

<div data-bbox="245 170 755 365" data-label="Section-Header"> <h2>PDO, Domain or Regime Shifts, and long-term patterns in gyre productivity & NAO effects on Gulf of Maine Production</h2> </div> <div data-bbox="341 378 659 405" data-label="Text"> <p>Class 27, Tu 9 December 2008</p> </div> <div data-bbox="531 497 789 541" data-label="Image"> </div>	<div data-bbox="816 134 1370 283" data-label="Section-Header"> <h3>Slide 1 PDO, Domain or Regime Shifts, and long-term patterns in gyre productivity & NAO effects on Gulf of Maine Production</h3> </div> <div data-bbox="816 371 940 403" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="293 768 732 808" data-label="Section-Header"> <h2>Remaining Lecture Schedule</h2> </div> <div data-bbox="238 842 758 1081" data-label="List-Group"> <ul style="list-style-type: none"> • Class 27, 12/9/08 <ul style="list-style-type: none"> ▸ Gyres, PDO & NAO ▸ No bacterial processes in 2008 • Class 28, 12/11/08 <ul style="list-style-type: none"> ▸ Final Class, Satellite Remote Sensing • Final Exam, 9 am - Noon 12/15 Monday <ul style="list-style-type: none"> ▸ 3 hour closed book, you can start at 10 if you wish ▸ UMB in classroom, Amherst & Lowell: pdf will be mailed to proctors ▸ Jadlyn starting at 10 am (do others want to start later too?) • Term papers (5-10 pages double spaced) due 12/22 by email (or earlier) </div>	<div data-bbox="816 737 1331 772" data-label="Section-Header"> <h3>Slide 2 Remaining Lecture Schedule</h3> </div> <div data-bbox="816 856 940 890" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="365 1257 647 1295" data-label="Section-Header"> <h2>Final exam essays</h2> </div> <div data-bbox="238 1333 763 1549" data-label="List-Group"> <ul style="list-style-type: none"> • Why are there so many benthic infaunal species in the deep sea? Provide arguments in favor of one or more theories for high deep-sea diversity. Does your chosen theory explain why diversity appears to be higher at intermediate depths (e.g., outer continental slope & rise)? [Chapter 5, Jumars & Gallagher (1982)] </div> <div data-bbox="531 1585 789 1627" data-label="Image"> </div>	<div data-bbox="816 1226 1179 1262" data-label="Section-Header"> <h3>Slide 3 Final exam essays</h3> </div> <div data-bbox="816 1348 940 1379" data-label="Text"> <p>NOTES:</p> </div>

<p style="text-align: center;">Final exam essays</p> <ul style="list-style-type: none"> Using Townsend & Spinrad's paper, especially the nomogram, as a guide, when should the spring bloom occur in a 35-m deep water column in Western Massachusetts Bay? Usually, the large spring bloom in MA Bay occurs in March. Is a March spring bloom consistent with Sverdrup's critical depth concept? Reconcile the disparities. [Chapter 11, Townsend & Spinrad (1986), Sverdrup (1953)] 	<p>Slide 4 Final exam essays</p> <p>NOTES:</p>
<p style="text-align: center;">Final exam essays</p> <ul style="list-style-type: none"> In the 1970's, the dominant paradigm for central North Pacific gyre planktonic ecosystems concluded that the gyre ecosystems were 'slow, stable and steady-state.' Describe several of the key studies that led to the rejection of that view. [Chapter 15, Peterson 1980, Platt et al. 1989] Describe the changes in the biological and chemical properties of a recently upwelled parcel of water as it is advected offshore from an upwelling center. Describe the location of your chosen upwelling center (e.g., Northern or Southern Hemisphere, Eastern or Western margins), the direction of upwelling favorable winds, and the movement of the parcel of water relative to the coastline. [Chapter 12, Ryther et al. 1971, Mann & Lazier] 	<p>Slide 5 Final exam essays</p> <p>NOTES:</p>
<p style="text-align: center;">Final exam essays</p> <ul style="list-style-type: none"> Describe the major features of Pearson & Rosenberg (1976, 1978) and the Rhoads et al. (1978) model for the effects of organic enrichment on benthic community structure. Include in your answer, the effects of organic enrichment on species diversity, benthic functional groups, population abundances, and depth to the redox potential discontinuity. [Chapter 6, Rosenberg 2001] The most widely used bioturbation model, the Goldberg-Koide model, isn't appropriate to model non-local mixing. What is non-local mixing, what functional groups of feeding guilds of benthic organisms might be responsible for non-local mixing, and how might non local mixing account for subsurface maxima in chlorophyll a within marine sediments? [Chapter 2, Shull 2001] 	<p>Slide 6 Final exam essays</p> <p>NOTES:</p>

Final exam essays

- Phytoplankton exhibit Redfield stoichiometry only when growing at high relative growth rates. Does the ubiquity of Redfield stoichiometry in the ocean indicate that phytoplankton are never nutrient-limited? [Chapter 10, Howarth (1988)]
- Is a subsurface fluorescence maximum always a subsurface chlorophyll *a* maximum? Include justification for your answer and a description of how the depth profiles of each can be measured. [Chapter 7, Lorenzen 1966, Falkowski & Raven Chapter 9]

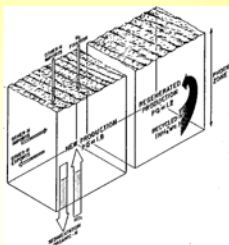
Slide 7 Final exam essays

NOTES:

The effective annual *f*-ratio may be 0.3 to 0.4, not 0.05 to 0.1!

Platt *et al.* 1989 Figure 1

- In a steady-state system
 - Sinking rate of nitrogen is balanced by the vertical (and horizontal) flux of nitrogen
 - Oxygen utilization beneath the euphotic zone represents the horizontal sinking of primary production and should be equivalent to new production
 - New production could be measured by the vertical flux of NO_3^-
 - Total production = New production $\times 1/f$
- Problems with this 'chemostat' view
 - Gyres may not be 'steady-state,' with mini-blooms with high *f* ratios
 - There can be pronounced vertical structure



Slide 8 The effective annual *f*-ratio may be 0.3 to 0.4, not 0.05 to 0.1!

NOTES:

Platt *et al.*'s consensus

Reconciling high short-term rates with bulk properties

- Fallacy of the average and mismatched time scales
 - The *f* ratios in the gyre are much higher than 0.1; 30% to 40% would be more reasonable
 - $2 \text{ g C m}^{-2} \text{ d}^{-1}$ production with the low Chl *a* standing stocks in the gyres would violate the quantum requirements of photosynthesis
- Two-layered vertical structure
 - Low *f* ratios in surface
 - High *f* ratios at nutricline
 - Vertical nitrate flux trapped at the subsurface chlorophyll maximum
- Non-steady-state
 - Blooms due to rainfall events & mesoscale eddies, hurricanes, cyclones, typhoons
 - Pacific: Long-term increases in Chl *a*, species composition, and nutrient input due to PDO
 - Temporal decoupling of autotrophy & heterotrophy



Slide 9 Platt *et al.*'s consensus

NOTES:

The fallacy of averages

Estimating total production from indirect estimates

$$XY \neq X \bar{Y} \quad (\text{unless } X \text{ and } Y \text{ are independent})$$

$$XY = X \bar{Y} + \text{Covariance}_{X,Y}$$

$$XY = X \bar{Y} + r_{X,Y} \sqrt{r^2_{X,Y} \bar{Y}^2}$$

where, $r_{X,Y}$ = correlation between X and Y

$r^2_{X,Y}$ = Variance of X

\bar{X} = Mean of X

$$P_t = P_{\text{mean}} \times \frac{1}{f_{\text{ratio}}}$$

$$P_t = P_{\text{mean}} \times \frac{1}{f_{\text{ratio}}} + \text{Covariance}(P_{\text{mean}}, f_{\text{ratio}})$$

$$= P_{\text{mean}} \times \frac{1}{f_{\text{ratio}}} + r_{P_{\text{mean}}, f_{\text{ratio}}} \sqrt{P_{\text{mean}}^2 \times f_{\text{ratio}}^2}$$

Welsh et al. 1988.
The fallacy of averages. Amer. Natur. 132: 277-288.

Slide 10 The fallacy of averages

NOTES:

Thermodynamic constraints

Effective f ratio can't be much lower than 0.4

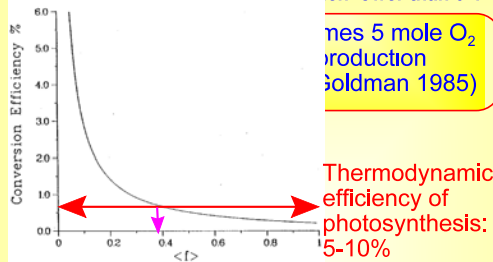


Fig. 2. Implied photosynthetic conversion efficiency as a function of annually averaged f -ratio at Station S in the Sargasso Sea, assuming that new production is 5 mol O_2 $m^{-2} yr^{-1}$

Slide 11 Thermodynamic constraints

NOTES:

Many gyre assimilation numbers used to estimate gyre productivity too high

Prakash et al. (1991)

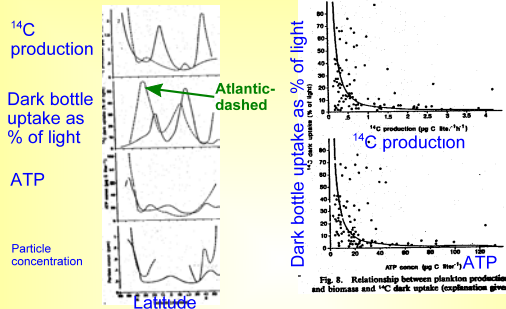


Fig. 3. Relationship between plankton production and biomass and ^{14}C dark uptake (explanation given)

Slide 12 Many gyre assimilation numbers used to estimate gyre productivity too high

NOTES:

Two-layered gyre model

King & Devol (1979), Altabet: High f ratios at SSCM.

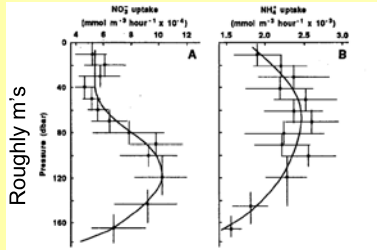


Fig. 2. Depth profiles of rate of uptake of nitrate and ammonium as ^{15}N . The vertical bars represent the range of the depth bin and the horizontal bars the standard error of the mean.

Most of the vertical NO_3 flux is trapped at the SSCM, where f ratios could be very high

Slide 13 Two-layered gyre model

NOTES:

Primary production in the deep-blue sea: Light quality effects in the N. Pacific gyre

Laws et al. (1984) Table 3: $\approx 400\text{--}500 \text{ mg C m}^{-2} \text{ d}^{-1}$

About 2x-4x earlier productivity estimates
High phytoplankton rates

911

Table 3. Autotrophic production from depth profile studies at about 28°N , 155°W . Incident irradiance (I_0) expressed as $\text{Einsteins m}^{-2} \text{ d}^{-1}$ of 400–700-nm light. Production expressed as $\text{mg C m}^{-2} \text{ d}^{-1}$ or $\text{mg N m}^{-2} \text{ d}^{-1}$.

1985	Location	I_0	Autotrophic assimilation based on ^{14}C uptake		Gross autotrophic assimilation	
			C	N^*	C	N
21 Aug	$28^\circ 6.4'\text{N}$, $155^\circ 2.1'\text{W}$	49.1	Surface–1% I_0	268	48	
			1% I_0 –200 m	36	7	
			Total	304	55	
27 Aug	$28^\circ 28.7'\text{N}$, $154^\circ 34'\text{W}$	49.5	Surface–1% I_0	242	39	
			1% I_0 –200 m	54	10	
			Total	296	49	
2 Sep	$29^\circ 5.1'\text{N}$, $154^\circ 4.7'\text{W}$	48.5	Surface–1% I_0	308	53	
			1% I_0 –200 m	37	7	
			Total	345	60	

* Calculated with the methodology of DiTullio and Laws (1983).

Slide 14 Primary production in the deep-blue sea: Light quality effects in the N. Pacific gyre

NOTES:

Post Platt et al. (1989) Developments

- Karl's domain shift hypothesis
 - The Pacific gyre can switch from N to P limitation
 - The Pacific is more iron limited than the Atlantic and N fixation can be limited by Fe availability
- Pacific Decadal oscillation accounts for the nearly 2x increase in Chl a and production



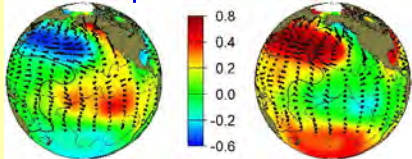
Slide 15 Post Platt et al. (1989) Developments

NOTES:

Pacific Decadal Oscillation (PDO)

PDO strongly related to long-term ENSO patterns

Temperature anomalies



Warm phase on CA coast; cool in gyre

Cold phase on CA coast; warm in gyre

<http://tao.atmos.washington.edu/pdo/>

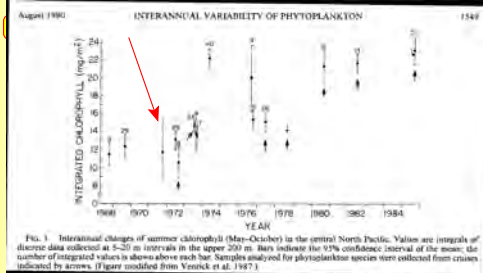
EEOS630

Slide 16 Pacific Decadal Oscillation (PDO)

NOTES:

Pacific decadal oscillation: 2x Chl a increase from '68 to '84, esp at SSCM

Venrick *et al.* (1987), Venrick(1990)

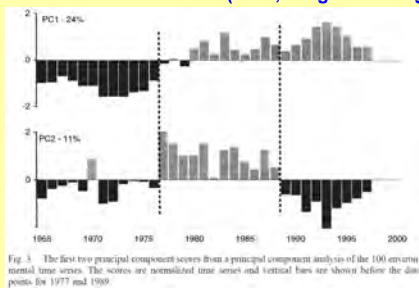


Slide 17 Pacific decadal oscillation: 2x Chl a increase from '68 to '84, esp at SSCM

NOTES:

Pacific Regime shifts (1977, 1989)

Hare & Mantua (2000, Prog. Oceanogr.)



Slide 18 Pacific Regime shifts (1977, 1989)

NOTES:

PDO Regime Change/Domain Shift

Scheffer et al. 2001 Nature 413: 591-596

Catastrophic shifts in ecosystems

Marine Science: Steve Carpenter, Jonathan A. Rabalais, Carl Folgar, & Brian Wilson

Department of Aquatic Ecology and Water Quality Management, Wageningen University, 6500 AH Wageningen, The Netherlands; School of Fisheries, University of Washington, 1950 NE Pacific Street, Seattle, Washington 98195, USA; School of Fisheries, University of Washington, 1950 NE Pacific Street, Seattle, Washington 98195, USA; School of Fisheries, University of Washington, 1950 NE Pacific Street, Seattle, Washington 98195, USA; School of Fisheries, University of Washington, 1950 NE Pacific Street, Seattle, Washington 98195, USA

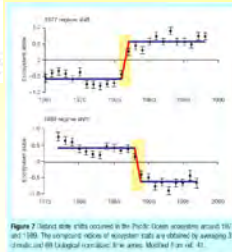
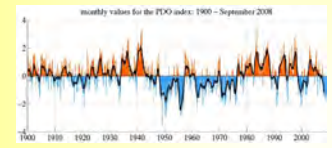
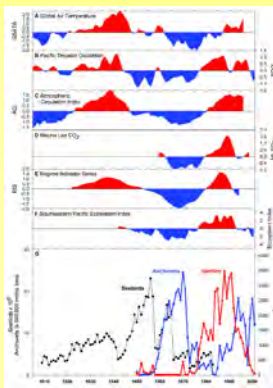


Figure 2. Distinct shifts in the Pacific Ocean ecosystem around 1977 and 1989. The sharp shifts in ecosystem state are obtained by averaging 31 months and 60 100-day smoothed time series. Modified from ref. 45.

Slide 19 PDO Regime Change/Domain Shift

NOTES:



PDO Regime Changes Sardines off Peru with warm phases, Anchoveta with cold phases

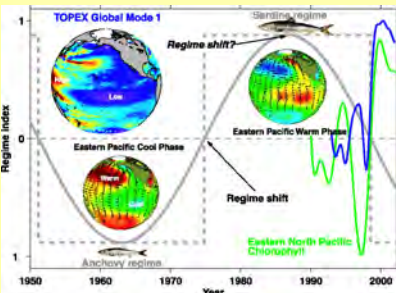
Chavez et al. (2003) Fig. 1; Peruvian fish landings

Slide 20

NOTES:

Anchovy & Sardine Regimes

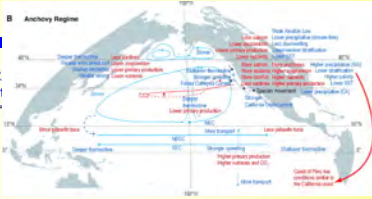

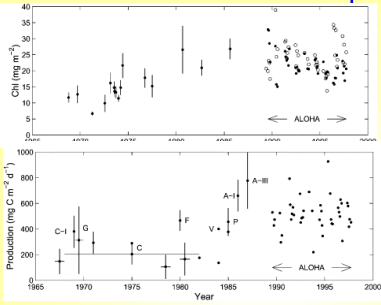
Chavez et al. 2003



This has a much bigger effect on Northern Anchovy than Lasker's stable ocean hypothesis

Slide 21 Anchovy & Sardine Regimes

NOTES:

<p>1960s -> 1978 Anchovy (Cold) Regime</p> <p>Chavez et al. (2003) Science</p> <ul style="list-style-type: none"> ● California current <ul style="list-style-type: none"> ▪ Higher nutrients ▪ High macrozooplankton (<i>Calanus pacificus</i>) off California ▪ More seabirds ▪ More salmon ● Gyre <ul style="list-style-type: none"> ▪ Deeper gyre thermocline ▪ Chl a concentration 2 ▪ lower gyre productivity 	<p>Slide 22 1960s -> 1978 Anchovy (Cold) Regime</p> <p>NOTES:</p>
<p>1930s & 1980s Sardine (Warm) Regime</p> <p>Chavez et al. (2003)</p> <ul style="list-style-type: none"> ● California & Peru in 1930s & 1980s: Sardine Regime <ul style="list-style-type: none"> ▪ Low macrozooplankton off CA ▪ Deeper thermocline ▪ Less salmon ▪ Off Alaska & British Columbia <ul style="list-style-type: none"> ▪ More salmon ▪ Higher production ● Gyres <ul style="list-style-type: none"> ▪ Shallower thermocline ▪ Much higher production in gyres 	<p>Slide 23 1930s & 1980s Sardine (Warm) Regime</p> <p>NOTES:</p>
<p>The domain-shift hypothesis</p> <p>2x -3x increase in Chl a and production</p>  <p>Karl et al. (2001): No strong evidence for trace metal effects on production</p>	<p>Slide 24 The domain-shift hypothesis</p> <p>NOTES:</p>

Trichodesmium & gyre N₂ fixation

Mat-forming N₂-fixing cyanobacterium, Capone et al. (1997)

Karl: regime change with more Fe in Pacific in the 1990s

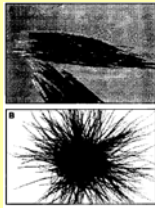
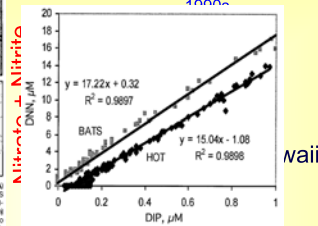


Fig. 1. Examples of Trichodesmium colonies. (A) Filamentous mat-forming colony of *T. thuyae*. (B) Single colony of *T. thuyae*. Colonies are typically 2 to 5 mm in length (filamentous) or diameter (puffed) and are composed of tens to hundreds of aggregated filaments (trichomes). Each trichome consists of tens to hundreds of cells (typically ~100); cells are generally 5 to 15 µm in diameter but can range up to 50 µm in length (100 photos by H. Platt).



More Fe-rich dust & N fixation in Atlantic (Wu et al. 2000)

Slide 25 Trichodesmium & gyre N₂ fixation

NOTES:

Conclusions on gyres

From stable deserts to non-steady-state systems

- Thesis
 - Gyres as chemostat: slow (desert-like, 5-d doubling time), slow production (slow) stable, steady-state
- Antithesis: high μ , high productivity ($>> 1 \text{ g C m}^{-2} \text{ d}^{-1}$)
- Synthesis: high μ , moderate production, non steady-state on short & long time scales
- Mesoscale eddies, storms that produce short-term blooms important in controlling DIN flux: episodic
- Effective f_{ratio} , over the monthly time scale, are high, roughly 30-40%
- Long-term decadal scale changes in nutrient input to the gyres, due to the Pacific decadal oscillation (PDO)
 - Doubling of Chl a from the 1950s to the 1980s
 - Regime change due to
 - change in depth to the nutricline
 - enhanced Fe input. Increased frequency of N₂ fixing *Trichodesmium* in the Pacific in the 1990s

Slide 26 Conclusions on gyres

NOTES:

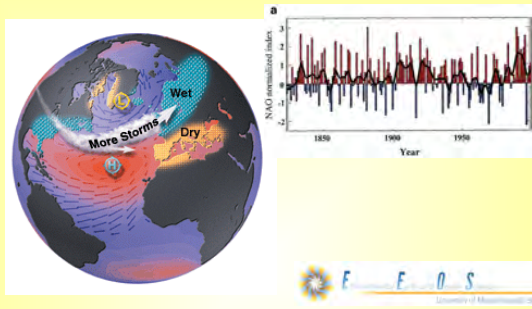
NAO & Gulf of Maine Copepods & Right Whales



Slide 27 NAO & Gulf of Maine Copepods & Right Whales

NOTES:

Positive NAO

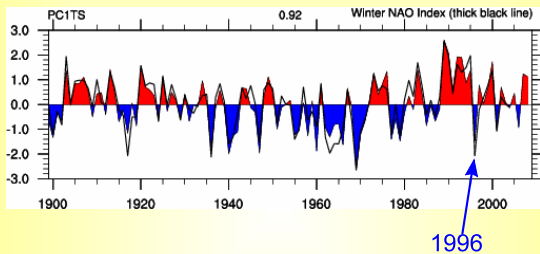


Slide 28 Positive NAO

NOTES:

NAO Index '00 to '08, note 1996 Negative NAO event

<http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html#naopcdfs>

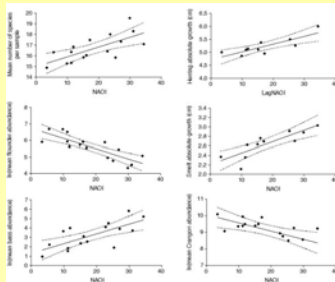


Slide 29 NAO Index '00 to '08, note 1996 Negative NAO event

NOTES:

NAO on European fish stocks

Atrill & Power (2001) Nature

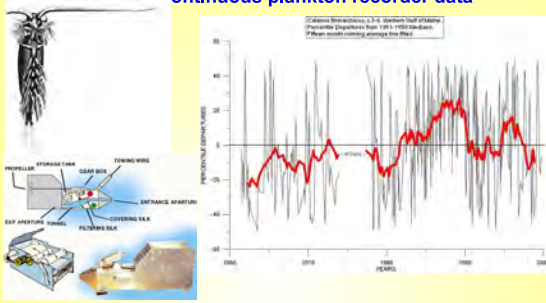


Slide 30 NAO on European fish stocks

NOTES:

Gulf of Maine *C. finmarchicus*

Hardly continuous plankton recorder data

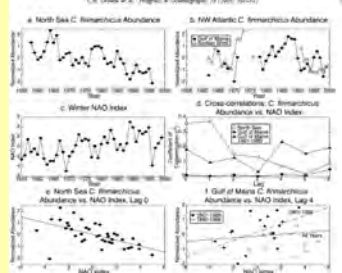


Slide 31 Gulf of Maine *C. Finmarchicus*

NOTES:

C. finmarchicus & NAO

Positive correlation with GOM Calanus, neg with N Sea



Greene et al.
(2003)

Slide 32 *C. Finmarchicus* & NAO

NOTES:

Positive NAO & the Gulf of Maine

Warm Slope water in nutrient-rich

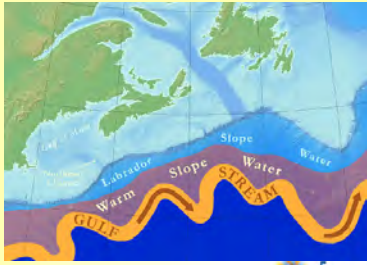


Slide 33 Positive NAO & the Gulf of Maine

NOTES:

Low NAO & the Gulf of Maine

Labrador slope water is colder & nutrient poor



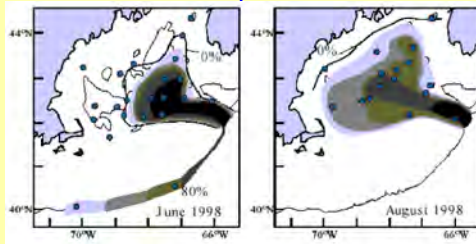
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Slide 34 Low NAO & the Gulf of Maine

NOTES:

1996-1998 Negative NAO event

Labrador Current water, cold, low salinity, nutrient poor



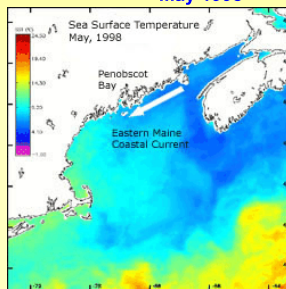
E F O S
University of Massachusetts - Dartmouth

Slide 35 1996-1998 Negative NAO event

NOTES:

Eastern Maine Coastal Current

May 1998



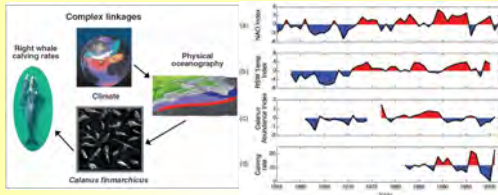
E F O S
University of Massachusetts - Dartmouth

Slide 36 Eastern Maine Coastal Current

NOTES:

NAO & Right Whales

Greene & Pershing 2004 *Front. Ecol. Environ.* 2: 29-34



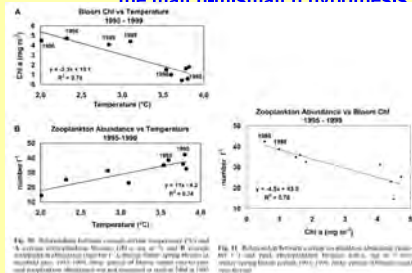
The interaction is not simple. 1996 event associated with high calving rates

Slide 37 NAO & Right Whales

NOTES:

Blooms in MA Bay

Keller et al. (2001): Explained lack of 1998 bloom with the match-mismatch hypothesis

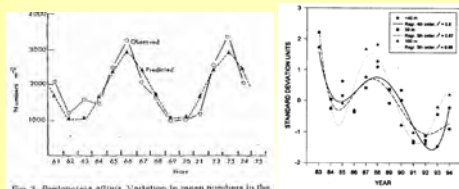


Slide 38 Blooms in MA Bay

NOTES:

Long-term cycles in N. Europe

Gray & Christie (1983) *Pontoporeia* cycles; Tunberg & Nelson (1998) Swedish NAO cycles in infaunal abundance



Slide 39 Long-term cycles in N. Europe

NOTES: