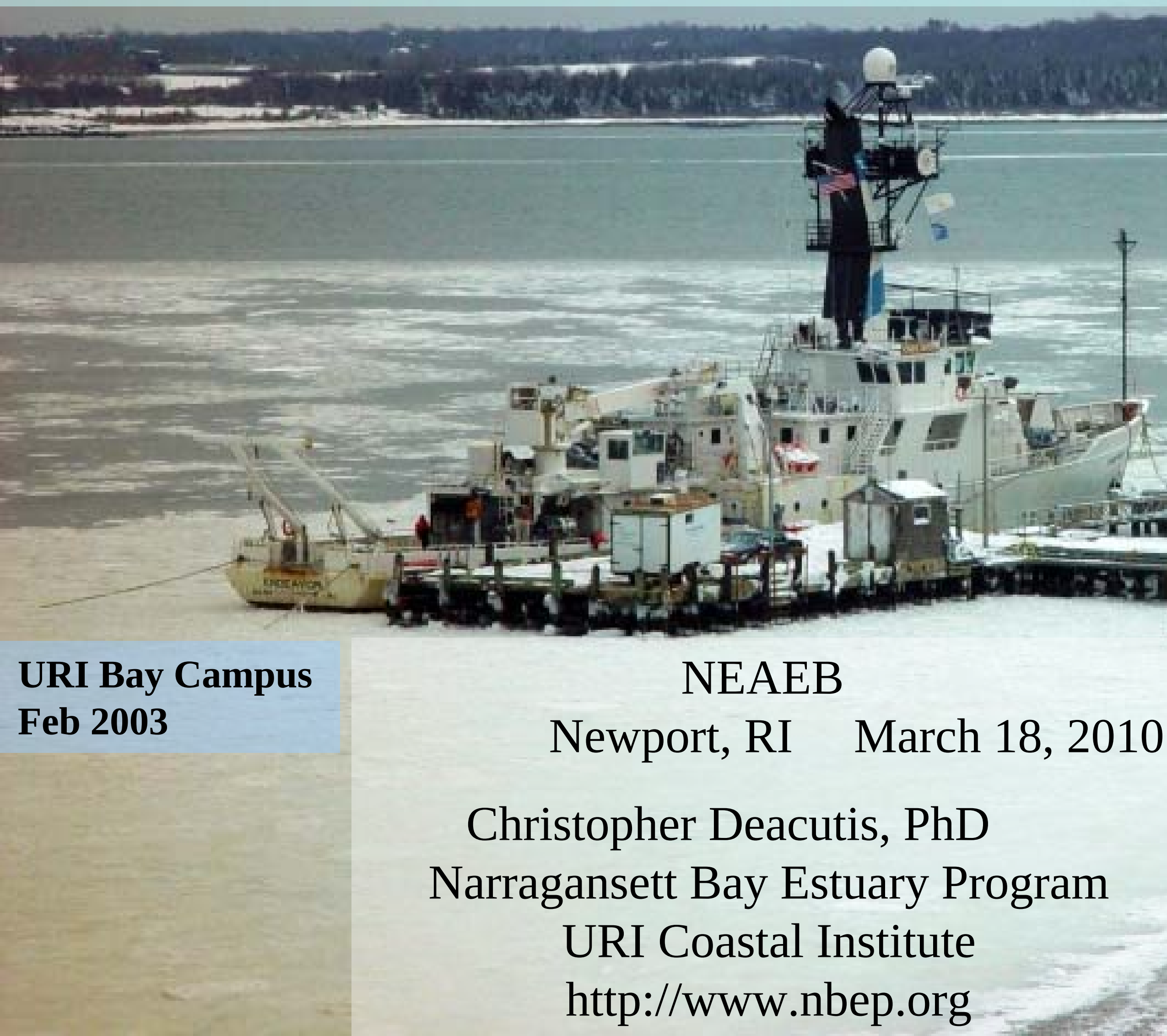
A Changing World : A Changing Bay?

Water Quality Conditions in Narragansett Bay and Potential Climate-Driven Concerns

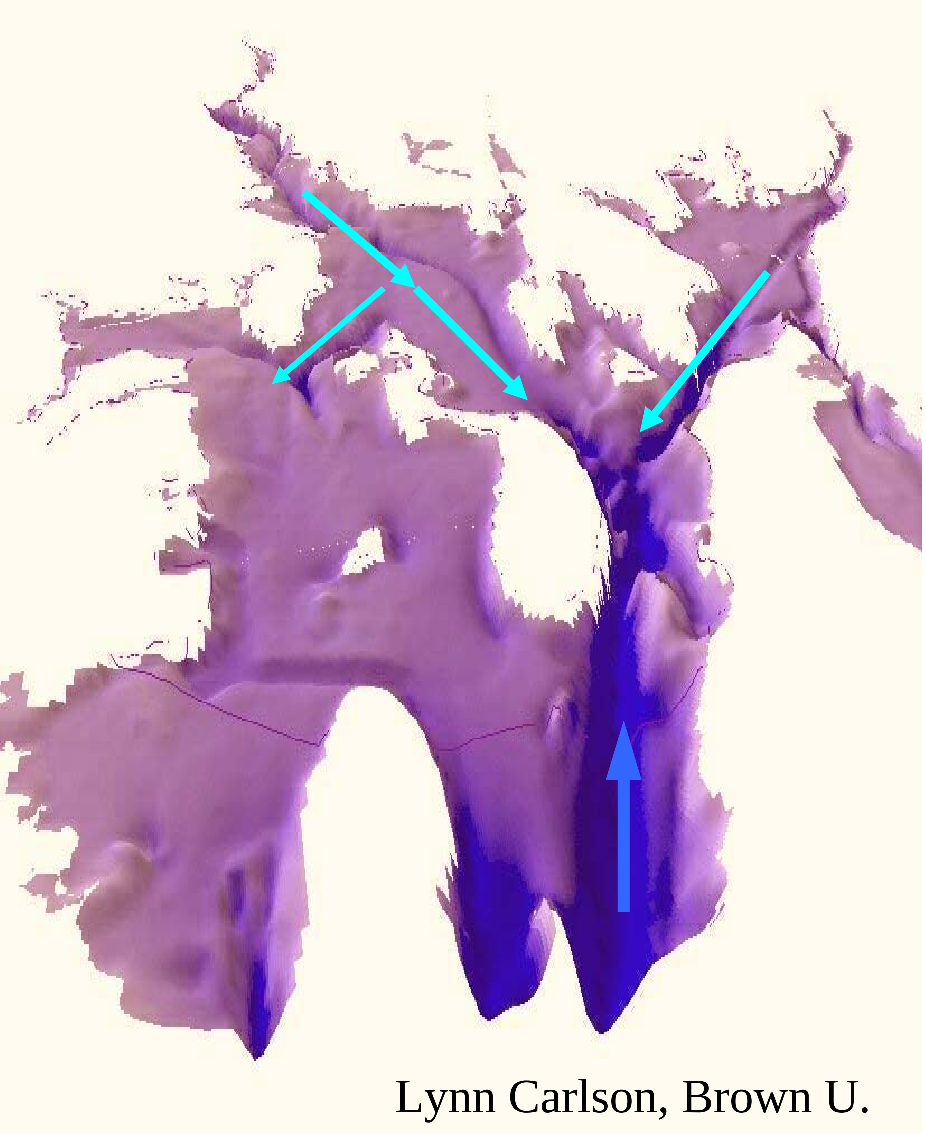
Greenwich Bay
August 20, 2003



URI Bay Campus
Feb 2003

NEAEB
Newport, RI March 18, 2010

Christopher Deacutis, PhD
Narragansett Bay Estuary Program
URI Coastal Institute
http://www.nbep.org

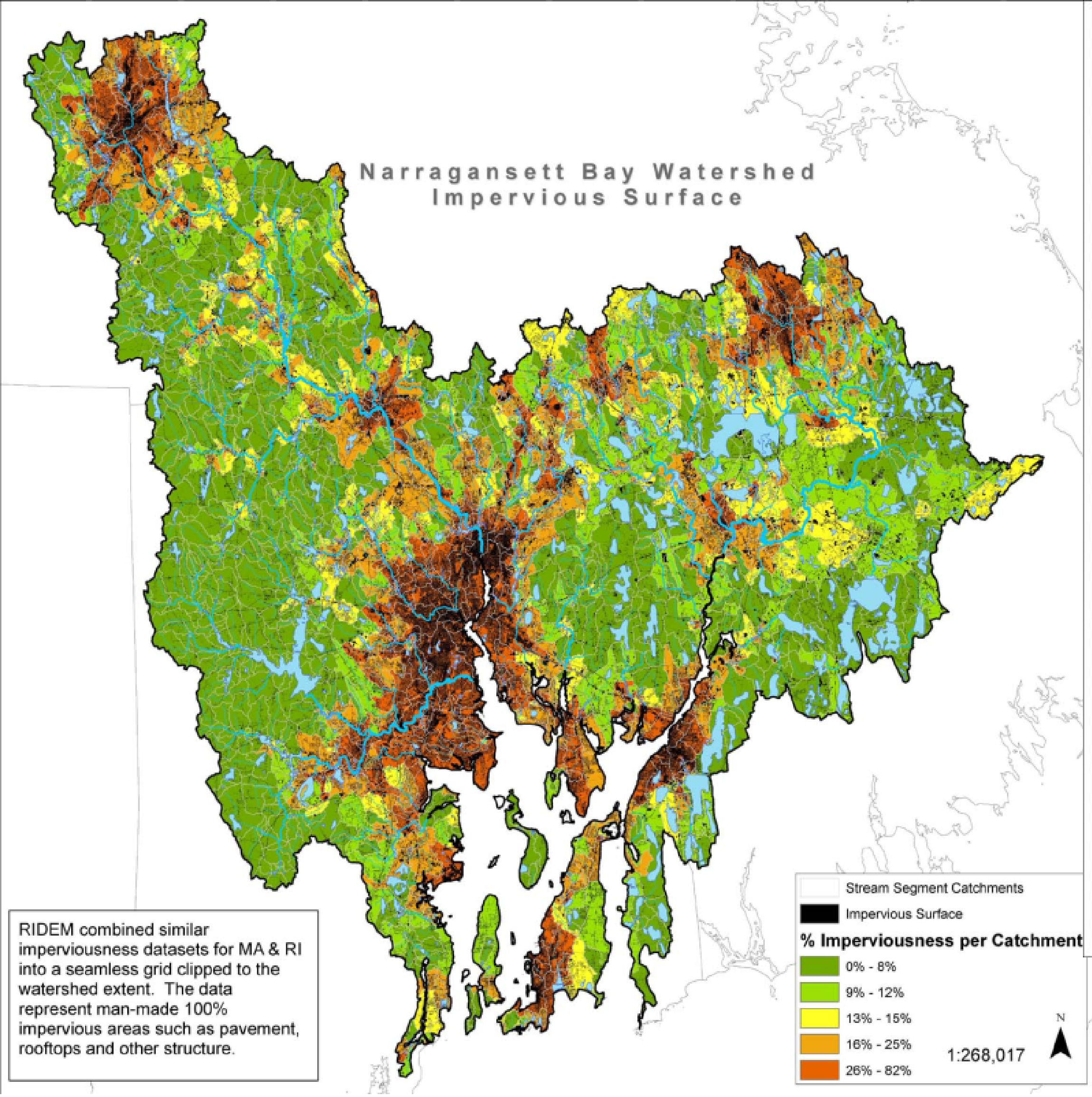


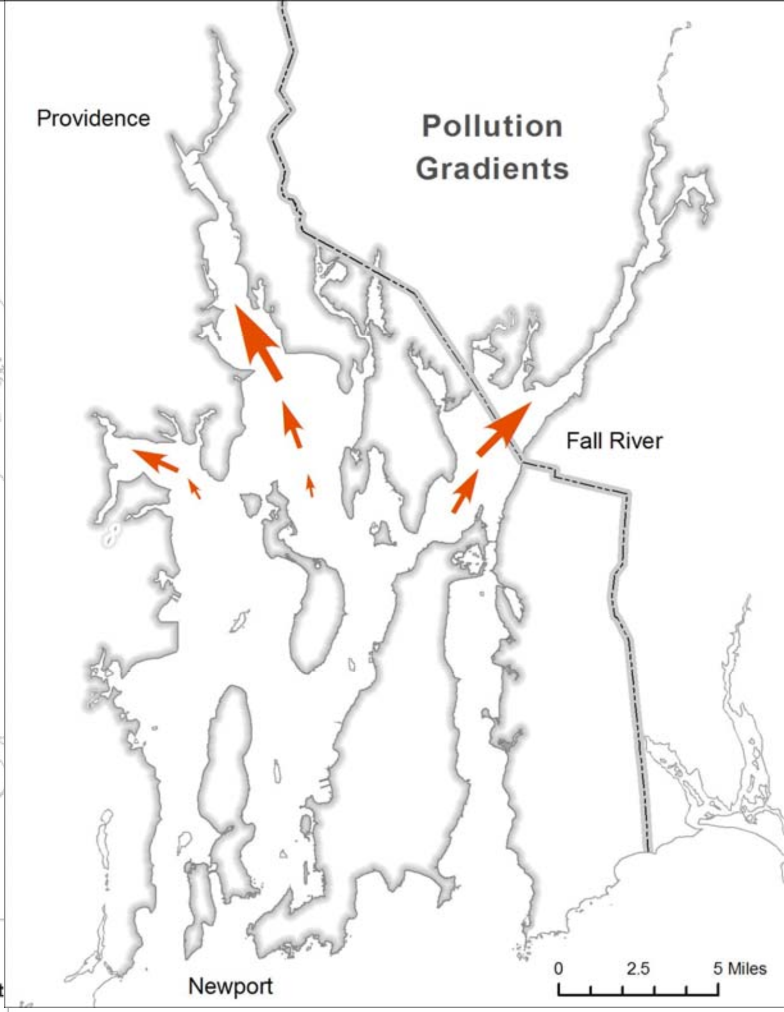
Lynn Carlson, Brown U. GIS lab

104 m3/sec

61% of drainage basin in MA

N-S Pollution Gradient STP





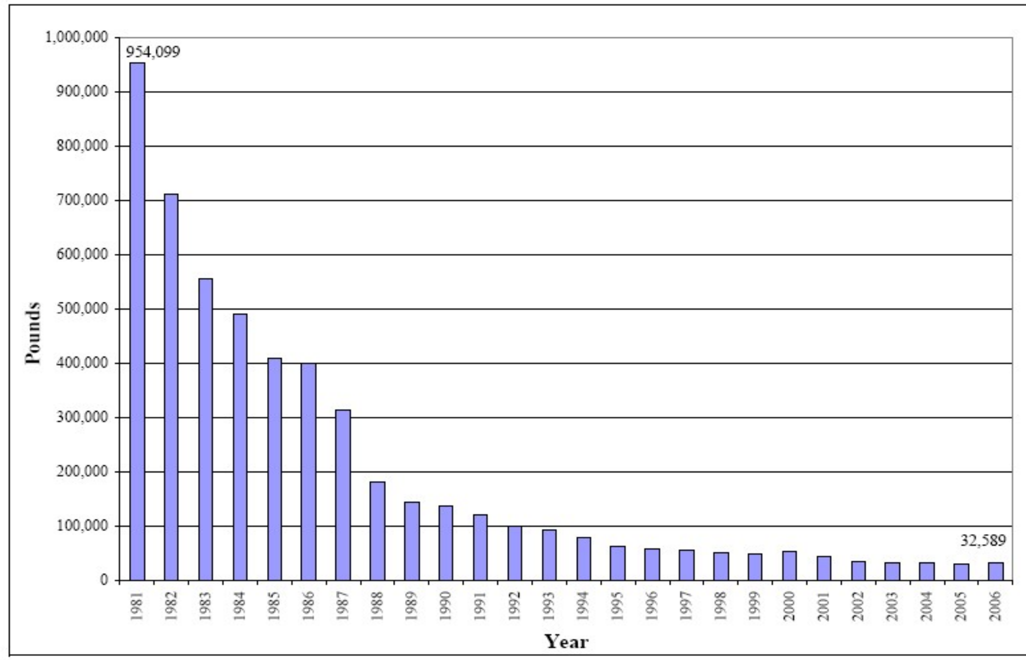
N-S Pollution Gradients

map source: P Jordan, RIDEM

The “old days” - 1980’s
- Jewelry Plating Factory
West Warwick RI - owner fined
for discharging heavy metals
speaks his mind

Toxics from Point sources in 21st century ? Good News ! Success thanks to pretreatment…& economy

FIGURE 11
Field’s Point Total Metals Influent Loading Trend Analysis



Decreases in metal loadings from Fields Point Wastewater Treatment Facility, 1981 – 2006. From 2006 Annual Pretreatment Report, NBC.

Next Decade: Greater toxics load from stormwater ?
- Expect incr. runoff volumes + flashiness - need deal with *old* stormdrains + Hg incr. if we burn more coal

FROM: Oviatt, C., A. Keller, & L. Reed. 2002. Annual Primary production in Narragansett Bay with no Bay-Wide Winter-Spring Phytoplankton Bloom. Estuarine, Coastal and Shelf Science 54(6): 1013-1026.

Up-Bay gradient: nutrients + Chl *a* & bacterial productivity

- Max nutrients & Chl *a* *in* ***upper 1/3rd*** *of Bay*

April '97-'98

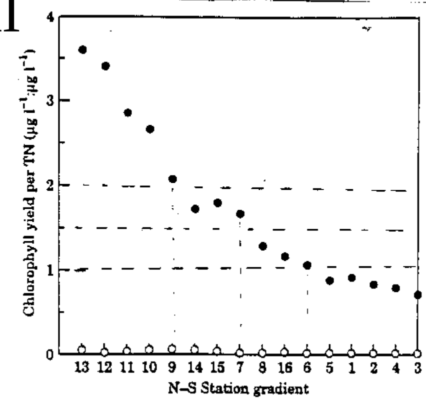


FIGURE 5. Mean chlorophyll, (µg l⁻¹) yield at each station normalized by mean total nitrogen concentration (TN), (µg l⁻¹) during winter and summer in a north - south gradient along the axis of Narragansett Bay. Actual station numbers noted on the x-axis. ○ Winter; ● Summer.

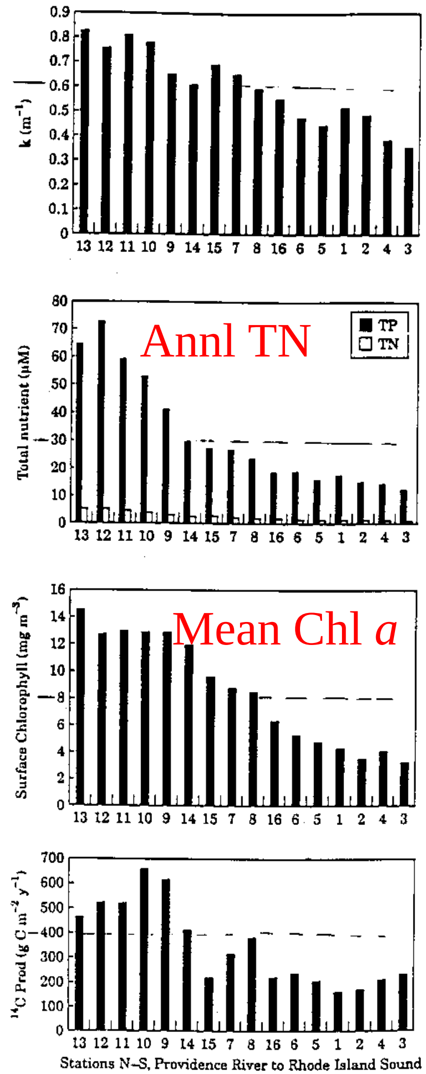


FIGURE 6. North to south gradient of bay survey stations for annual mean attenuation coefficients, (m⁻¹), average winter to summer total nutrients, µM, annual mean chlorophyll, (µg l⁻¹) and annual mean ¹⁴C productivity, (g C m⁻² y⁻¹).

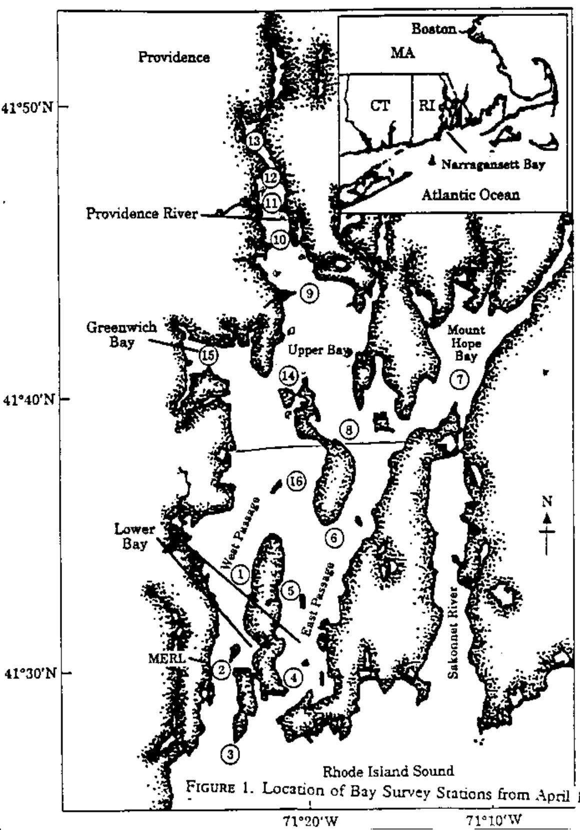
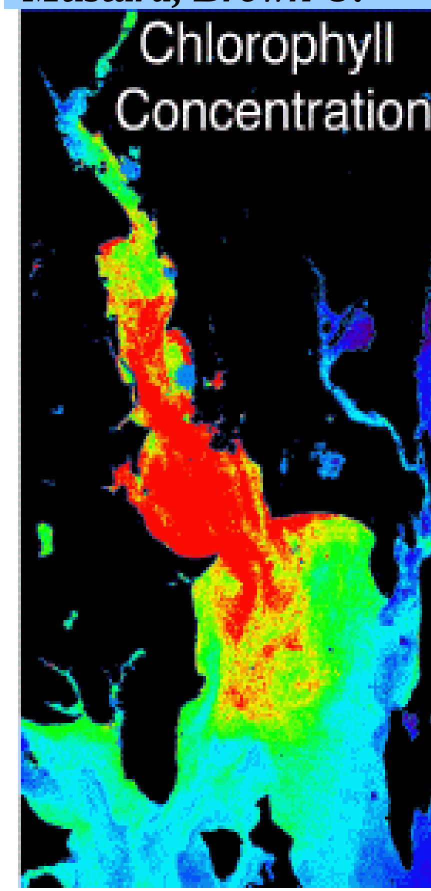
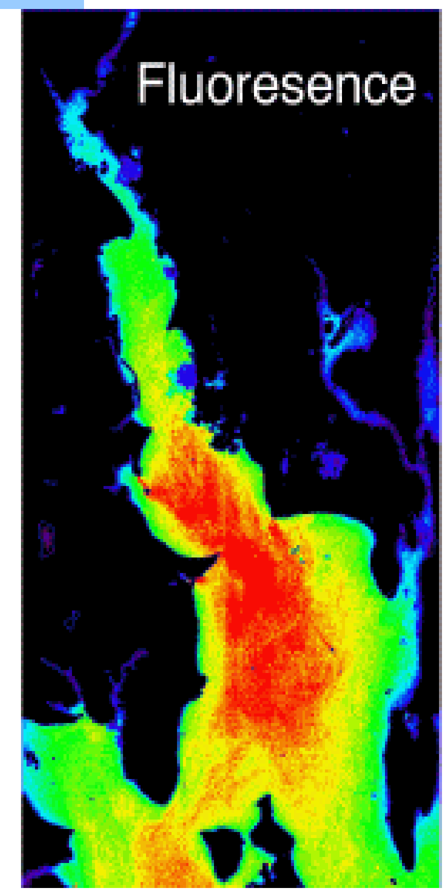


FIGURE 1. Location of Bay Survey Stations from April 1997 through April 1998. Water for ¹⁴C incubations was collected

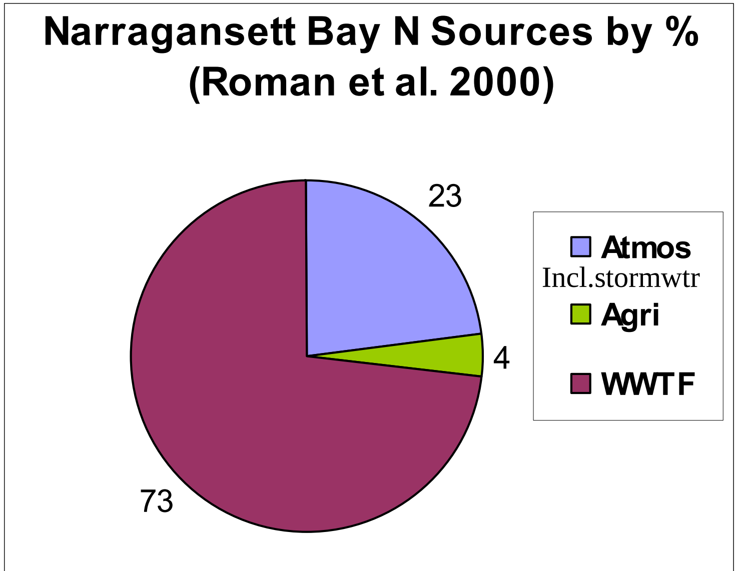
Estimate of Relative Concentrations of Chlorophyl Pigments - *Mustard, Brown U.*

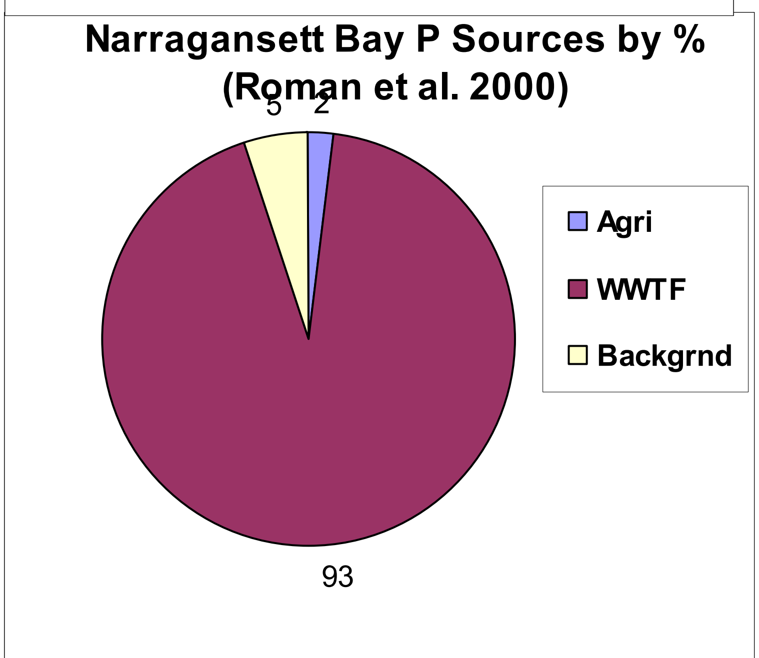


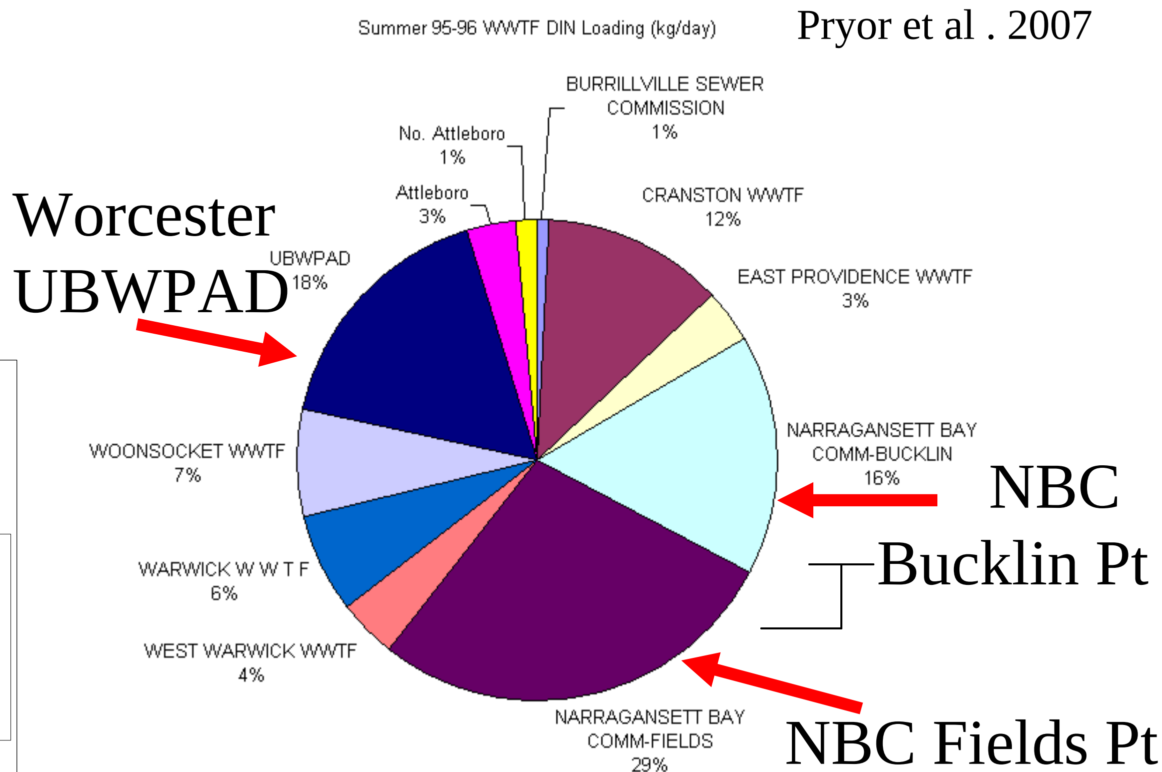


WasteWater Treatment Facilities

= 68-73% Tot. Diss.Inorg. Nitrogen (DIN) load to Narragansett Bay

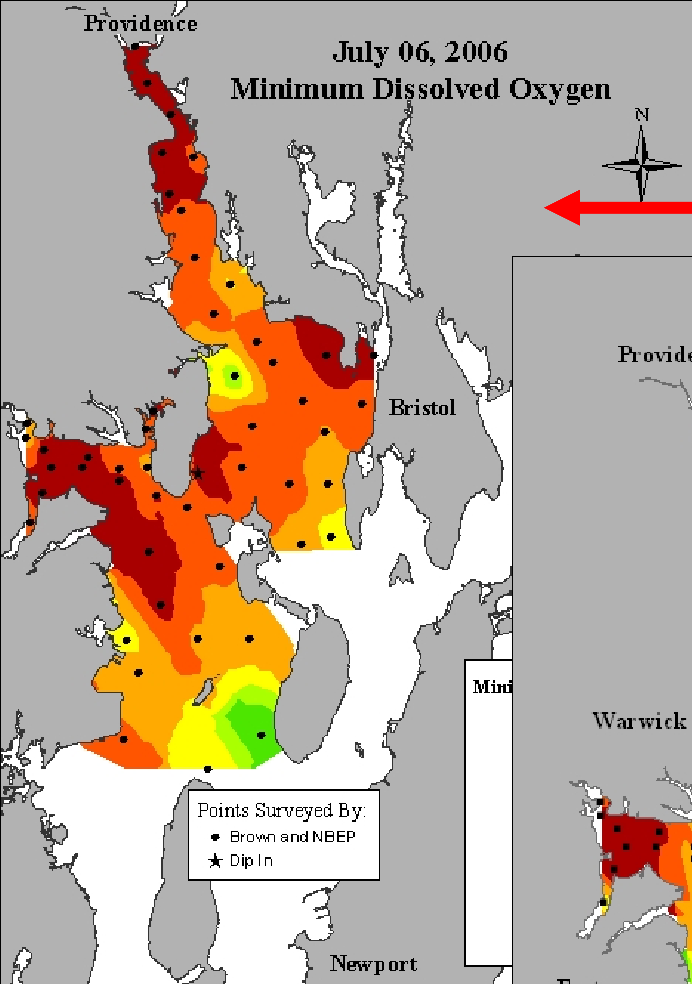




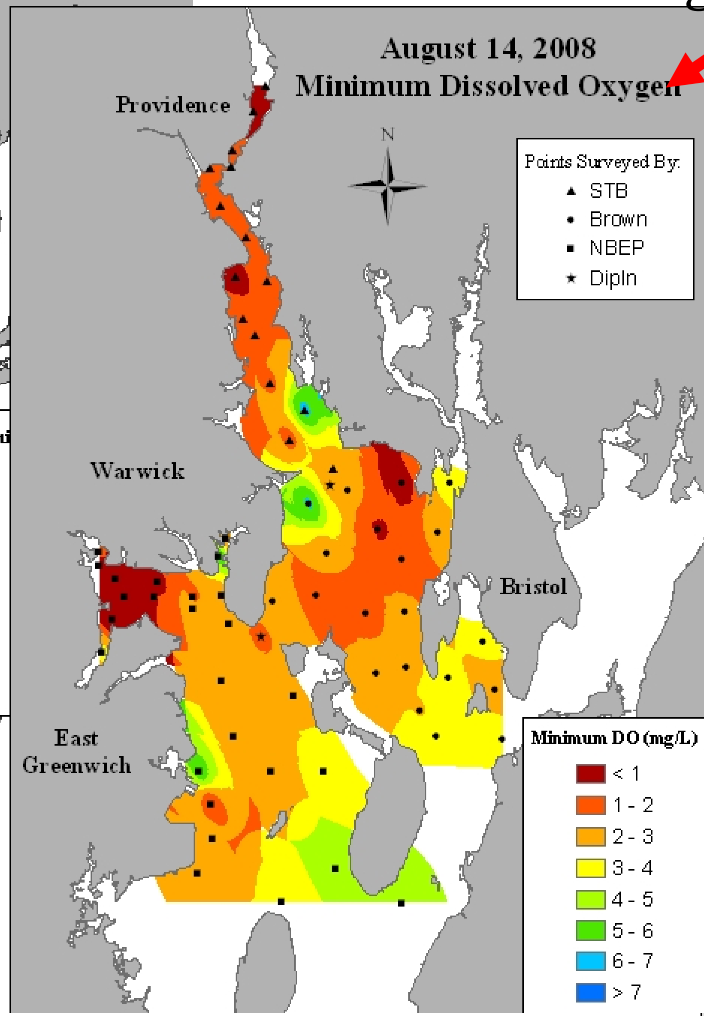


Blackstone River WWTFs =
2nd largest source N load after Direct Discharges to Providence-Seekonk R.

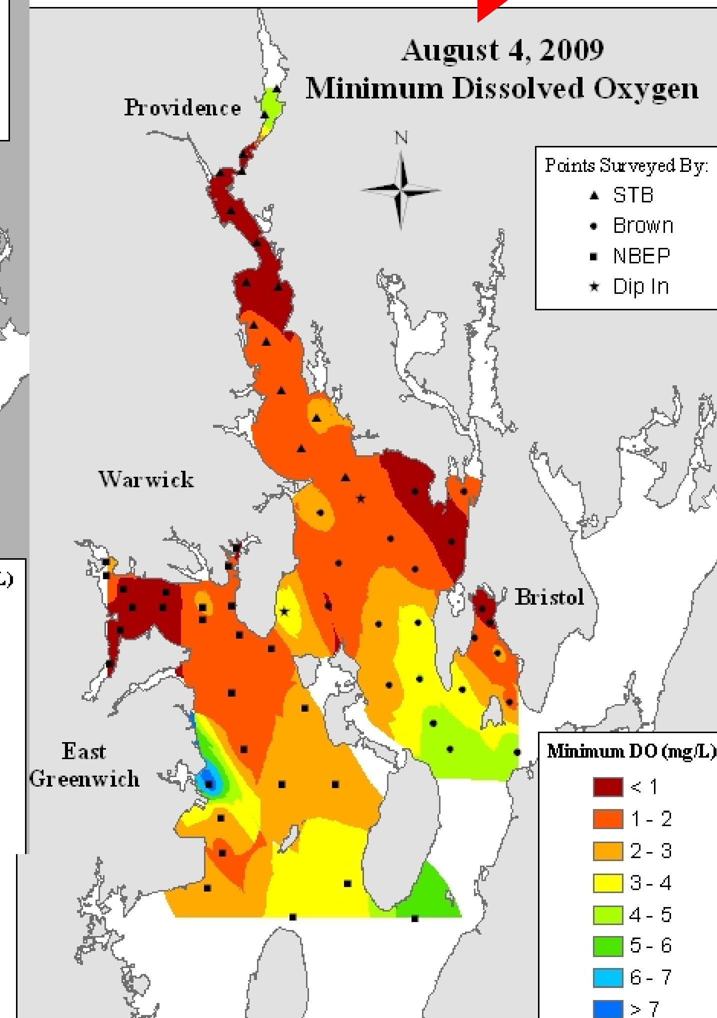
Any Evidence of Serious Problems from Excess Nutrients?



July 6, 2006



Aug 14, 2008

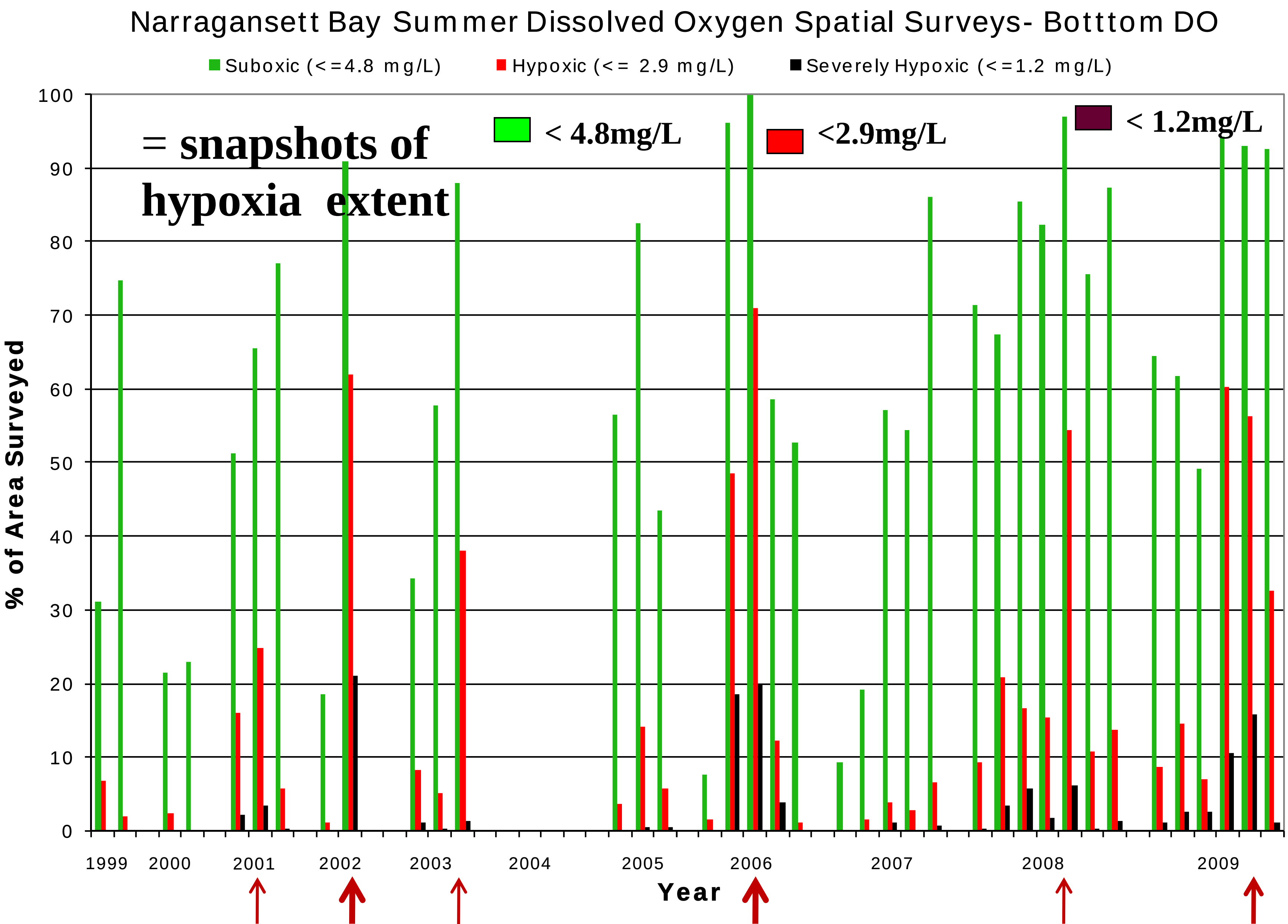


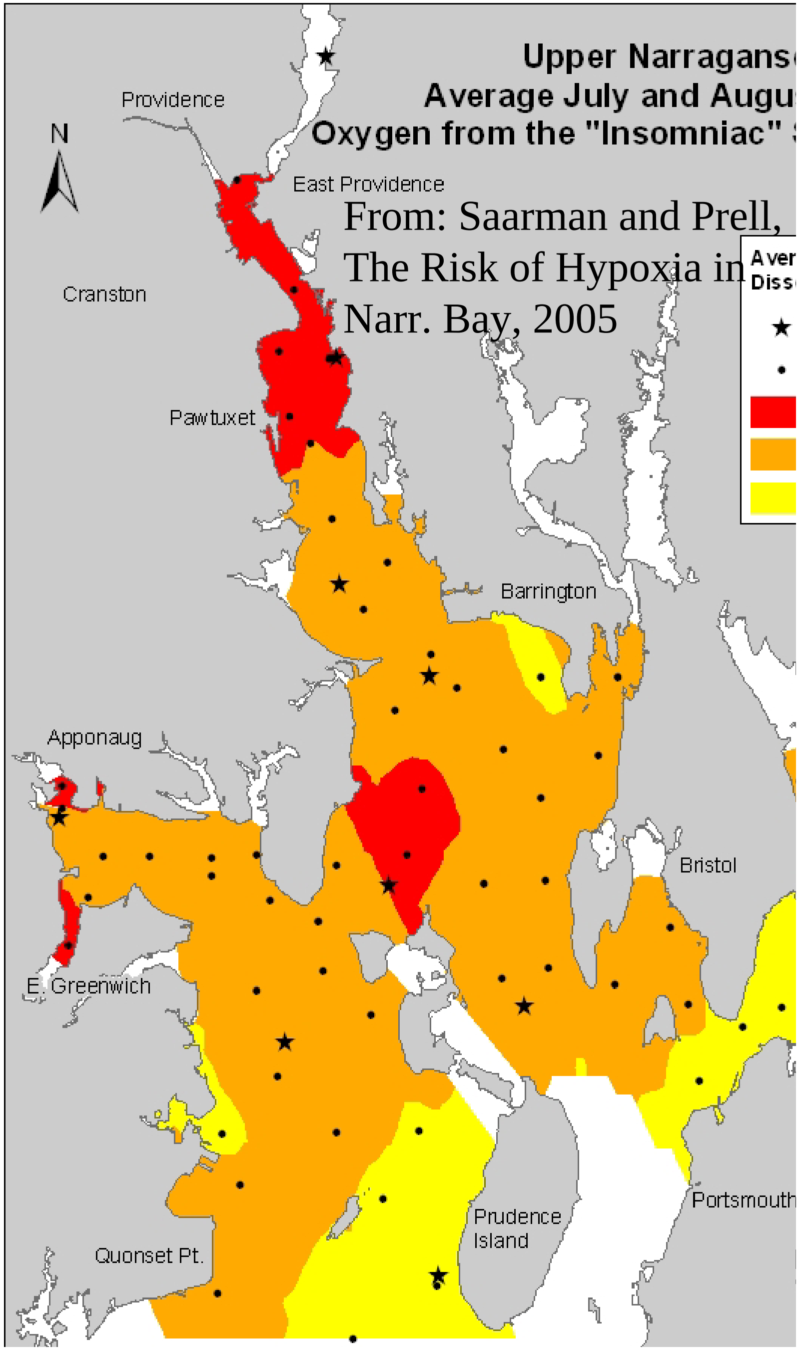
Aug 4, 2009

Upper half of Bay -

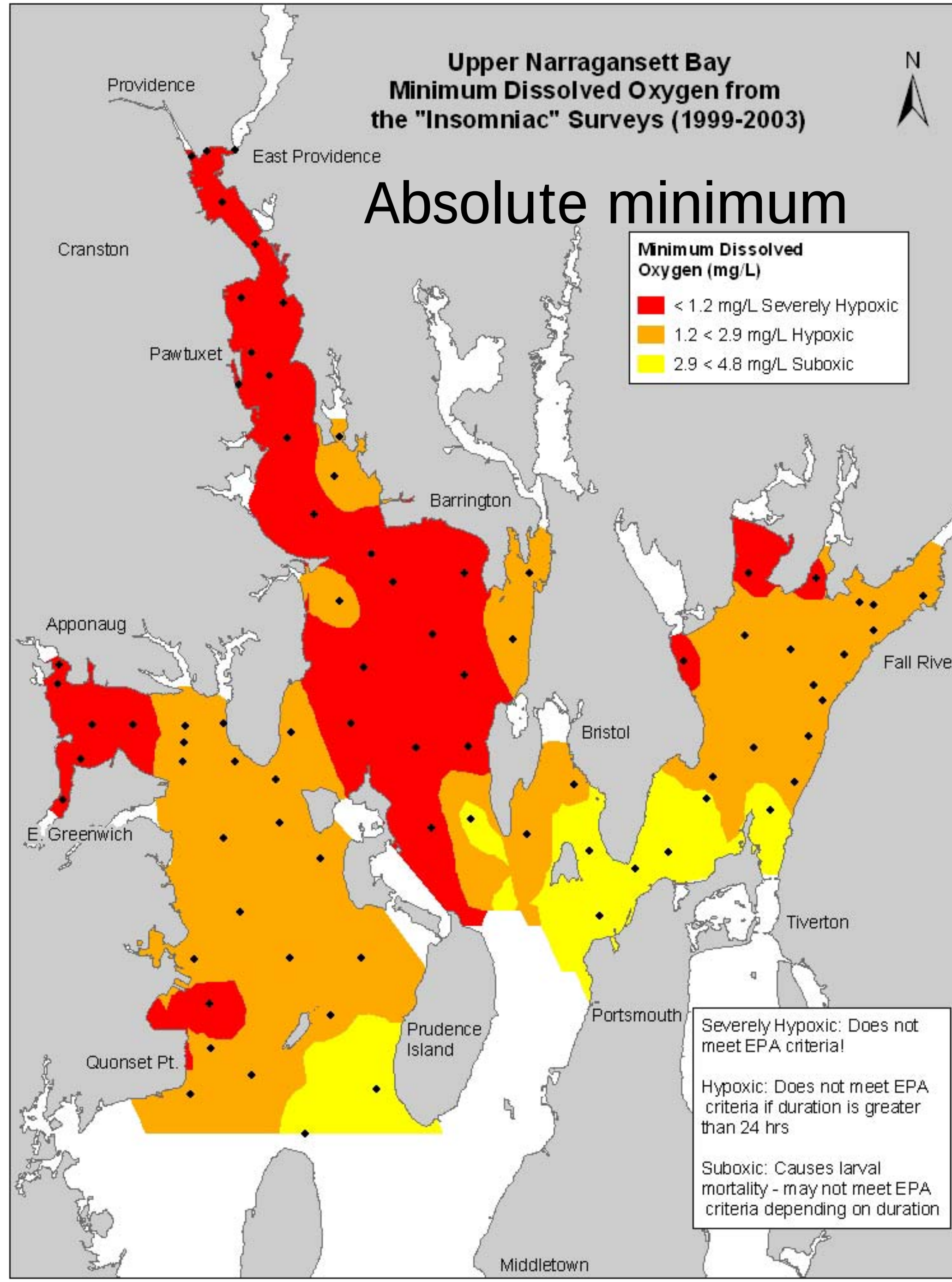
still **serious hypoxia stress summers** – ***not* just "a perfect storm"** **scenario**

% of Survey Area at various hypoxic levels each survey date 1999-2009 (Total area surveyed ~ 150 km^2) - Murray, unpub.





From: Saarman and Prell, The Risk of Hypoxia in Narr. Bay, 2005



Absolute minimum

Continued **Evidence of Problems of Eutrophication :**

- Sulfidic waters Greenwich Cove
  August 18 2009

Fish kill Chepiwanoxet Greenwich Bay August 1,2009

Piscivore Feast

Juv. Winter Flounder

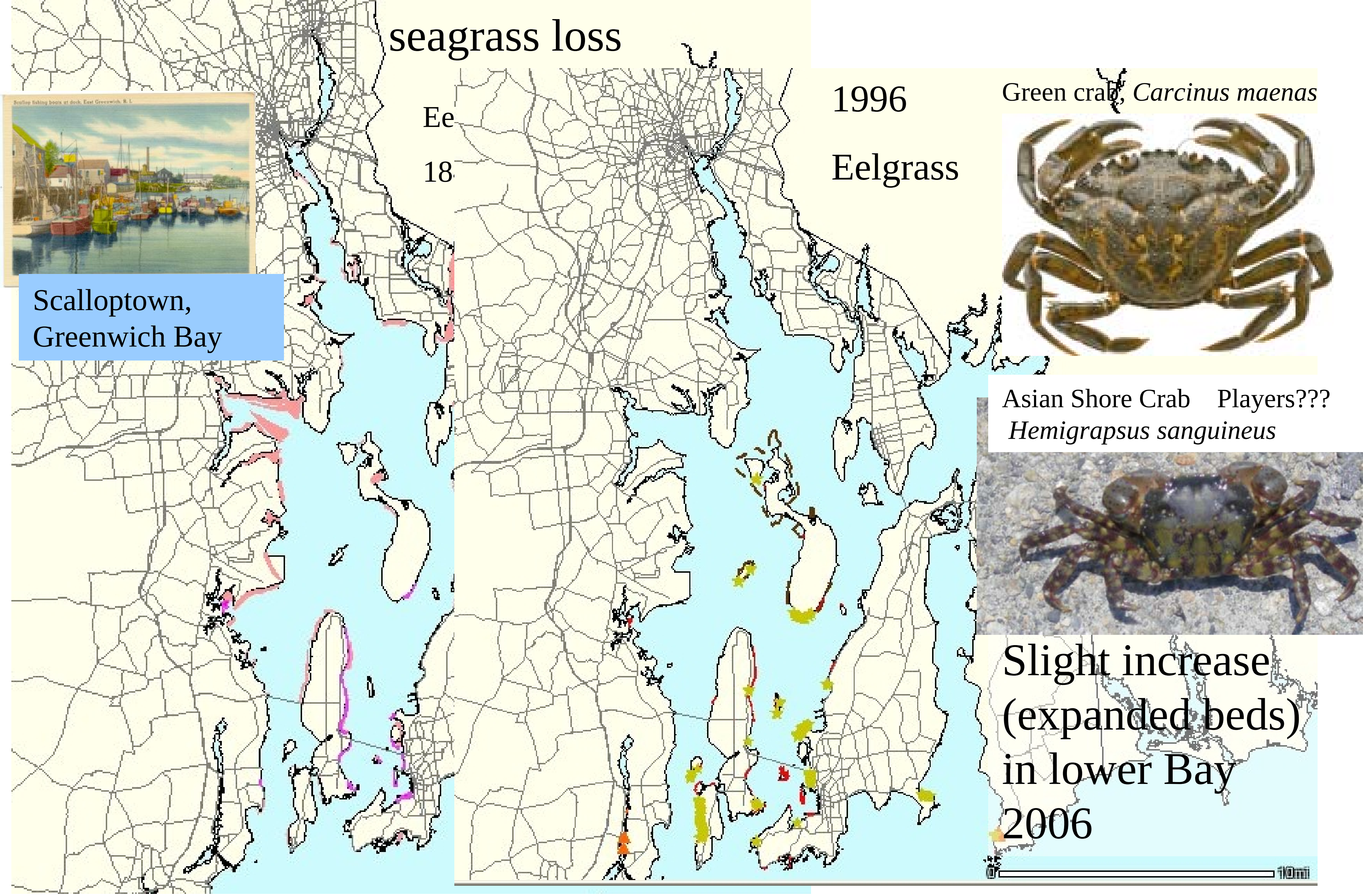
Kill 8-1-09

Occupessatuxet - Greene Is.
2006

Large Drift Macroalgae Biomass

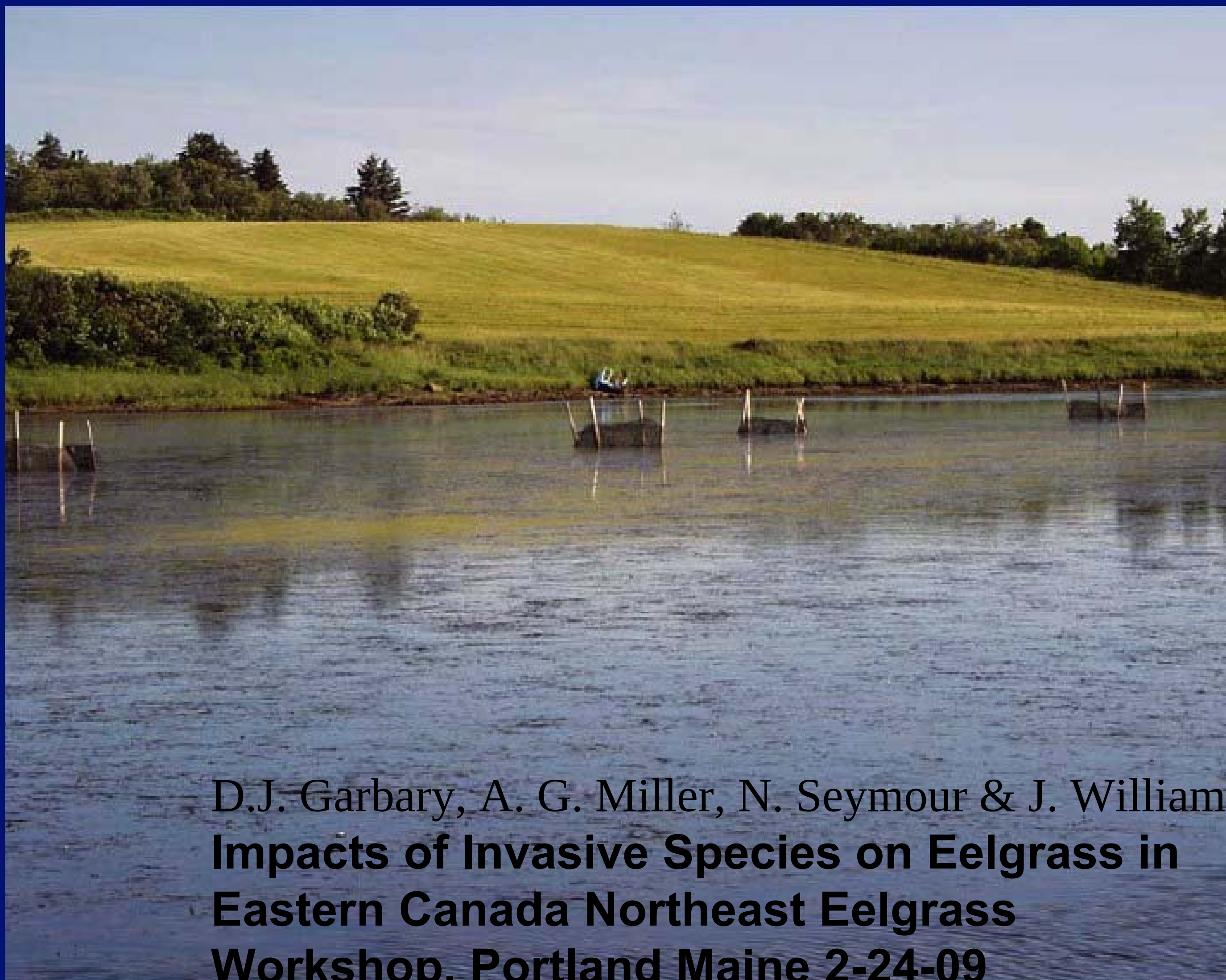
Passeeonkquis Cove
2007

Mouth of
Potowomut R 2007



Temp rise + Nutr load has been associated with seagrass loss + increased invasions – but ***what*** species is important !!!

Act 3 - Enclosure Experiment
Tracadie Harbour

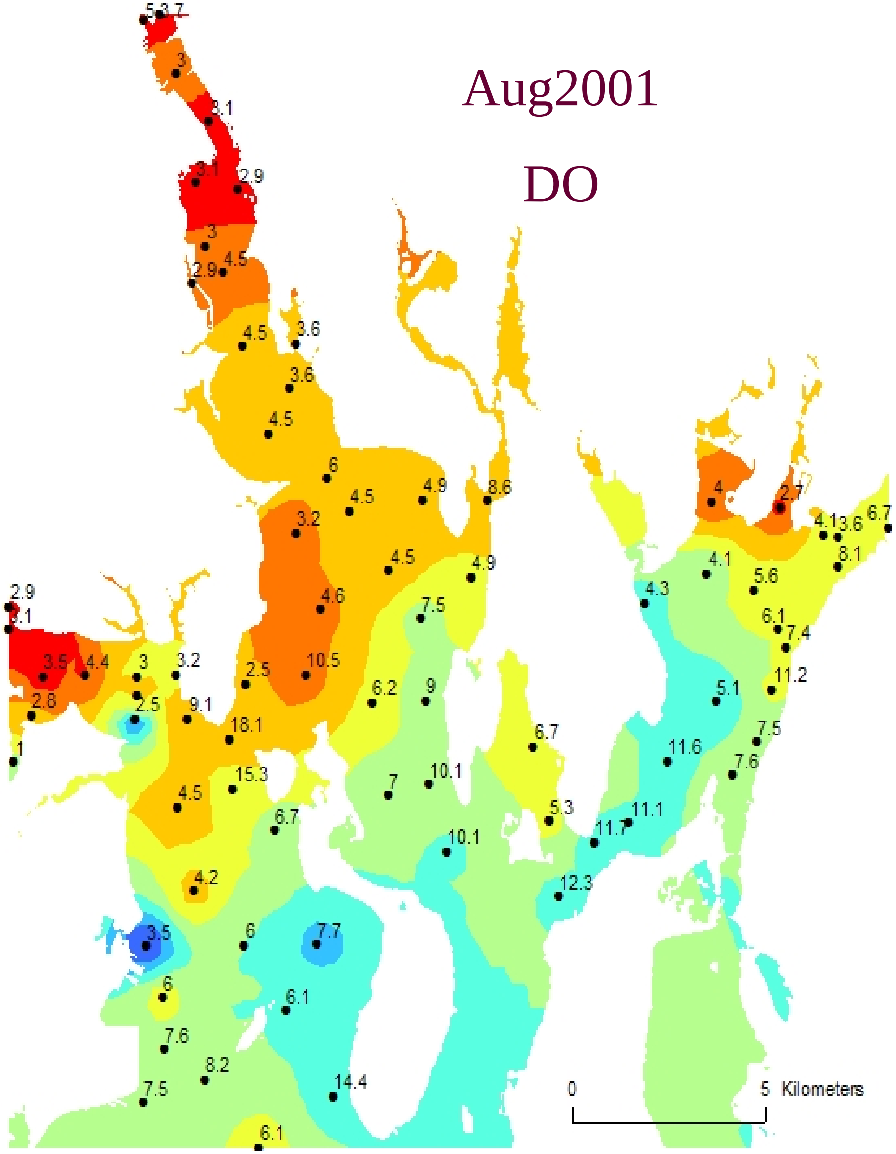


D.J. Garbary, A. G. Miller, N. Seymour & J. Williams

Impacts of Invasive Species on Eelgrass in Eastern Canada Northeast Eelgrass Workshop, Portland Maine 2-24-09

Green Crab Increase associated w/ eelgrass loss in Nova Scotia

Evidence of Hypoxia Impacts to Benthic Community Diversity ?



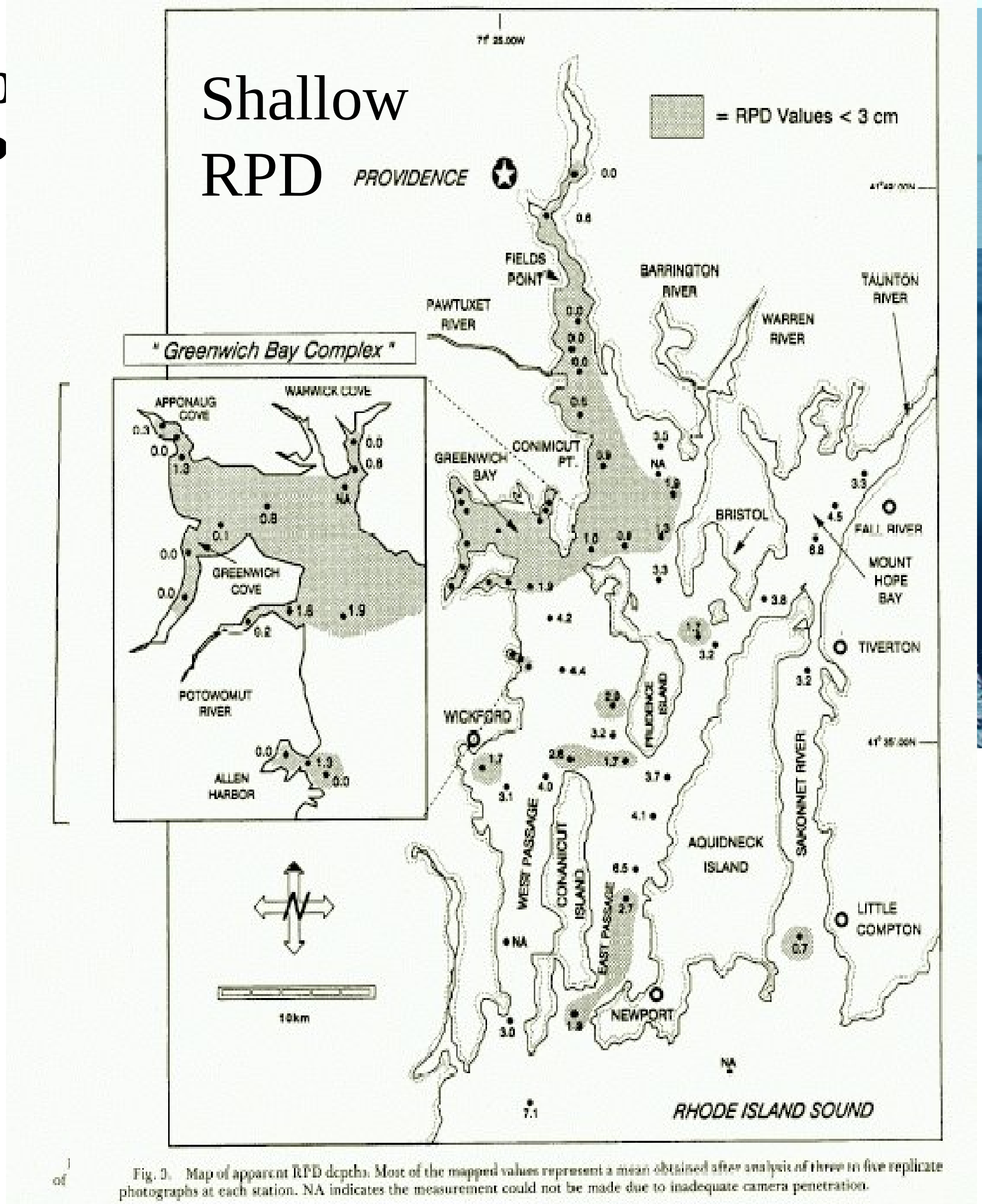
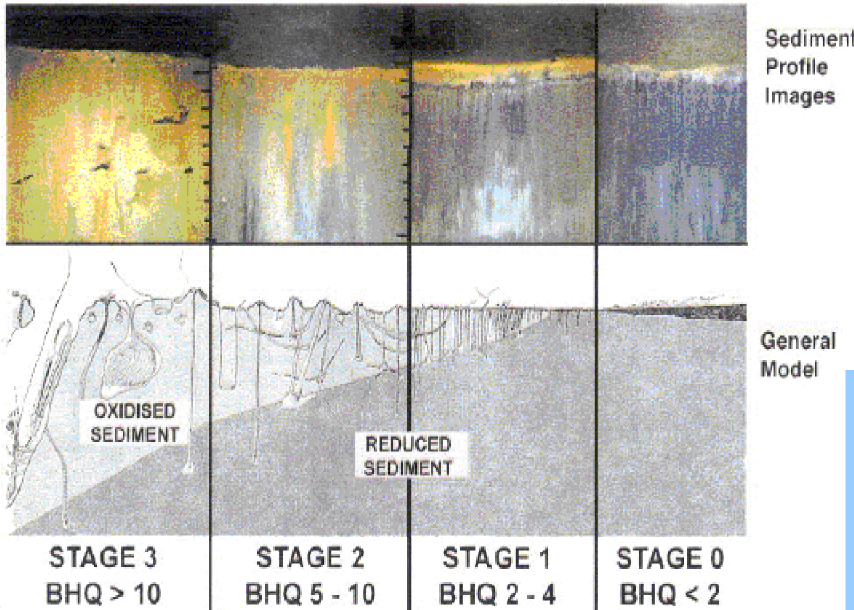


Fig. 3. Map of apparent RPD depths. Most of the mapped values represent a mean obtained after analysis of three to five replicate photographs at each station. NA indicates the measurement could not be made due to inadequate camera penetration.

Valente et al. 1992

- consequence : decreased Diversity + loss of some important benthic orgs. + altered nutrient cycling



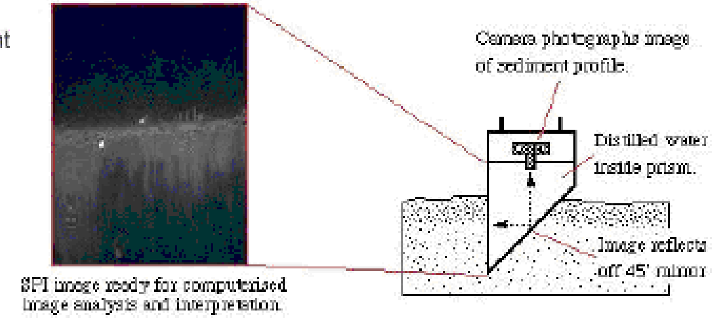
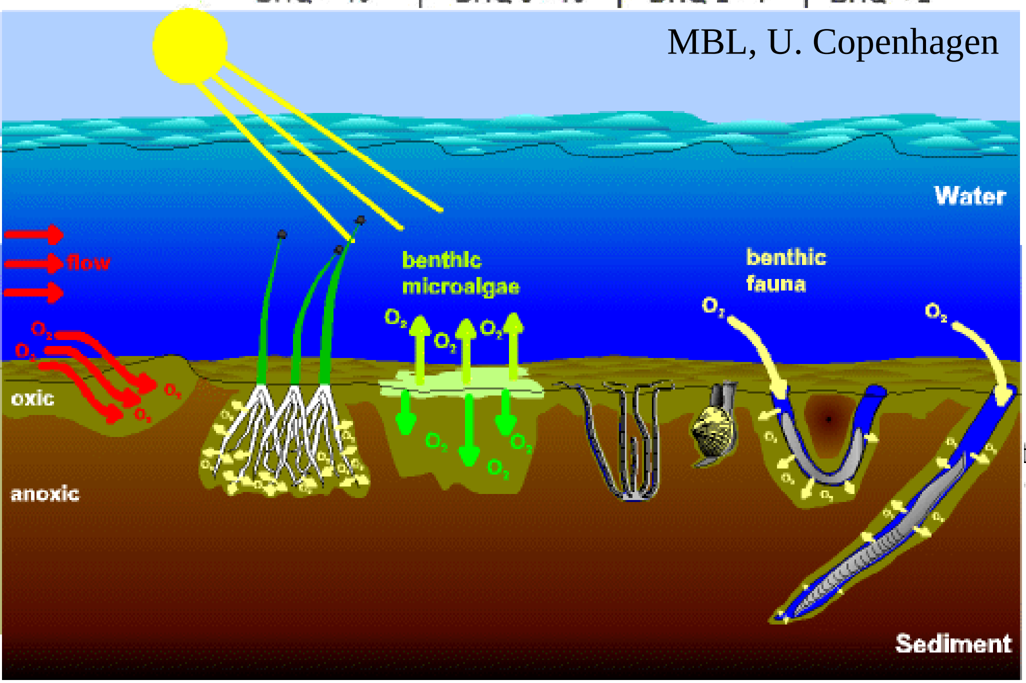


Figure 1-5: Schematic of SPI function.

Stage 3	Stage 1
deeper living sp (aerate the sed.)	shallow/surface living
deep aRPD	shallow aRPD
equilibr.sp	opportunist - pioneering sp.
deposit & filter feeders	deposit feeders
high individual Biomass	low indiv. biomass
long-lived	short-lived
	≤ 2.6 mg/L for > 17 da in a month

(Cichetti et al. 2006)

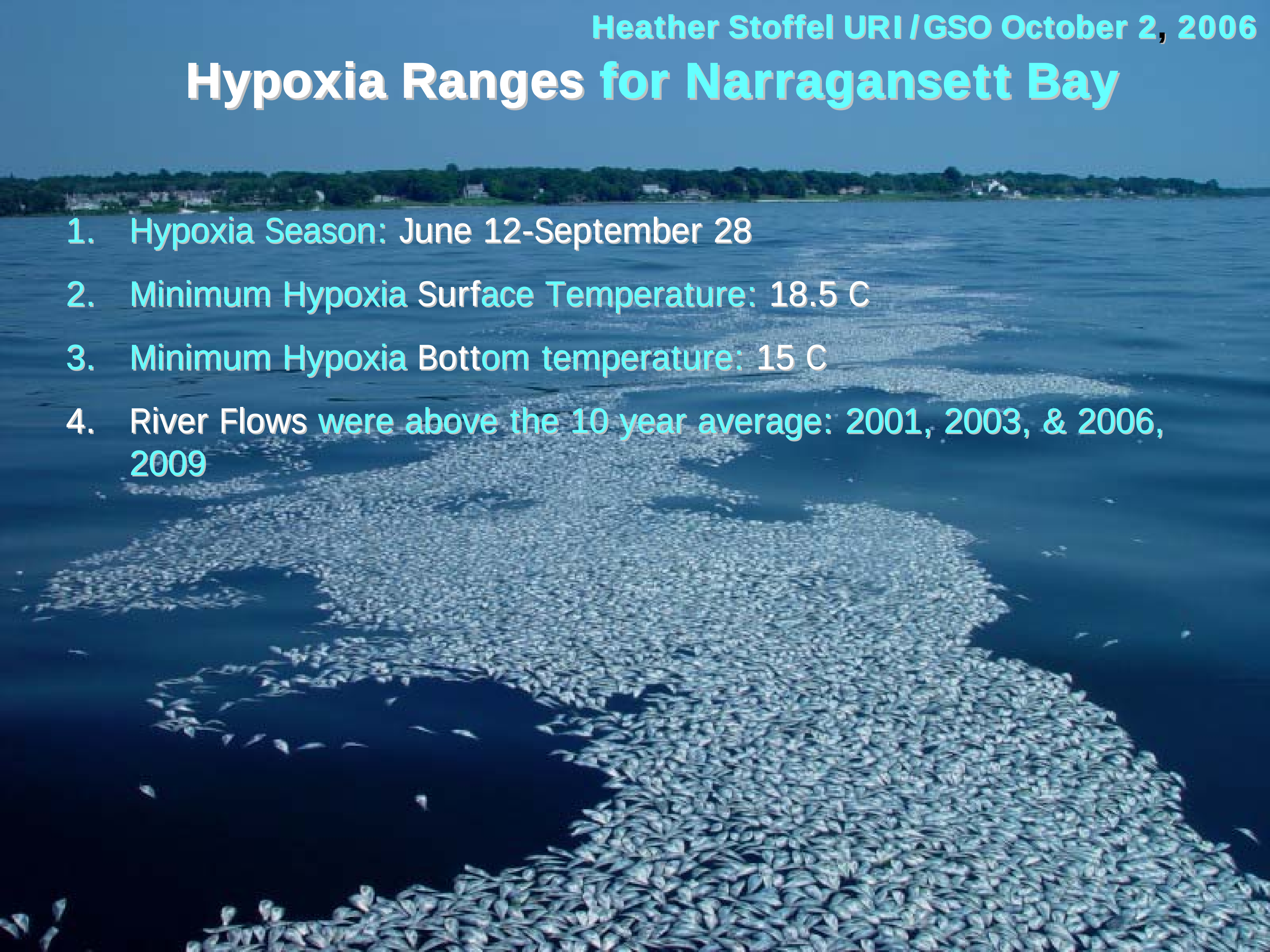


Altered nutrient cycling under hypoxia

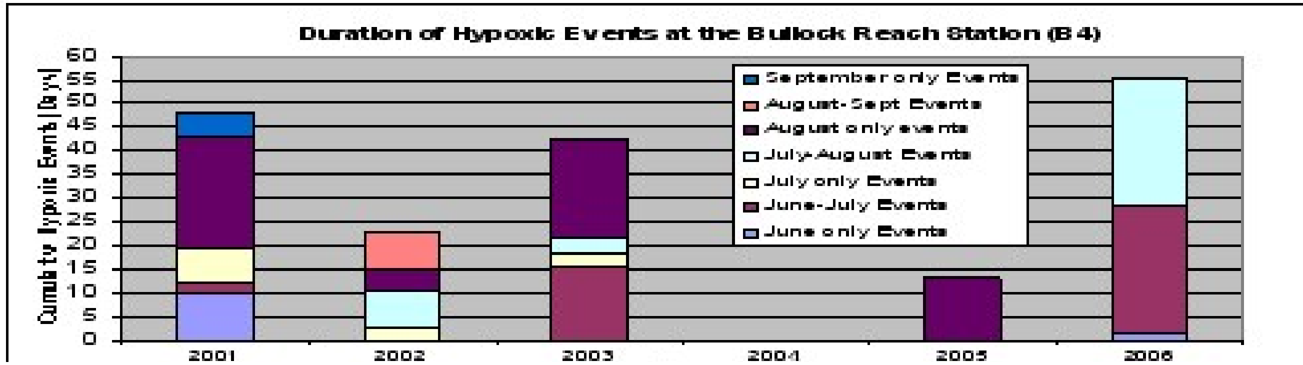
Heather Stoffel URI / GSO October 2, 2006

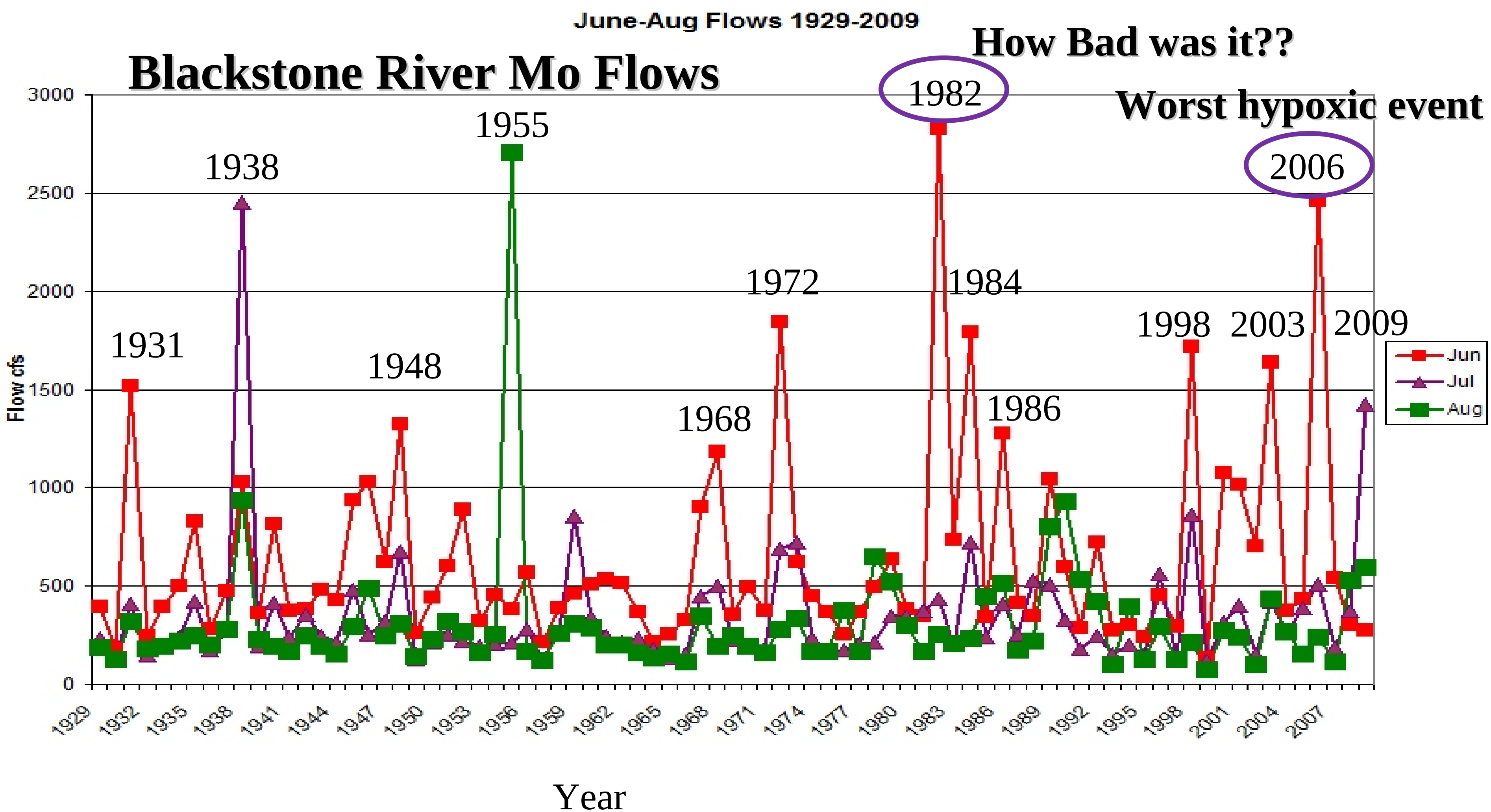
Hypoxia Ranges for Narragansett Bay

1. Hypoxia Season: June 12-September 28
2. Minimum Hypoxia Surface Temperature: 18.5 C
3. Minimum Hypoxia Bottom temperature: 15 C
4. River Flows were above the 10 year average: 2001, 2003, & 2006, 2009

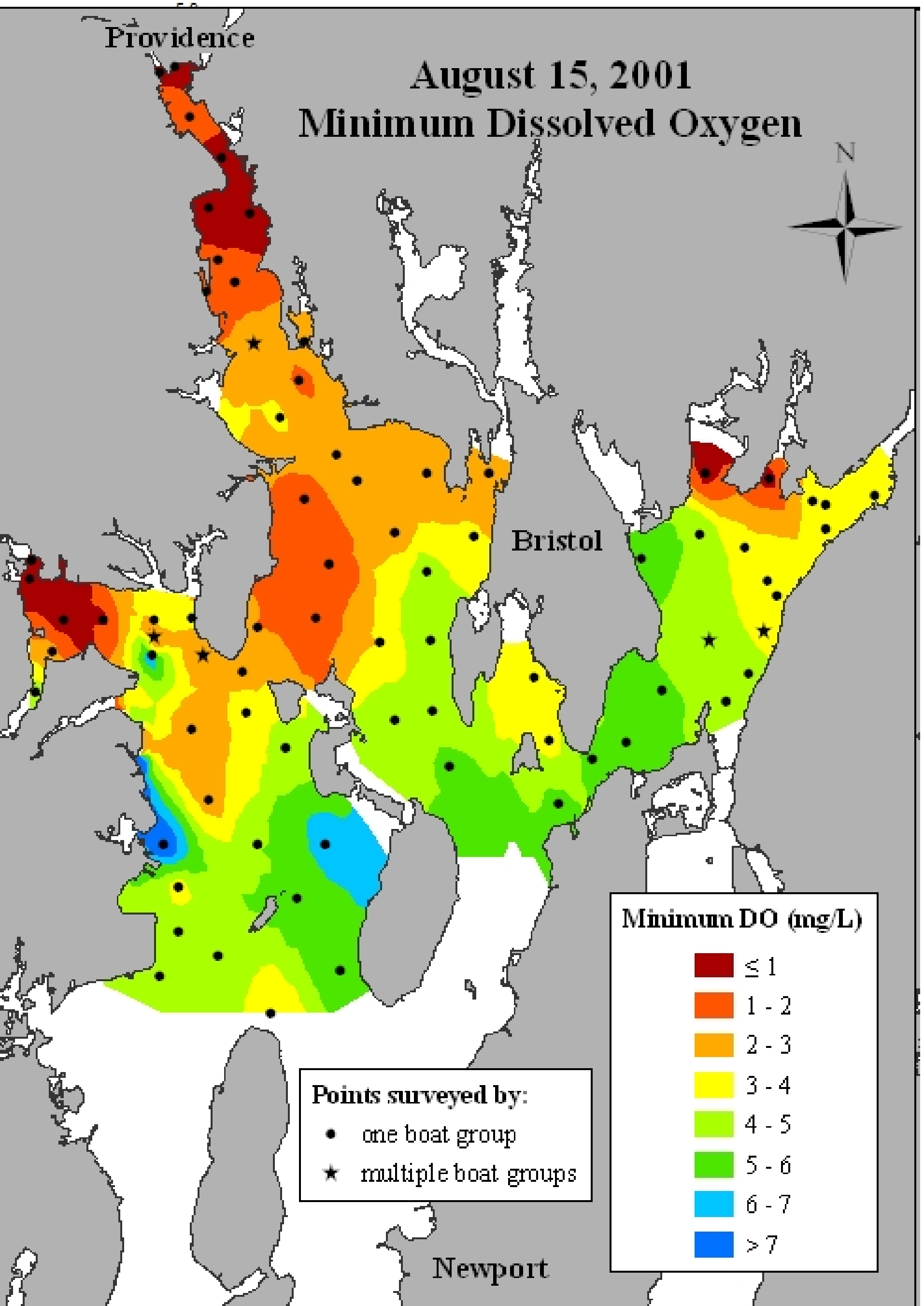


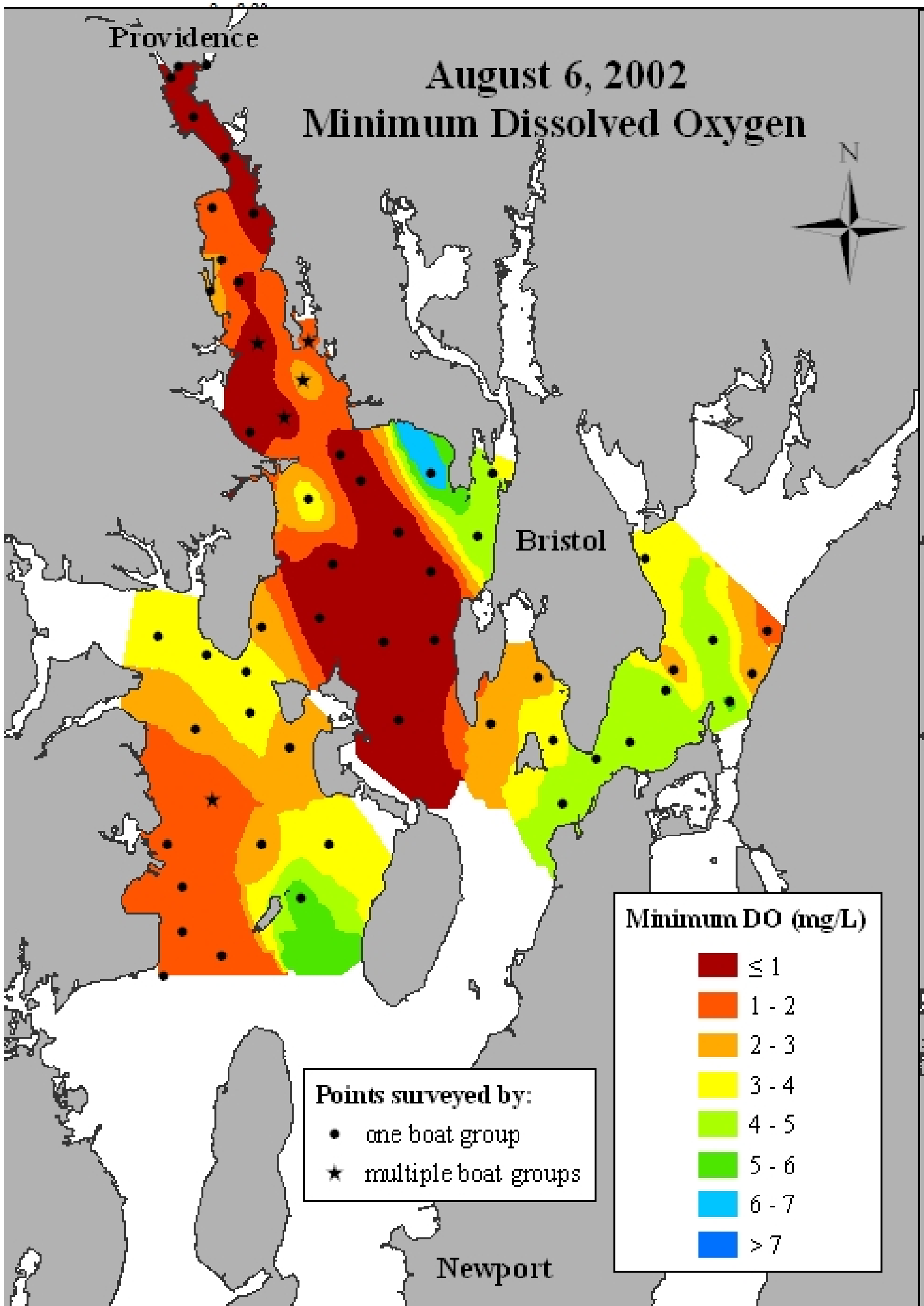
Severe hypoxic summers **linked to June** (or *July) FW river flows (Codiga *et al*. 2009)





Do *not* need strong Stratification for Severe Hypoxia





The Critical Importance of Circulation / Flushing to local **ecology** & **hypoxia** susceptibility

e.g., **Greenwich Bay once** called "**Scalloptown**"

High Diversity - extensive **eelgrass & oyster & scallop beds**

- **slow flush** = **retention of planktonic larvae**

  including fish and (in 1940's and 50's) scallops and oysters

- Same **physical "good" characteristic = BAD for nutrients:**

  retain nutrients & **phyto**plankton conc.

- **nutrients** begin to **increase (1970's?)** : **high sensitivity to hypoxia**

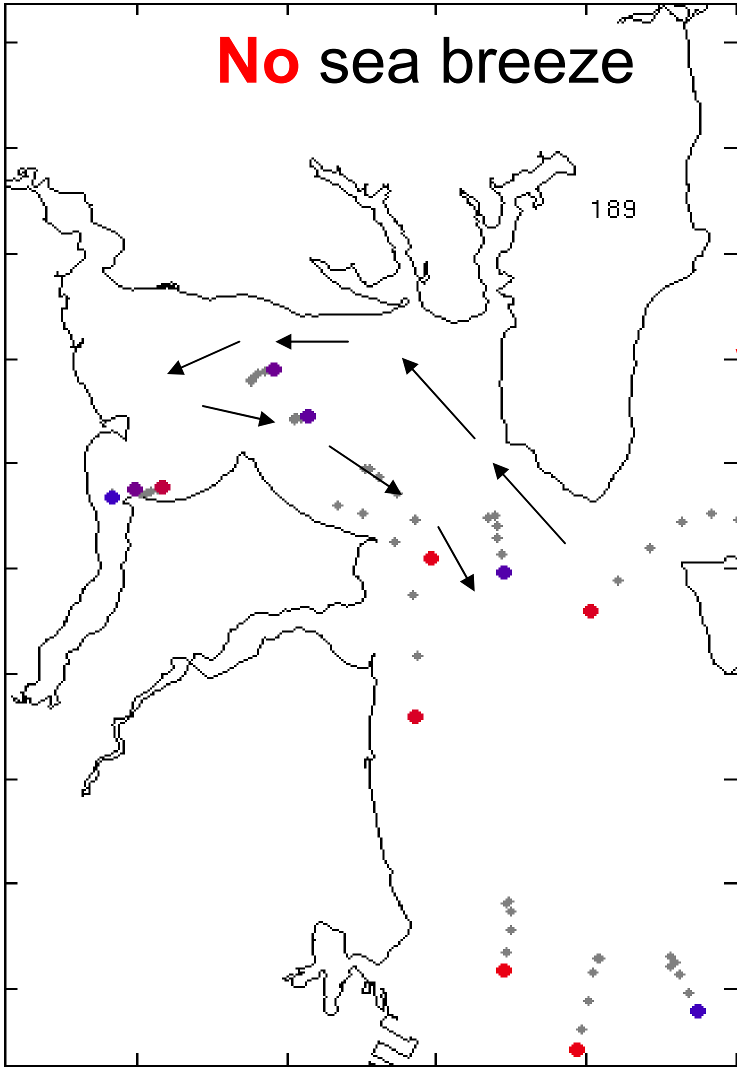
  - *even* **if shallow** (high mixing)!

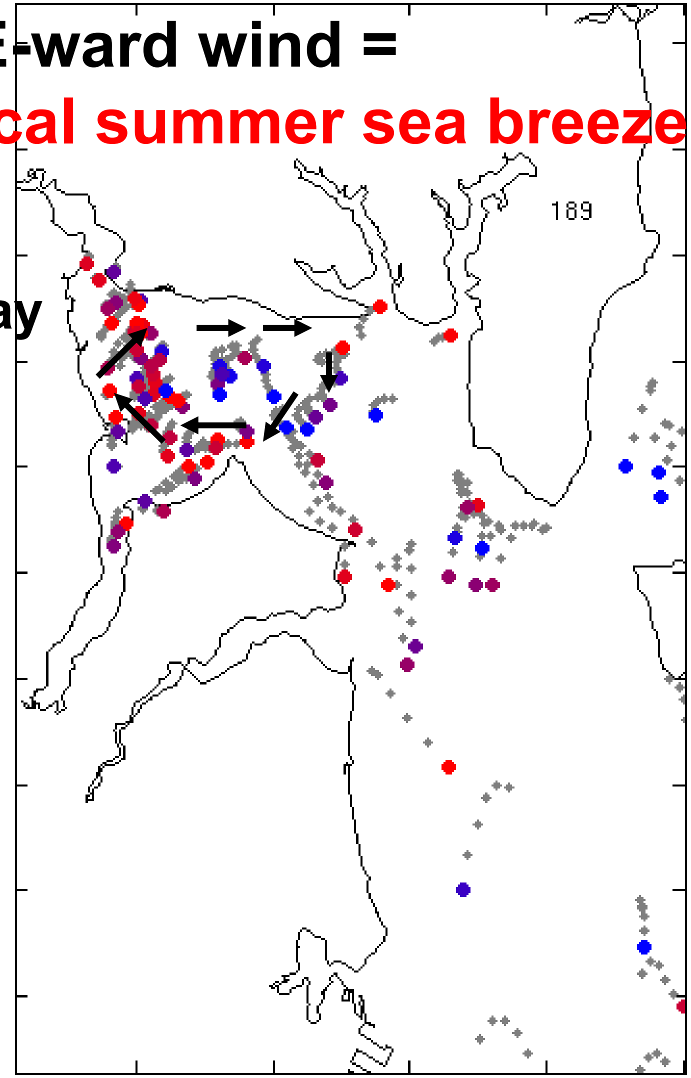
- *****Any changes in circulation drivers** a **key factor** for changes (e.g., changes in **sustained wind direction** in Narr. Bay)

- **for local conditions: consider local geographic orientation and winds !!!**

C. Kincaid & Christelle Balt

10 days of simulation - residual flows predicted distinctly diff. in the 2 cases.



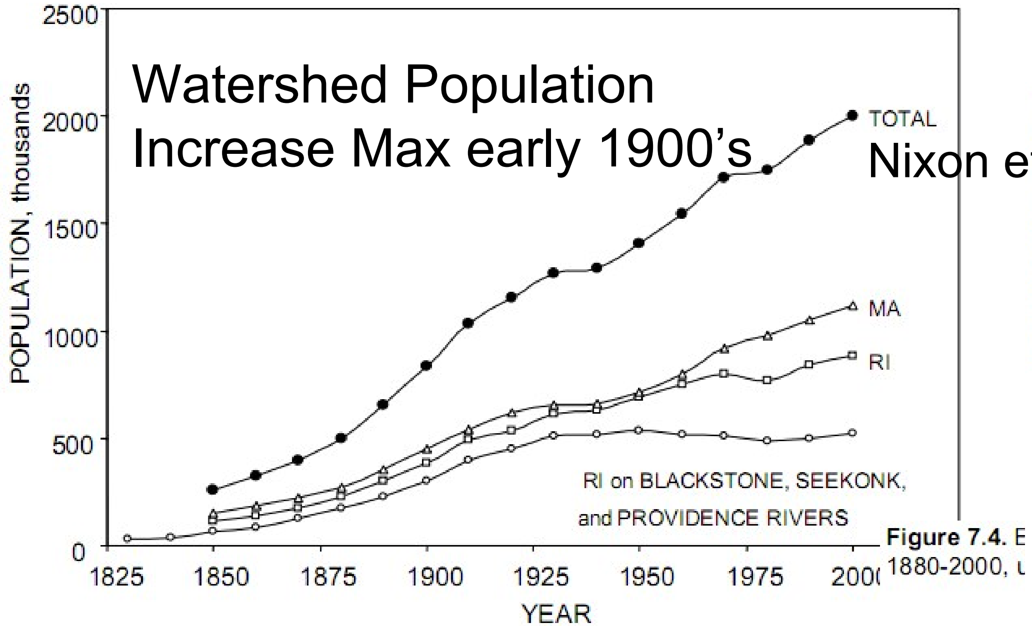


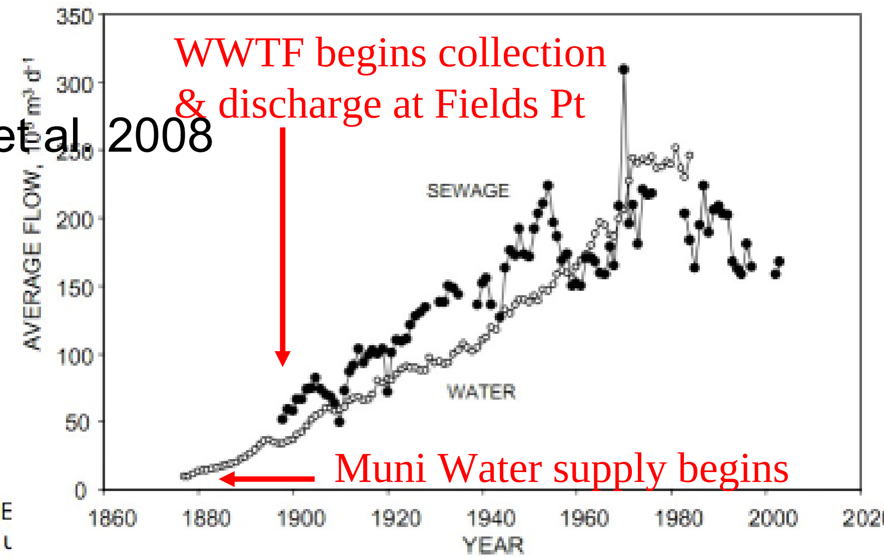
Greenwich Bay
wind-driven
GYRE

summer 2006

JUSTIN M. ROGERS, M.S. 2008 URI

HISTORY of N LOADING to Bay



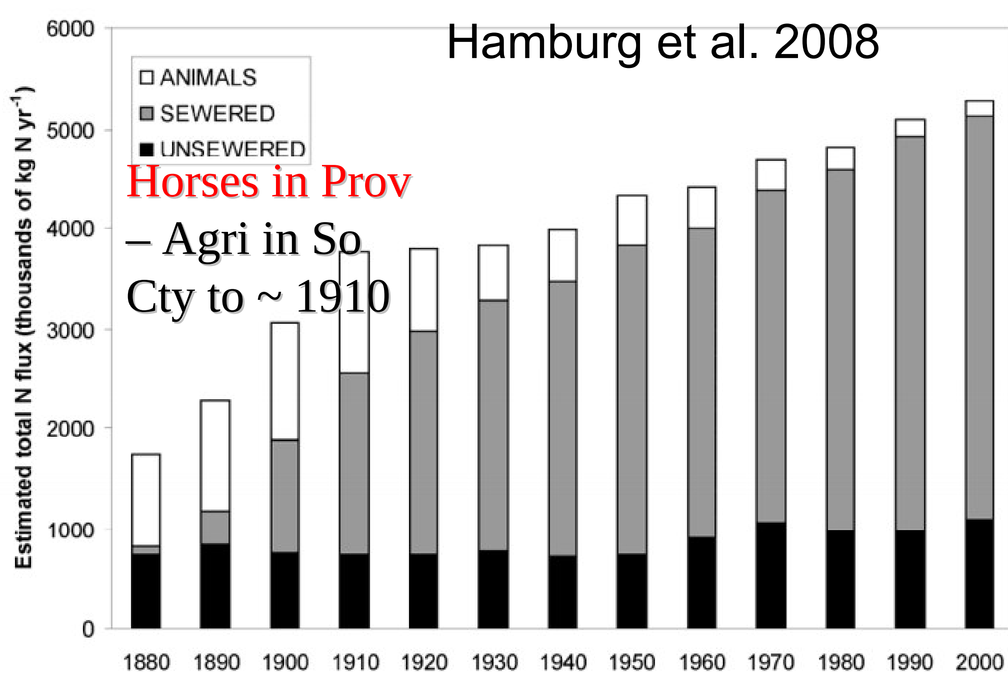


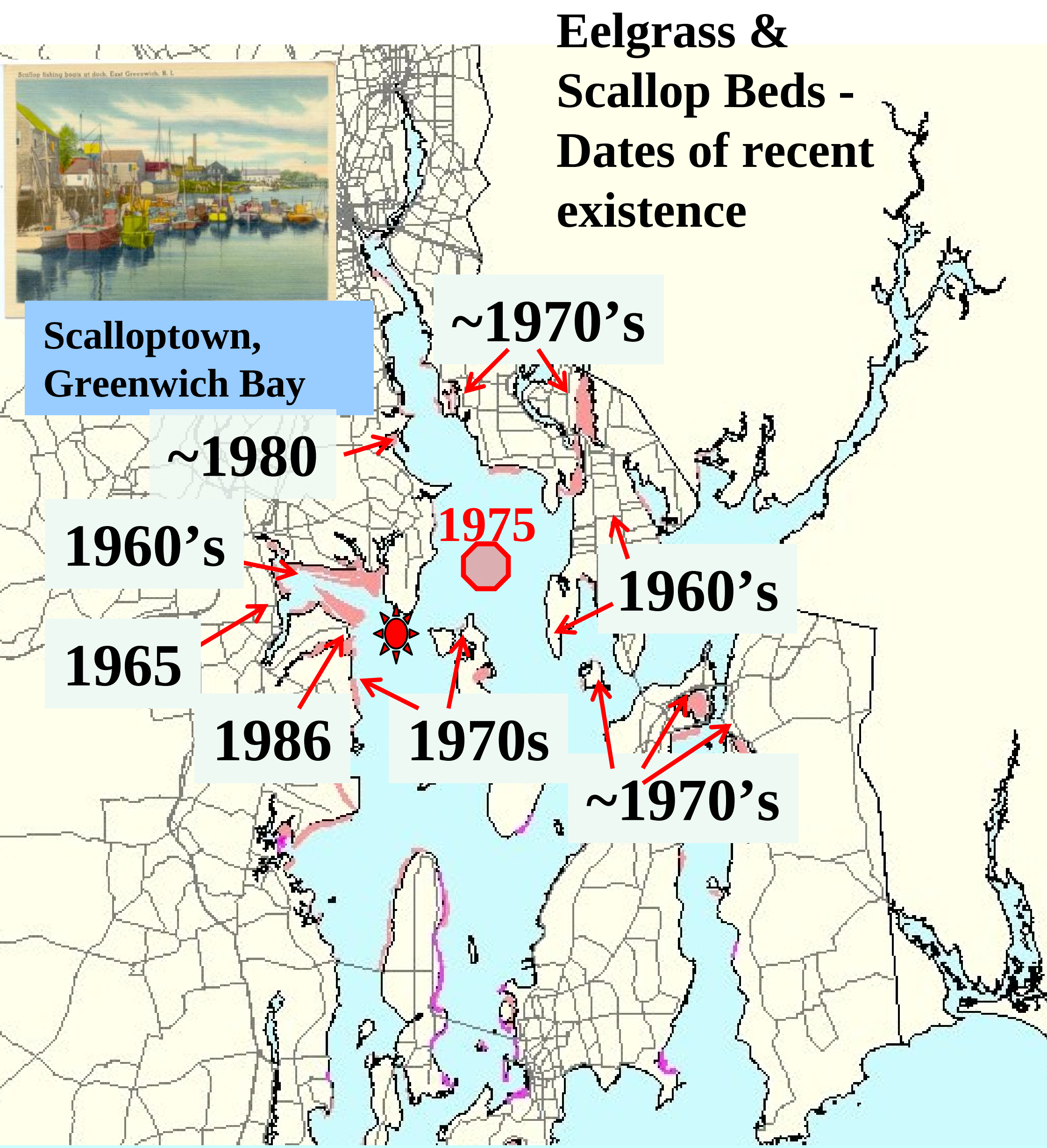
Max load N Increase in early 20th century - BUT - at *very* high load now and continuing

TN ~ 5X precolonial (Nixon 1997)

– ea 21st cent = 1st decreases

So how long has low DO been a problem beyond Providence River ? (known problems in Prov. R. late 1800's)





How long has Hypoxia been a problem *beyond* Providence River ? (known problems Prov. R. late 1800's)

Little DO data -
1 EIS study Prov. River by US ACE
37 sampling days
Jun-Aug 1959
(Nixon et al. 08)

Few low DO examples- mainly at mouth of Greenwich Bay
9/72 data points < 3 mg/L
4/72 ≤ 2 mg/L

Eelgrass cannot survive in high DIN environment – yet still exists until recently

BUT -Water Warming in 1970's-2000's

Winter Surf. Water Deviation 1880 - 2000

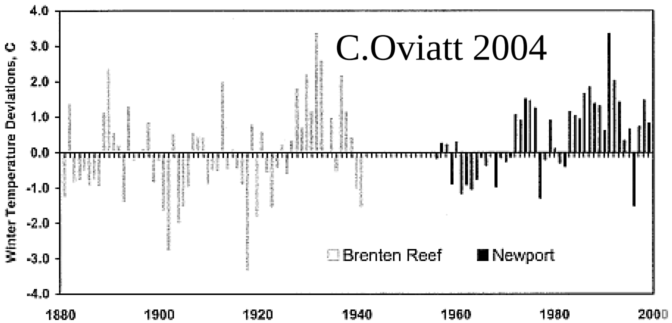


Fig. 1. Winter water temperature deviations in degrees Centigrade from the mean at the Brenton Reef Light Ship prior to 1939 and from Newport Harbor after 1955. No data was available for the interval between the two data sets. Mean tempera-

Annual water temp:

+2°F since 1960

wntr +3°F

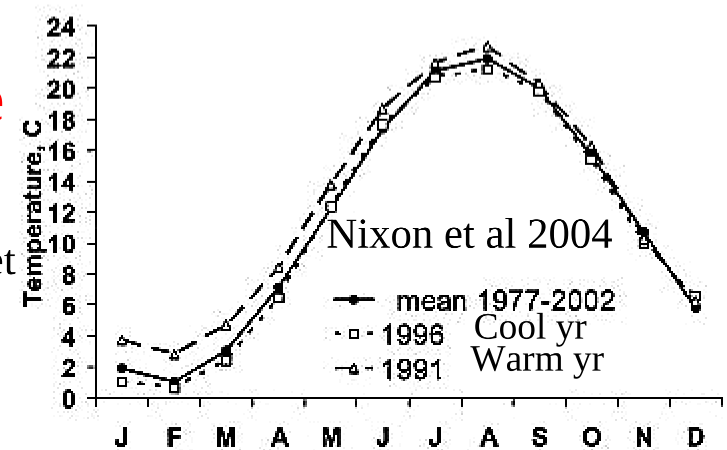
(Nixon *et al*. 04)

Extreme hot periods will intersect species temp. limits

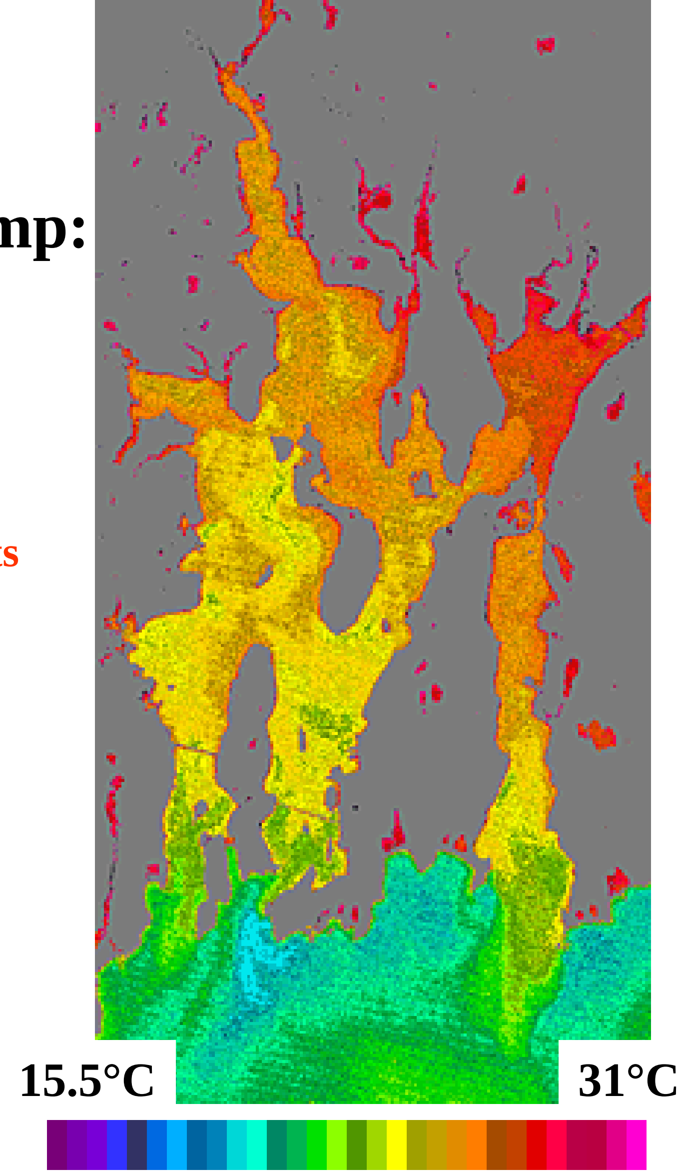
Winter Temps esp large ▲

Hi N + Temp Incr = Double whammy for eelgrass (Blintz et al. 2003)

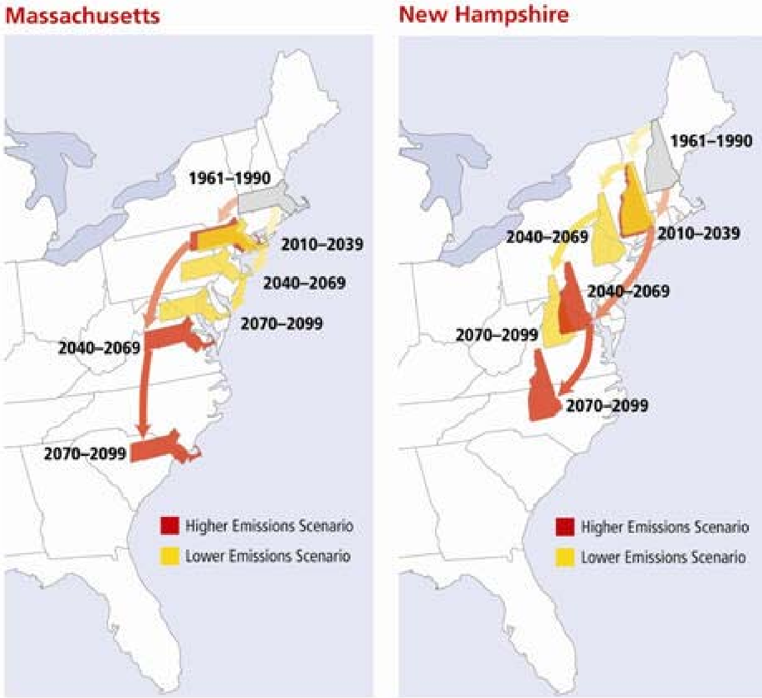
Monthly Woods Hole Temperature



Incr esp. winter temps - Some areas even warmer due anthro. heat input (MHB)



Temperature of Narragansett Bay July 7, 1999. Landsat image from: J.Mustard, Brown University.

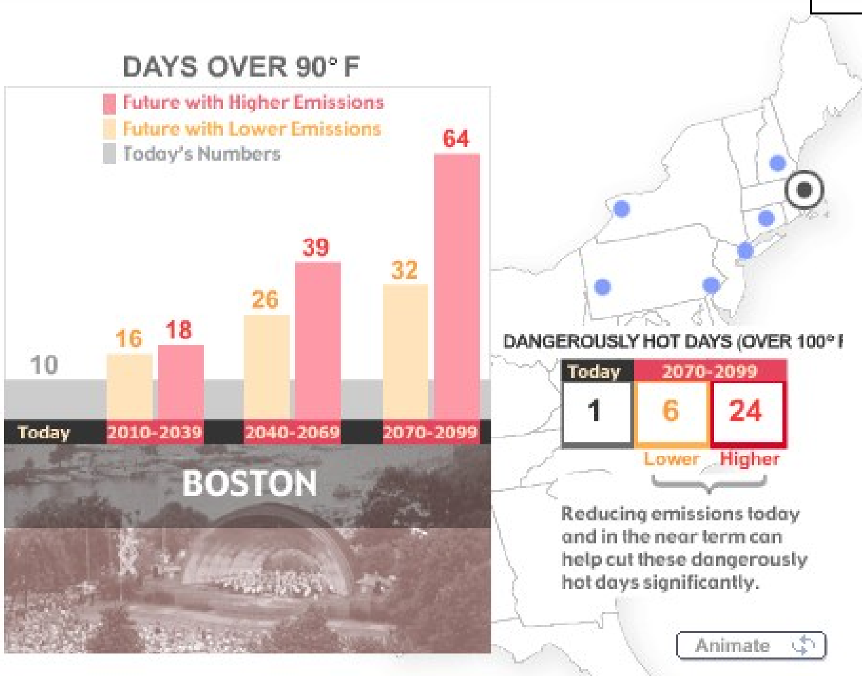


Climate Change in the U.S. Northeast

(http://www.northeastclimateimpacts.org)

Issue - Not just the ***Avg.*** Temp
-- **Frequency & Duration** of ***Extreme* temp events** likely to be **major drivers** in Ecosystem species shifts - **other species** besides humans also **succumb to extreme heat waves – shallow areas will be most at risk**

IMPACTS ▸ Extreme Heat in Our Cities



RI region projected to have **weather** typical of present **coastal So. Carolina or Georgia**

Temp *will* rise another + 4°to 6°C = 7.2-10.8 °F by 2100 ?

(* 1°F = 1.8 °C)

Hit "Eco-Thresholds" ???

Temperature going up overall **Why care ?**

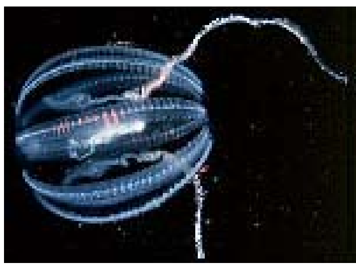
Temp. has *LARGE* effect on biol. Communities due

physiology / metabolism / changes in species activity etc.

= complicated unpredictable system response

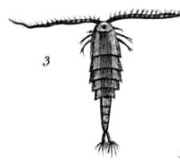
– reach possible "phase shift" points ?

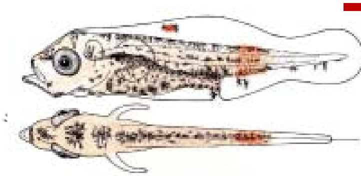
Predator Pop Increases



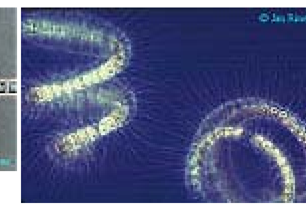
Ctenophore (*Mnemiopsis*)

Grazers





Phytoplankton



©Jan Rines

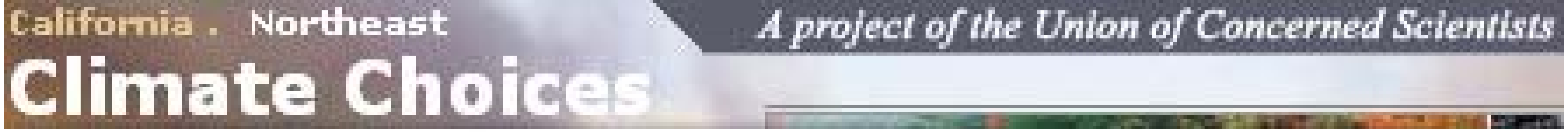
– **responses *often not predictable* until observed** and tease out why

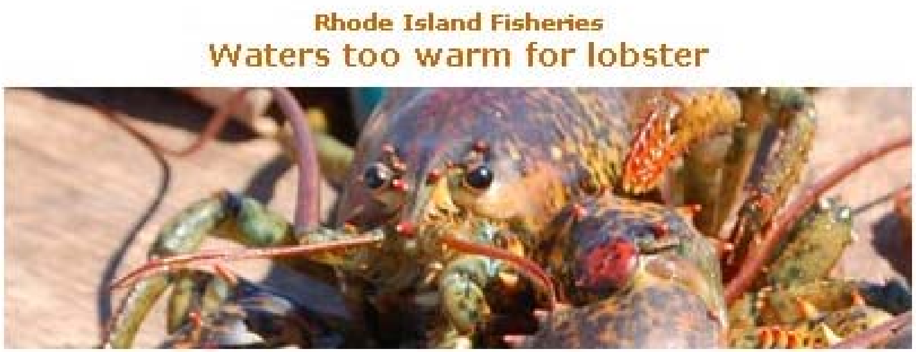
-Disruption of W-Spr blooms due "early grazing"?

= loss of food to benthos

-Disruption of food webs : cascade effects e.g., combjellys now reproducing / "blooming" ~ 4 mo. earlier : 1 potential consequence: pred. on grazers = less fish?

- summer phyto blooms↑ ? = **More hypoxia in summer ?**





Examples of Warm water

Changes to biological communities

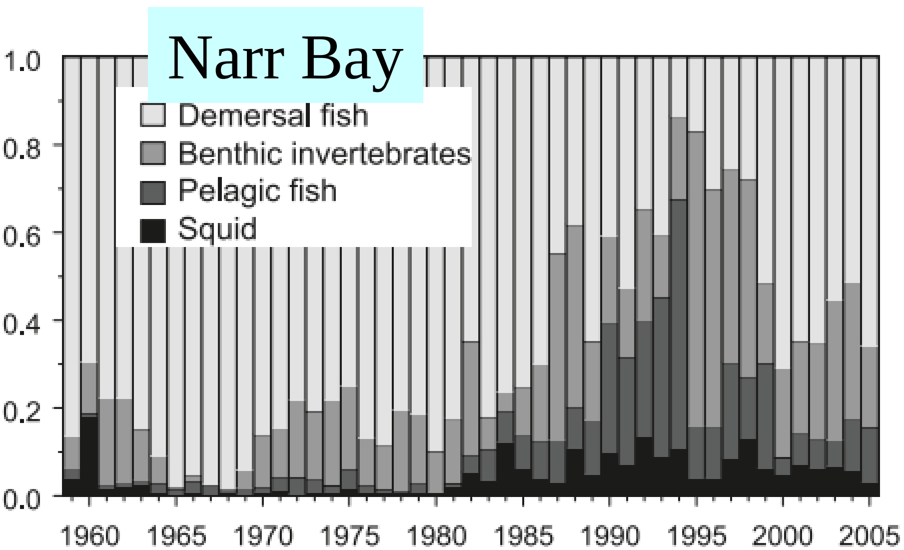
Water temps. - projected to exceed max. heat stress threshold for Amer. Lobster LIS and RI (So. Of Cape Cod)

Union of Concerned Scientists

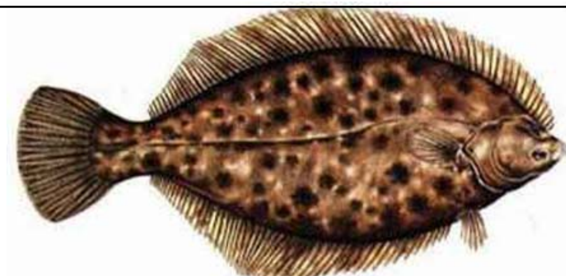
+ May be interaction with hurricanes & hypoxia & temp & lobster die-offs

Sept. 19 -22, 1999 – great LIS lobster die off *****Hurr. Floyd – LIS Sept. 19, 1999**

(base on Paerl et al 2001 – Pamlico Sound impacts)

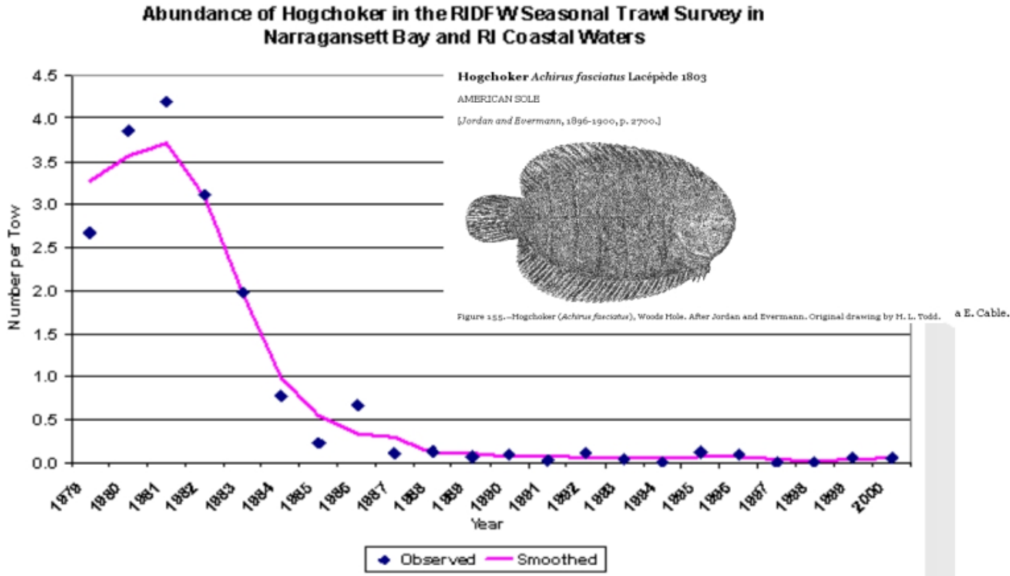


Collie et al. 2008 – warm water sp up



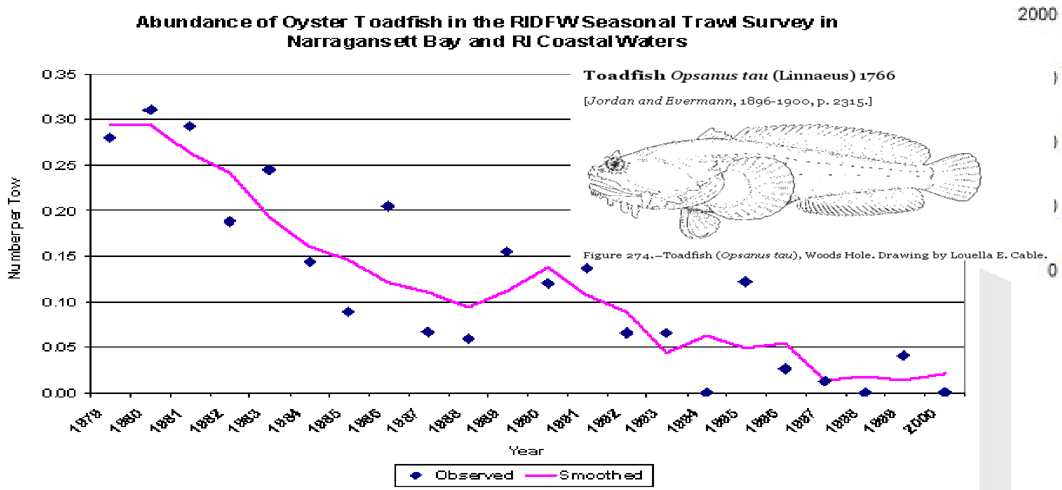
http://www.atlanticanglers.com/fish/ images/winter_flounder

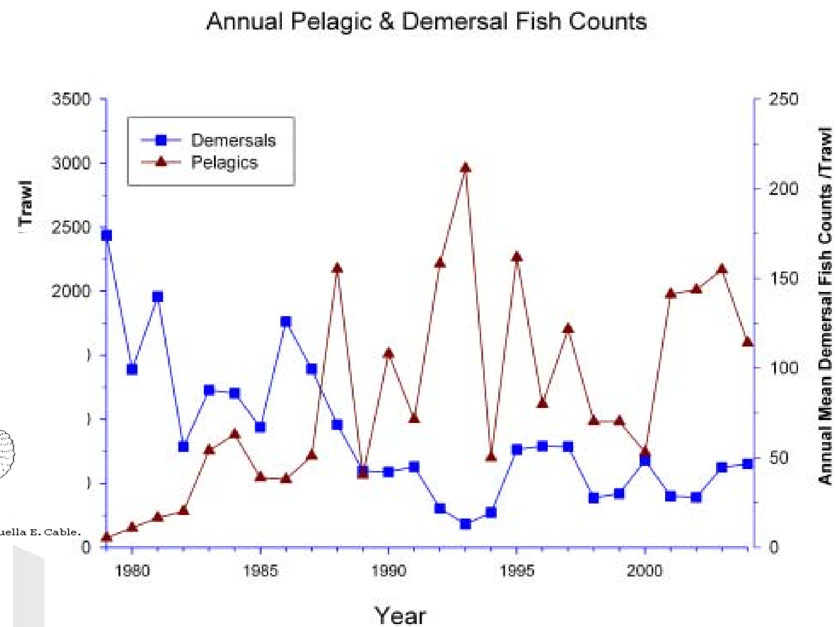
Loss of Boreal (No. cold-water) species in So. NE area e.g.,Winter Flounder (winter breeder) population significant declines So. of Cape Cod , especially Narragansett Bay



Losses of cool-water sp (e.g., W.F.) may link to warming **BUT** some species shifts - ***not likely* due from temperature increase** - Are they linked to **WQ low DO or other changes ?**

Data from M. Gibson (RIDEM F&W)





Any Links for Warming impacts on D.O.?

- **Inner Danish Coastal Waters** (betw. North Sea and the Baltic Sea)

3D circ. model w/ Temp. function (DO consumption due incr. respiration)

Add + 3 ºC

Model Results : severe hypoxic area - incr 150%
- predicts: hypoxia to cover most of Inner Danish Coastal Waters in future + prevail through summer and autumn months - leave large bottom "dead zones"

"hypoxia may generally be the most significant negative effect of global warming on coastal marine biodiversity"
Jørgen LS Hansen, J Bendtsen 2009. Effects of climate change on hypoxia in the North Sea - Baltic Sea transition zone

NOTE ***Results show - particulate organic C from water column will be respired in the water column = less org C food deposited to the sediments = less benthic food = predict shift in the overall ecosystem structure …happening in NARR BAY ???

Gelatinous Plankton less sensitive to low D.O.
Shift to more Gelatinous Predators?

Ctenophore *Mnemiopsis leidyi* – shifting bloom to earlier in season

- **1950-1979** bloom mainly **late summer-ea. fall**
- **1980's & 1990's – shift to late spr-ea. summer due warmer winters**
  – now co-occur w/ time of max fish larvae (B. Sullivan et al. 2001)

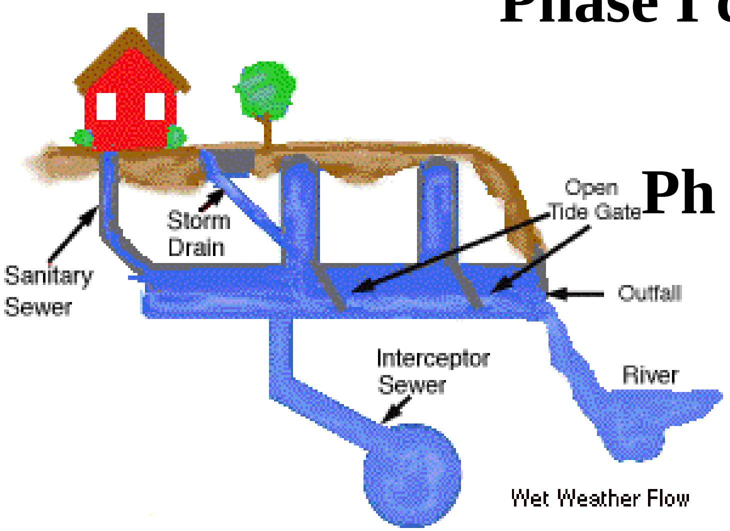
Combined Sewer Treatment - part of changes

Mainly decr. Pathogens (fecal coliform) – BUT - retaining stormwater - limited nutrient change but MAY be significant change in stormwater FW delivery ! Unknown Effects on estuarine circulation / flushing and hypoxia!

Will it decrease stratification (good)? It *is* catching more storms in the 0.5 - 1”/24hr storms…BUT – getting more storms > 2” ?

3 mi. CSO Treatment Tunnel Phase I completed

Nov 2008 Ph II coming

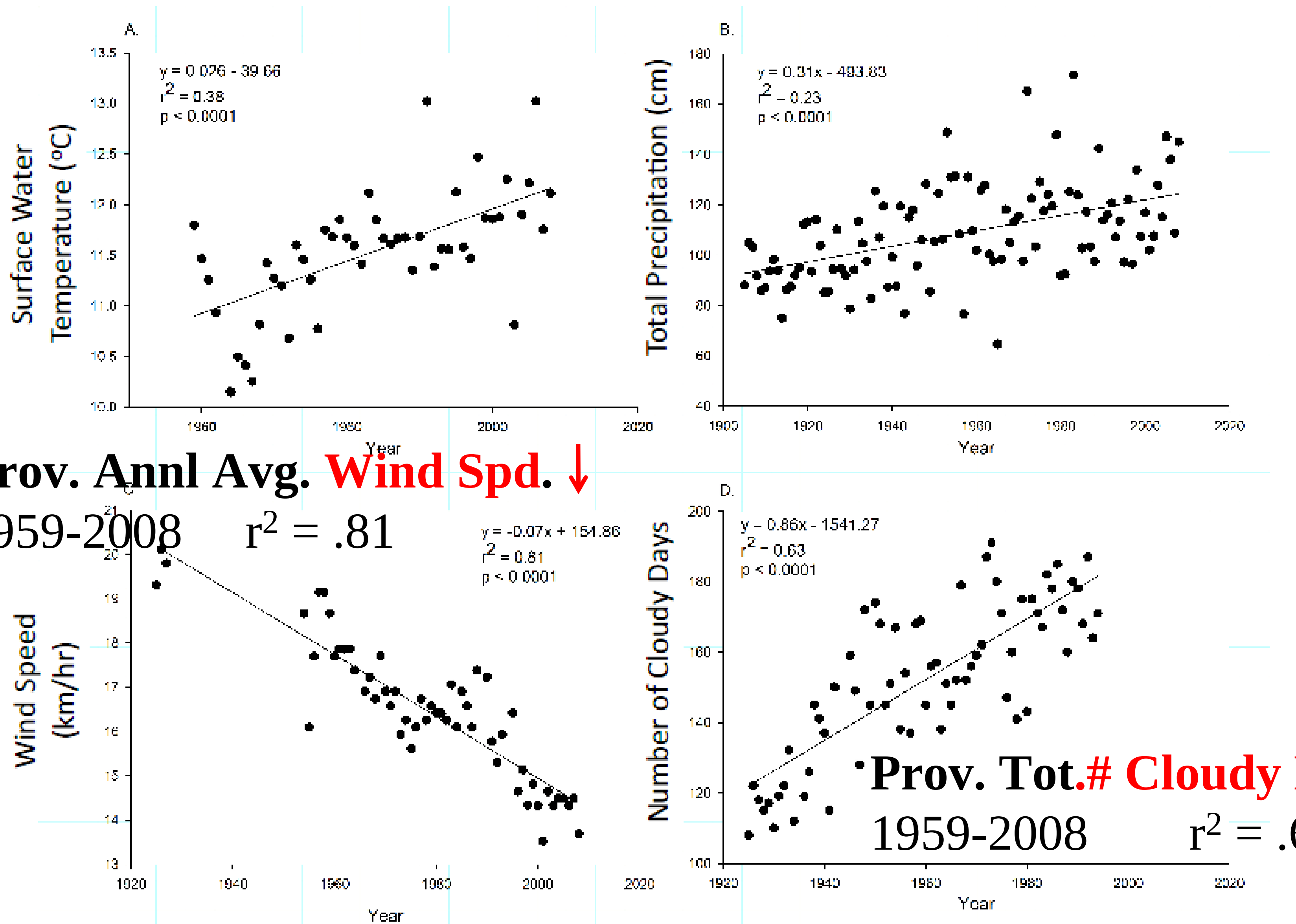


Annl Avg. Surf.Water Temp.↑
Fox Is. 1959-2008 $r^2 = .38$

Prov.Annl Avg. Precip.↑
1959-2008 $r^2 = .23$

Prov. Annl Avg. Wind Spd.↓
1959-2008 $r^2 = .81$

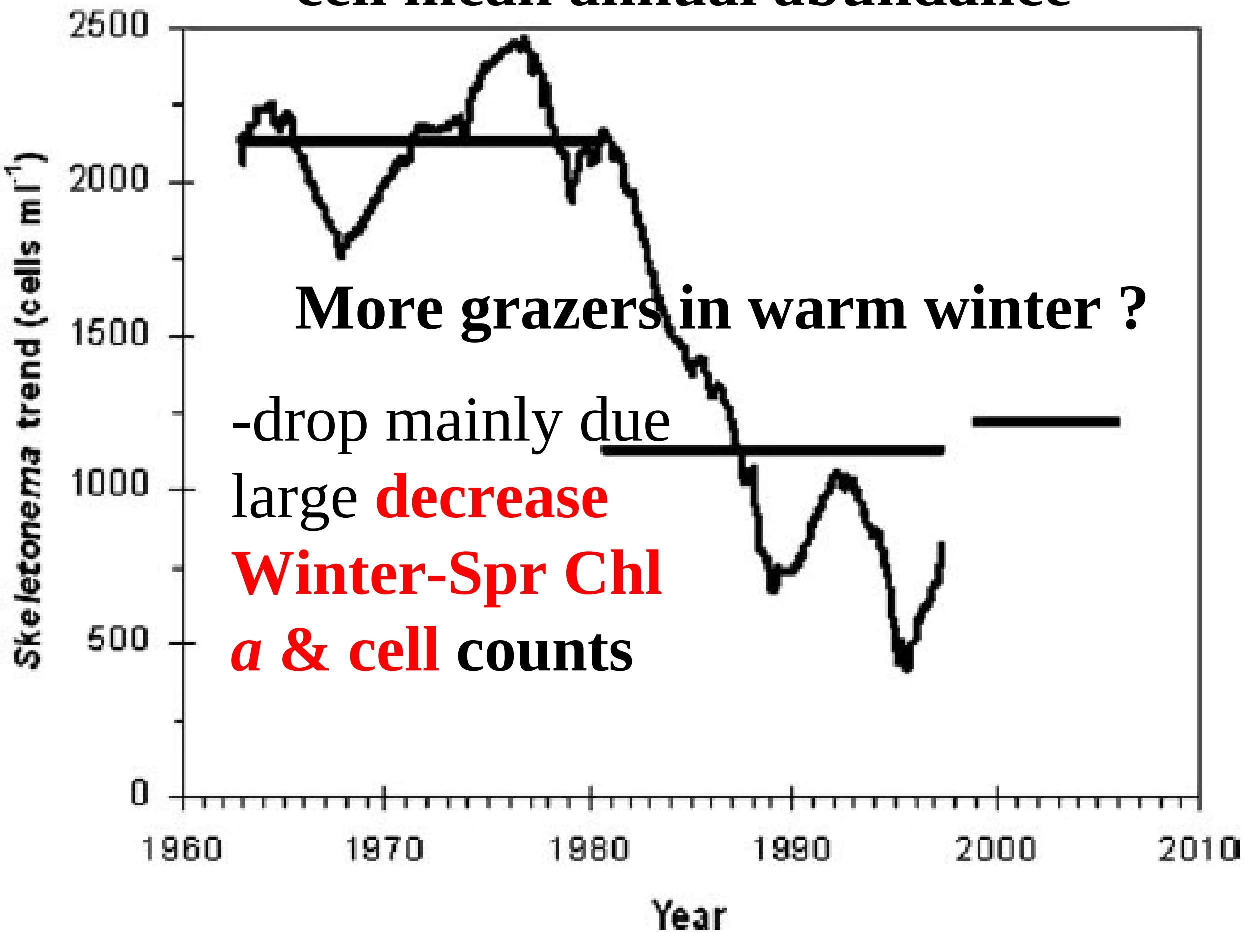
Prov. Tot.# Cloudy Days↑
1959-2008 $r^2 = .63$



Melrose et al. 2009

D.G. Borkman, T. Smayda / Journal of Sea Research 61 (2009) 84–94

Skeletonema spp.
cell mean annual abundance



More grazers in warm winter ?

-drop mainly due large **decrease Winter-Spr Chl *a* & cell counts**

Fig. 3. Long-term (1959–1997) lower Narragansett Bay *Skeletonema* spp. trend derived from time series analysis (continuous line). Mean *Skeletonema* abundance levels (2137 cells ml^{-1}) prior to, and after (1128 cells ml^{-1}) an August 1980 change point, and the mean abundance during 1999–2005 (1220 cells ml^{-1}) all shown as horizontal lines.

Chorophyll *a* and cell counts decr. at **mid- lower Bay** (**Fox** Island)

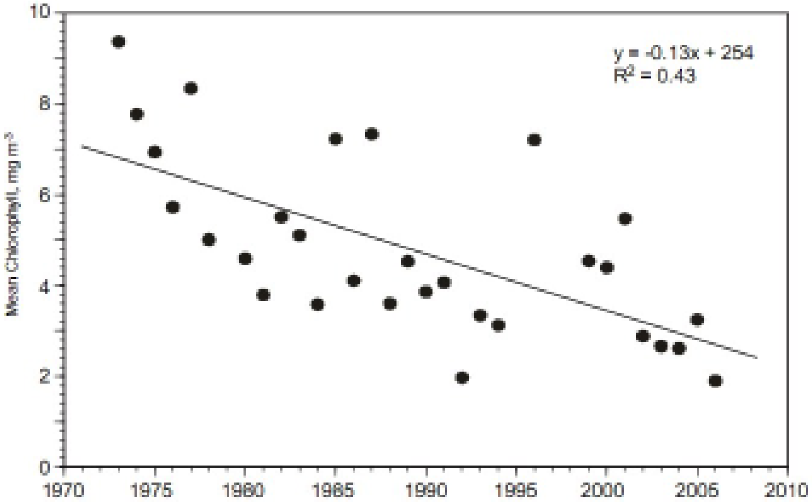
-**1980 "change point"** (***NOT*** lower nutrients – **BUT** time of **2ndry** trt improvements - mid 80's…*or* is it **NAO** etc.?)

- **Decoupling** of water col. Winter PP & benthos ?

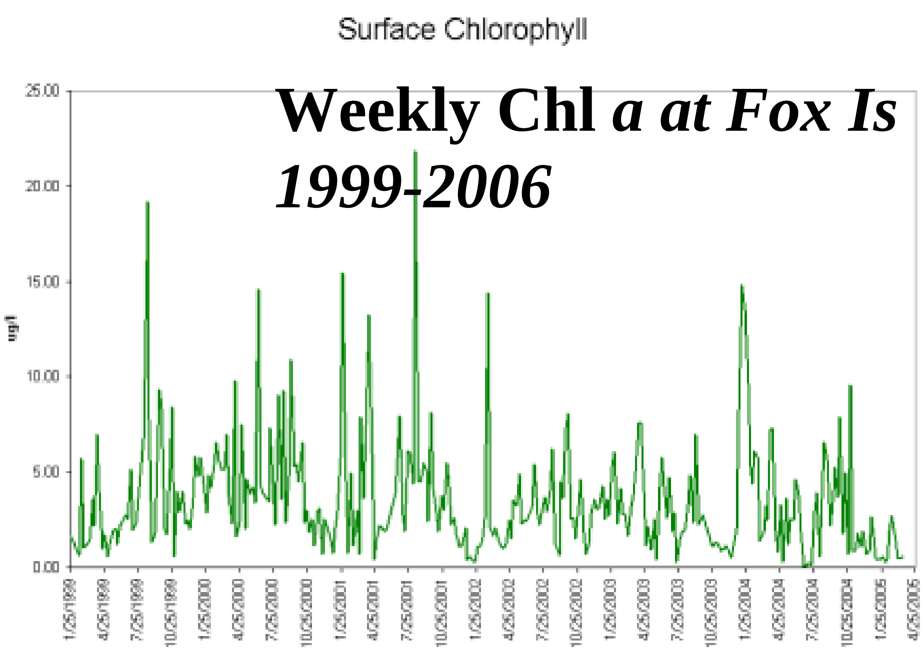
(Nixon Lab)

Same Pattern for upper half of Bay ???

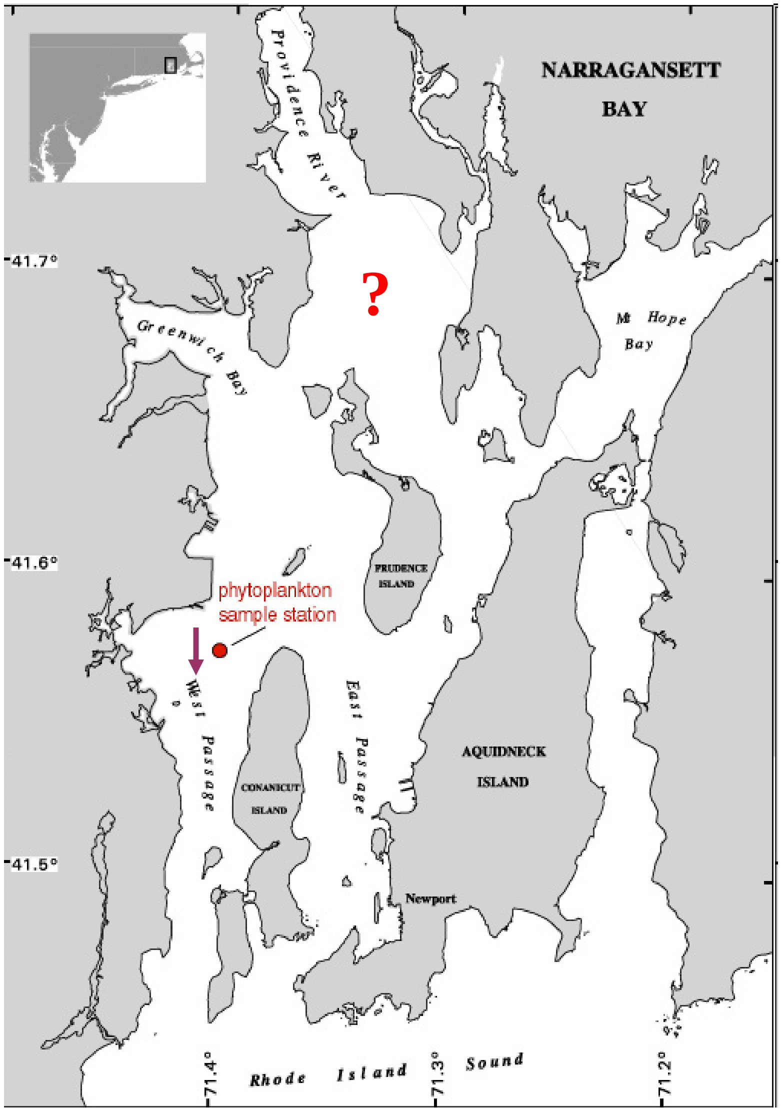
Prob : *NO* good chl *a* time series for upper half of Bay



Annual Chl *a at Fox Is 1972-2006*



Weekly Chl *a at Fox Is 1999-2006*

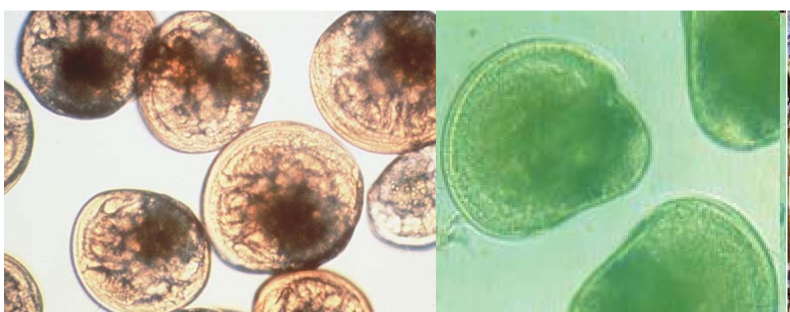


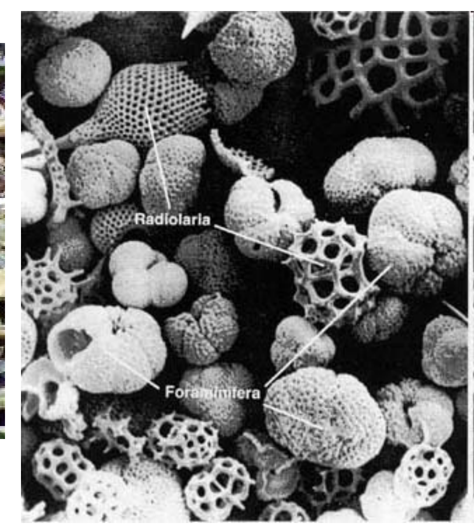
pH changes

CO_2 causing slight decr. (~ - 0.1) in avg. pH in seawater (carbonate system) - larvae of species that form Ca CO_3 shells / plates esp. vulnerable e.g., coral, oysters, mussels, quahogs, and some echinoderms (e.g.,starfish) PROB : Pac NW - oyster sets failing

pH not well tracked in estuaries + **natural fluctuation** due high photosynthesis rates (**high pH in phyto**plankton blooms) & **low pH in hypoxic** areas where CO_2 incr due bacterial respiration.

– some sp. affected **may not be commercially imp**ortant **but** may be **ecologically important** e.g. forams?





Rising acidity of estuary waters may spell trouble for oysters and other shellfish

-Inside Smithsonian Research Spr2008

Kimbra Cutlip

Recap - Changes since 1960's (due climate change?)

1. **Surface Water Temp incr. - Narr. Bay** :ann.water temp: **~ +1.1°C** since 1960 + **winters have warmed ~ +1.5°C (Nixon *et al*. 04, Oviatt 04) + *will* rise +4°C? +6°C? by 2100**
   = altering metabolic rates + species shifts at all trophic levels

2. **Precipitation rates & Cloudiness increasing - Winters in NE wetter - changes to PP ? + alters salinity & density stratification in upper 1/3 of Bay on seasonal (high riverflow) basis + alters estuarine circulation of Bay**

3. **Changes in seasonal average wind direction +/or speed ? - will *alter estuarine circ. & stratification* = *hypoxia* duration▲???**

4. **Ocean acidification (decr pH affects shelled orgs - $CaCO_3$)**
   - Recent evidence of neg. impact to bivalve larvae (oyster)

5. **Sea level rising - projected min ~1 m (low ball)**
   - impact on shallow habitat? - salt marsh hab?
   - new shallow habitat formation?

Major Groups of Pollutants – responses to ▲???

- **Nutrients - ↑ with stormwater flow incr., but good ability to decr. point source loads significantly (35%)**
  - **- Decr Hypoxia Severity ? Duration?↓**
- **Temp Incr - Effects on sp distrib – warm sp ↑ Cool sp.↓**
  - **Hypoxia ?**
- **Toxics - unclear - Point sources (U.S.) ↓ for typical toxics but new issues like endocrine disrupters**
- **Sediments – likely ↑ due increased stormwater + flashy flows**
- **Pathogens - likely ↑ due stormwater + incr. Temp.**
  - **- leading to *in situ* growth ?**

Facing Future?

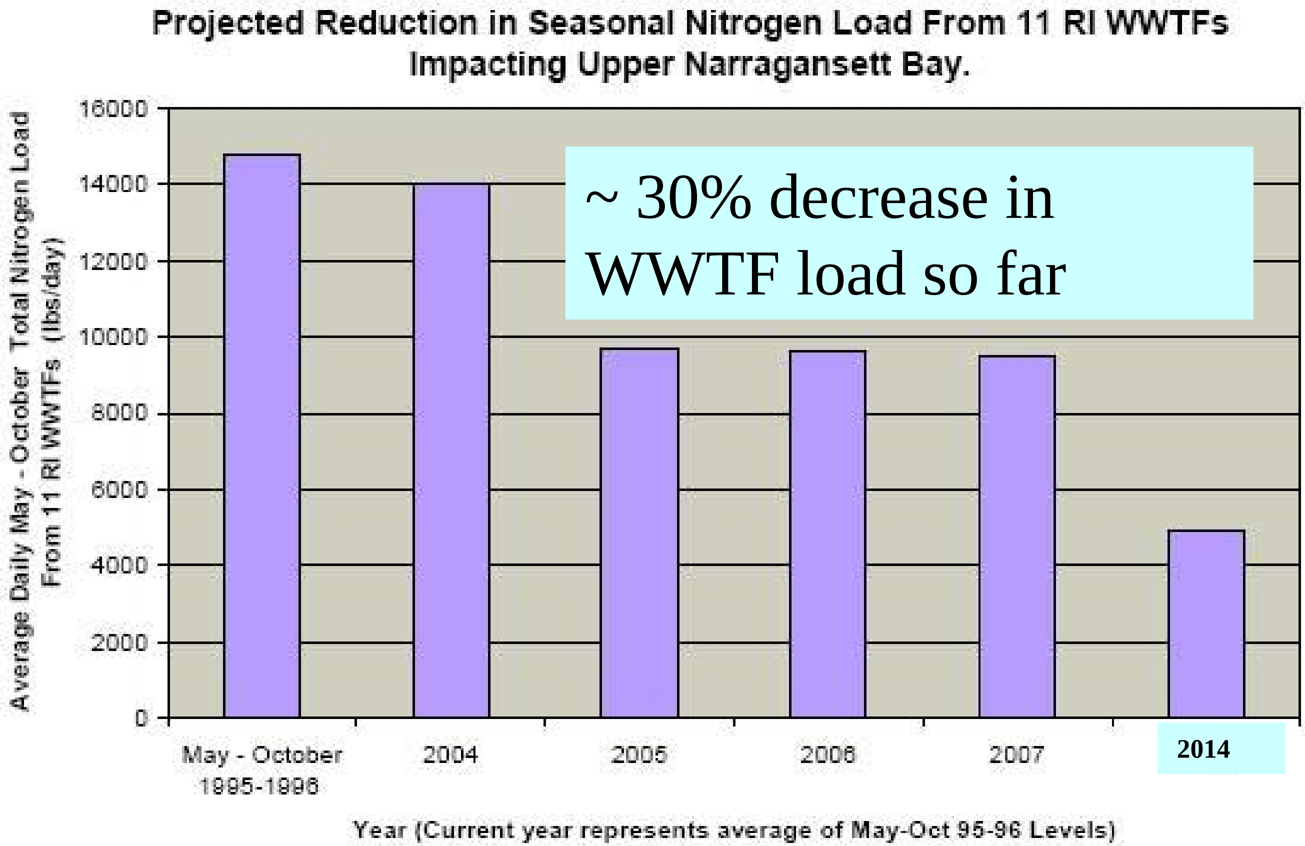
– Not just Sea Level Rising and Temperature Increases :

Climate - Driven Changes to *whole* Ecosystem

Will effect backgrnd conc. N, toxics due stormwater + mult. complex ecological responses to changing physical drivers

- Incr FW Flow & decr wind speeds change stratification + flushing rate !!!!
- Temp Incr increases respiration + bacterial growth !!!
- Water Column stratification ▲??? (Sal/Temp/Wind)
- Incr Hypoxia ??? -Decouple bottom - respire all org C in water col (starve benthos even with plenty of surface food !)
- Incr. Cloudiness - impacts on Prim Prod?
- Species Shifts Driven by temp. & other climate factors
  - Gelatinous Predators ↑ Southern Species shift north?
  - Phytoplankton changes in bloom timing, conc. + *sp*. shifts

Projecting a decrease of 50% DIN from WWTF loads from new permit limits
~ 35 % decrease Tot DIN to Bay (BUT > for Upper Bay)



- Bad Decision ? Controversy Rearing?

Is there potential to reach tot N level too low to sustain present shellfisheries & fisheries w/ the projected AWT load decreases?

I Historical record of RI fisheries (including shellfisheries)

Oviatt et al. 2003

V

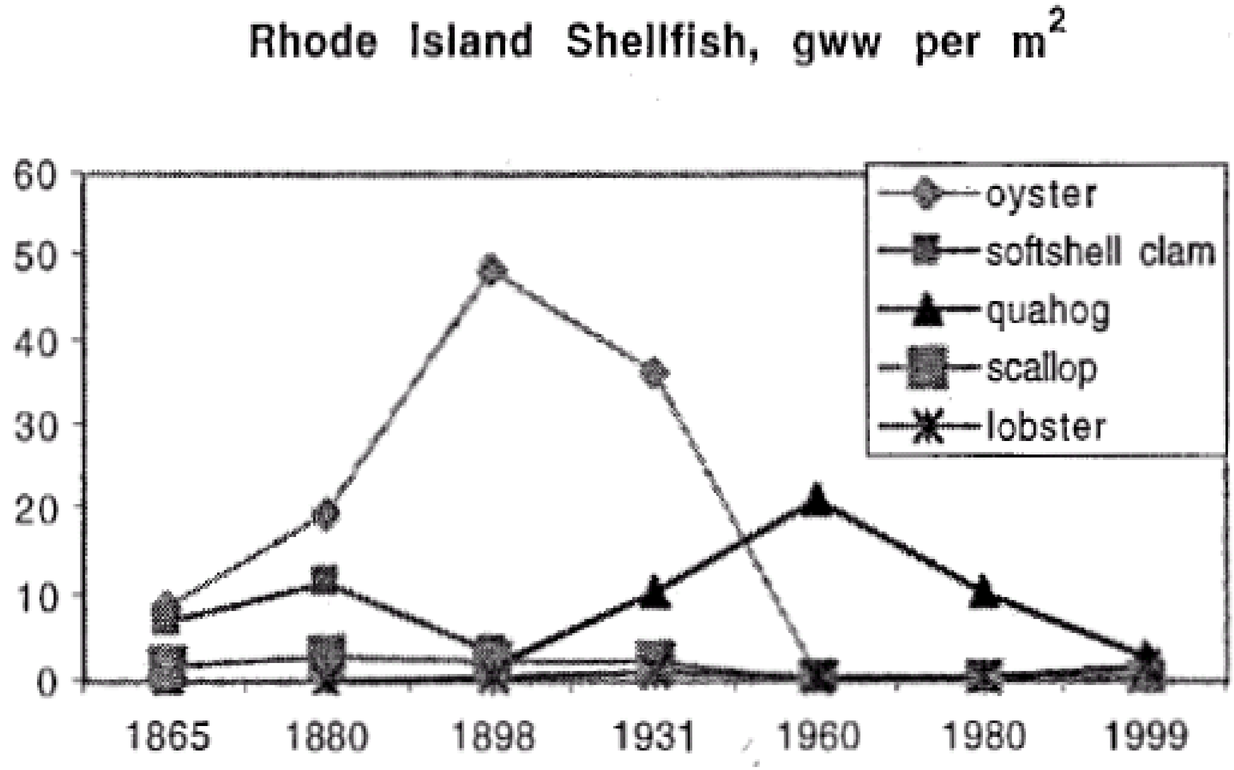


FIGURE 10. Rhode Island landings of shellfish to 3 miles offshore. Biomass was estimated according to area of habitat (see Table 1).

ing

r Bay

F

C

l.

Projections for Tot N load after decr (tertiary Trt) ~ 1950s-1960s

Any evidence of Positive Responses in Other Systems w/ Decreased N load ?

Tampa Bay FLA – mid **1970's = 9.9 ton N**/yr (**60% drop N due 1984** AWT removal of WWTF effluent

1985-91 = **3.9 ton** N/yr to Tampa Bay) (deep well injection)

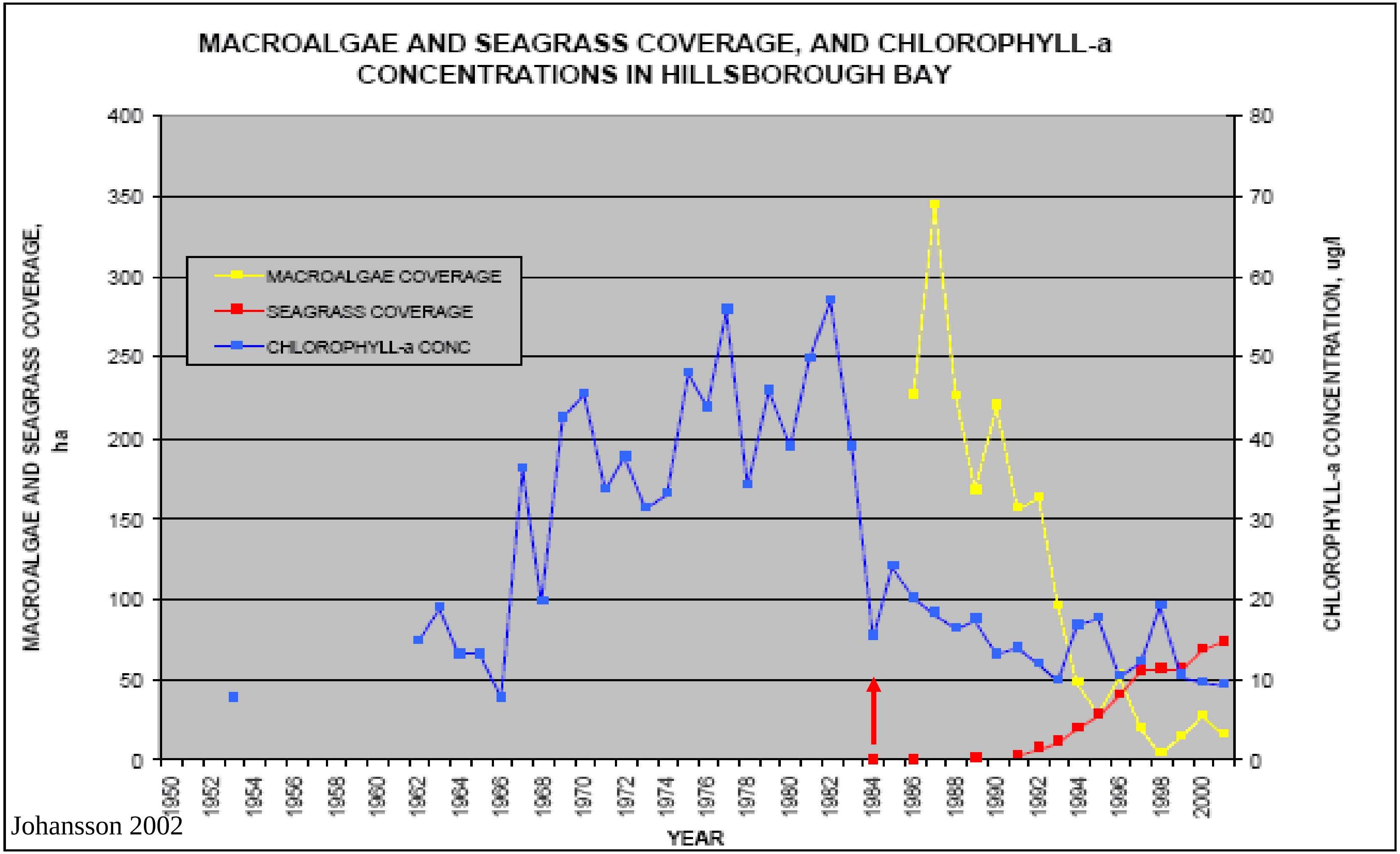


Figure 13. Macroalgae, seagrass coverage and chlorophyll a concentrations in Hillborough Bay, Florida.

Realize **ECOSYSTEM CHANGE**

IS* COMING – *inevitable

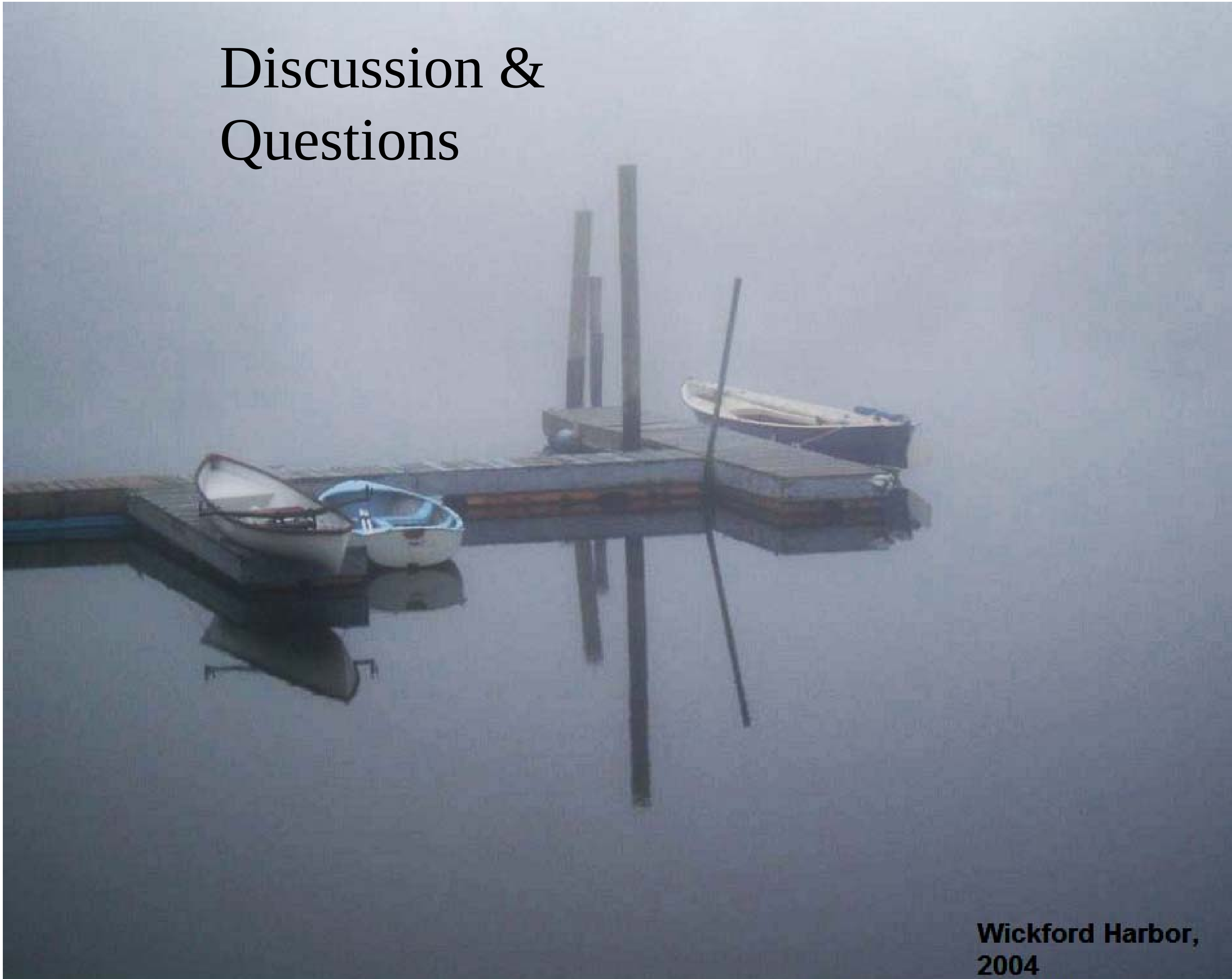
prioritize efforts - Be Adaptive in Management Responses - concentrate on where get best outcomes

minimize the most serious impacts from the changes

Recognize Climate may shift assimilative capacity

DO NOT AVOID dealing with the coming changes !!!

Whether or not you build/plan for it , changes will come !!!



Wickford Harbor,
2004
C.Deacutis

“Mitigation and Adaptation are decisions to be made by society, but they should be informed by Science .” Jane Lubchenco (NOAA) 2008

“Adaptive Mgt” response ?
Less “bean counts” & legalese - more focus on Ecosystem Responses and Basic Reasoning and Thoughtful Actions based on facts available

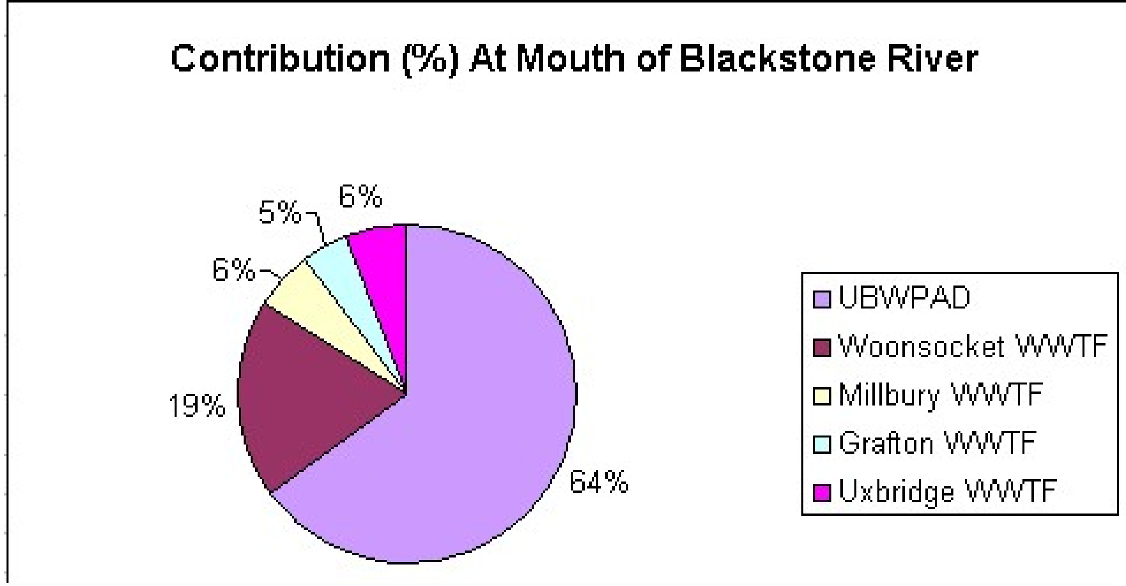
1. Need to better understand how ecosystem works
2. Need Document changes (= smart monitor commit)
+ Understand Consequences of these changes
4. Develop , evaluate , prioritize options for mgt. responses with potential to alter/ minimize neg. impacts from changes

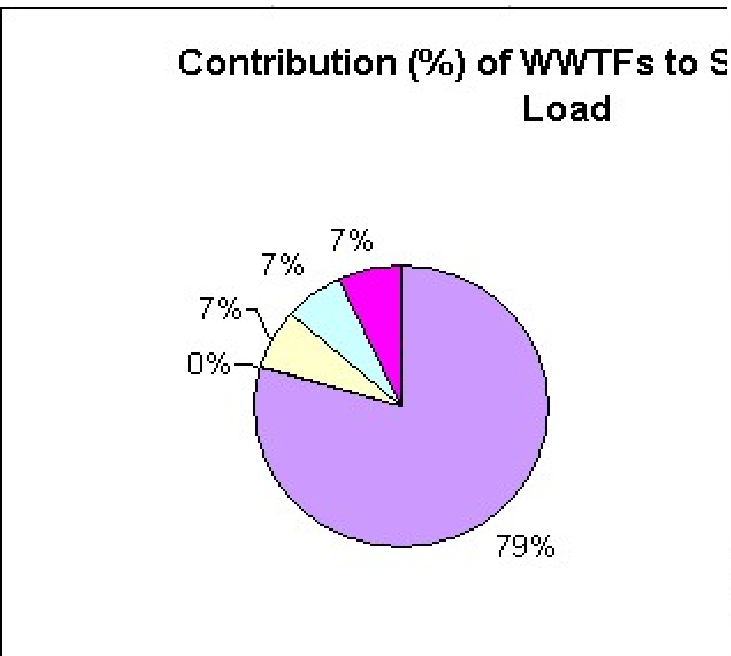
keep forward motion towards desired goal

DIN Load at mouth of Blackstone from WWTFs

WWTFs represent 68-73% of total DIN load to Narragansett Bay

Blackstone River WWTFs = 2nd largest source N load after Direct Discharges to Providence-Seekonk R.





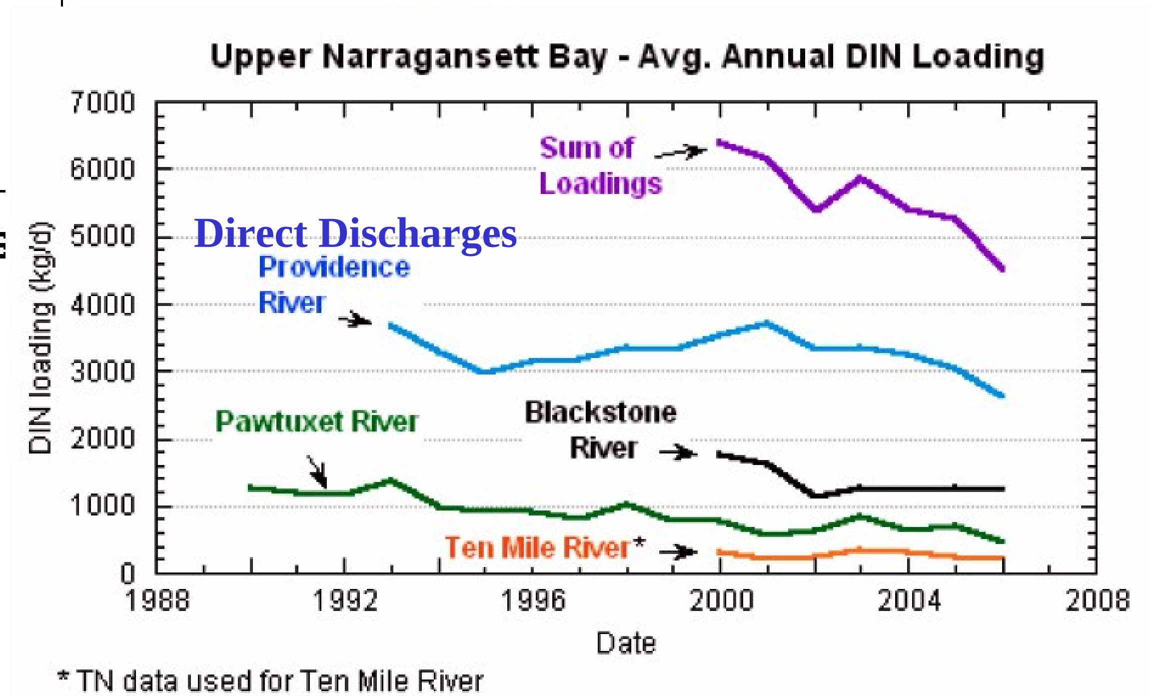


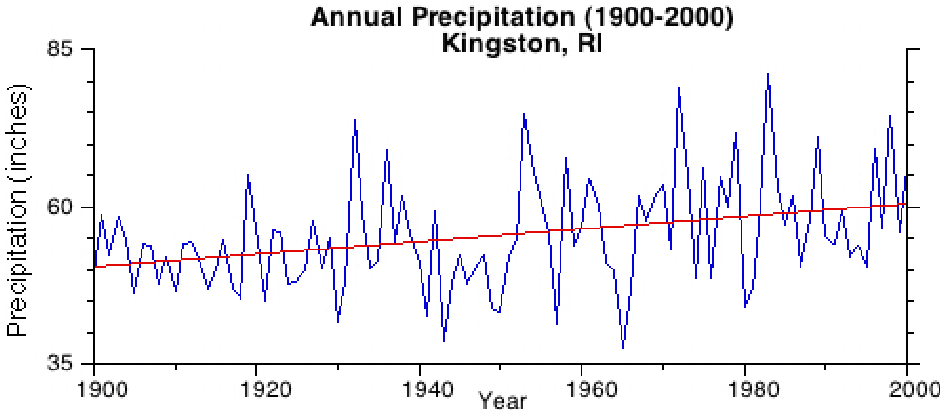
Figure 14 – Average annual WWTF DIN load to Providence-Seekonk River. Note that estimates of attenuation from RIDEM (2004) have been applied to discharges carried by tributaries. Pryor et al . 2007

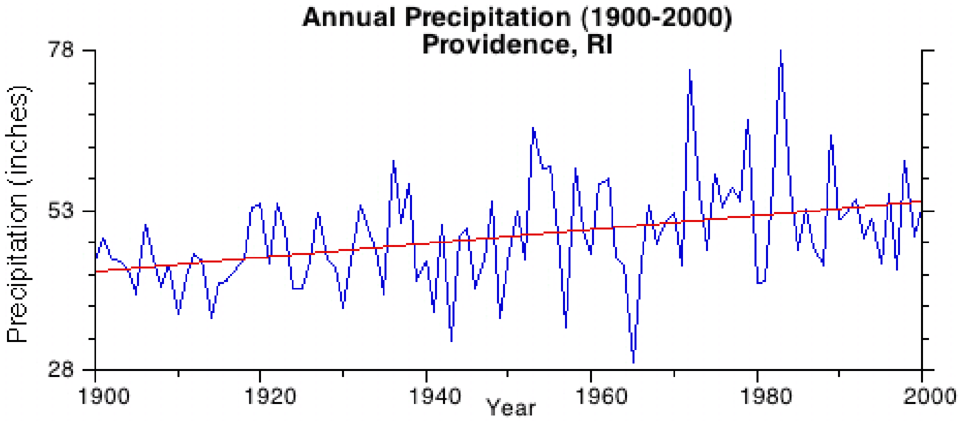
• Avg annual precipitation - increased 30.5 cm over last 100yrs

• Precipitation in NE predicted to increase in Spring

- decr. in late summer / fall

- incr. 20-30% in the winter over the next 100 years.



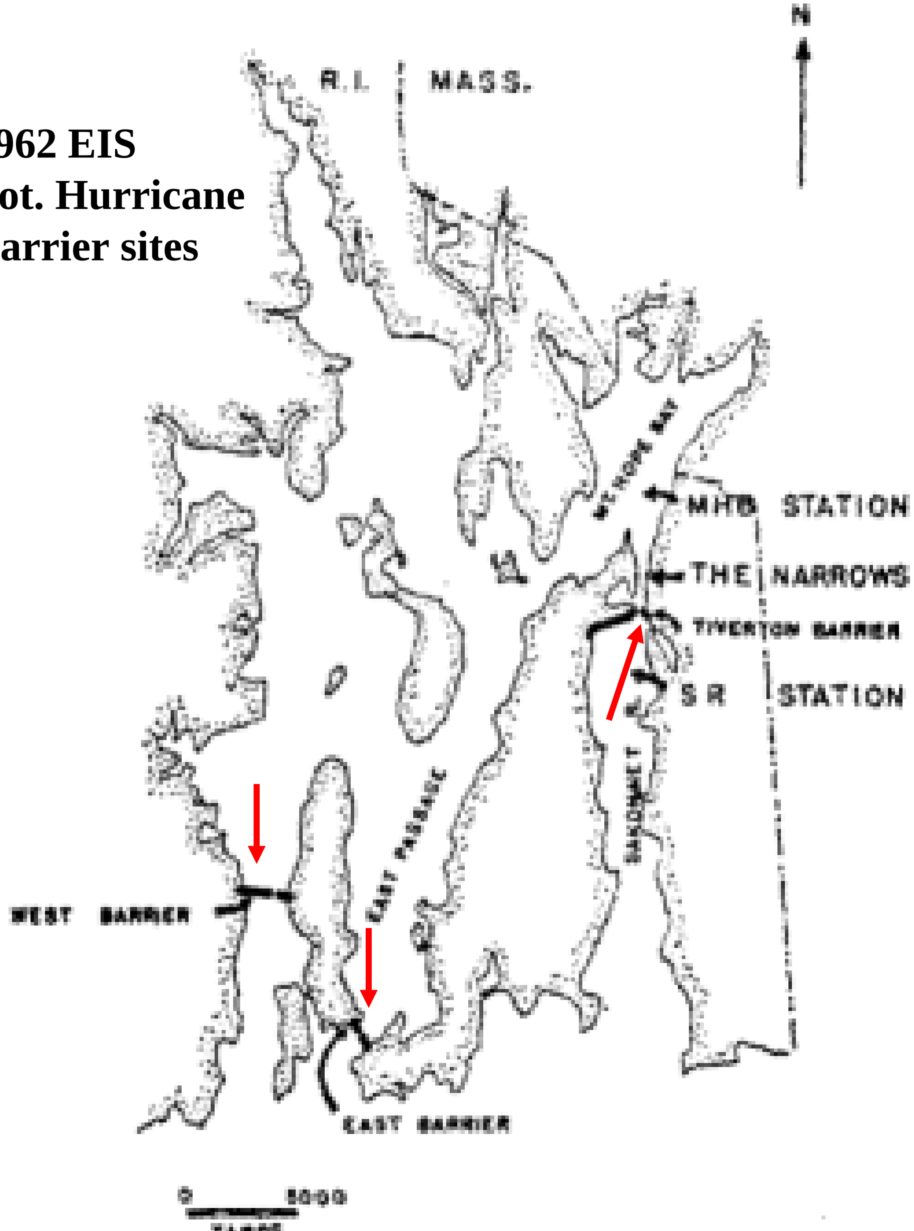


•New England - 1948 – 2006 : frequency of heavy storms increased 61 % = largest rise of any U.S. region. - RI - heavy rain / snowfall 88 % more common in Rhode Island vs. 60 years ago (1948-2006)

Environment Rhode Island Research & Policy Center 2007

Climate Change in the U.S. Northeast ***A report of the Northeast Climate Impacts Assessment (NCIA), October 2006*** **(http://www.northeastclimateimpacts.org)**

1962 EIS
Pot. Hurricane
Barrier sites



We Do Not Understand Estuarine Ecosystem responses well

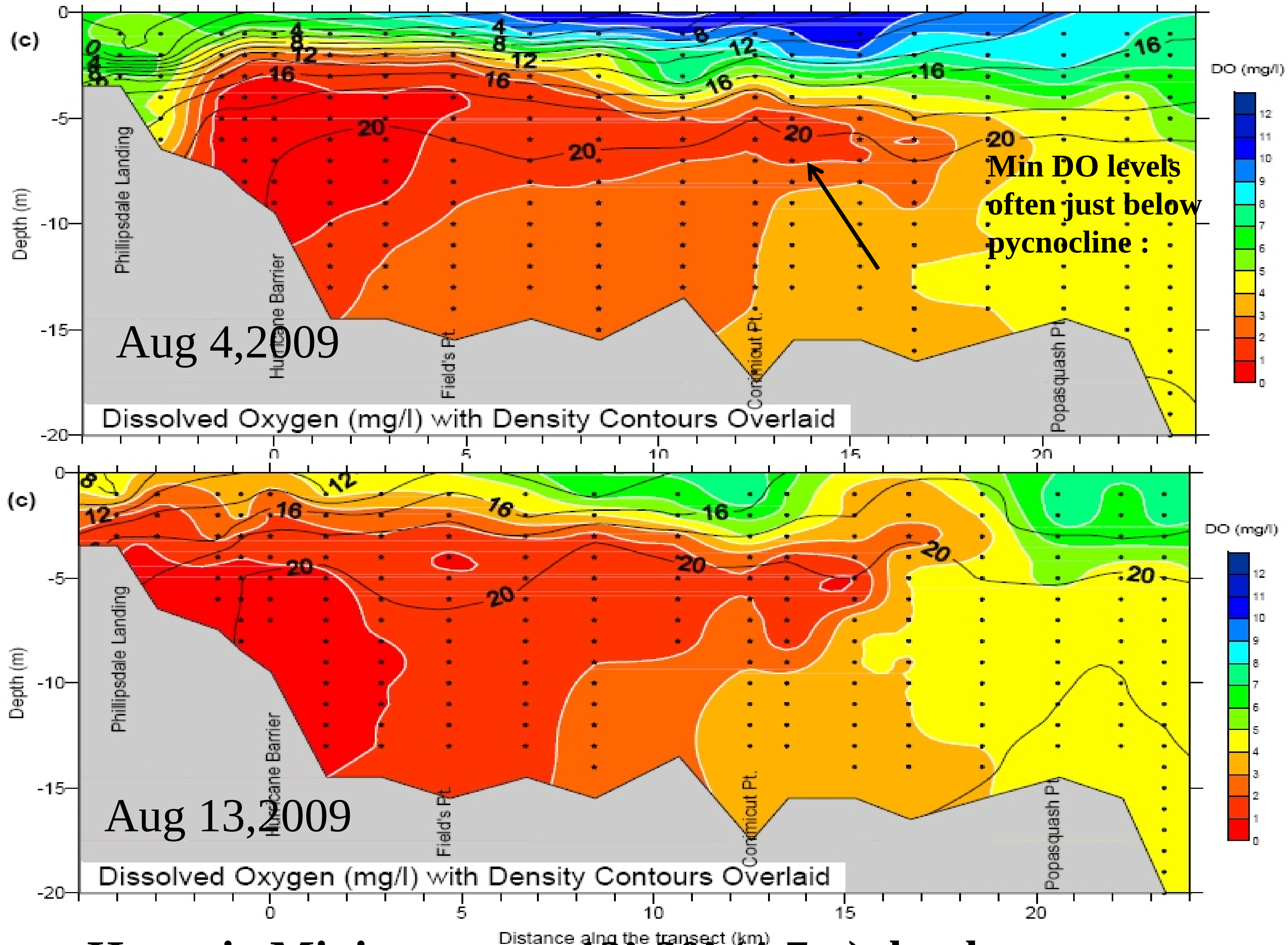
Need careful thought, logic and ADAPTIVE decisions.

Very close calls of serious errors in past w/o recognizing the dangers:

e.g., EIS for orig Hurricane Barrier positioning :

Original hurricane barrier placement for EIS - Today, we realize the decreased flushing would lead to a Bay with terrible WQ

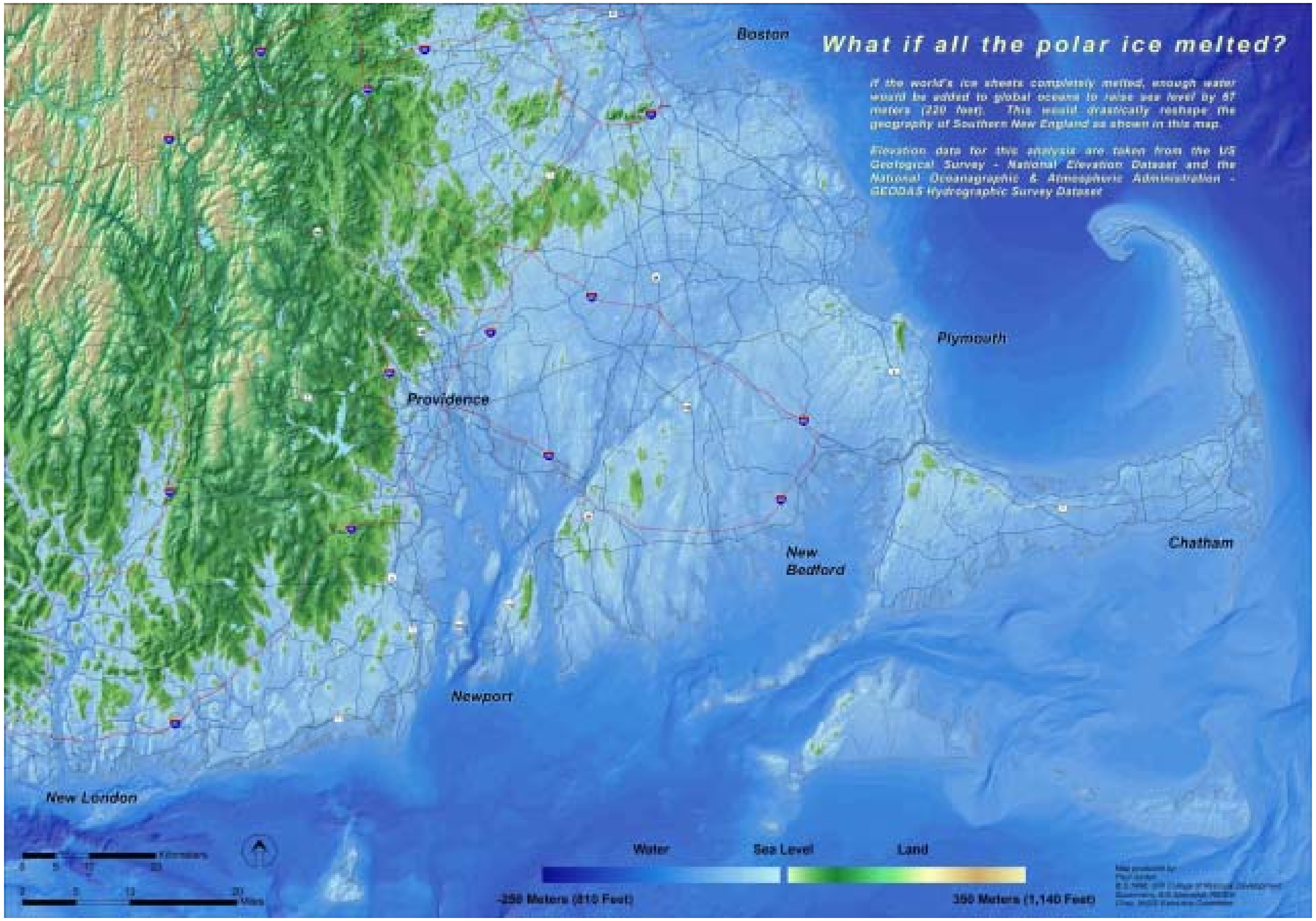
Ship Channel - Providence down to Bristol (top 1/3rd of Bay)



Hypoxia Minimum - at 12'-20' (4-7m) depth zone

The Future : Significant Changes in water classes and areas to Salt water A class waters?

Unanticipated Benefit - **no more Cape Cod summer traffic !**



Paul Jordan, RIDEM poster “what if scenario” :
Full melt of polar ice caps on land

Expect : Sea Level Rise

(Due : Thermal expansion of seawater ; Melting of glaciers and ice caps (on land) ; snowfall – melting rate)

Sea Level Rise: Observed vs. Projected Models underestimate ! (var. sources : J. King)

Interval	Model Prediction mm/year	Observed mm/year
1993 - 2003	2.6	3.1
1961 - 2003	1.2	1.8

Conclusion: NE *at least* 3' rise *highly likely* next 100 yrs - may be greater

Conclusion : Expect *faster rise* vs original estimates

BUT - There *will* be some changes in water classes to Salt water !

Quonnie Pond: present sea level

Quonnie Pond: 3 ft. sea level rise ~90 yrs (source : J. King, URI)

Loss of CWA USES ? Should we do TMDL's for areas like this?

Potential Changing Habitat
- loss of saltmarsh wetlands filtering services

- increased shallow open water for macroalgae problems ?

Paul Jordan, RIDEM
SL rise of 5’ - Wickford,RI