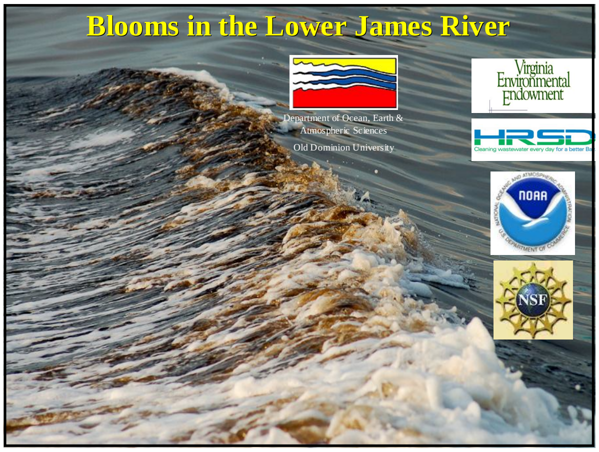
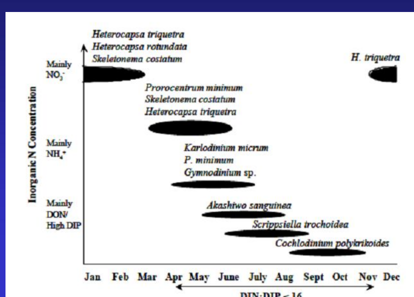


Lower James River

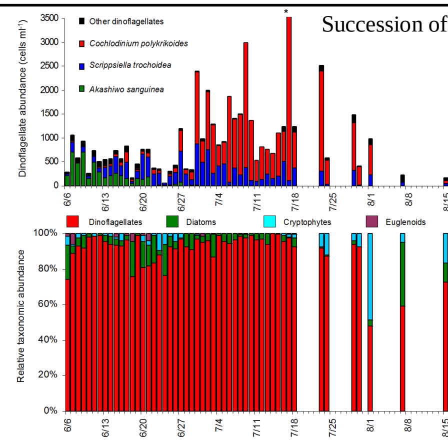
- Over the last 20 years, bloom forming dinoflagellates have become increasingly abundant in the tidal rivers of lower Chesapeake Bay.[2]
- Linked with eutrophication and anthropogenic perturbations
- Specific species occur with regular seasonality
- Nutrients and physical parameters vary on timescales ranging from minutes to years.
- Targeted bloom sampling only occurs after bloom has already formed, therefore we can only speculate about cause of bloom

2. Burchardt and Marshall 2004.

Bloom Seasonality



Succession of blooms



Bloom formation vs. maintenance: local conditions and transport at tidal time scales

INITIATION

Growth vs. loss balance

- Nutrients
- Light
- Mixing
- Grazing
- Microbial interactions
- Viruses

MAINTENANCE & PROLIFERATION

Transport

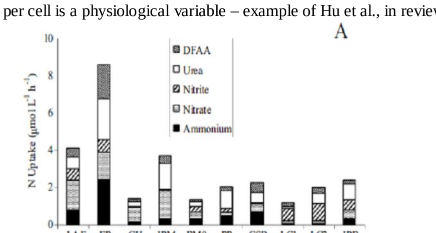
- Tidal advection
- Wind driven
- River flow

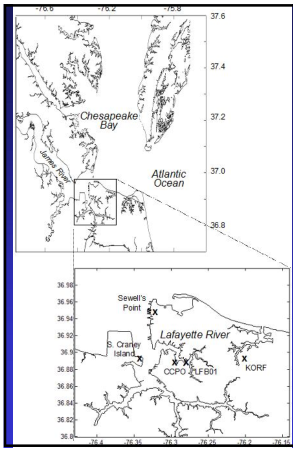
Biomass may accumulate in unproductive areas

The organisms are weird: Mixotrophy

Cochlodinium and everything else we've looked at utilizes a wide variety of N compounds, thus no single N species can be linked to bloom formation (Mulholland et al., 2009)

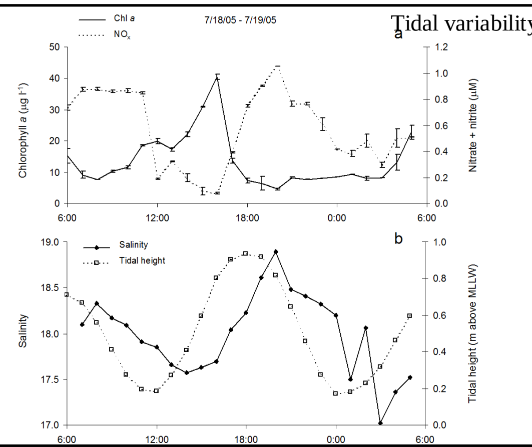
Chl a per cell is a physiological variable – example of Hu et al., in review





Timescales of sampling – different information

- Hourly sampling - tidal
- Daily sampling, tidally coordinated
- Weekly sampling
- Monthly sampling



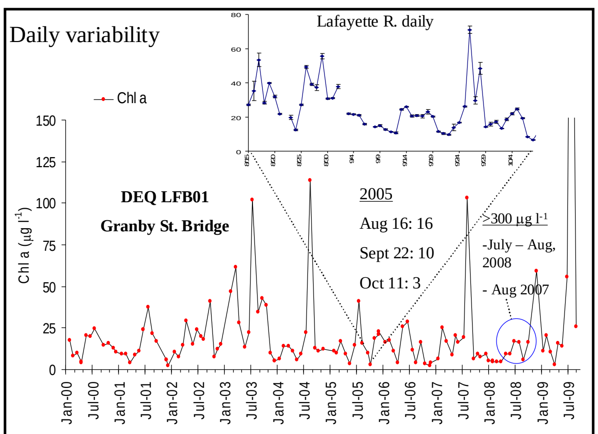
Chl *a* varies depending on the time of day

Date	Species	Chl a µg l⁻¹	cell count cells ml⁻¹	time (hr)	chl/cell µg cell⁻¹ (x 10⁻⁶)
4/19/2002	*Prorocentrum minimum*	2.69	12,000		0.22
4/3/2003	*Prorocentrum minimum*	17.77	40,000		0.44
4/30/2003	*Prorocentrum minimum*	23.47	11,880	1200	1.98
4/30/2003	*Prorocentrum minimum*	191.89	238,000	1600	0.81
4/30/2003	*Prorocentrum minimum*	11.51	7,100	2000	1.62
4/30/2003	*Prorocentrum minimum*	4.77	682	2400	7.00
5/1/2003	*Prorocentrum minimum*	24.47	9,240	0400	2.65
5/1/2003	*Prorocentrum minimum*	16.10	5,400	0800	2.98
5/6/2003	*Prorocentrum minimum*	9.76	25,000	1200	0.39
5/6/2003	*Prorocentrum minimum*	3.37	858	2400	3.92
5/8/2003	*Prorocentrum minimum*	1.87	25,000		0.07
6/17/2003	*Akashiwo sanguinea*	74.83	5,560	1200	13.50
6/17/2003	*Akashiwo sanguinea*	21.32	1,044	2400	20.40
6/19/2003	*Akashiwo sanguinea*	24.8	976	1200	25.40
6/19/2003	*Akashiwo sanguinea*	221.33	6,206	2400	35.70
5/13/2002	*Akashiwo sanguinea*	27.01	8,900		3.04
5/15/2002	*Akashiwo sanguinea*	29.20	10,000		2.92
5/16/2002	*A. sanguinea, Skeletonema costatum*	16.08	7,800		2.06
9/25/2002	*Cochlodinium sp.*	17.85	10,000		1.78
2/5/2003	*Heterocapsa triquetra*	17.81	2,000		8.90

Table 2. Ambient nutrient concentrations and cell abundance over a diel cycle spanning from April 30-May 1, 2003 during a *P. minimum* bloom (> 99% of all species present).

Time	Temp °C	NH_4^+ (µM)	NO_3^- (µM)	Urea (µM)	DFAA (µM)	Chl *a* (µg l⁻¹)	Cells (cells ml⁻¹)
1100	19	0.77 (0.11)	0.88 (0.17)	0.24 (0.03)	0.16 (0.01)	23.5	11,880
1600	22	0.50 (0.29)	0.65 (0.16)	0.32 (0.02)	0.23 (0.02)	192	238,000
2000	20	0.62	0.93 (0.17)	0.79 (0.02)	0.14 (0.01)	11.5	7,100
2400	19.8	1.52 (0.35)	0.66 (0.04)	0.56 (0.01)	0.24 (0.01)	4.8	682
400	19.8	1.07 (0.43)	0.04 (0.02)	0.70 (0.04)	0.34 (0.03)	24.5	9,240
800	19	1.05 (0.37)	0.12 (0.02)	0.96 (0.14)	0.37 (0.01)	16.1	5,400

- N concentrations highly variable on diel timescales
- Cell concentrations highly variable on diel timescales (behavior, advection?)

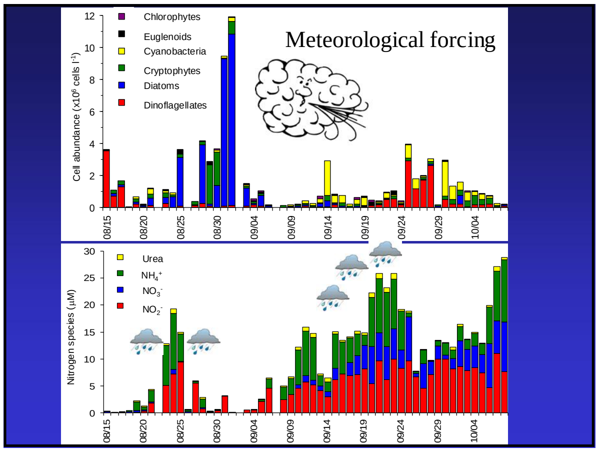


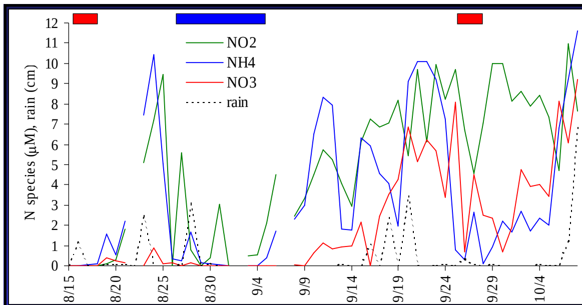
Proactive bloom sampling -

at relevant timescales for bloom initiation

Sample before, during, and after a bloom to better understand bloom initiation with respect to nutrient uptake dynamics and ambient nutrient concentrations on short timescales

To identify triggers and controls on bloom formation

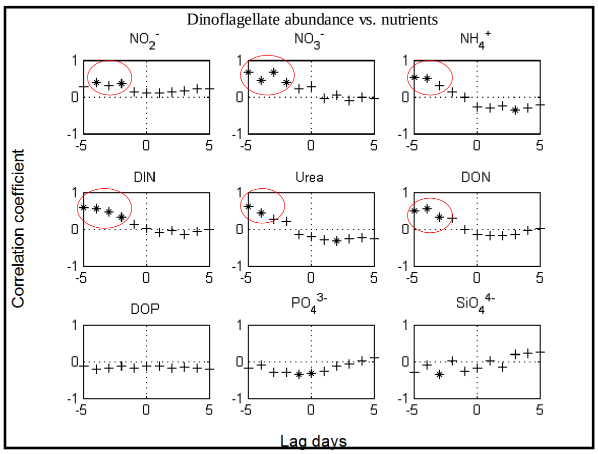




•Meteorological triggers

•Increases in nutrient concentrations followed rain events and period of high wind/low biomass

•Also benthic injection due to high winds

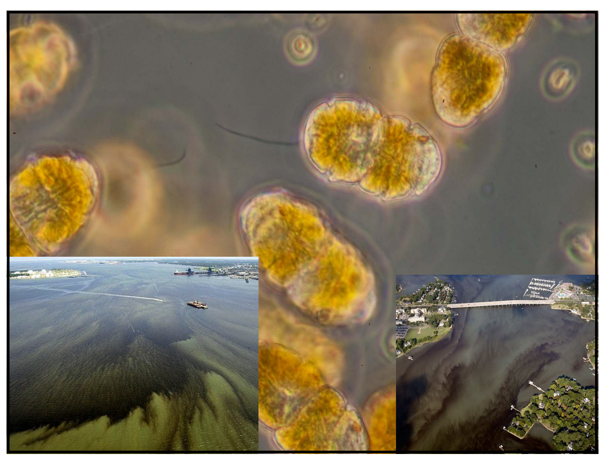


Observations from daily sampling

- 2-5 day lagged positive correlation between N and dinoflagellates suggests N affects bloom formation
- The form of N *was* unimportant for dinoflagellate bloom development; total N is important
- Dinoflagellate blooms linked to precipitation and neap tides, low wind speeds, & high nutrients
- Wind speed and direction may determine whether diatom or dinoflagellate bloom forms through their effects on stratification

Cochlodinium polykrikoides in Chesapeake Bay - transport

- Lower York River late 60's (Mackiernan, MS thesis, 1968) and 70's (Zubkoff and Warriner, 1975; Ho and Zubkoff, 1979)
- 1992 York R. bloom entered Chesapeake Bay and James River (Marshall, 1995)
- Extensive blooms in the James River and lower Chesapeake Bay in 2007 (Mulholland et al 2009), 2008 (Morse et al. 2011), and 2009 (Morse et al.2011)



Impacts

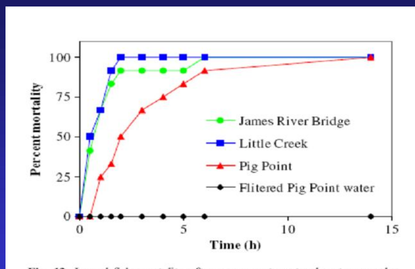
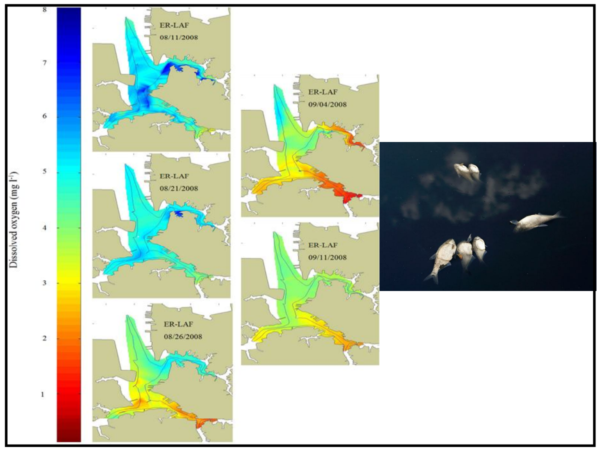
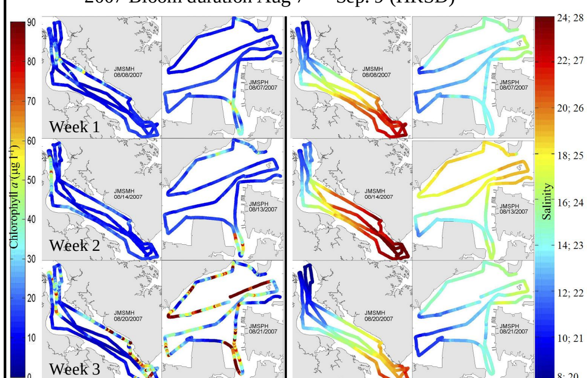


Fig. 12 Larval fish mortality after exposure to natural water samples collected from the lower Chesapeake Bay system containing bloom concentrations of *C. polykrikoides* on 6 Sept 2007

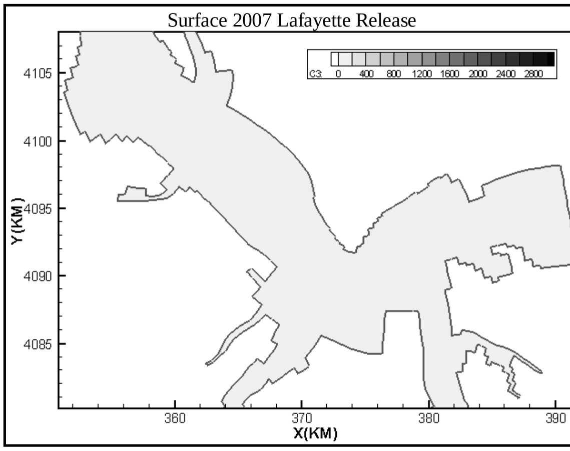
C. polykrikoides exerts negative effects on phytoplankton (Tang and Gobler (2010), copepods (Jiang et al. 2009), benthic grazers and fish (Gobler et al. 2008; Mulholland et al. 2009)

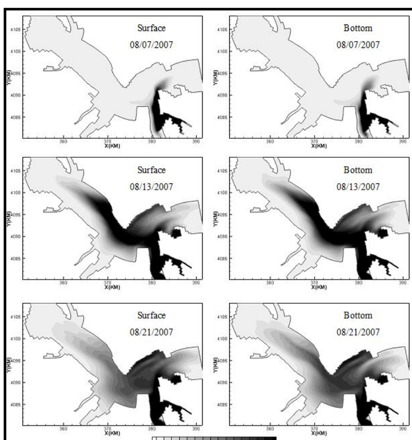


2007 Bloom duration Aug 7* – Sep. 9 (HRSD)



Surface 2007 Lafayette Release

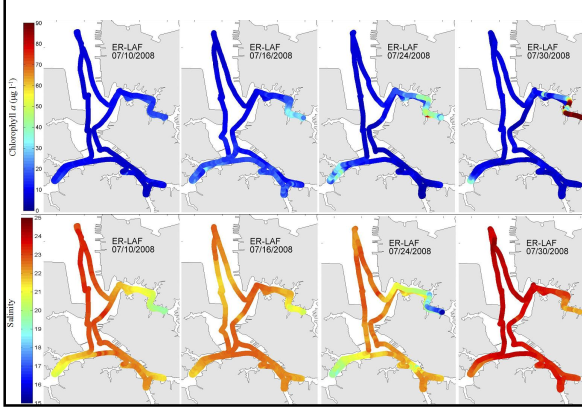




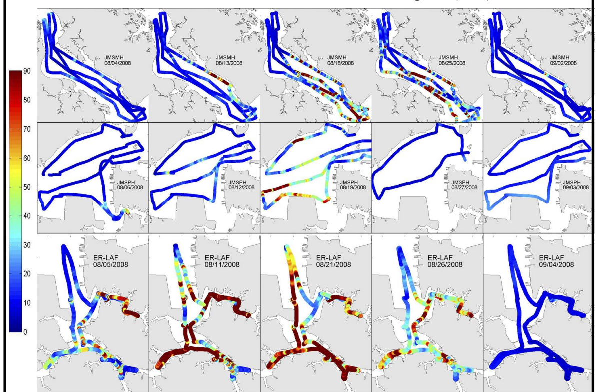
James River 2007 dynamic conditions

Dye released in LAF on 8/6 from 00:00 to 12:00

Bloom initiation in the Lafayette River during 2008

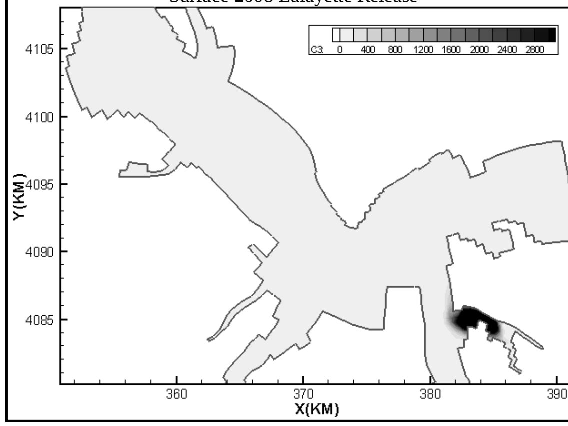


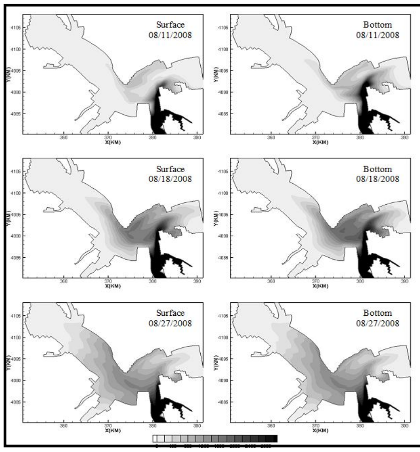
2008 Bloom duration Jul 24 – Aug 26 (Chl)



Week 2 Week 3 Week 4 Week 5 Week 6

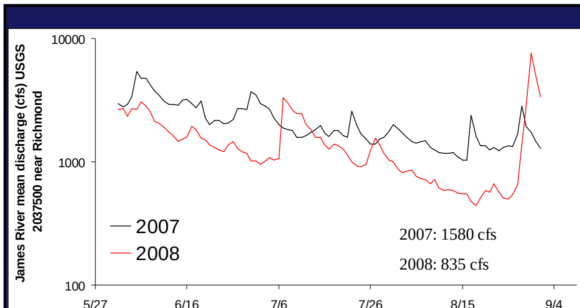
Surface 2008 Lafayette Release



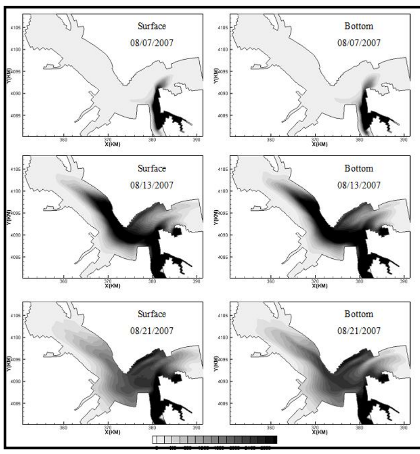


James River 2008 dynamic conditions

Dye released in LAF on 8/3 from 00:00 to 12:00

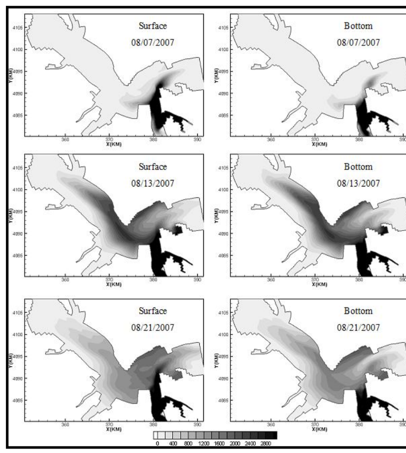


James River flow affects intensity of eddy circulation at HF and stratification at Newport News Point (Shen et al. 999)



James River 2007 dynamic conditions

Dye released in LAF on 8/6 from 00:00 to 12:00

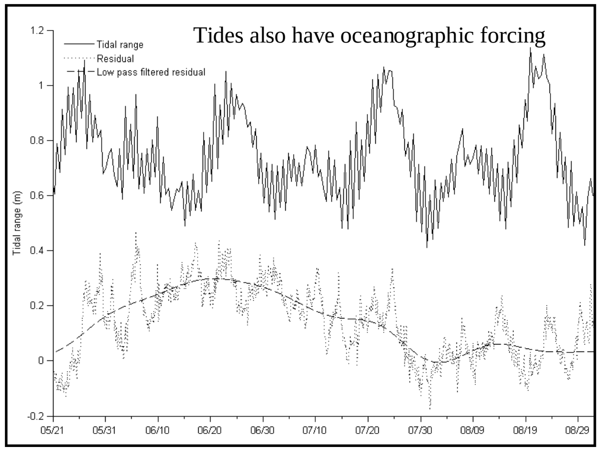


James River 2007 low flow conditions

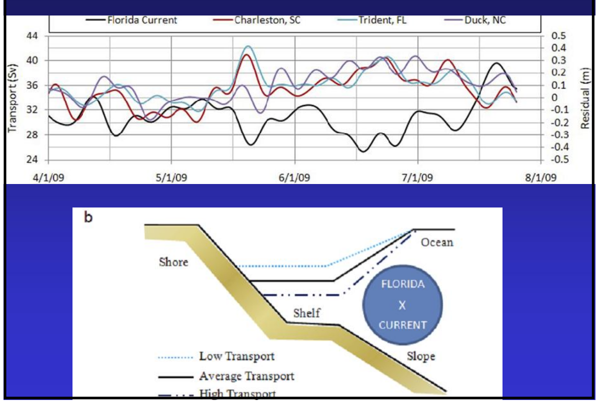
Reduced overall transport, but extent of transport is similar

Meteorological forcing

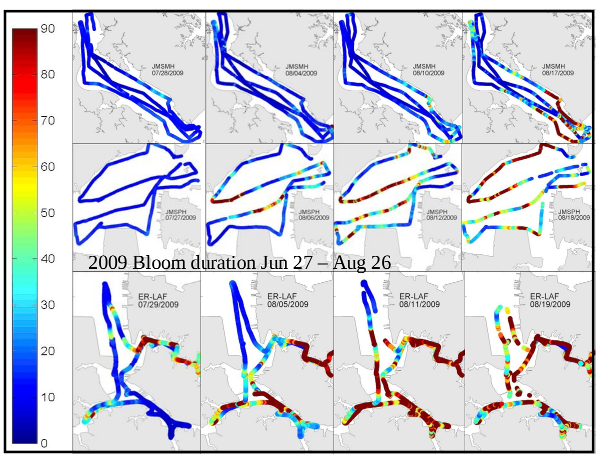
- Blooms initiate in Lafayette River
- Localized sites of initiation and growth of the mesohaline portion of the James River in 2008
- Bloom initiation coincided with intense, highly localized rainfall events prior to/during neap tides
- Blooms dissipated in response to increased wind-driven mixing, ~ 30 days after entering James R.
- Local conditions in the Bay control *amount* of transport in James River, but *extent* of bloom controlled by circulation
- Seasonal rainfall patterns, increased stratification, nutrient loading, spring-neap tidal modulation, and complex estuarine mixing and circulation control blooms



Sweet et al. 2009 NOAA Technical Report NOS CO-OPS 051



Virginian Pilot photo 2009



Findings

- The Lafayette River appears to be the initiation grounds for blooms
- Prolonged drought, N-loading and runoff from summer storms, and decreased tidal straining during neap tides leads to bloom formation (stratification + nutrients = bloom)
- Other meteorological and oceanographic forcing as well!
- No single N compound can be implicated in triggering blooms
- James River circulation is important and controls the distribution and duration of the bloom in the lower Chesapeake Bay region

Summary

- Meteorological forcing – stratification, mixing and benthic nutrient injection, rain
- Transport – initiation or accumulation sites? Mapping is a good tool
- Timescales of variability – monitoring vs. blooms
- Biology and ecology – diverse, chl relationships, nutrients

Other problems for managing HABs

- Monitoring programs aren't sampling HABs
- Monitoring programs are unlikely to sample HABs and ad hoc sampling is biases
- Spatial and temporal variability of HABs different from that of monitoring programs

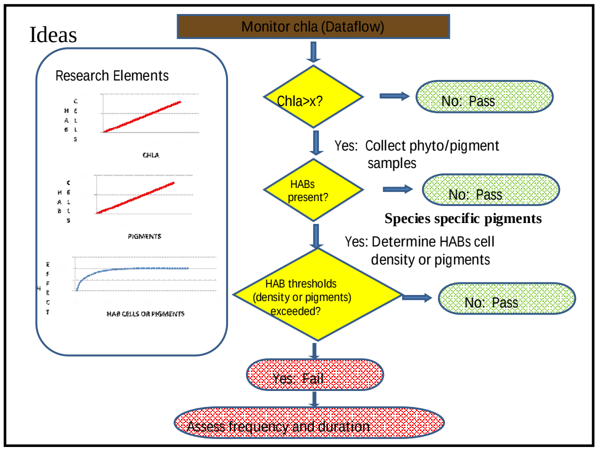
So far

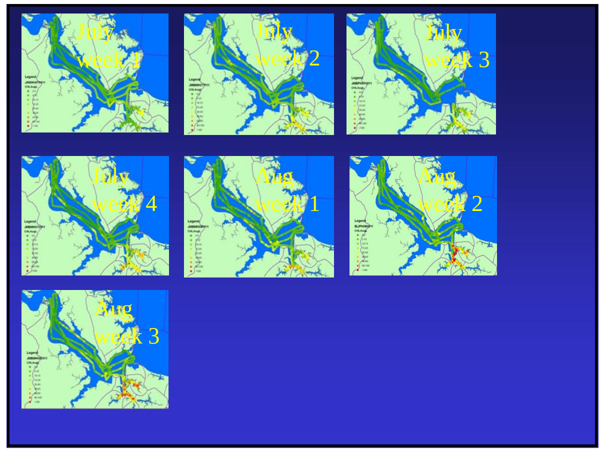
- No good relationship between Chl *a* and abundance and harmful effects
- Chl *a* per cell varies with cell size (species)
- Many species are known mixotrophs. Does Chl *a* per cell vary with respect to C nutrition?

  (preliminary experiments for one HAB suggest the answer is "yes" – Hu et al. in review)

HAB species

- Vary taxonomically
- Vary in chl *a* content
- Shifts
  - By season (T)
  - By locale (S‰)
  - By species
- Sampling design for monitoring programs – detection is statistically improbable


Ideas
Monitor chla (Dataflow)
Research Elements
CHLA
PIGMENTS
HAB CELLS OR PIGMENTS
Chla>x?
No: Pass
Yes: Collect phyto/pigment samples
HABs present?
No: Pass
Species specific pigments
Yes: Determine HABs cell density or pigments
HAB thresholds (density or pigments) exceeded?
No: Pass
Yes: Fail
Assess frequency and duration


July week 1
July week 2
July week 3
July week 4
Aug week 1
Aug week 2
Aug week 3