

The Seasonal Production cycle in MA Bay, including the subsurface chl a maximum; The geritol solution or 'why no spring blooms in the Southern Ocean & subarctic Pacific'

Class 21, 11/13/08 Th

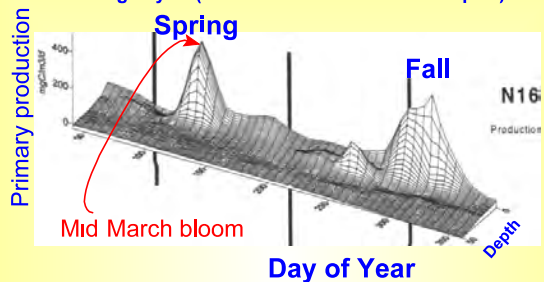
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Slide 1 The Seasonal Production cycle in MA Bay, including the subsurface chl a maximum; The geritol solution or 'Why no spring blooms in the Southern Ocean & subarctic Pacific?'

NOTES:

1995 Seasonal production

Craig Taylor (MWRA 1995 water-column report)



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Slide 2 1995 Seasonal production

NOTES:

BH-MA Bay: A tidal front

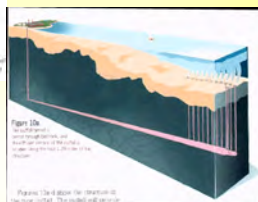
MWRA State of the Harbor Report & Mann & Lazier

Boston Harbor/Inner Broad Sound



Fig. 4.10 Cross-section through a tidally mixed front with vertical density differences and horizontal density differences from the stratified side to the mixed side. As the front passes, the density differences are removed, and the water is mixed. The density differences are removed, and the water is mixed.

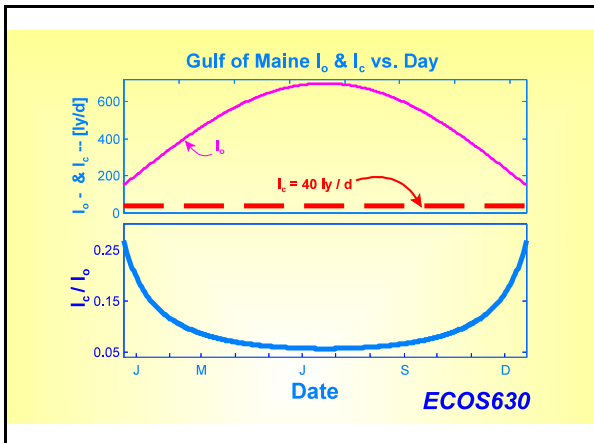
Stratification can occur in any month (snow melt inversions), but stable pycnocline develops in March



Slide 3 BH-MA Bay: A tidal front

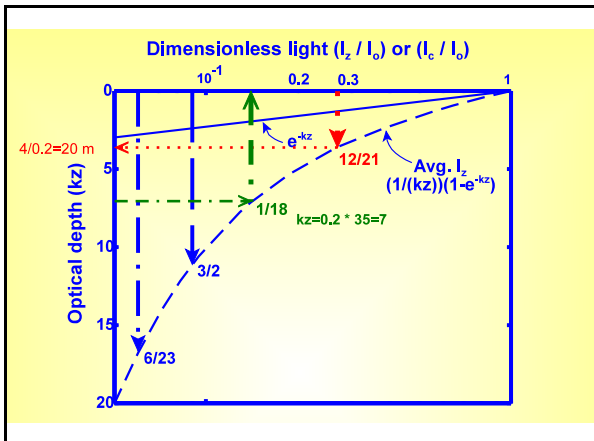
NOTES:

Slide 4



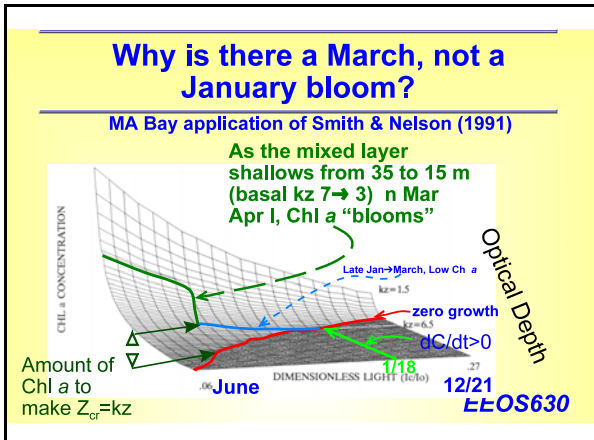
NOTES:

Slide 5

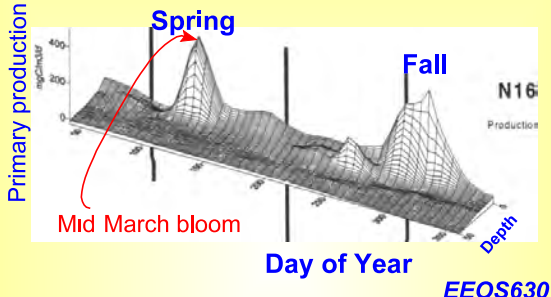
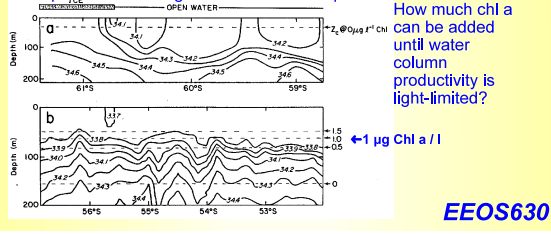
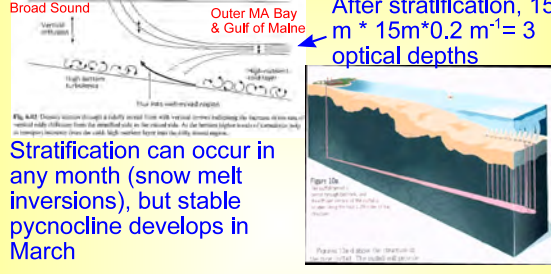


NOTES:

Slide 6 Why is there a March, not a January bloom?

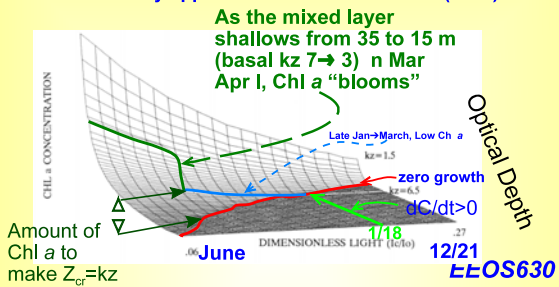


NOTES:

<p>1995 Seasonal production</p> <p>Craig Taylor (MWRA 1995 water-column report)</p> 	<p>Slide 7 1995 Seasonal production</p> <p>NOTES:</p>
<p>No blooms in the Southern Ocean: Why? Light limitation</p> <p>Nelson & Smith (1991) offer 1 explanation</p> <p>Depth to mixed layer deep, only small increases in Chl a possible before light limitation controls production</p> 	<p>Slide 8 No blooms in the Southern Ocean: Why?</p> <p>NOTES:</p>
<p>BH-MA Bay: A tidal front</p> <p>MWRA State of the Harbor Report & Mann & Lazier</p> <p>Boston Harbor/Inner Broad Sound: $35\text{m} \times 0.2\text{ m}^{-1} = 7$ optical depths</p> <p>Outer MA Bay & Gulf of Maine: After stratification, $15\text{ m} \times 15\text{m} \times 0.2\text{ m}^{-1} = 3$ optical depths</p>  <p>Stratification can occur in any month (snow melt inversions), but stable pycnocline develops in March</p>	<p>Slide 9 BH-MA Bay: A tidal front</p> <p>NOTES:</p>

Why is there a March, not a January bloom?

MA Bay application of Smith & Nelson (1991)



Slide 10 Why is there a March, not a January bloom?

NOTES:

Excursis on subsurface chlorophyll maxima

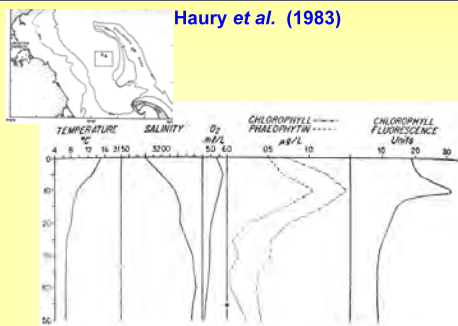
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Slide 11 Excursis on subsurface chlorophyll maxima

NOTES:

MA Bay subsurface Chl a maxima

Haury et al. (1983)

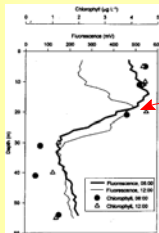


Slide 12 MA Bay subsurface Chl a maxima

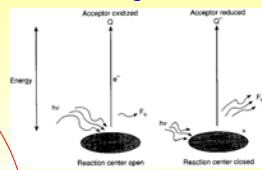
NOTES:

Maxima: Fluorescence vs. Chl vs. Carbon

Falkowski & Raven Figure 9.6



As noted by Cullen, Fluorescence max not necessarily a Chl max nor Carbon max

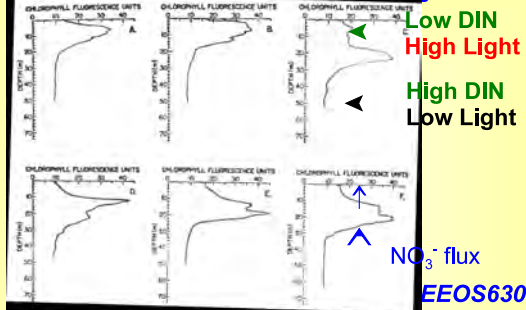


Slide 13 Maxima: Fluorescence vs. Chl vs. Carbon

NOTES:

Internal waves and MA Bay SSCM

Houry et al. (2002) internal wave propagation

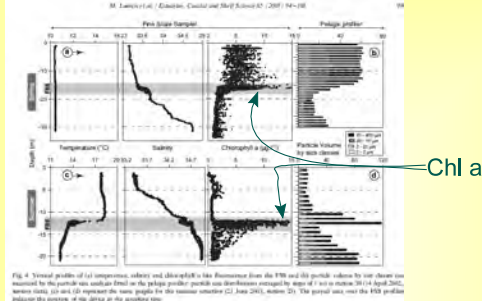


Slide 14 Internal waves and MA Bay SSCM

NOTES:

Fine structure of the SSCM

Linven et al. (2005)



Slide 15 Fine structure of the SSCM

NOTES:

Fine structure of the SSCM

Lunven et al. (2005): Diatoms & dinoflagellates (motile)

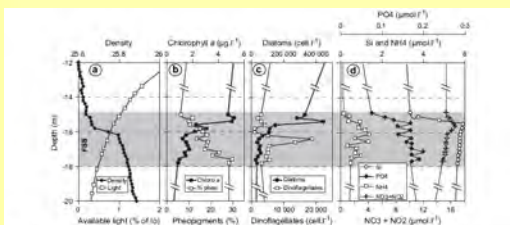


Fig. 5. Vertical profiles of (a) density and available light, (b) chlorophyll *a* and phytoplankton, (c) diatoms and dinoflagellates, (d) dissolved inorganic Si, PO₄, NH₄, NO₃, and NO₂, and (e) silicic acid and nitrate on 14 April 2003. (a) – density and available light; (b) – chlorophyll *a* and phytoplankton; (c) – diatoms and dinoflagellates; (d) – dissolved inorganic Si, PO₄, NH₄, NO₃, and NO₂; (e) – silicic acid and nitrate. The data were obtained from the samples collected by the FSS.

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Slide 16 Fine structure of the SSCM

NOTES:

Fine structure of the SSCM

Lunven et al. (2005)

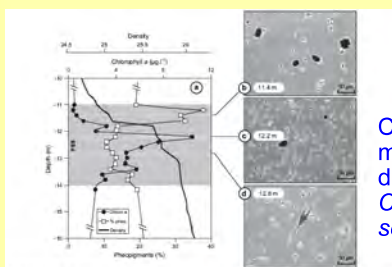


Fig. 7. Vertical profiles of density, chlorophyll *a*, and phytoplankton on 17 June 2003. The data were obtained from the samples collected by the FSS. The blue lines were located below the profiles and not damaged by collection of *Chaetoceros* counts. The water above the profiles mostly contained individual diatoms and the maximum number of diatoms was observed in the layer (b). Diatoms, *Chaetoceros*, and dinoflagellates were observed below the maximum of chlorophyll *a* (b).

C) Sinking
mats of the
diatom
Chaetoceros
socialis

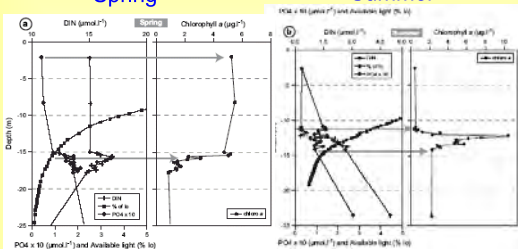
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Slide 17 Fine structure of the SSCM

NOTES:

Fine structure of the SSCM

Lunven et al. (2005): 0.5% light level at base of SSCM
Spring Summer



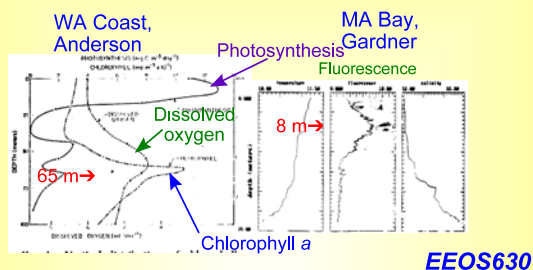
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Slide 18 Fine structure of the SSCM

NOTES:

SSCM off the Washington-Oregon Coast, also off California

West coast vs. MA Bay

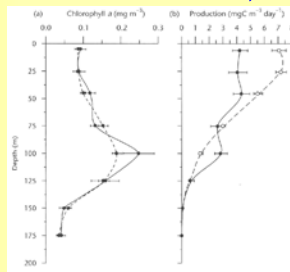


Slide 19 SSCM off the Washington-Oregon Coast, also off California

NOTES:

Central N. Pacific gyre: Typical tropical structure

SSCM at 100 meters; Miller (2004) Fig. 10.6



In Lundven's European coastal zone & in MA Bay, the SSCM can be a major component of total water column production

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Slide 20 Central N. Pacific gyre: Typical tropical structure

NOTES:

North Pacific gyre chl maximum

Karl et al. (1996) Deep-Sea Res II 43: 129-146

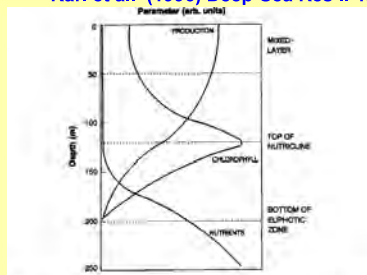
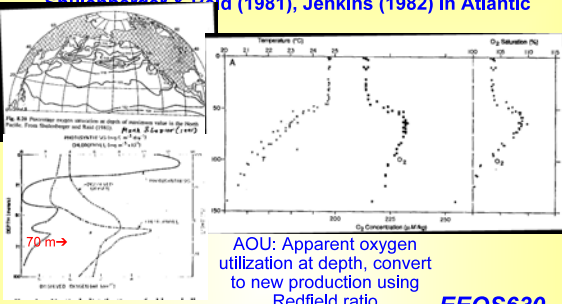
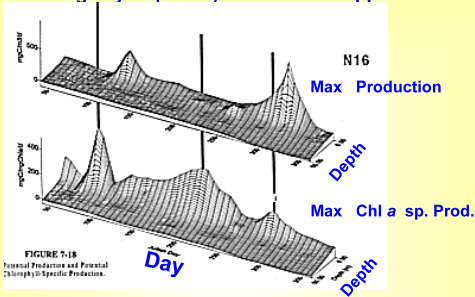


Fig. 5. Schematic representation of the upper water column distributions of light, nutrients, chlorophyll a and primary production in the oligotrophic North Pacific subtropical gyre.

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Slide 21 North Pacific gyre chl maximum

NOTES:

<p>SSCM O₂: 120% saturation</p> <p>Chulankasorn & Reid (1981), Jenkins (1982) in Atlantic</p>  <p>AOU: Apparent oxygen utilization at depth, convert to new production using Redfield ratio</p> <p>EEOS630</p>	<p>Slide 22 SSCM O₂: 120% saturation</p> <p>NOTES:</p>
<p>Massachusetts Bay Production</p> <p>Cole-Cloern relationship & Subsurface Chlorophyll maxima</p> <p>EEOS630</p>	<p>Slide 23 Massachusetts Bay Production</p> <p>NOTES:</p>
<p>1995 MA Bay Production</p> <p>Craig Taylor (WHOI) Model P vs. I approach</p>  <p>FIGURE 7-18 Potential Production and Potential Chlorophyll Specific Production.</p>	<p>Slide 24 1995 MA Bay Production</p> <p>NOTES:</p>

Cole-Cloern relationship: No N!

82% of variance explained by $BZ_p I_0$

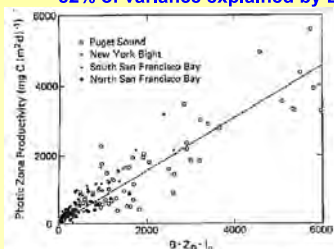


Fig. 2. Regression of photic zone productivity against the composite parameter $BZ_p I_0$ for 211 incubation experiments. $P = 150 \pm 0.73 (BZ_p I_0)$; $r^2 = 0.82$; S_{est} (standard error of the estimate) = 410

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Slide 25 Cole-Cloern relationship: No N!

NOTES:

Cole-Cloern works in MA Bay

$BZ_p I_0$ accounts for 82% of production why?

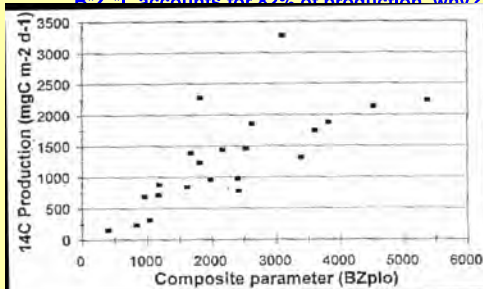


Figure Kelly/Doering MA Bay data

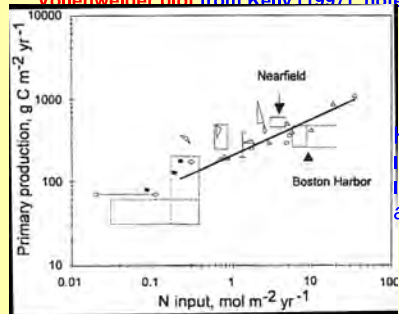
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Slide 26 Cole-Cloern works in MA Bay

NOTES:

MA Bay production \propto N Loading

Vollenweider plot from Kelly (1997): note log-log scale



Higher N input results in higher Chl a

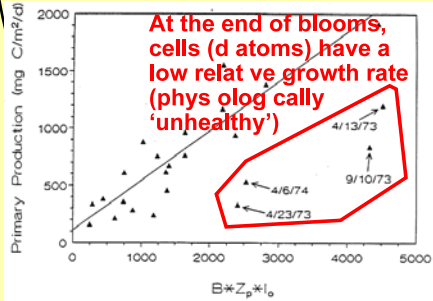
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Slide 27 MA Bay production \propto N Loading

NOTES:

Bz_pI_o model fails after blooms

Jim Shine (1992) UMASS Ph.D., Parker (1975 data)



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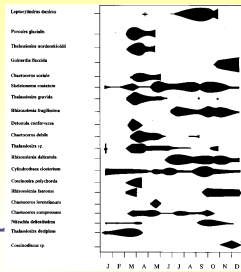
Slide 28 BzpIo model fails after blooms

NOTES:

Phytoplankton succession in bay

Diatom species composition from Parker (1975)

- Rapid reduction of dissolved inorganic nitrogen to < 1 μM at end of bloom
- Rapid succession of diatom species at the termination of the spring bloom
 - Bloom species settle out to the bottom
 - Very high fluorescent yield
 - Low relative growth rates:
 - High C:Chl a ratios
 - Low assimilation numbers

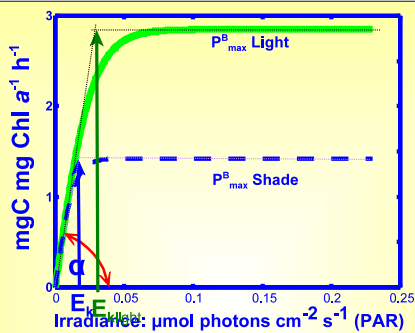


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Slide 29 Phytoplankton succession in bay

NOTES:

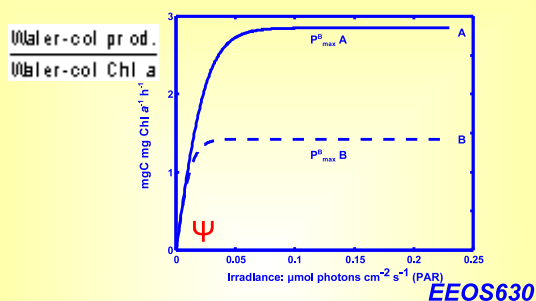
Chl a-specific gross productivity



Slide 30 Platt's (1986) Explanation

NOTES:

Platt's bioptical model

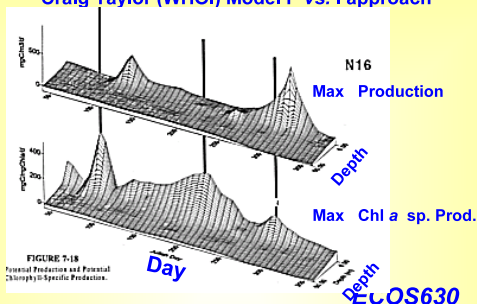


Slide 31 Platt's bioptical model

NOTES:

1995 MA Bay Production

Craig Taylor (WHOI) Model P vs. I approach



Slide 32 1995 MA Bay Production

NOTES:

Cole-Cloern relationship

82% of variance explained by $BZ_p I_0$

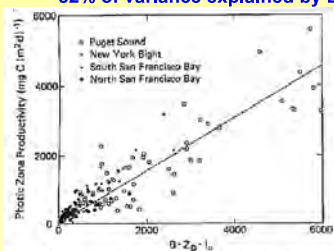


Fig. 2. Regression of photic zone productivity against the composite parameter $BZ_p I_0$ for 211 incubation experiments. $P = 150 + 0.73 (BZ_p I_0)$; $r^2 = 0.82$; S_{est} (standard error of the estimate) = 410

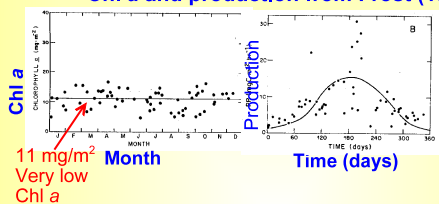
Slide 33 Cole-Cloern relationship

NOTES:

<div data-bbox="264 163 763 231"> <h2>Why does the Cole-Cloern model work?</h2> </div> <div data-bbox="298 241 719 268"> <p>Wofsy is wrong, Platt (1986) appears correct</p> </div> <div data-bbox="235 275 771 533"> <ul style="list-style-type: none"> • Wofsy (1983) <ul style="list-style-type: none"> ▶ Nutrient-rich lakes, bays and estuaries: <ul style="list-style-type: none"> ■ Phytoplankton grow until the mixed layer is equivalent to five optical depths. ■ Production is light-controlled, and nutrients are usually in excess {Wofsy incorrect: Nutrients still limit yield as noted in Howarth's (1988) 2nd sense of nutrient limitation • Platt (1986) <ul style="list-style-type: none"> ▶ Succession among phytoplankton groups leads to phytoplankton acclimated to current nutrient input regime ▶ Their P vs. I parameters are close to temperature-controlled optima </div> <div data-bbox="654 514 771 541"> <p>EEOS630</p> </div>	<div data-bbox="816 132 1403 205"> <h2>Slide 34 Why does the Cole-Cloern model work?</h2> </div> <div data-bbox="816 294 938 325"> <p>NOTES:</p> </div>
<div data-bbox="305 693 719 730"> <h2>Why does the model work?</h2> </div> <div data-bbox="302 739 724 766"> <p>Wofsy is wrong, Platt (1986) appears correct</p> </div> <div data-bbox="235 766 758 1008"> <ul style="list-style-type: none"> • Bio-optical models & Ψ (psi) <ul style="list-style-type: none"> ▶ Platt (1986) Initial slope of the generalized P vs. I relationship, Ψ (pronounced <i>psi</i>), relatively constant at $0.4 \text{ g C g}^{-1} \text{ Chl a m}^{-2} \text{ mol}^{-1} \text{ photons}$ ▶ Raven & Falkowski (1997) Figure 9.9 <ul style="list-style-type: none"> ■ Ψ not a constant <ul style="list-style-type: none"> ◦ Higher at low light intensities ◦ Lower in nutrient-stressed cells • A high relative specific growth rate produces the Cole-Cloern or Malone-Platt relationship <ul style="list-style-type: none"> ▶ If relative growth rate is high (coupled mainly to temperature), then ▶ There must be a close coupling between nutrient loading and Chl a concentration </div> <div data-bbox="654 1039 771 1066"> <p>EEOS630</p> </div>	<div data-bbox="816 661 1320 697"> <h2>Slide 35 Why does the model work?</h2> </div> <div data-bbox="816 783 938 814"> <p>NOTES:</p> </div>
<div data-bbox="295 1209 719 1325"> <h2>Why no phytoplankton bloom in the Subarctic Pacific?</h2> </div> <div data-bbox="272 1339 725 1457"> <p>Parsons et al. (1966): the Major Grazer hypothesis Evans & Parslow's Micrograzer Hypothesis Martin's Iron Hypothesis Ecumenical Iron hypothesis</p> </div> <div data-bbox="654 1526 771 1554"> <p>EEOS630</p> </div>	<div data-bbox="816 1148 1399 1220"> <h2>Slide 36 Why no phytoplankton bloom in the Subarctic Pacific?</h2> </div> <div data-bbox="816 1308 938 1339"> <p>NOTES:</p> </div>

No bloom at Station P in the Subarctic Pacific

Chl a and production from Frost (1987)



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Slide 37 No bloom at Station P in the Subarctic Pacific

NOTES:

The 'Major Grazer' hypothesis

Macrozooplankton grazing keeps bloom in check

Major grazer Hypothesis

- Heinrich (1957)
- Beklemishev (1957)
- McAllister (1960)
- Parsons et al. (1966)
- Fulton (1973)



Neocalanus plumchrus & *N. cristatus*:

- Horseshoe-sized calanoids
- Keep blooms in check due to unique life history



Zooplankton biomass

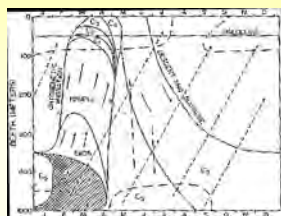
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Slide 38 The 'Major Grazer' hypothesis

NOTES:

Neocalanus life history, different from *Calanus finmarchicus*, *Calanus pacificus* & *Pseudocalanus*

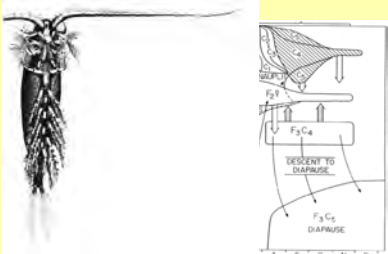
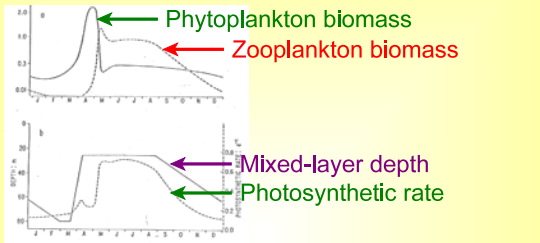
Reproduce at depth, CIII stages feeding on bloom



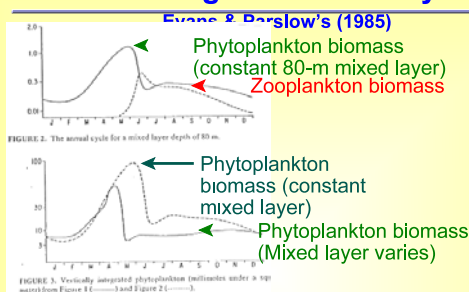
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Slide 39 *Neocalanus* life history, different from *Calanus finmarchicus*, *Calanus pacificus* & *Pseudocalanus*

NOTES:

<p>N. Atlantic <i>Calanus</i> life history</p> <p><i>Calanus finmarchicus</i>: the N. Atlantic dominant</p>  <p>Females must feed to produce eggs: 20-30 d lag</p> <p>EEOS630</p>	<p>Slide 40 N. Atlantic <i>Calanus</i> life history</p> <p>NOTES:</p>
<p>The micrograzer hypothesis: ciliates</p> <p>Evans & Parslow's (1985) model</p> <p>EEOS630</p>	<p>Slide 41 The micrograzer hypothesis: ciliates</p> <p>NOTES:</p>
<p>Blooms with constant mixed layers</p> <p>Evans & Parslow (1985), Figures 2 & 3</p>  <p>Phytoplankton biomass</p> <p>Zooplankton biomass</p> <p>Mixed-layer depth</p> <p>Photosynthetic rate</p> <p>FIGURE 3. (a) The annual cycle of Model I phytoplankton (—) and zooplankton (---) biomass, expressed in milligrams of nitrogen per cubic meter, for the parameters of Table 1. (b) The annual cycle of mixed layer depth (—) and photosynthetic rate (---) (g₀ d⁻¹).</p> <p>EEOS630</p>	<p>Slide 42 Blooms with constant mixed layers</p> <p>NOTES:</p>

Protozoan grazing & winter standing stocks the key!

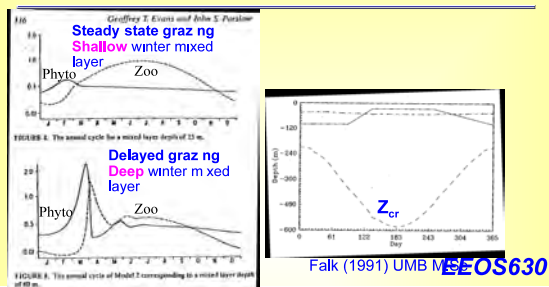


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Slide 43 Protozoan grazing & winter standing stocks the key!

NOTES:

Permanent halocline is one key to the lack of spring bloom in the N. Pacific



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Slide 44 Permanent halocline is one key to the lack of spring bloom in the N. Pacific

NOTES:

Evans & Parslow's micrograzer hypothesis

- North Pacific blooms are kept in check by protozoan grazing
- The permanent halocline in the North Pacific (relatively high rainfall relative to evaporation) results in a permanent surface mixed layer and higher winter-time production than the N. Atlantic
- Protozoan grazer standing stocks remain high during the winter and can keep phytoplankton in check

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Slide 45 Evans & Parslow's micrograzer hypothesis

NOTES:

Problems with the “naive” micrograzer hypothesis

- Why are there spring and fall blooms in areas like MA Bay, where the critical depth usually always exceeds the bottom depth?
- What controls diatom production, a group that owes much of its evolutionary success to its resistance to microzooplankton grazing?

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Slide 46 Problems with the “naive” micrograzer hypothesis

NOTES:

Martin’s Geritol solution

The late John Martin’s hypothesis created a frenzy of activity in 1989: based on a talk at WHOI



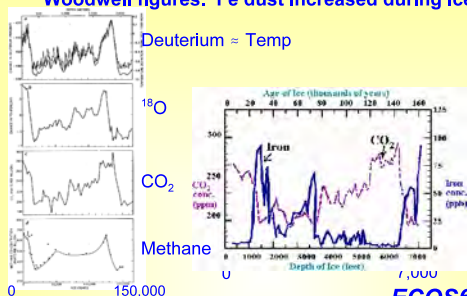
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Slide 47 Martin’s Geritol solution

NOTES:

The Greenhouse effect & Fe

Woodwell figures. Fe dust increased during ice ages



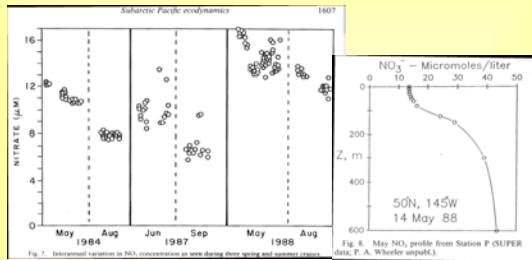
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Slide 48 The Greenhouse effect & Fe

NOTES:

High nitrate all year at Station P

Data from Frost (1991): 5-17 $\mu\text{M NO}_3^-$, which is higher DIN than MA Bay in winter (about 15 $\mu\text{M NO}_3^-$)



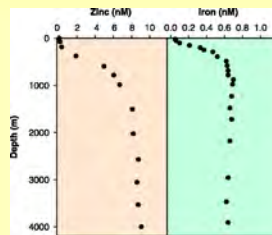
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Slide 49 High nitrate all year at Station P

NOTES:

Iron & Zn depletion in surface water

Morel & Price (2003) Subarctic Pacific



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Slide 50 Iron & Zn depletion in surface water

NOTES:

Roles of Fe in plant metabolism

Geider & LaRoche (1994)

- Cytochrome oxidase
- Fe-superoxidize dismutase
- Catalase
- Peroxidase
- Ferredoxin (needed for N_2 fixation)
- Nitrate reductase, nitrite reductase
- Glutamate synthetase
- Others

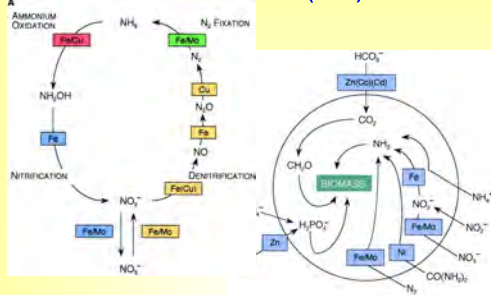
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Slide 51 Roles of Fe in plant metabolism

NOTES:

Key uses of Fe & Zn by microbes

Morel & Price (2003)



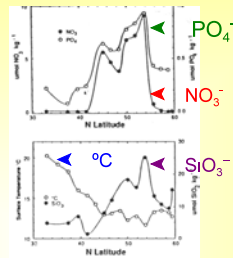
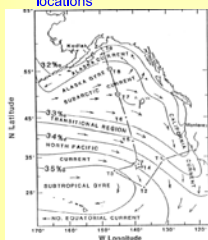
Slide 52 Key uses of Fe & Zn by microbes

NOTES:

Martin & Fitzwater's Fe hypothesis

They argue that iron, not grazing, limit standing stocks

Martin & Fitzwater's (1988) & Martin et al. (1989) sampling locations



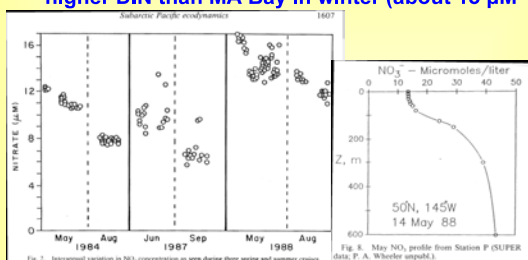
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Slide 53 Martin & Fitzwater's Fe hypothesis

NOTES:

High nitrate all year at Station P

Data from Frost (1991): 5-17 μM NO_3^- , which is higher DIN than MA Bay in winter (about 15 μM)



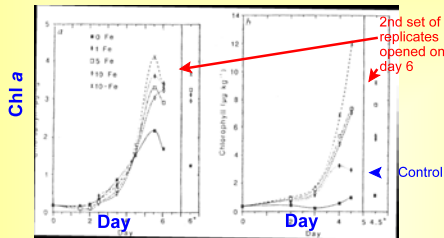
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Slide 54 High nitrate all year at Station P

NOTES:

Martin & Fitzwater (1988), Martin et al. (1999)

Increase in Chl a at Station P, T7



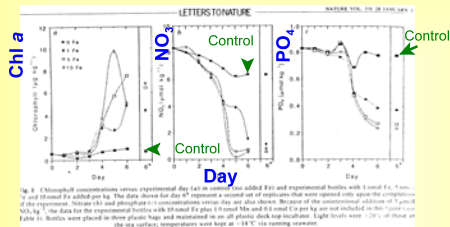
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Slide 55 Martin & Fitzwater (1988), Martin et al. (1999)

NOTES:

Station P: Effects of Fe on Chl a, N & P

No replicates, Banse (1990) noted the statistical problems



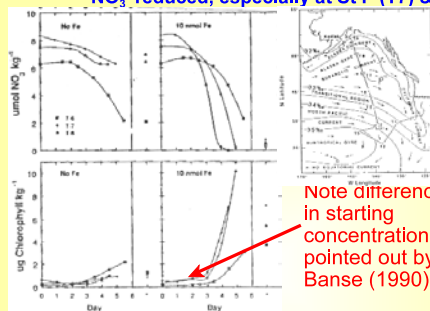
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Slide 56 Station P: Effects of Fe on Chl a, N & P

NOTES:

Fe effect dependent on lat & long

NO₃⁻ reduced, especially at St P (T7) & T8



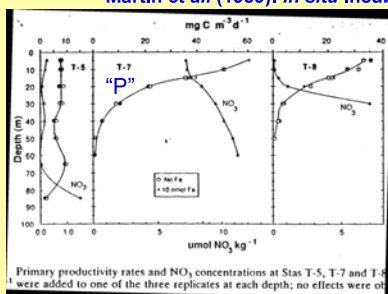
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Slide 57 Fe effect dependent on lat & long

NOTES:

No Fe effect on production!

Martin *et al.* (1989): *in situ* incubations



Primary productivity rates and NO_3^- concentrations at Stas T-5, T-7 and T-8 were added to one of the three replicates at each depth; no effects were observed.

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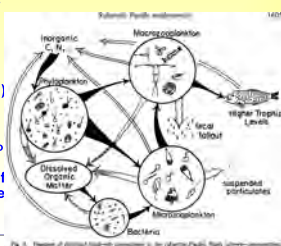
Slide 58 No Fe effect on production!

NOTES:

The ecumenical Fe hypothesis

Morel (1991), Miller *et al.* (1991)

- Small phytoplankton (<10 μm) less affected by low Fe
 - Use NH_4^+ as primary N source
 - Outcompete diatoms for NH_4^+ and Fe
 - Are Grazer-limited
 - Grow with high relative growth rates
- Large phytoplankton cells (>10 μm) Fe-limited
 - More likely to use NO_3^- ; Nitrate reductase requires Fe;
 - Outcompeted for Fe due to low surface:volume ratios
- Fe additions leads to stimulation of large cells which synthesize nitrate reductase and remove NO_3^-



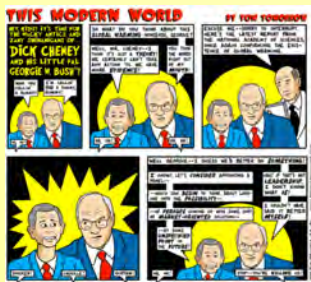
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Slide 59 The ecumenical Fe hypothesis

NOTES:

Market-oriented CO_2 solution

Carbon credits for the geritol solution



What is the geritol solution & could it work?

Chisholm, S. W., P. G. Falkowski and J. J. Cullen. 2001. Dis-crediting ocean fertilization. *Science* 294: 309-310.

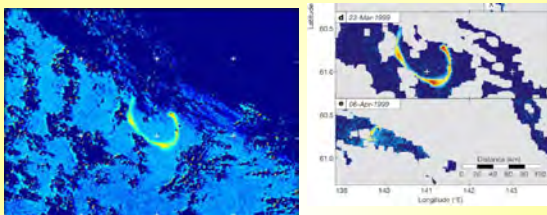
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Slide 60 Market-oriented CO_2 solution

NOTES:

SOIREE (Southern Ocean iron release experiment)

SeaWiFS Image of 100 km bloom, 30 d after Fe-II spike



Abraham *et al.* 2000

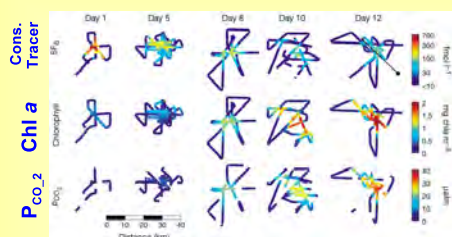
Slide 61 SOIREE

(Southern Ocean iron release experiment)

NOTES:

IRONEX III, SOIREE

Boyd *et al.* (2000) Figure 2



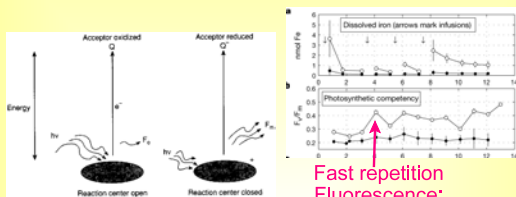
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Slide 62 IRONEX III, SOIREE

NOTES:

Variable fluorescence & Fe limitation

$$\text{Photosynthetic competency} = F_v = (F_m - F_o) / F_m$$



$$\text{Photosynthetic competency} = F_v = (F_m - F_o) / F_m$$

Fast repetition
Fluorescence:
1st indicator of
bloom

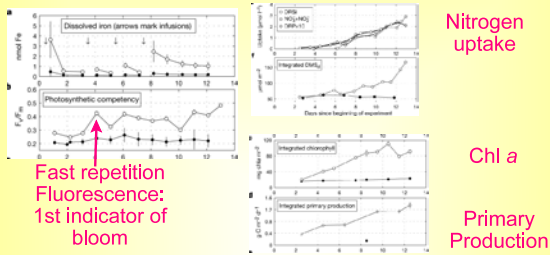
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Slide 63 Variable fluorescence & Fe limitation

NOTES:

IRONEX III: bloom by 30-50 μm diatoms

Boyd *et al.* (2000) Fig. 3

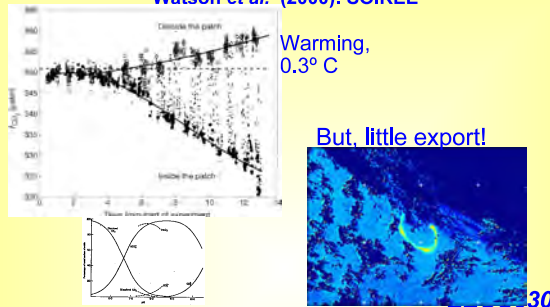


Slide 64 IRONEX III: bloom by 30-50 μm diatoms

NOTES:

Fe increases CO_2 gradient

Watson *et al.* (2000): SOIREE



Slide 65 Fe increases CO_2 gradient

NOTES:

SOIREE: major results

Confirms the 'ecumenical' iron hypothesis

- Increase in photosynthetic parameters by day II, measured by variable fluorescence
- Increase in large chain-forming diatoms by day 5: 30-50 μm cell size
- Microzooplankton abundance quadrupled
 - Grazing only on small phytoplankton cells ($< 20 \mu\text{m}$ cells)
- **No evidence of macrozooplankton response**
 - **No increased carbon export to sediment traps**
- Partial pressure of CO_2 decreased in surface ocean; this gradient would increase the atmosphere to ocean flux of CO_2

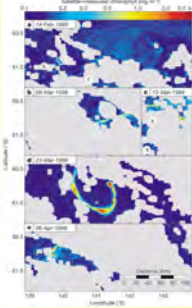
Slide 66 SOIREE: major results

NOTES:

SOIREE

Abraham *et al.* 2000. Importance of stirring

- 150-km long bloom 6 weeks after the Fe fertilization experiment
- 23 March 1999
 - 3 mg Chl $a\ m^{-3}$
 - In an area where SeaWiFS indicates the mean Chl a was $0.2 \pm 0.06\ mg\ Chl\ a\ m^{-3}$ (15X increase)
- Stirring plays a key role
 - Fit growth rates of $\mu = 0.19\ d^{-1}$
 - Loss due to horizontal diffusion = $0.07\ d^{-1}$
 - Loss due to grazing = $0.01\ d^{-1}$
 - Loss due to sinking = $0.02\ d^{-1}$
- Accumulation of 600-3000 t of algal C



Slide 67 SOIREE

NOTES:

C:N:P:Fe Redfield ratios

C:N:P:Fe ≈ 106:16:1:(0.003 to 0.0003)

- Lab cultures
 - Geider & LaRoche (1994)
 - Dinoflagellate (*Gymnodinium*) N:Fe ≈ 2000
 - Diatom N:Fe ≈ 10,000
 - *Synechococcus* (blue green) N:Fe ≈ 3000
 - Sunda *et al.* (1995), quoted in Fung *et al.* (2000)
 - Measured range N:Fe 13,000 - 116,000
 - Low productivity N:Fe ≈ 60,000 C:Fe 400,000
 - High productivity N:Fe ≈ 34,000 C:Fe 220,000
 - Boyd *et al.* (2004) Gulf of Alaska bloom
 - N:Fe 5800
 - C:Fe 38,000

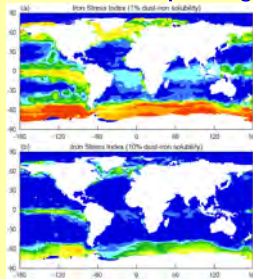
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Slide 68 C:N:P:Fe Redfield ratios

NOTES:

Iron stress in the oceans

Zones where Fe:N uptake > Fe:N supply (from dust & upwelling), Fung *et al.* (2000)



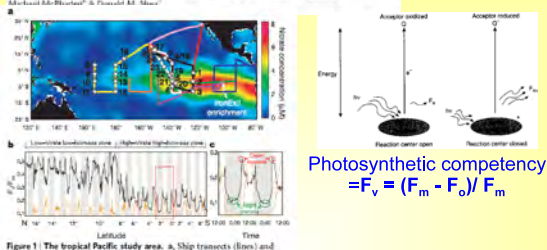
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Slide 69 Iron stress in the oceans

NOTES:

Controls on tropical Pacific Ocean productivity revealed through nutrient stress diagnostics

Michael J. Behrenfeld¹, Ruby Wittington¹, Robert M. Sherrell¹, Francisco P. Chavez², Peter Strutton¹, Michael E. Rienecker³, & Pauline M. Marra¹



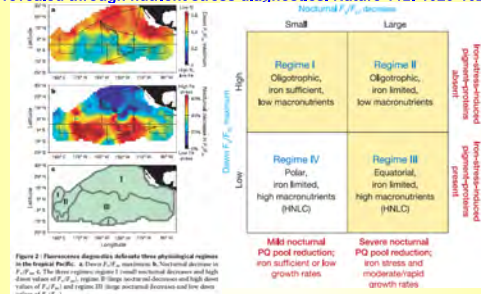
Nature 442: 1025-1028. August 2006 **EEOS630**

Slide 70 The ecumenical Fe hypothesis

NOTES:

Iron-limitation zones

Behrenfeld, M. J. et al. 2006. Controls on tropical ocean productivity revealed through nutrient stress diagnostics. Nature 442: 1025-1028.



Slide 71 Iron-limitation zones

NOTES:

Does Fe limit production in the Southern California Bight?

Bruland et al. (2001) Limnol. Oceanogr

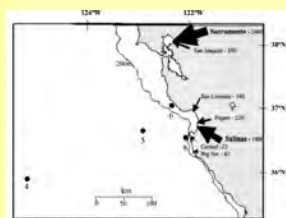


Fig. 1. Map of the Southern California Bight showing the location of the study area and the distribution of iron and other nutrients.

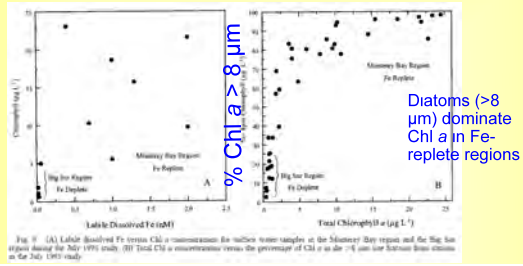
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Slide 72 Does Fe limit production in the Southern California Bight?

NOTES:

Does Fe limit production in the Southern California Bight? Perhaps

Bruland et al. (2001) Limnol. Oceanogr



Slide 73 Does Fe limit production in the Southern California Bight? Perhaps

NOTES: