Retrospective Analysis of a Multidecadal Phytoplankton Time Series in Narragansett Bay: Ecological Threshold Responses to Climate and Nutrient Stressors

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ECOLOGICAL RELEVANCE OF THRESHOLDS INVESTIGATED

- **To facilitate understanding of the causes and consequences of climate change on a representative temperate estuary using the climate change indicators, such as temperature, North Atlantic Oscillation Index, Gulf Stream Index**
- **Quantifying the role of short- and long-term changes in nutrients and their ratios on phytoplankton functional group selection and linked trophic processes**
- **Establishing importance of external vs. internal ecosystem drivers on plankton processes**

ECOSYSTEM SERVICES IMPACTED BY THRESHOLDS

- **Nutrient Cycling, Water Quality**
- **Plankton Dynamics, Harmful Algal Blooms, Fisheries**

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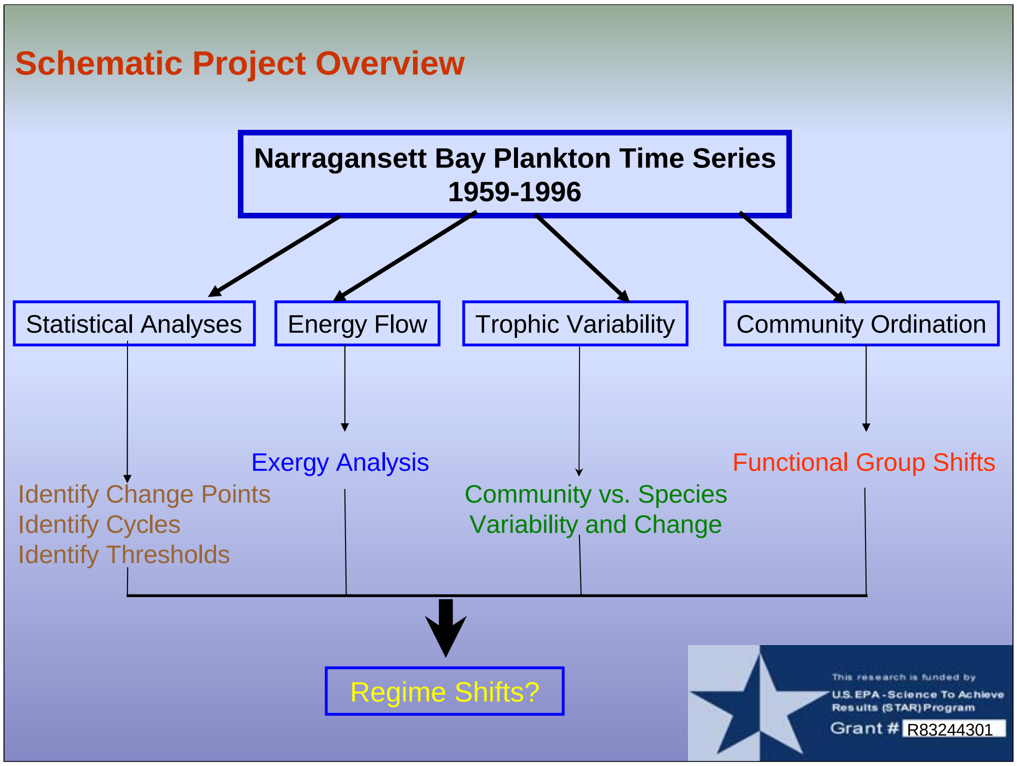
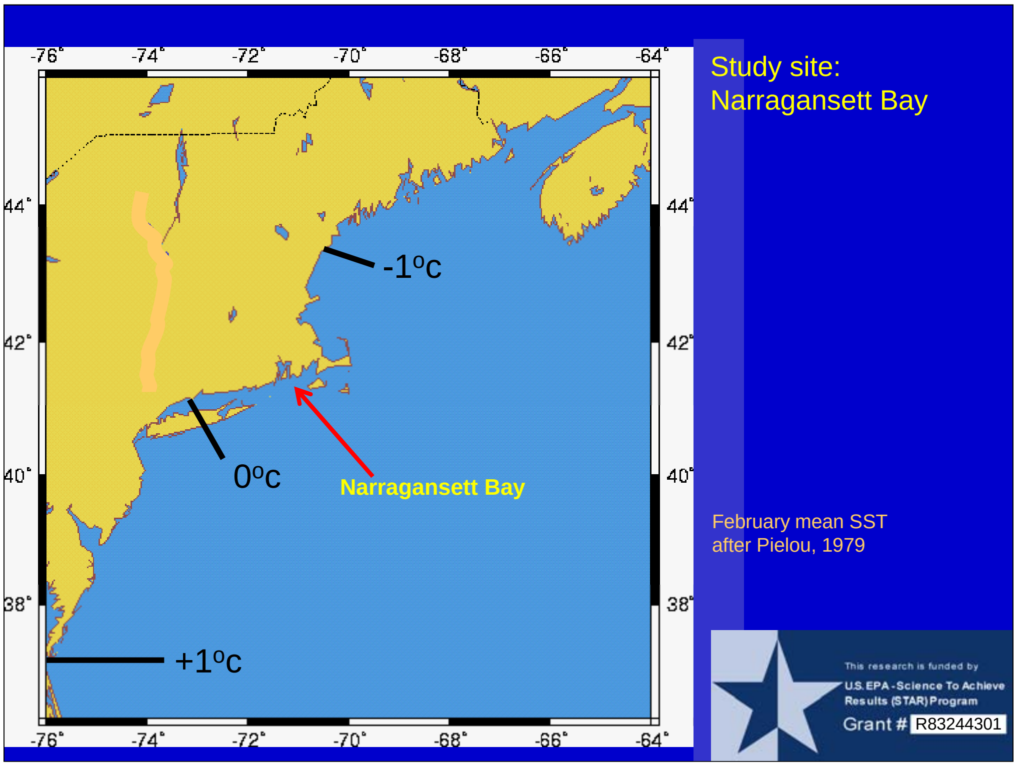


This is the longest dataset of its type. Measurements are taken weekly. It is important to remember that many different processes occur on a daily or even hourly basis.



Narragansett Bay is at a biogeographical junction. The area is particularly vulnerable to climate change.

Aerial photo of Narragansett Bay
(Courtesy of R. L. Wilke)

Narragansett Bay

ca. 328 km^2
Mean depth: 8m (~60m maximum)
Salinity range: 20-32
Temperature range: -2 to 25 C

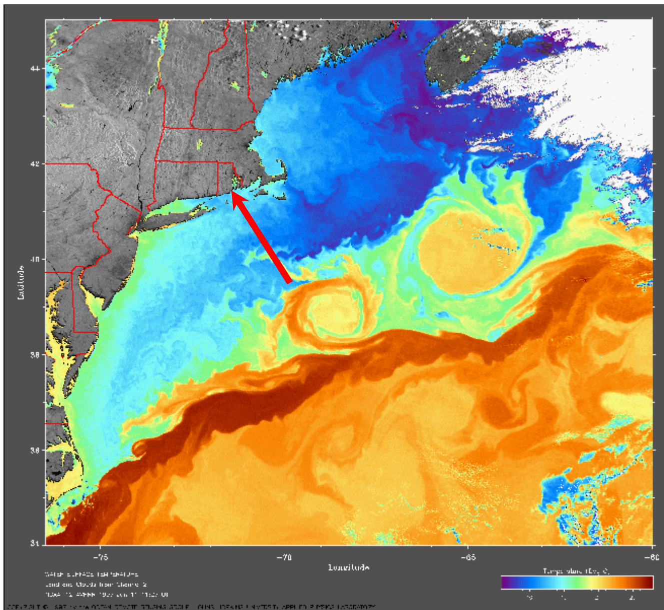
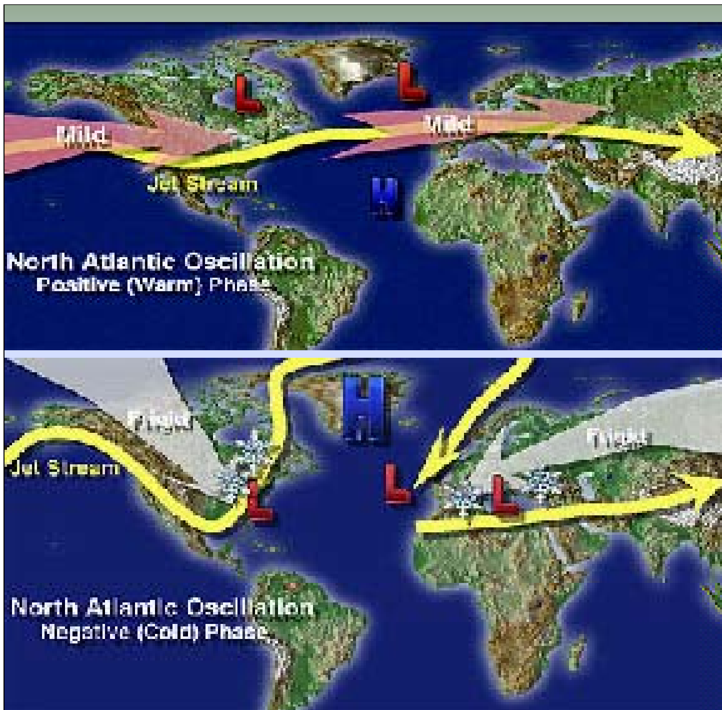


Figure 1: Location of long-term sampling station (Station II, approximately 41o 30' N, 71o 20' W) in the lower west passage of Narragansett Bay, Rhode Island. Inset: thermal image of Gulf Stream (image date 11 June, 1997; image source: http://fermi.jhuapl.edu/avhrr/gallery/sst/eddy_97jun11/eddy.html) showing Narragansett Bay (red arrow). Gulf Stream north wall is ca. 400 km south of Narragansett Bay and edge of warm core ring is ca. 230 km south of Narragansett Bay in this image.

The researchers are studying the role of the Gulf Stream Index.



North Atlantic Oscillation (NAO)

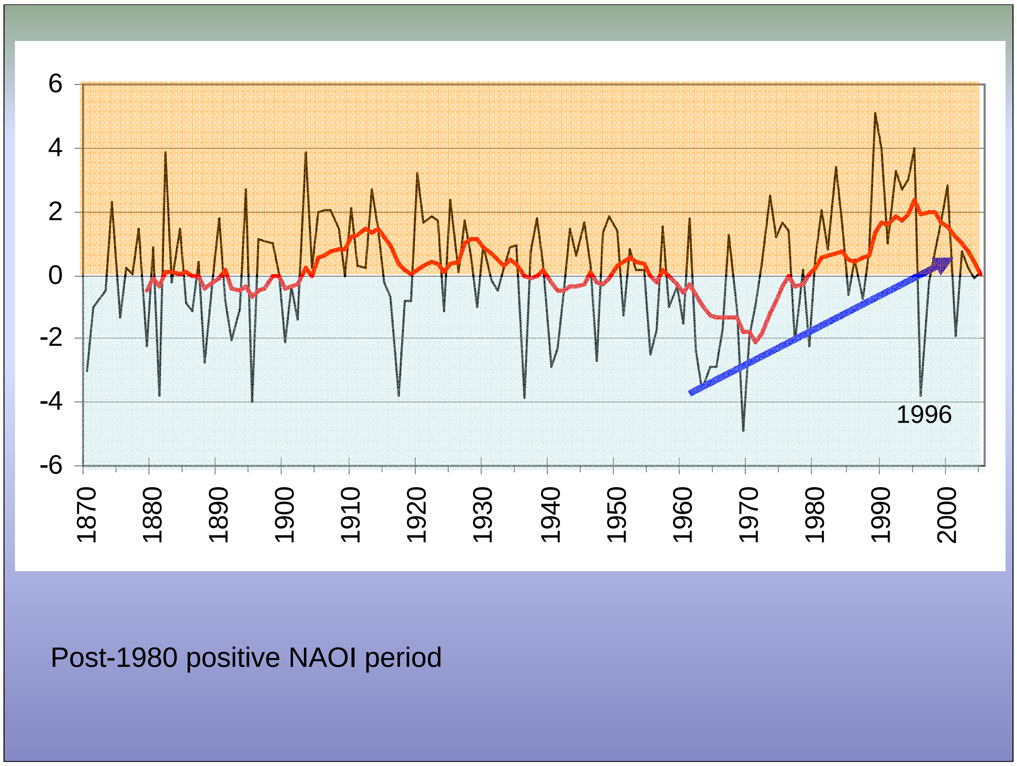
An index of 500mb (ca. 18,000 feet altitude) height and surface pressure over the North Atlantic.

Positive (warm) phase = low pressure Greenland, high pressure Azores

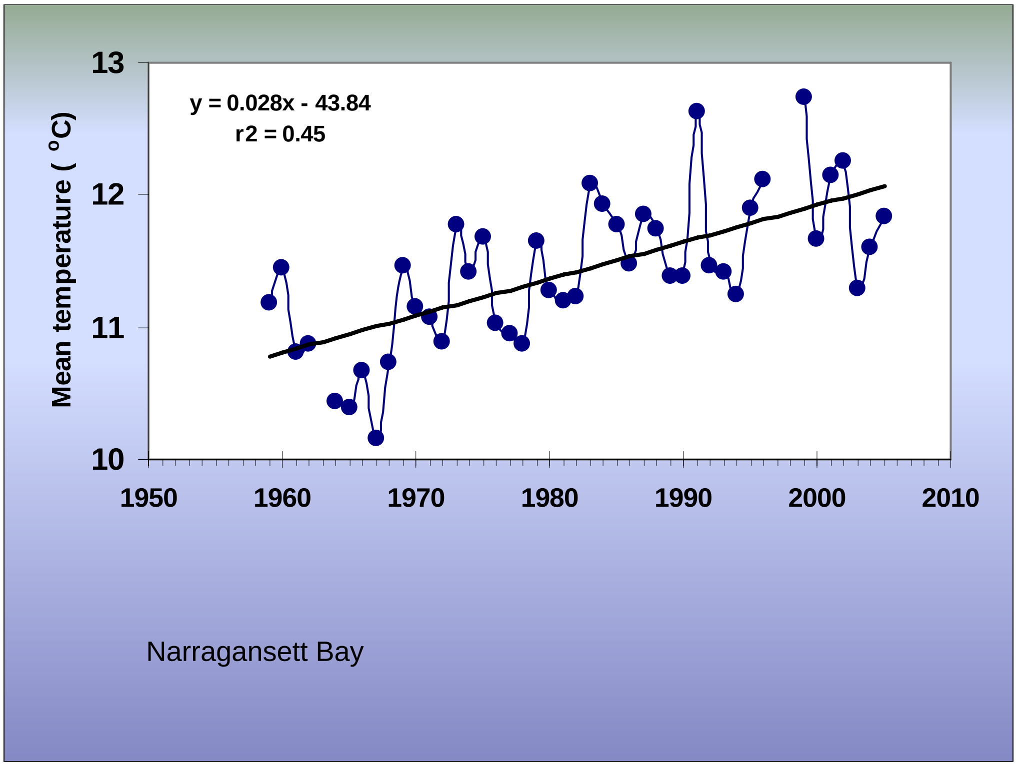
Negative (cold) phase = high pressure Greenland, low pressure Azores

Image credit: J. D'Aleo

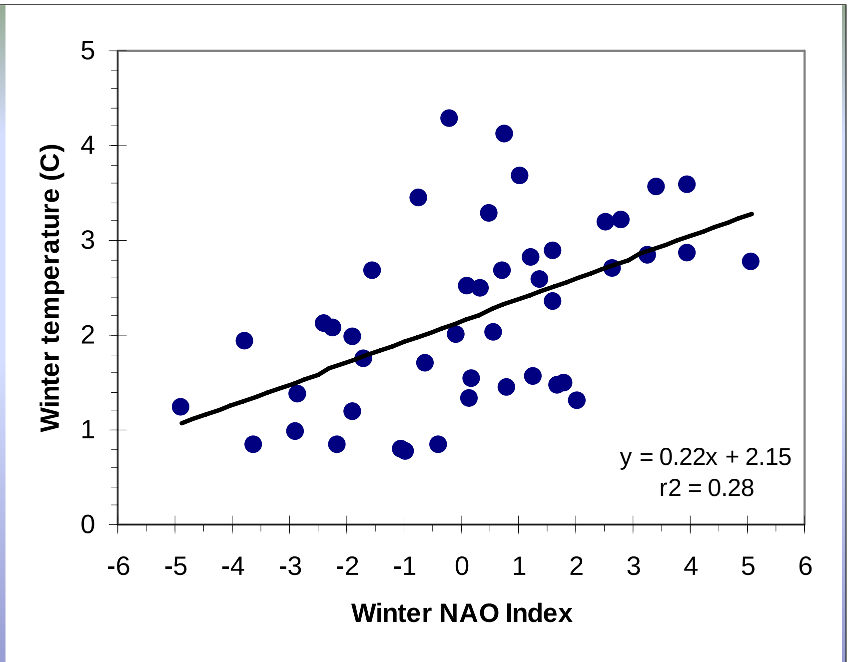
The North Atlantic Oscillation alters the temperature, wind, and amount of snow and/or rain.



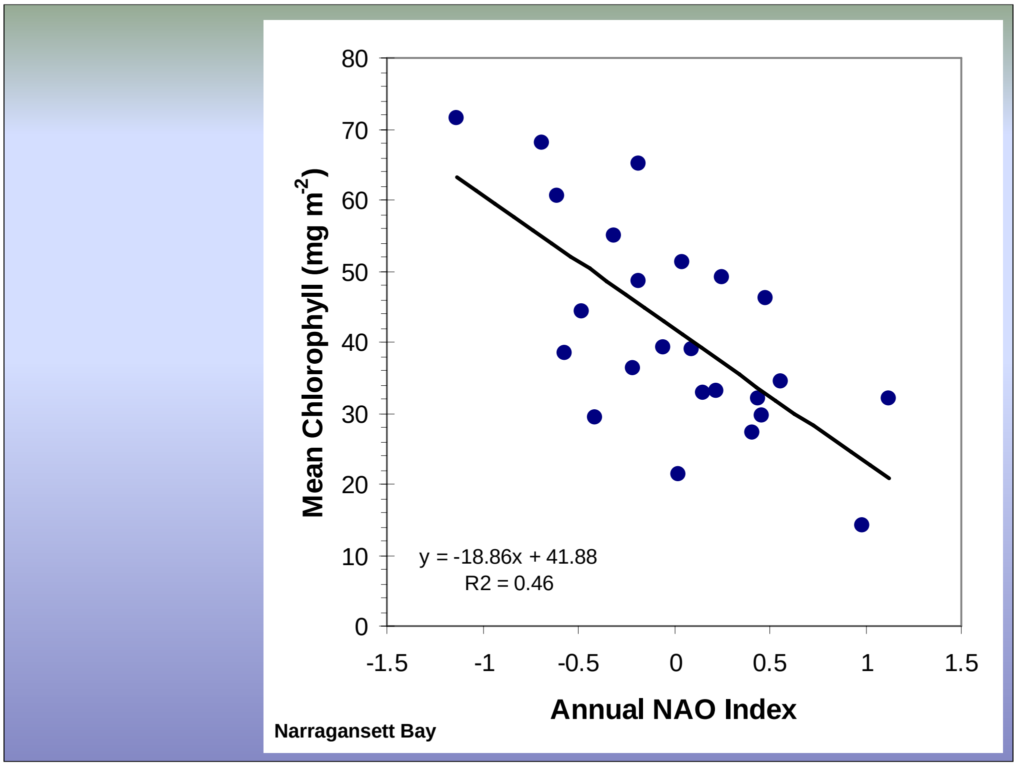
The period from 1960 to the present has been a period of warming.



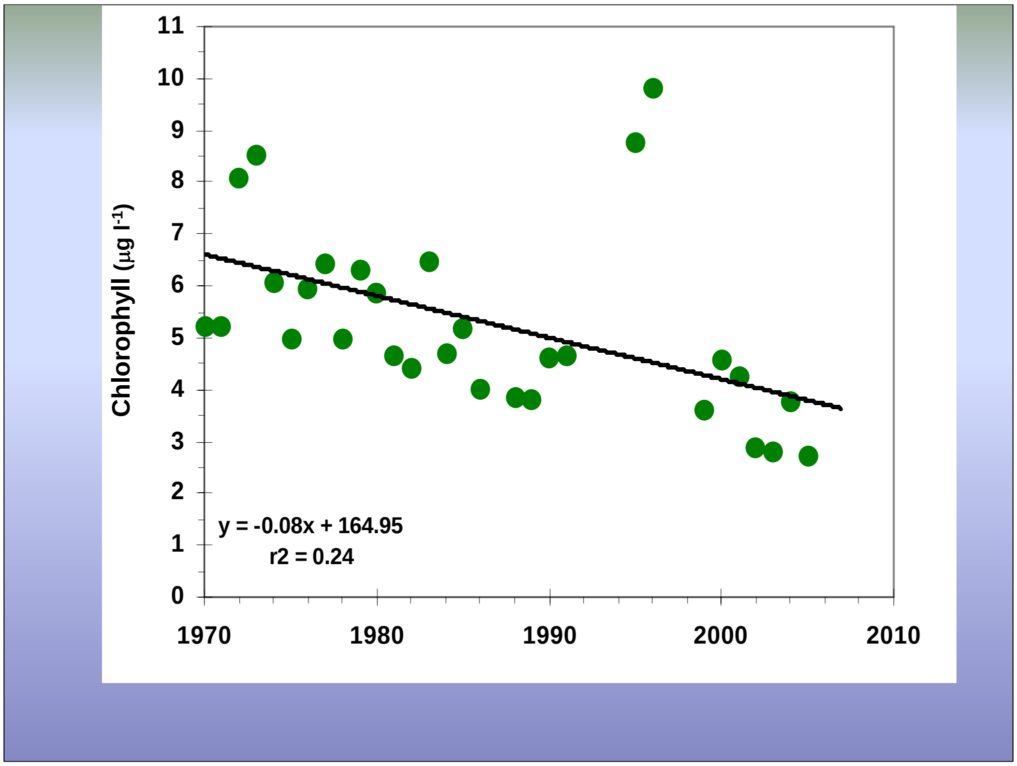
y = 0.028x - 43.84
r2 = 0.45
Mean temperature (°C)
13
12
11
10
1950
1960
1970
1980
1990
2000
2010
Narragansett Bay



Narragansett Bay



Mean Chlorophyll (mg m-2)
Annual NAO Index
y = -18.86x + 41.88
R2 = 0.46
Narragansett Bay



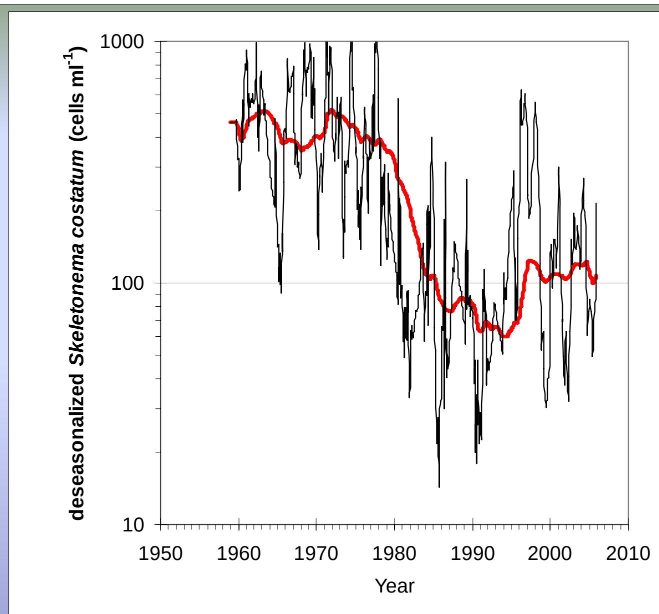
Chlorophyll (μg l-1)
11
10
9
8
7
6
5
4
3
2
1
0
1970
1980
1990
2000
2010
y = -0.08x + 164.95
r2 = 0.24

Skeletonema level declined :

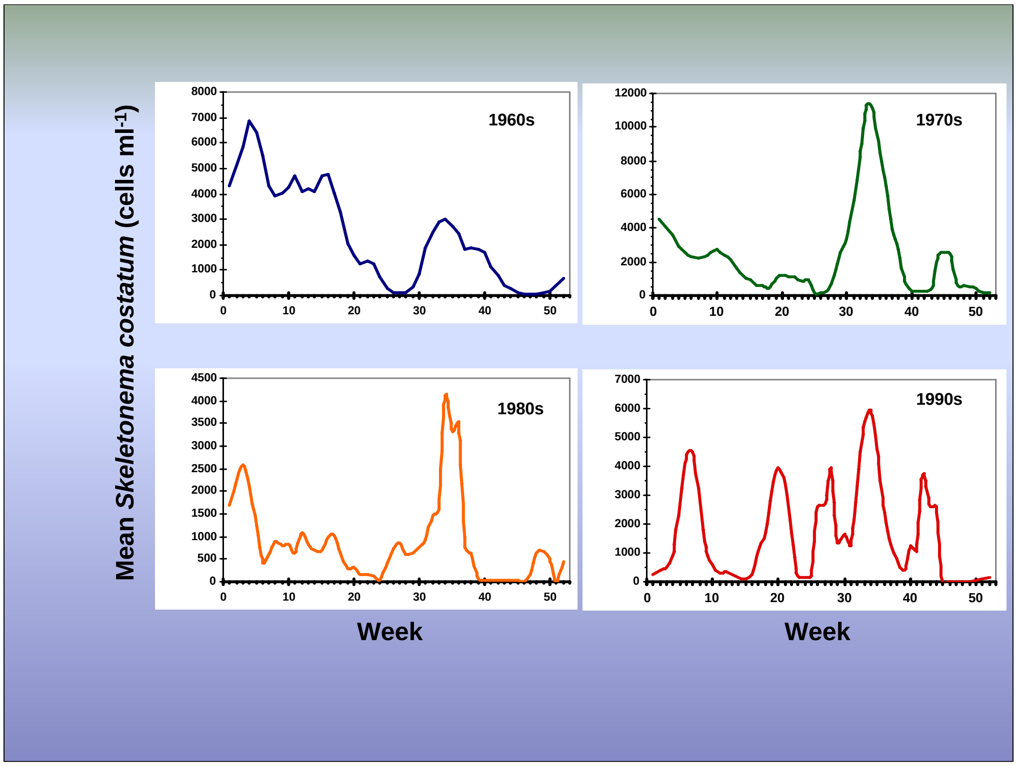
400 cells ml^{-1} pre-1980

90 cells ml^{-1} 1980-96

Updated:
111 cells ml-1 1997-2005



The early 1980s appear to be a change point.



In the 1960s, Narragansett Bay had a classic biological ocean environment, with a winter-spring bloom. In the 1970s, the winter-spring bloom disappeared; instead, the Bay had a summer bloom. An attempt to resurrect the winter-spring bloom appears in the 1980s. In the 1990s, blooming occurred across the seasons.

Narragansett Bay *Skeletonema* bloom timing, magnitude and duration - NAOI effects

Bloom response	(cold) (-) NAO Years	(warm) (+) NAO Years	p value
Annual maximum week	13	30	0.046
W-s bloom duration (weeks)	9	4	0.025
Maximum w-s abundance (cells ml^{-1})	24,967	1,713	0.009
1Q mean abundance (cells ml^{-1})	5,536	399	0.016
2Q mean abundance (cells ml^{-1})	2,578	166	0.009
% weeks >500 cells ml^{-1}	0.43	0.23	0.028

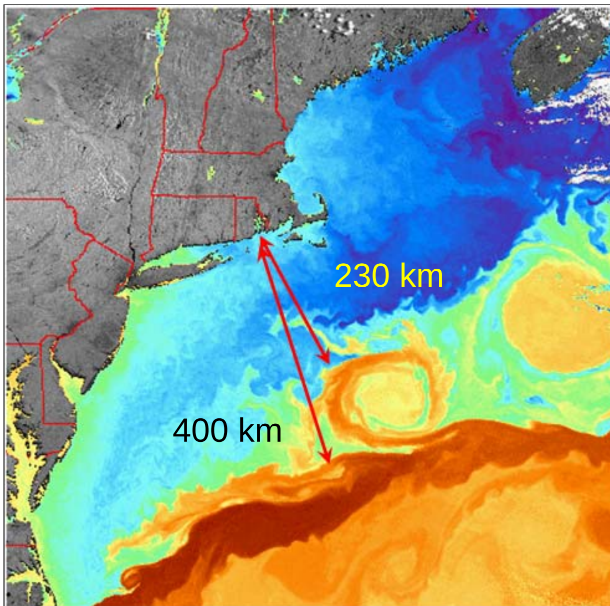
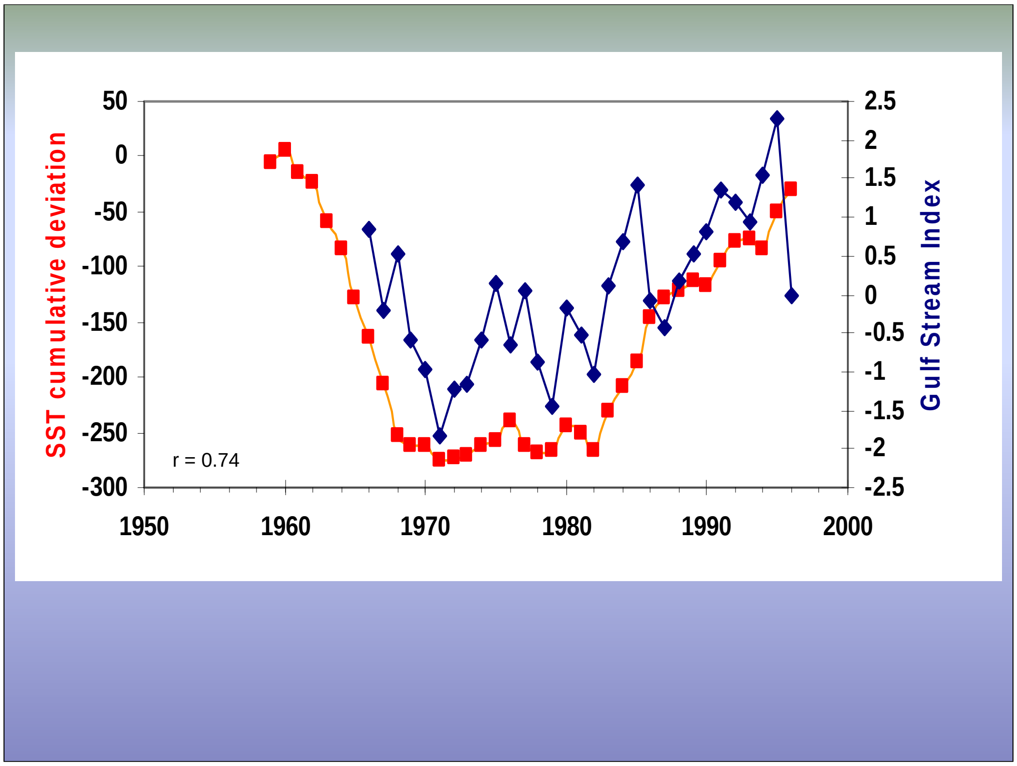


Image date:
11 June, 1997

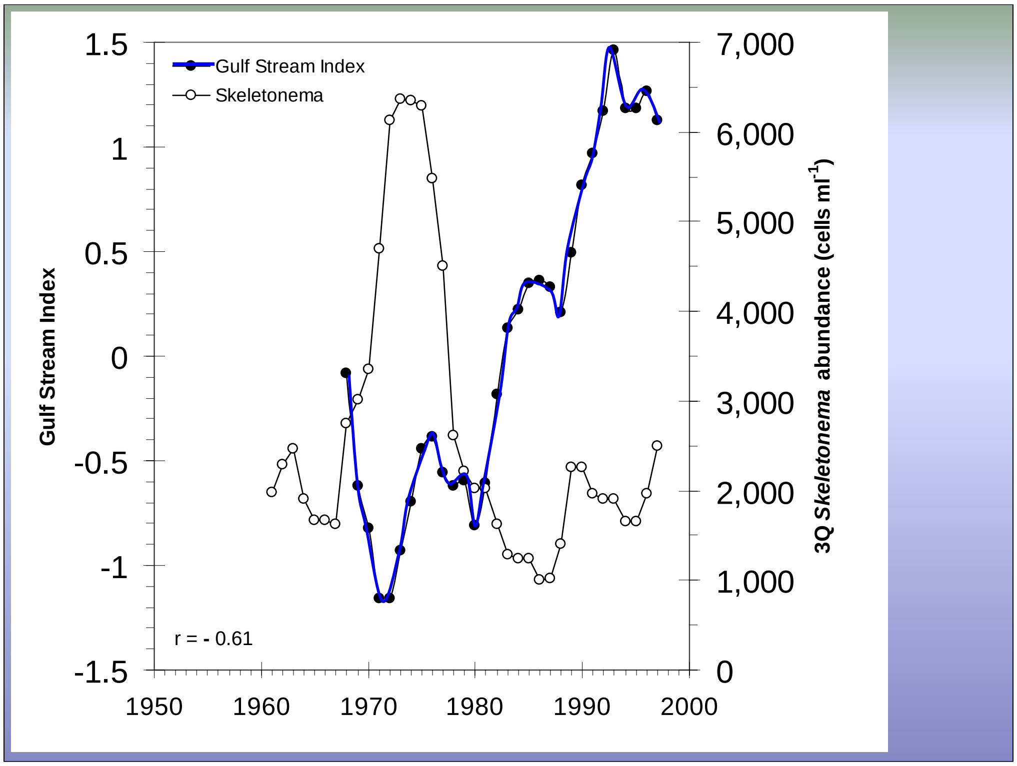
Gulf Stream influences on Narragansett Bay.

-Direct
- -Transport
    - fish
    - gelatinous zoopl
    - macrophytes
    - phytoplankton

-Indirect
- -Temperature
- -Salinity
- -Weather



SST = Sea Surface Temperature



Gulf Stream Index
Skeletonema
Gulf Stream Index
3Q Skeletonema abundance (cells ml-1)
r = - 0.61
1.5
1
0.5
0
-0.5
-1
-1.5
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1950
1960
1970
1980
1990
2000

***Skeletonema* bloom features during different Gulf Stream Index (GSI) states (1966-1996) as tested by Mann-Whitney test. GSI <0 corresponds to southerly displacement of Gulf Stream path; GSI >0 to northward displacement. Significant differences at $p < 0.10$ shown.**

Gulf Stream Position differences:

Bloom Character	GSI (-) Mean (n)	GSI (+) Mean (n)	p-value
Extreme (+) vs. (-) Gulf Stream years, i.e. most extreme North and South positions			
3Q mean (cells ml^{-1})	5,120 (5)	1,563 (5)	0.0283
S-f bloom peak (cells ml^{-1})	33,500(5)	14,480 (5)	0.0758
% weeks <10 cells ml^{-1})	0.15 (5)	0.41 (5)	0.0749
Gulf Stream < -1 vs. > +1			
W-s bloom peak (cells ml^{-1})	5,090 (5)	534 (3)	0.0253
% weeks <10 cells ml^{-1})	0.15 (5)	0.48 (3)	0.0512
Gulf Stream < -0.5 vs. > +0.5			
S-f bloom start (week)	28.0 (10)	31.6 (8)	0.0731
3Q mean (cells ml^{-1})	4,376 (9)	1,313 (8)	0.0161
S-f peak (cells ml^{-1})	24,754 (10)	10,664 (8)	0.0410
% weeks <10 cells ml^{-1})	0.20 (10)	0.36 (8)	0.0683
Gulf Stream < -0.1 vs. > +0.1			
% weeks <10 cells ml^{-1})	0.19 (13)	0.36 (10)	0.0233
Gulf Stream < 0 vs. > 0			
% weeks <10 cells ml^{-1})	0.20 (14)	0.33 (11)	0.0747

w-s = winter-spring, s-f = summer fall bloom

Skeletonema bloom thresholds

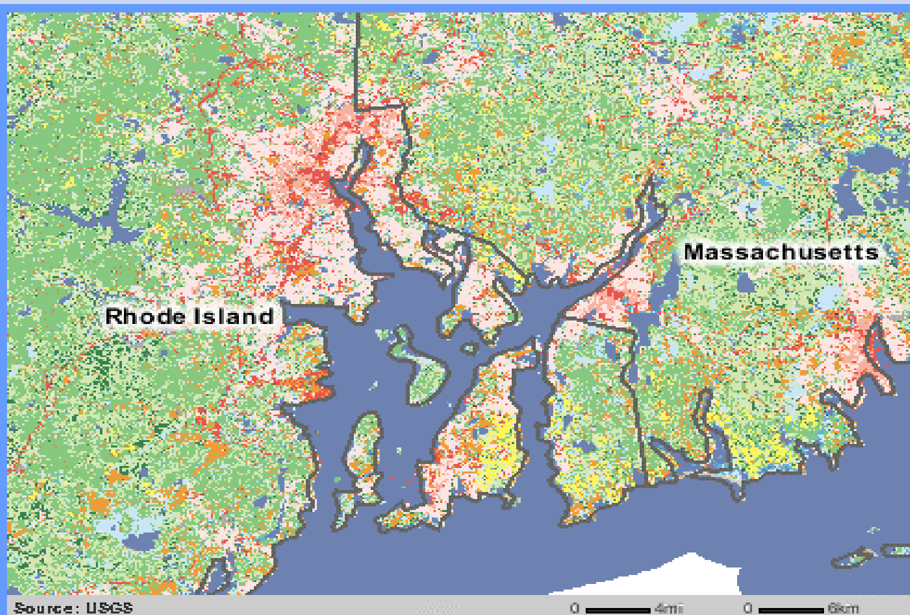
- **NAO**
  < - 0.7 ➔ winter-spring bloom
  > - 0.7 ➔ summer bloom

- **Winter (1Q) temperature**
  < + 2°C ➔ winter-spring bloom
  > + 2°C ➔ summer bloom

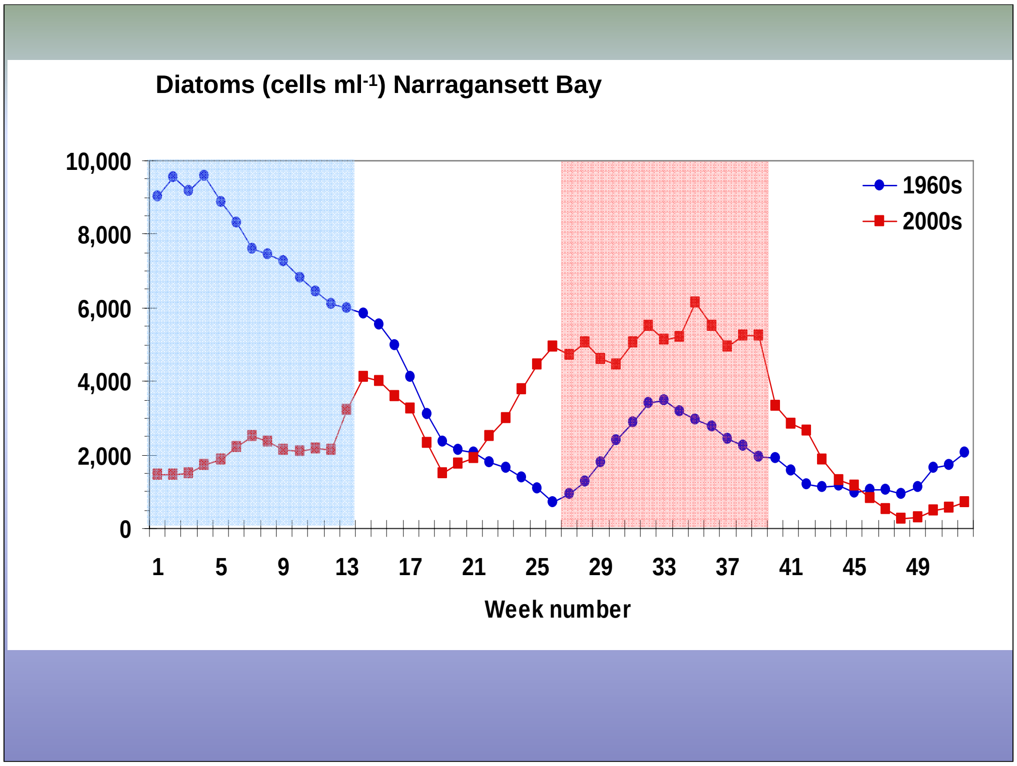
- **Winter (1Q) wind speed**
  > 5 $m\ s^{-1}$ ➔ winter-spring bloom
  < 5 $m\ s^{-1}$ ➔ summer bloom

- **Gulf Stream**
  < - 0.5 (= south) ➔ large summer bloom
  > + 0.5 (= north) ➔ small summer bloom

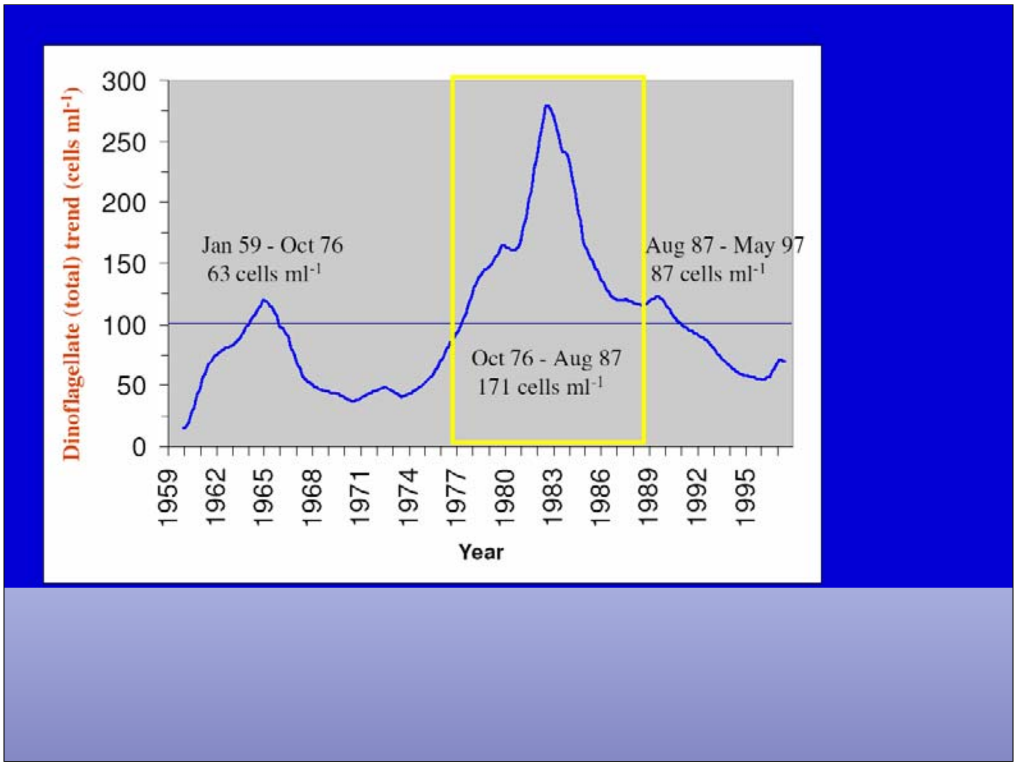
Internal Driver



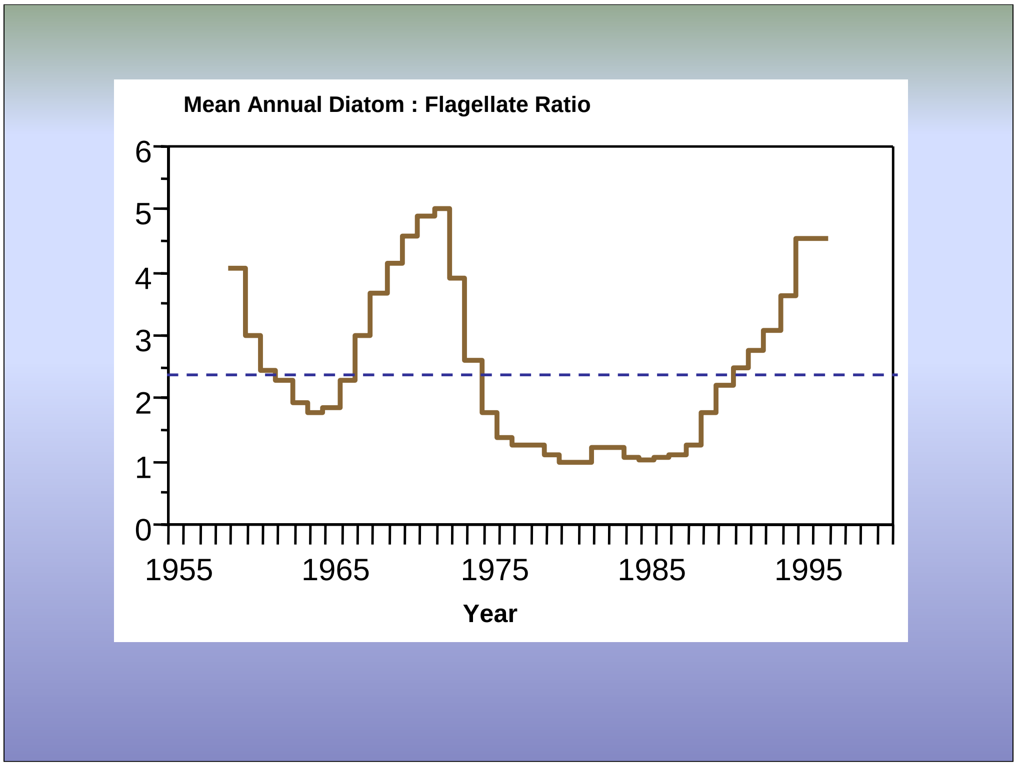
The red dots represent urbanized areas.

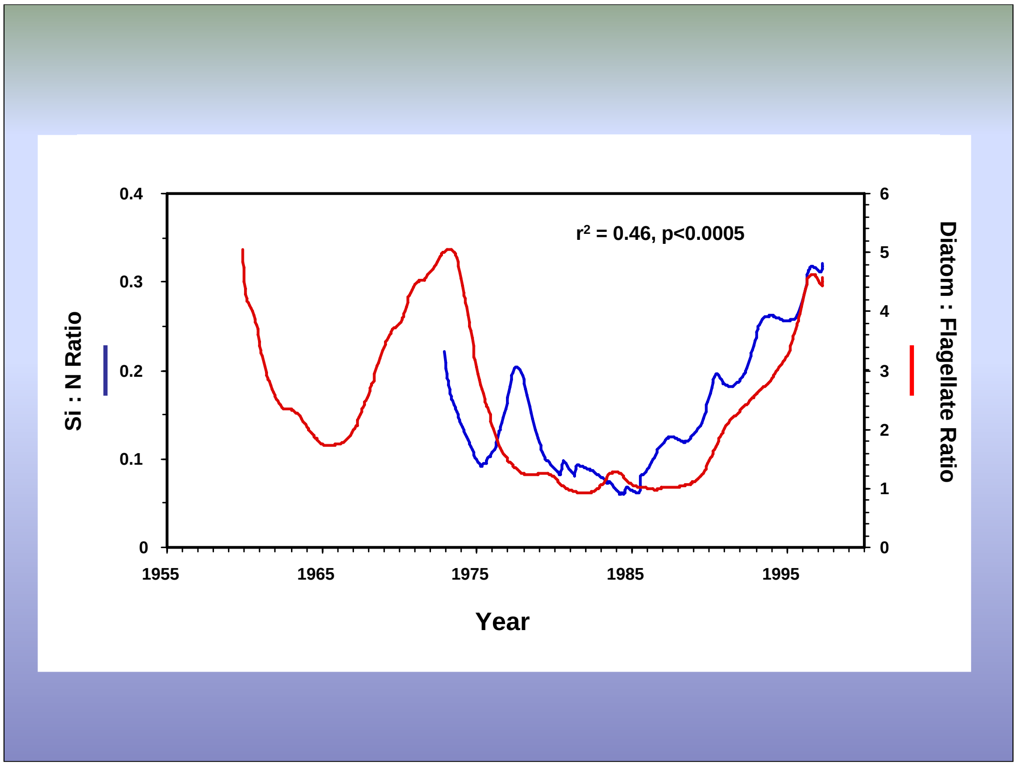


The impact nutrients may have on changes in abundance is a concern.



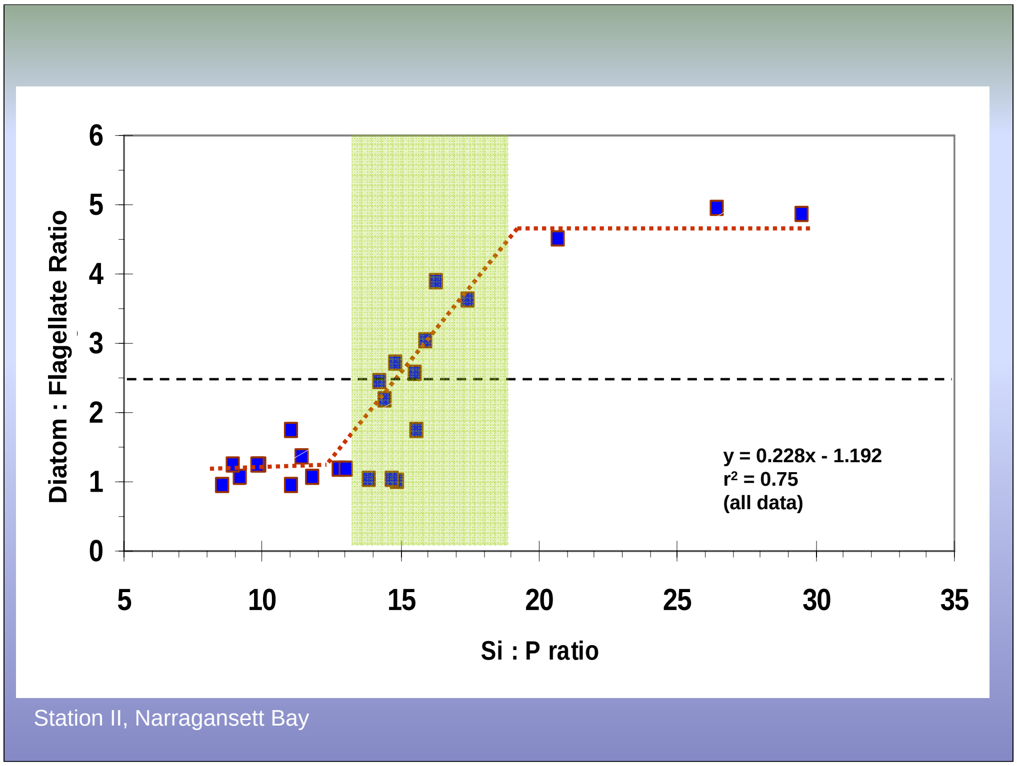
Dinoflagellate (total) trend (cells ml-1)
300
250
200
150
100
50
0
Jan 59 - Oct 76
63 cells ml-1
Oct 76 - Aug 87
171 cells ml-1
Aug 87 - May 97
87 cells ml-1
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
Year


Mean Annual Diatom : Flagellate Ratio
0
1
2
3
4
5
6
1955
1965
1975
1985
1995
Year



This graph shows the silicon-to-nitrogen ratio and the diatom-to-flagellate ratio.

Diatoms require silicon for metabolism and growth. Flagellates do not require silicon. The researchers hypothesize that the change in the silicon-to-nitrogen ratio over time initially will favor abundance and growth in diatoms.



This graph shows the silicone-to-phosphorus ratio and the diatom-to-flagellate ratio.

As the silicon-to-phosphorus ratio increases, diatoms become more predominant. The green area represents a potential threshold.

SURPRISING RESULTS; "LESSONS LEARNED"

- **Occurrence of rhythmic behavior**
- **Subtle external and internal driver effects**
  - **External: NAO; Gulf Stream position**
  - **Internal: Nutrients and their ratios**
- **Nutrient ratio effects were detected**

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MANAGEMENT APPLICATION OF THRESHOLD RESULTS

- **External drivers: difficult to manage, but have forecast potential**
- **Internal drivers (e.g., nutrients): more manageable; "resource" can be regulated**
- **Uncertain how external and other internal drivers might modify the "resource mitigation"**

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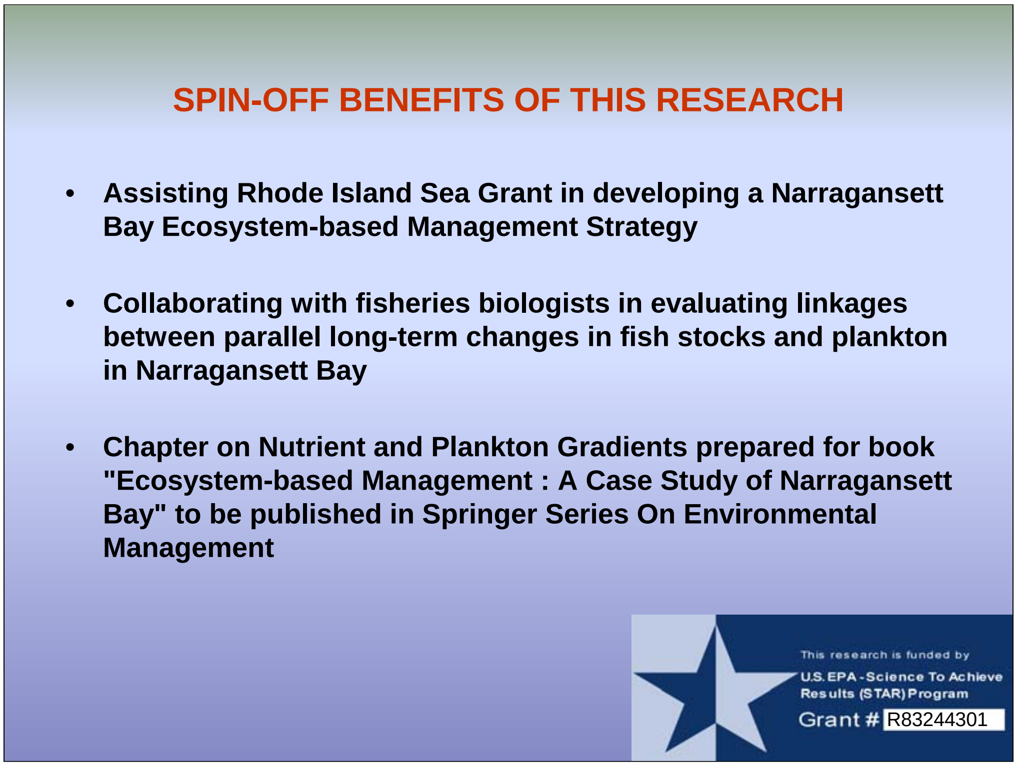
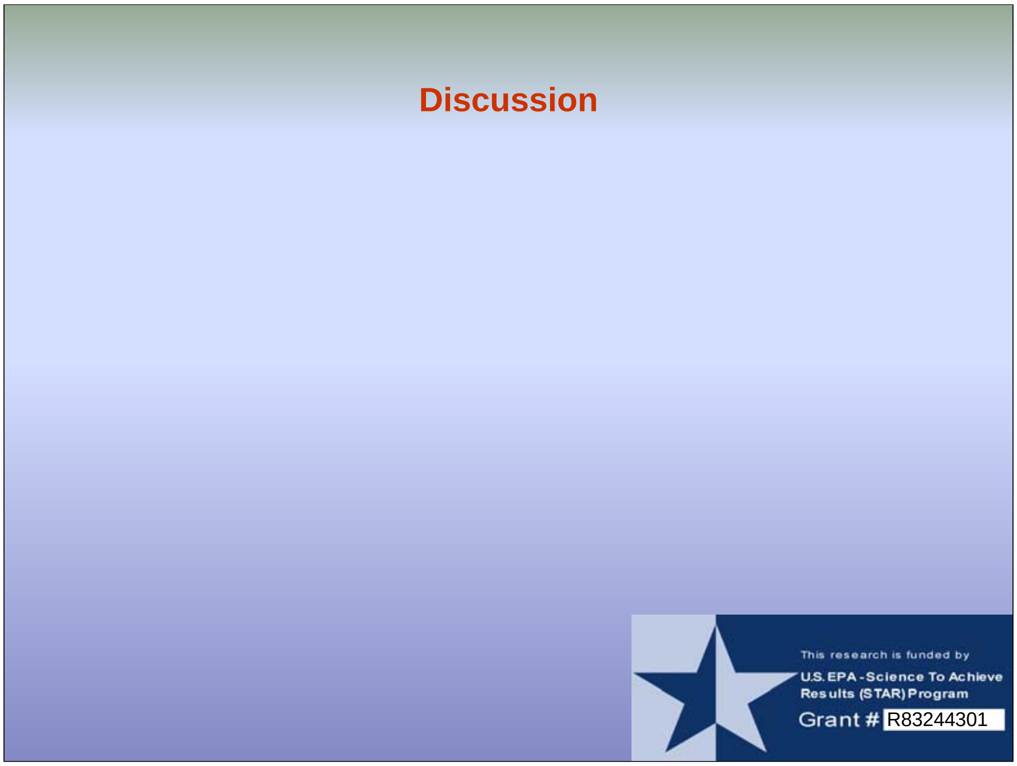


A question for future study is, “Is it possible that external drivers set the boundaries and internal drivers work within that system?”



A participant asked if fisheries biologists have biomass data. Dr. Smayda responded that they do not. They are using a numerical metric, not a size metric.

Another participant commented on the shift of the bloom time in the early 1980s. When this occurred, it appeared that the number of species also decreased.

Another participant pointed out that the long-term data collected could be used to identify metrics and, ultimately, potential thresholds. Dr. Smayda agreed. He added that changes in temperature may be connected to recycling. The difficulty lies in determining when a parameter is a surrogate and when it is a mechanism.

One participant commented that the peaks for diatoms have changed over time and asked if the curve had changed annually in terms of productivity of the diatoms under the different temperature regimes. Dr. Smayda responded that he did not know if this was the case for diatoms as a whole. There was, however, one species that was important previously, but no longer is important. The calculations suggest that its disappearance represented a loss of 15 to 20 percent of the production during the winter. For the rest, the annual production appears to be relatively stable.