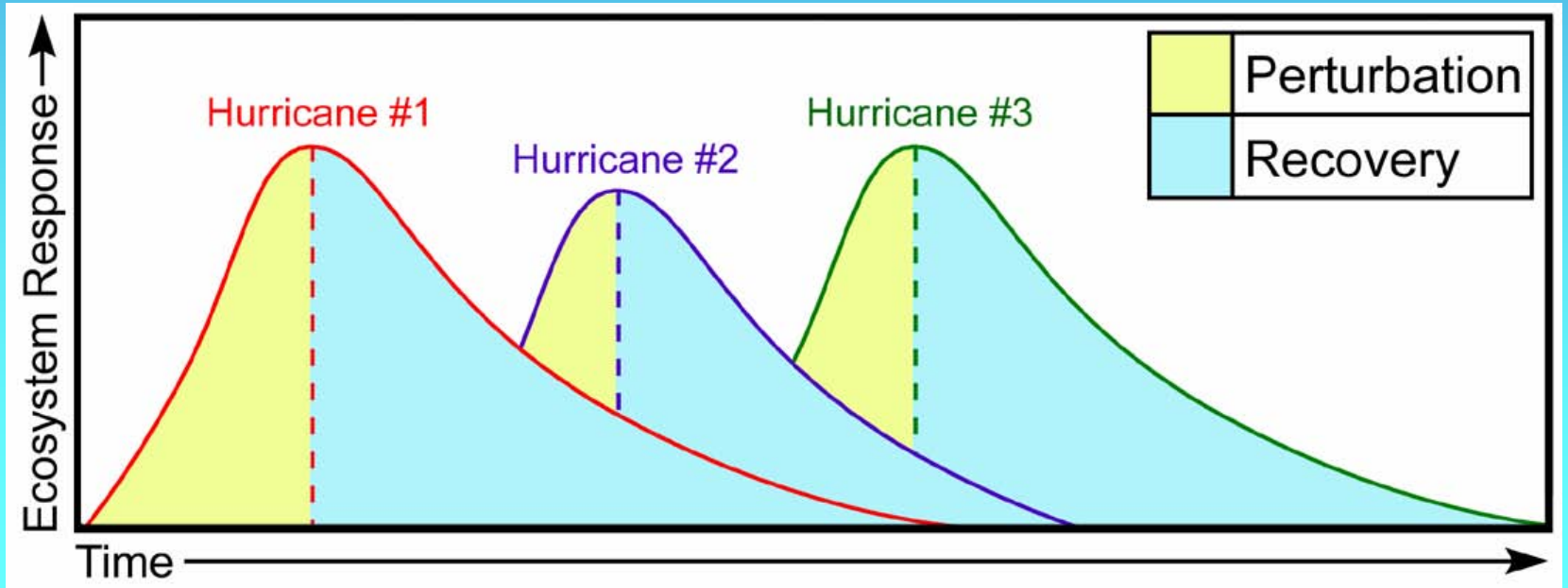
The approach and passage of category 1 Hurricane Ophelia resulted in a 3-week period of sustained winds that greatly perturbed the estuaries in eastern North Carolina (Figure 1). In particular, the Neuse River Estuary (NRE) experienced a significant storm surge and wind mixing, followed by large stormwater 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

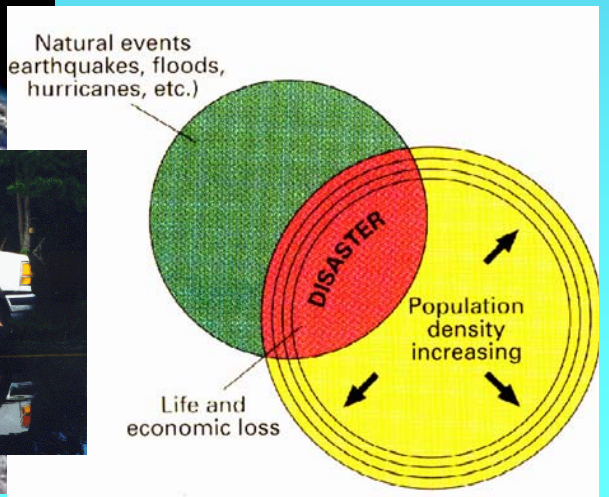
Increase in "extremeness" and scales of storm events? Emanuel 2005

Multi-annual ecological effects and recovery?



Long-Term Human Health & Management Issues

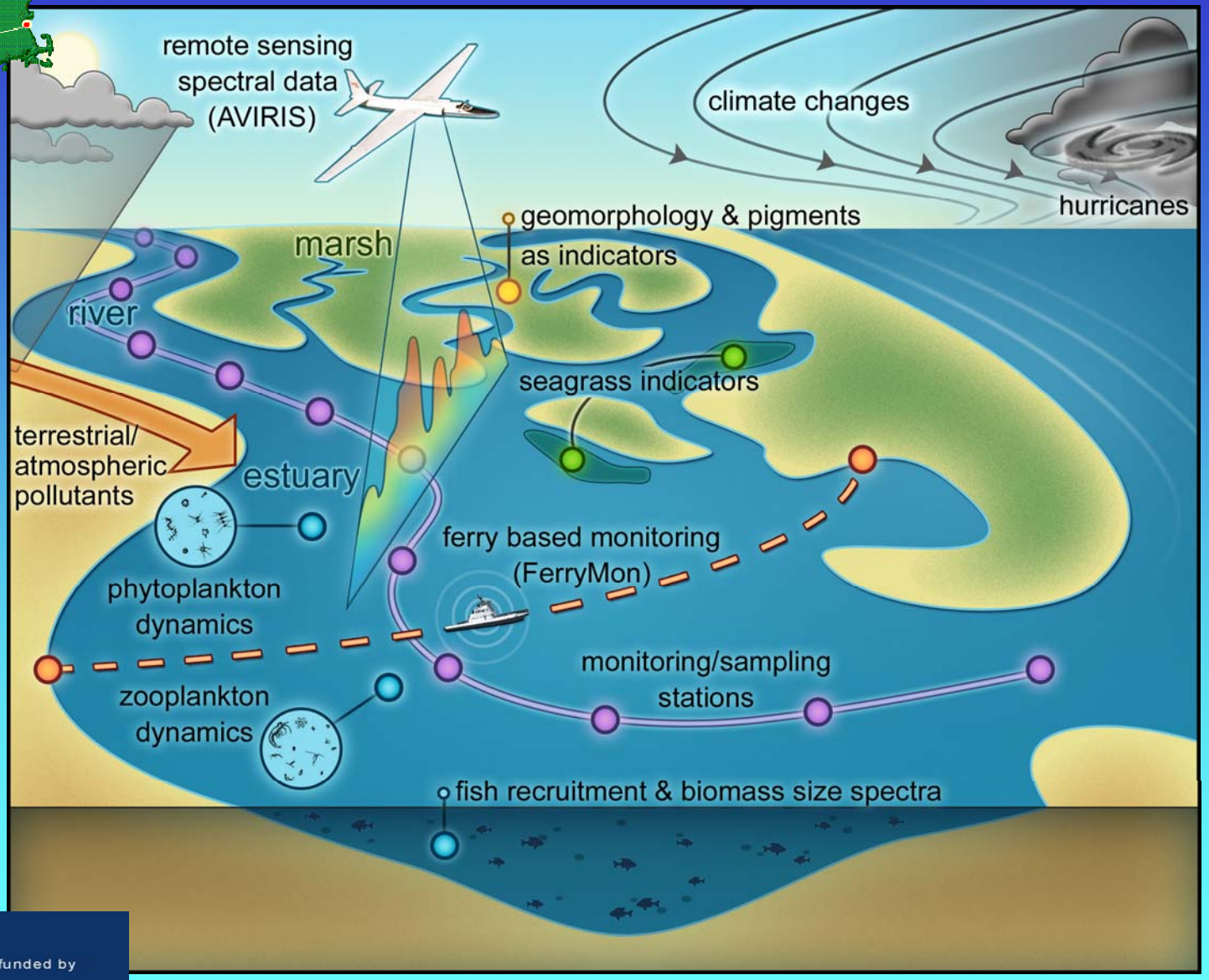
- Nutrient-Pathogen loadings are largely anthropogenic, and complicated by Hurricanes/floods. These are *natural* events exacerbated by human development in coastal watersheds
- Hurricanes are *individualistic* in terms of hydrologic, nutrient and other pollutant impacts.
- Water-quality, habitat & health 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



Coastal Indicators as Management Tools: www.aceinc.org

Atlantic Coast Environmental Indicators Consortium

Plum Island LTER
Chesapeake Bay
Neuse/Pamlico
North Inlet



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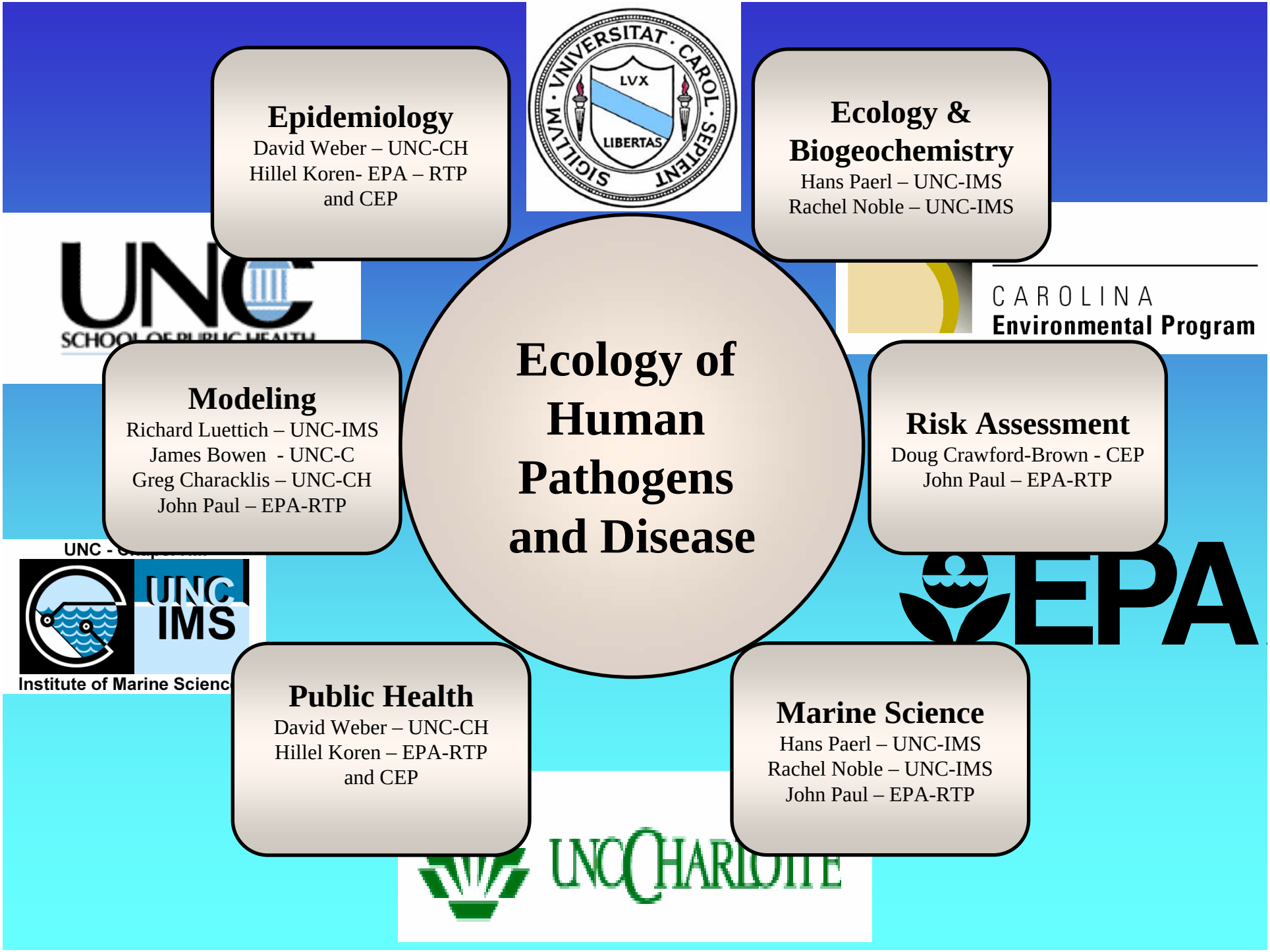
Epidemiology
David Weber – UNC-CH
Hillel Koren- EPA – RTP
and CEP
Ecology & Biogeochemistry
Hans Paerl – UNC-IMS
Rachel Noble – UNC-IMS
Ecology of Human Pathogens and Disease
Modeling
Richard Luettich – UNC-IMS
James Bowen - UNC-C
Greg Characklis – UNC-CH
John Paul – EPA-RTP
Risk Assessment
Doug Crawford-Brown - CEP
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Public Health
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John Paul – EPA-RTP
UNC
SCHOOL OF PUBLIC HEALTH
CAROLINA
Environmental Program
UNC IMS
Institute of Marine Scienc
EPA
UNC CHARLOTTE

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)

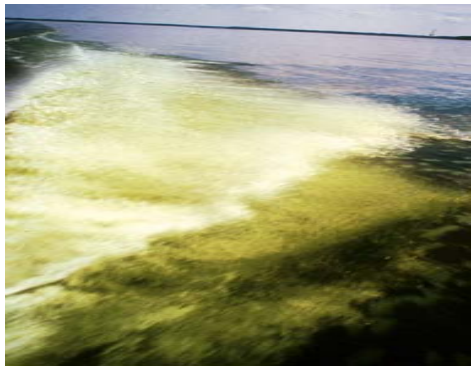
- Apply microbial diagnostic (molecular/biochemical) indicators to determine water quality, ecosystem condition, health and safety for consumers (HABS, pathogens)
- Microbial indicators should be useful for mechanistic probabilistic models
- Deploy Indicators in Monitoring Programs and on Platforms
- 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**

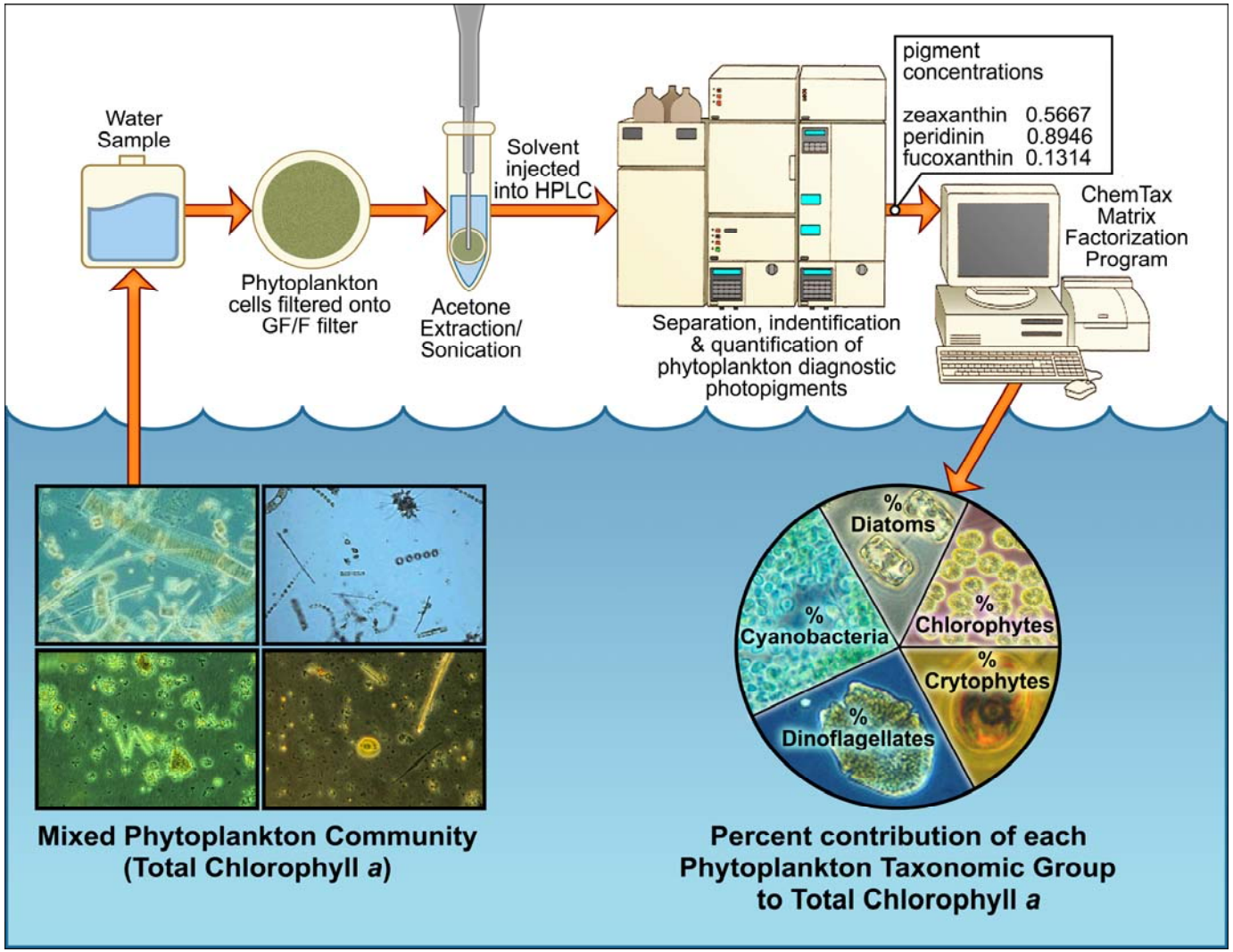
(lakes, reservoirs, streams, rivers)

- **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