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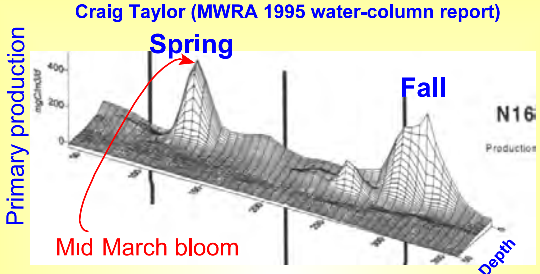
Slide 1 The Seasonal Production cycle in MA Bay, including the subsurface chl a maximum; The geritol solution or 'Why no spring blooms in the Southern Ocean & subarctic Pacific?'

NOTES:

1995 Seasonal production

Craig Taylor (MWRA 1995 water-column report)



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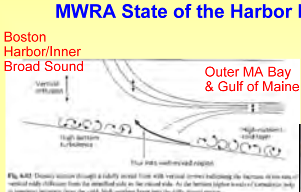
Slide 2 1995 Seasonal production

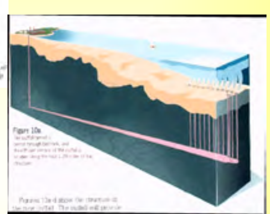
NOTES:

BH-MA Bay: A tidal front

MWRA State of the Harbor Report & Mann & Lazier

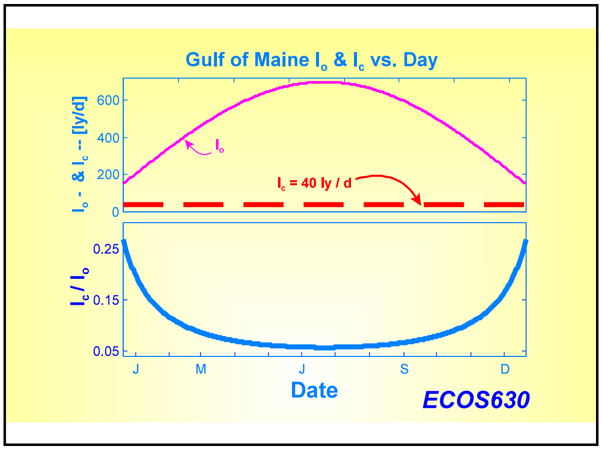


Stratification can occur in any month (snow melt inversions), but stable pycnocline develops in March



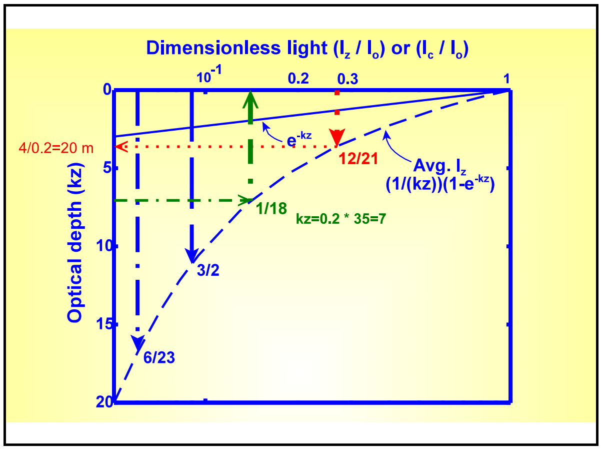
Slide 3 BH-MA Bay: A tidal front

NOTES:



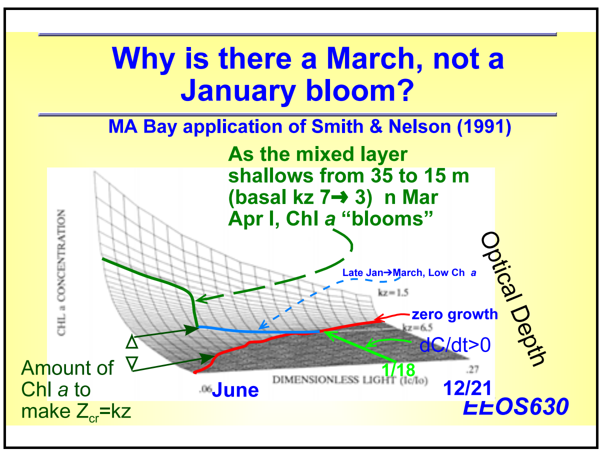
Slide 4

NOTES:



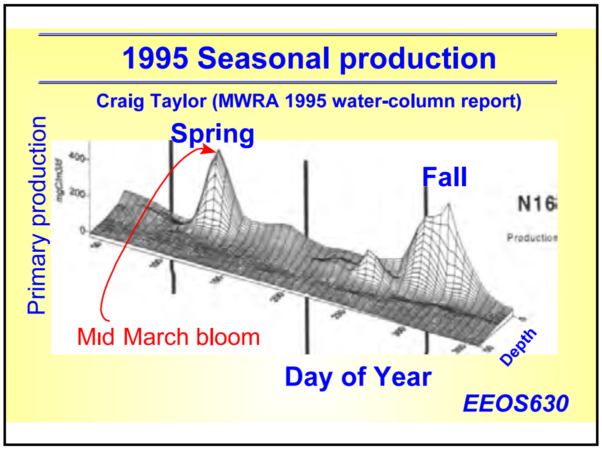
Slide 5

NOTES:



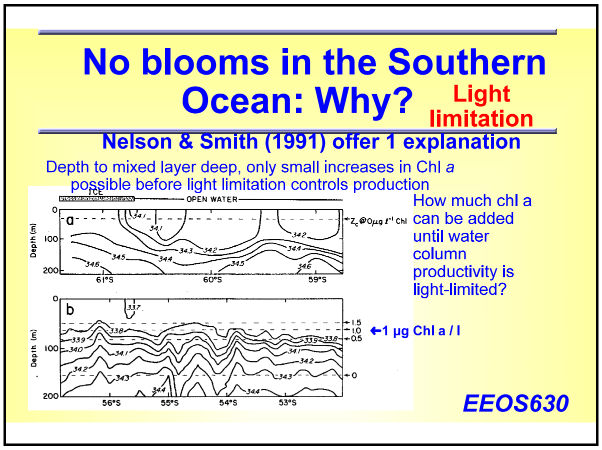
Slide 6 Why is there a March, not a January bloom?

NOTES:



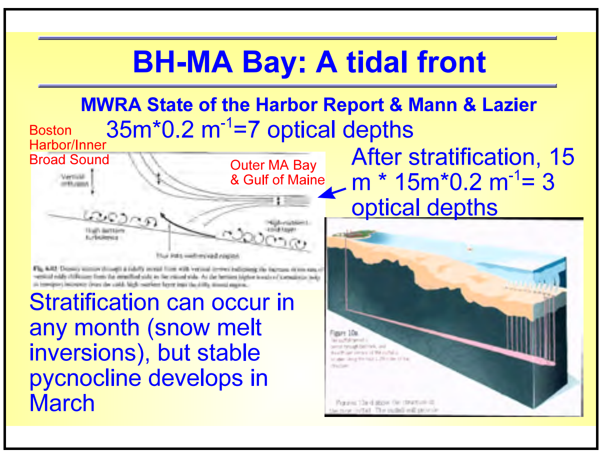
Slide 7 1995 Seasonal production

NOTES:



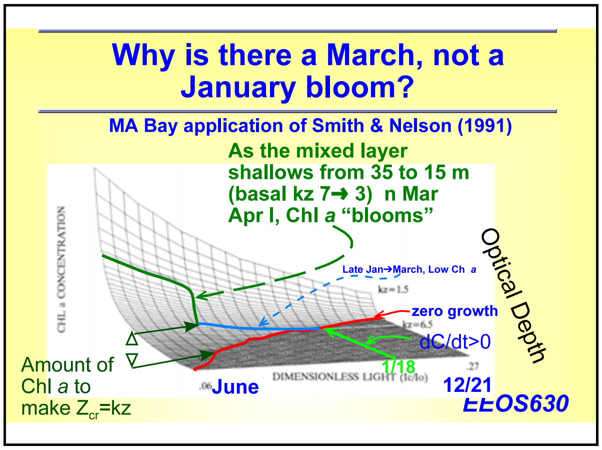
Slide 8 No blooms in the Southern Ocean: Why?

NOTES:



Slide 9 BH-MA Bay: A tidal front

NOTES:



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

NOTES:

Excursis on subsurface chlorophyll maxima

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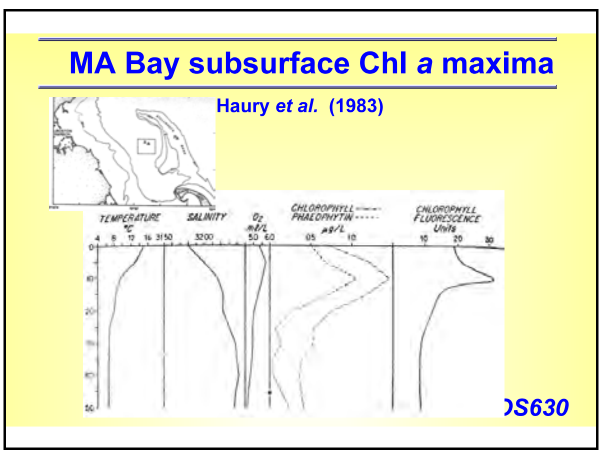
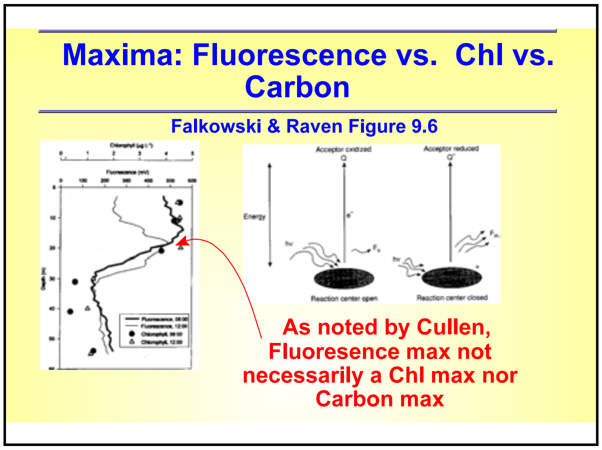
Slide 11 Excursis on subsurface chlorophyll maxima

NOTES:



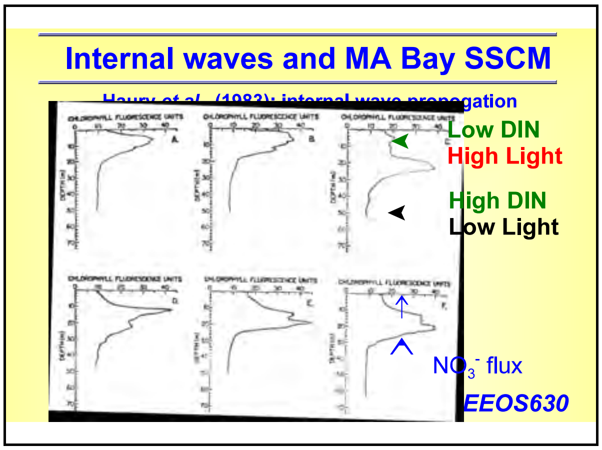
Slide 12 MA Bay subsurface Chl a maxima

NOTES:



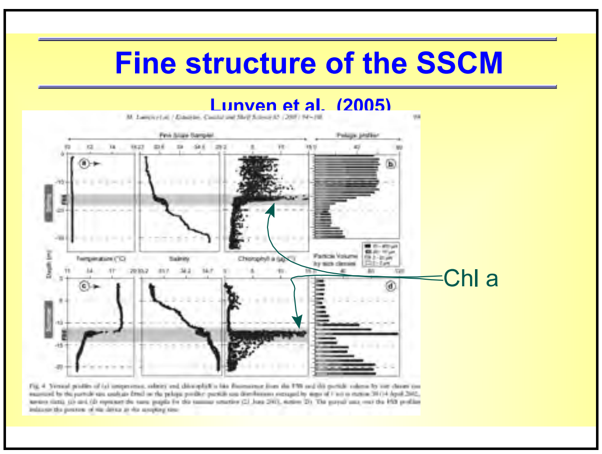
Slide 13 Maxima: Fluorescence vs. Chl vs. Carbon

NOTES:



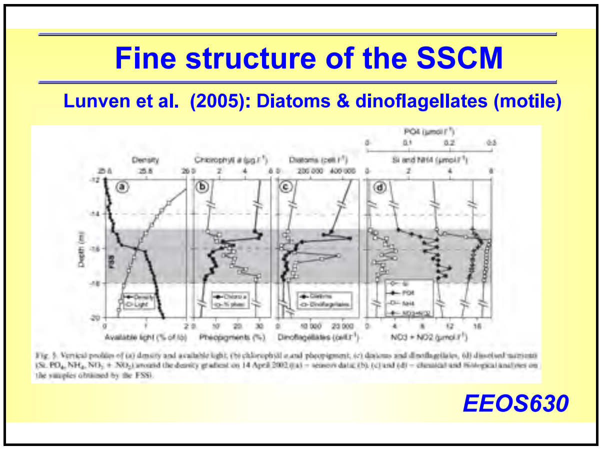
Slide 14 Internal waves and MA Bay SSCM

NOTES:



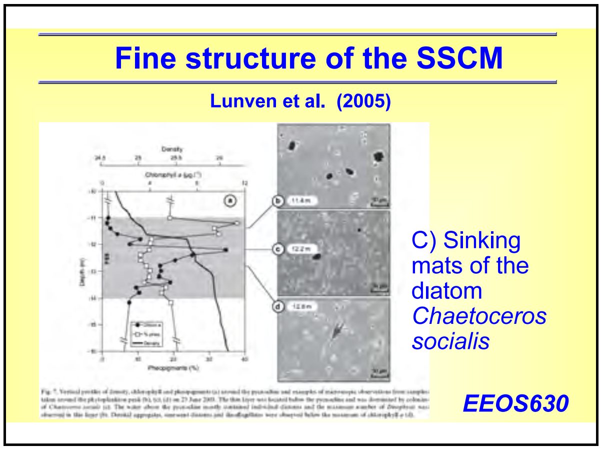
Slide 15 Fine structure of the SSCM

NOTES:



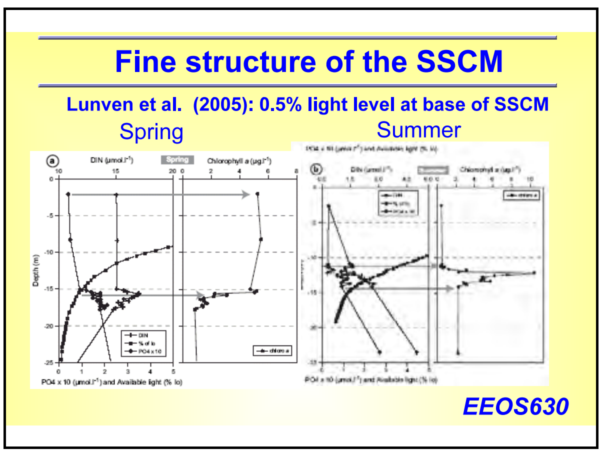
Slide 16 Fine structure of the SSCM

NOTES:



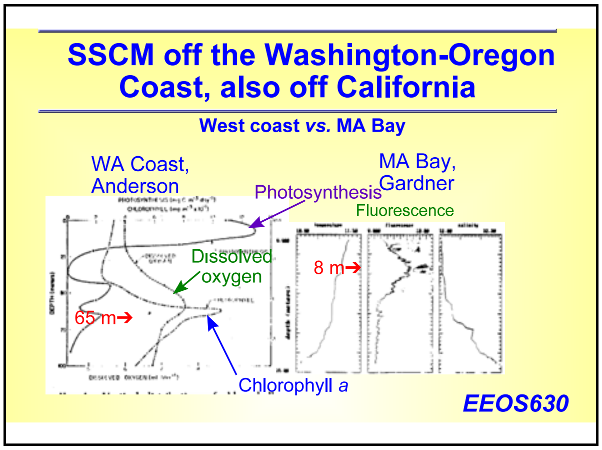
Slide 17 Fine structure of the SSCM

NOTES:



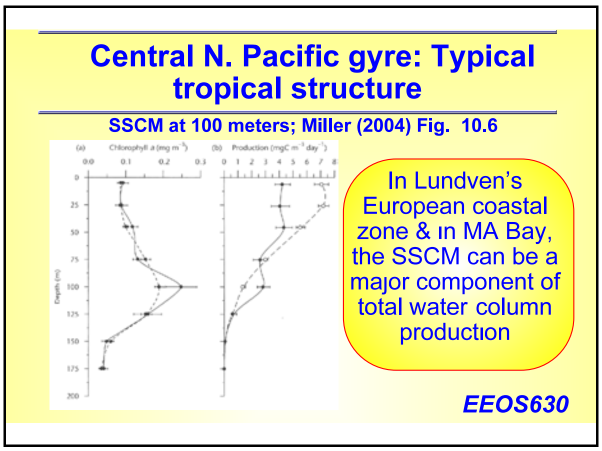
Slide 18 Fine structure of the SSCM

NOTES:



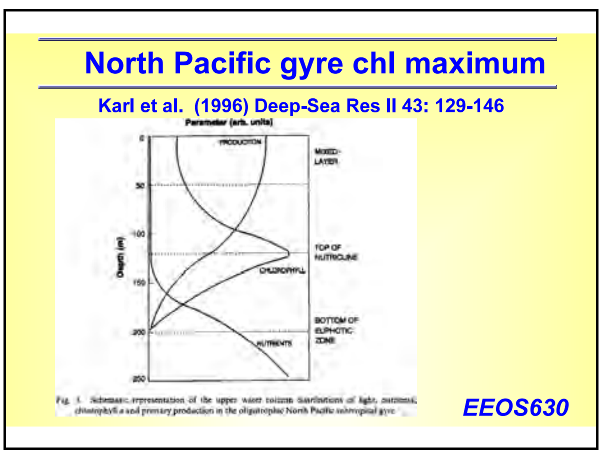
Slide 19 SSCM off the Washington-Oregon Coast, also off California

NOTES:



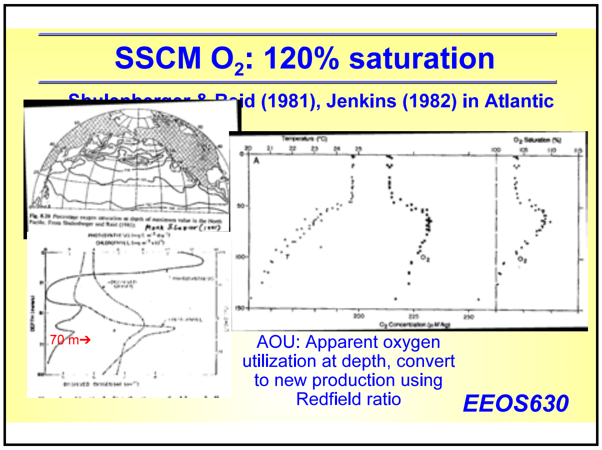
Slide 20 Central N. Pacific gyre: Typical tropical structure

NOTES:



Slide 21 North Pacific gyre chl maximum

NOTES:



Slide 22 SSCM O2: 120% saturation

NOTES:

Massachusetts Bay Production

Cole-Cloern relationship & Subsurface Chlorophyll maxima

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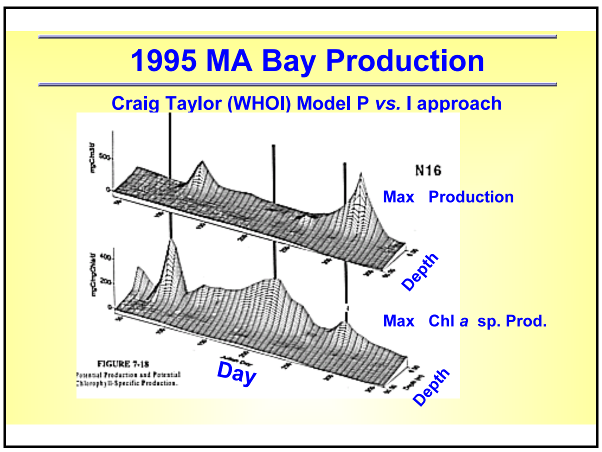
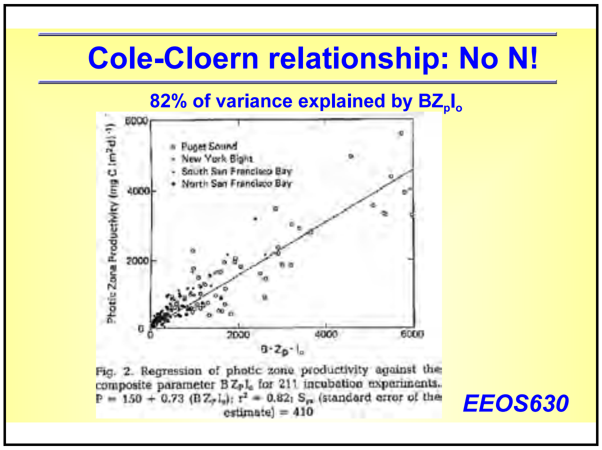
Slide 23 Massachusetts Bay Production

NOTES:



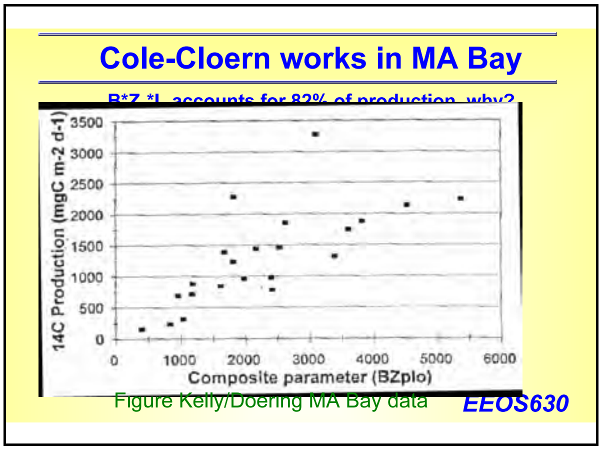
Slide 24 1995 MA Bay Production

NOTES:



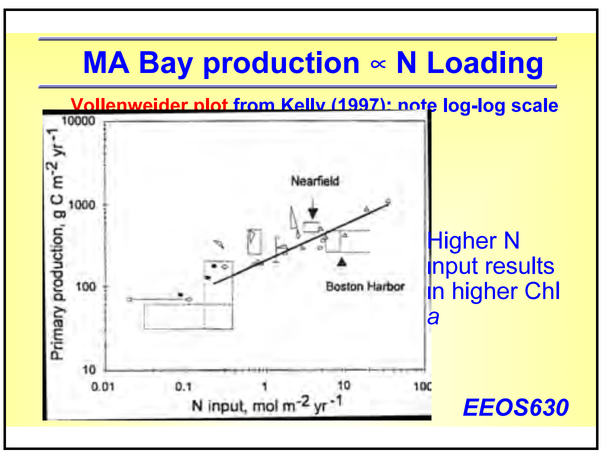
Slide 25 Cole-Cloern relationship: No N!

NOTES:



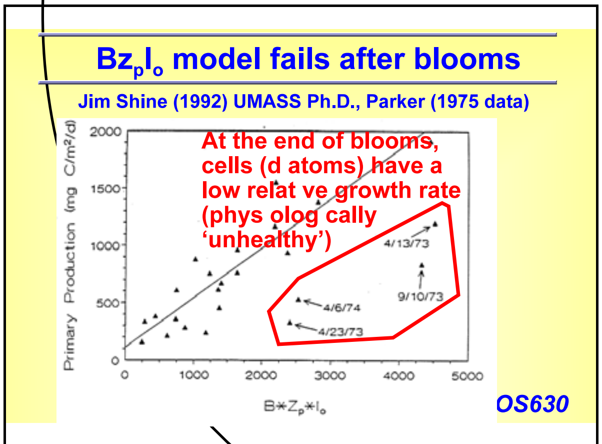
Slide 26 Cole-Cloern works in MA Bay

NOTES:



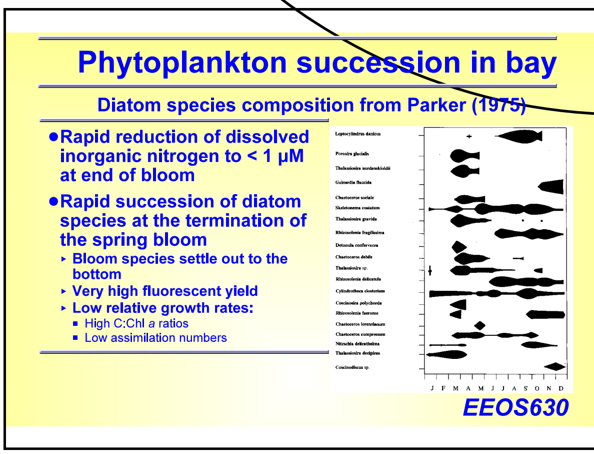
Slide 27 MA Bay production ∝ N Loading

NOTES:



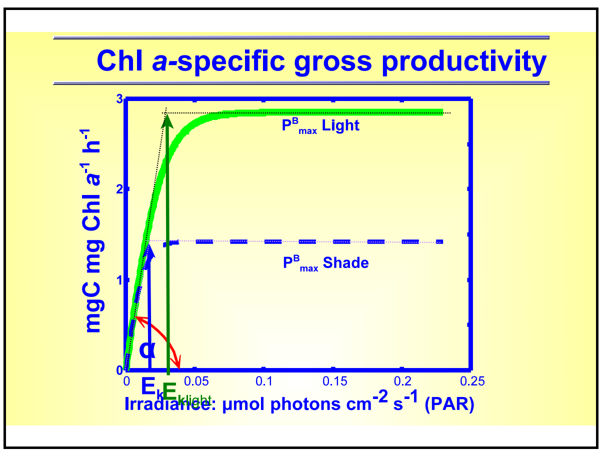
Slide 28 BzpIo model fails after blooms

NOTES:



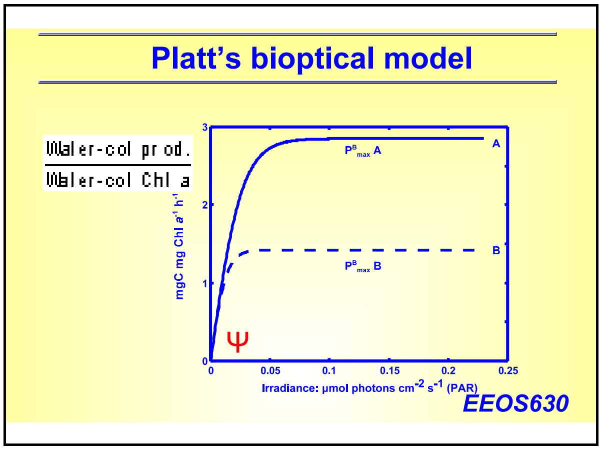
Slide 29 Phytoplankton succession in bay

NOTES:



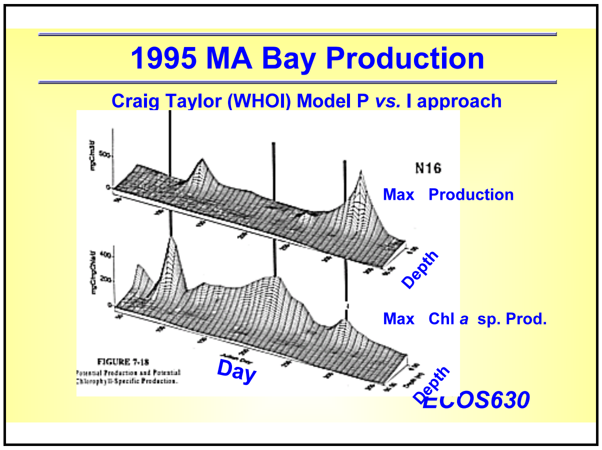
Slide 30 Platt's (1986) Explanation

NOTES:



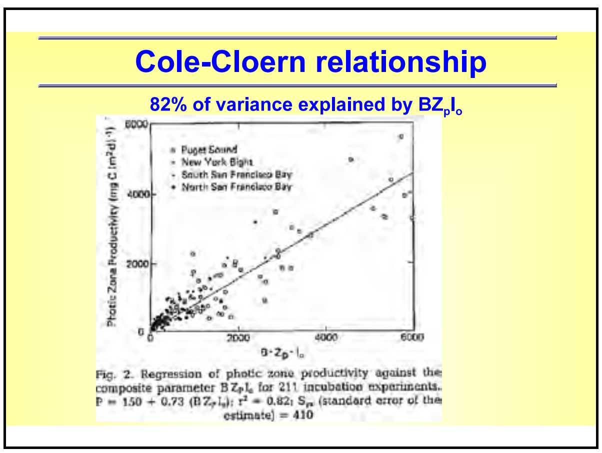
Slide 31 Platt's bioptical model

NOTES:



Slide 32 1995 MA Bay Production

NOTES:



Slide 33 Cole-Cloern relationship

NOTES:

Why does the Cole-Cloern model work?

Wofsy is wrong, Platt (1986) appears correct

- Wofsy (1983)
  - Nutrient-rich lakes, bays and estuaries:
    - 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)
  - Succession among phytoplankton groups leads to phytoplankton acclimated to current nutrient input regime
  - Their P vs. I parameters are close to temperature-controlled optima

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Slide 34 Why does the Cole-Cloern model work?

NOTES:

Why does the model work?

Wofsy is wrong, Platt (1986) appears correct

- Bio-optical models & Ψ (psi)
  - Platt (1986) Initial slope of the generalized P *vs.* I relationship, Ψ (pronounced *psi*), *relatively* constant at 0.4 g C g^{-1} Chl *a* m^{-2} mol^{-1} photons
  - Raven & Falkowski (1997) Figure 9.9
    - Ψ not a constant
      - Higher at low light intensities
      - Lower in nutrient-stressed cells
- A high relative specific growth rate produces the Cole-Cloern or Malone-Platt relationship
  - If relative growth rate is high (coupled mainly to temperature), then
  - There must be a close coupling between nutrient loading and Chl *a* concentration

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Slide 35 Why does the model work?

NOTES:

Why no phytoplankton bloom in the Subarctic Pacific?

Parsons et al. (1966): the Major Grazer hypothesis
Evans & Parslow's Micrograzer Hypothesis
Martin's Iron Hypothesis
Ecumenical Iron hypothesis

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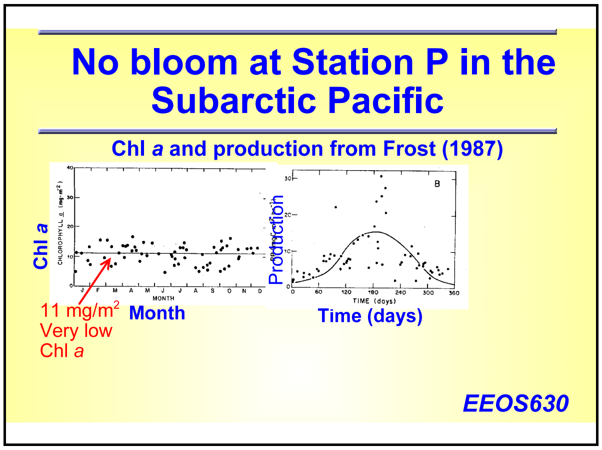
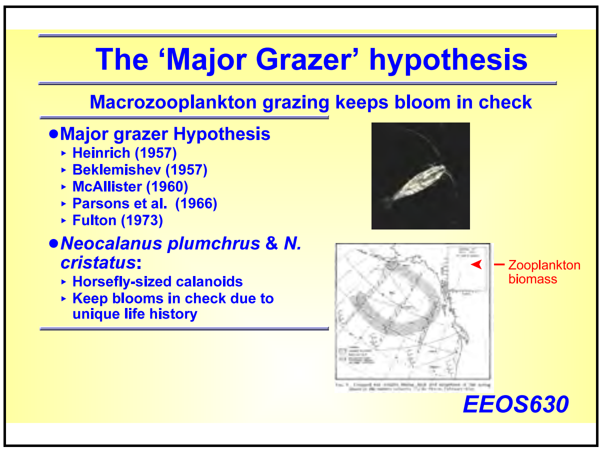
Slide 36 Why no phytoplankton bloom in the Subarctic Pacific?

NOTES:



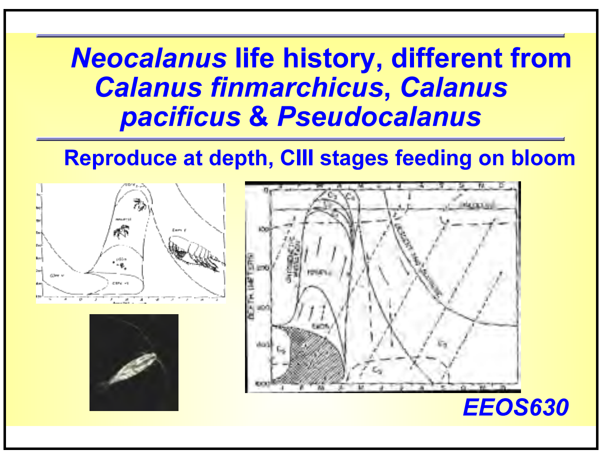
Slide 37 No bloom at Station P in the Subarctic Pacific

NOTES:



Slide 38 The ‘Major Grazer’ hypothesis

NOTES:

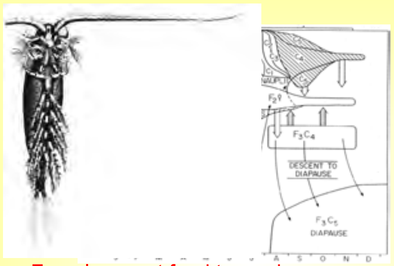


Slide 39 Neocalanus life history, different from Calanus finmarchicus, Calanus pacificus & Pseudocalanus

NOTES:

N. Atlantic *Calanus* life history

***Calanus finmarchicus*: the N. Atlantic dominant**



Females must feed to produce eggs: 20-30 d lag

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Slide 40 N. Atlantic Calanus life history

NOTES:

The micrograzer hypothesis: ciliates

Evans & Parslow's (1985) model

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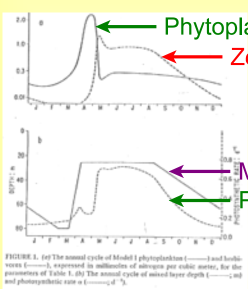
Slide 41 The micrograzer hypothesis: ciliates

NOTES:

Blooms with constant mixed layers

Evans & Parslow (1985), Figures 2 & 3



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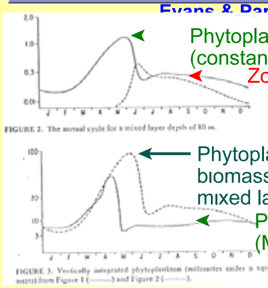
Slide 42 Blooms with constant mixed layers

NOTES:

Protozoan grazing & winter standing stocks the key!

Evans & Parslow's (1985)



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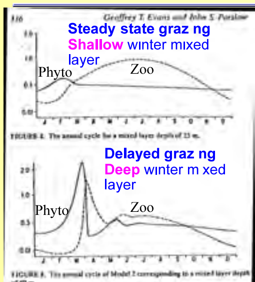
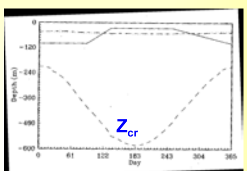
Slide 43 Protozoan grazing & winter standing stocks the key!

NOTES:

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





Falk (1991) UMB MS *EEOS630*

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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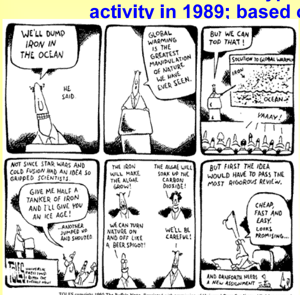
Slide 46 Problems with the "naive" micrograzer hypothesis

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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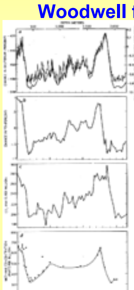
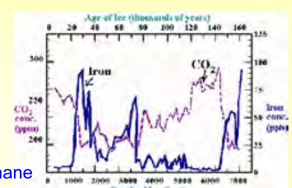
Slide 47 Martin's Geritol solution

NOTES:

The Greenhouse effect & Fe

Woodwell figures. Fe dust increased during ice ages





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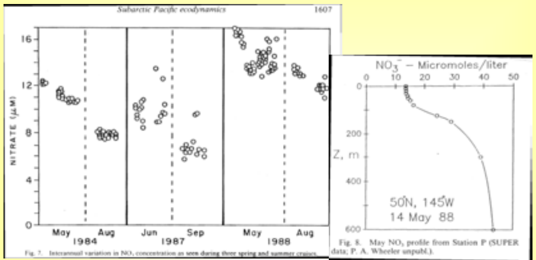
Slide 48 The Greenhouse effect & Fe

NOTES:

High nitrate all year at Station P

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



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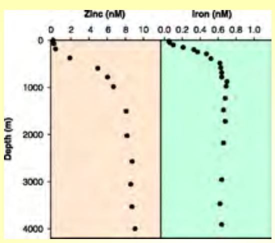
Slide 49 High nitrate all year at Station P

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
- Ferrodoxin (needed for N_2 fixation)
- Nitrate reductase, nitrite reductase
- Glutamate synthetase
- Others

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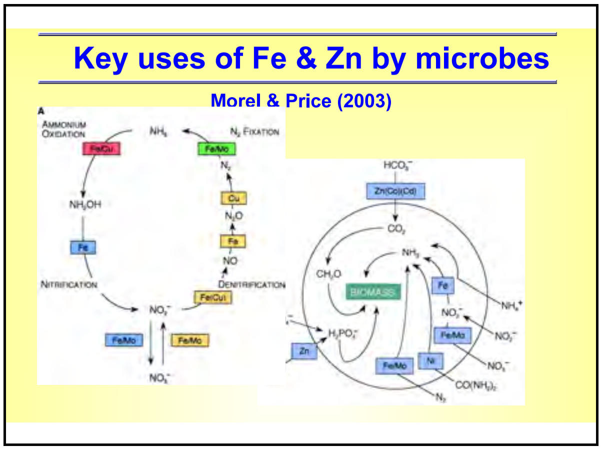
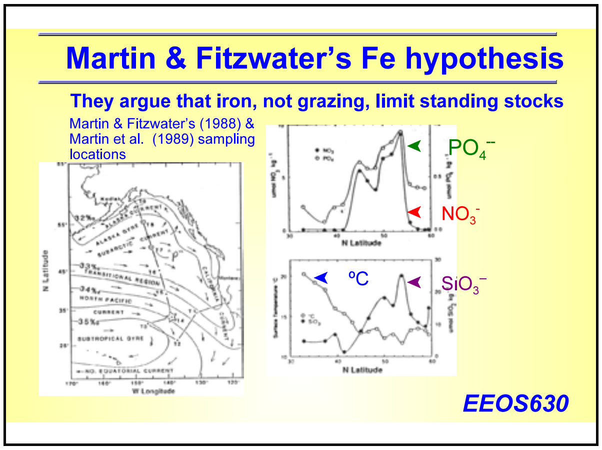
Slide 51 Roles of Fe in plant metabolism

NOTES:



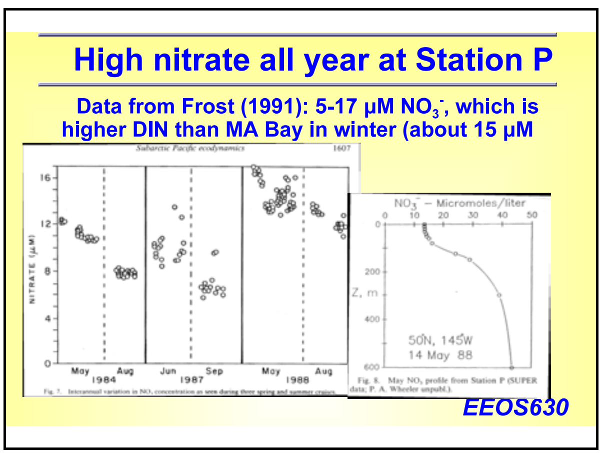
Slide 52 Key uses of Fe & Zn by microbes

NOTES:



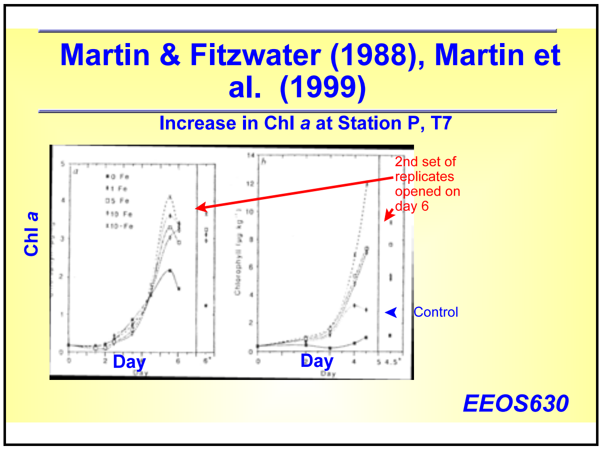
Slide 53 Martin & Fitzwater's Fe hypothesis

NOTES:



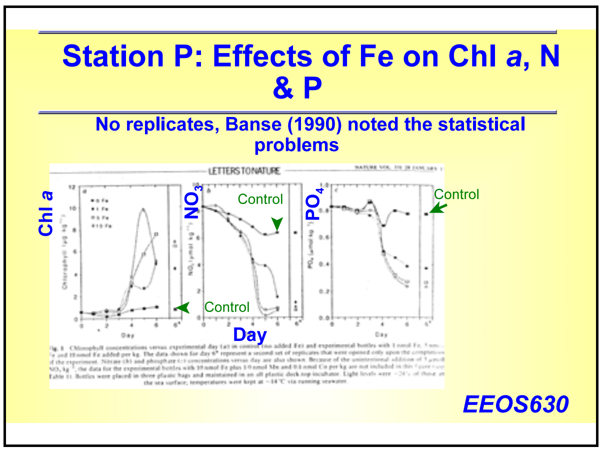
Slide 54 High nitrate all year at Station P

NOTES:



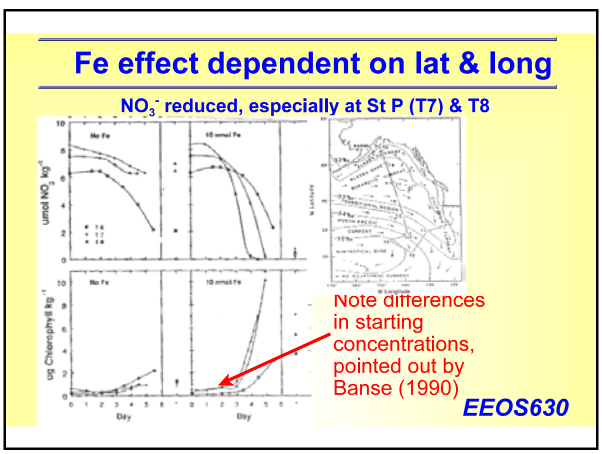
Slide 55 Martin & Fitzwater (1988), Martin et al. (1999)

NOTES:



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

NOTES:

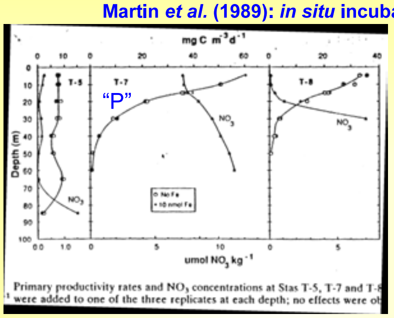


Slide 57 Fe effect dependent on lat & long

NOTES:

No Fe effect on production!

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



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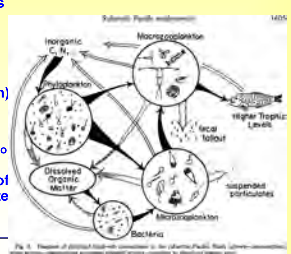
Slide 58 No Fe effect on production!

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:vol ratios
- Fe additions leads to stimulation of large cells which synthesize nitrate reductase and remove NO_3^-



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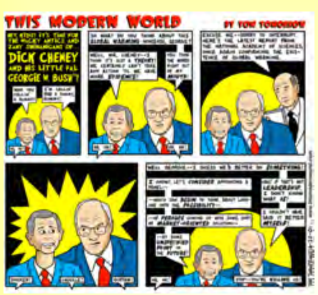
Slide 59 The ecumenical Fe hypothesis

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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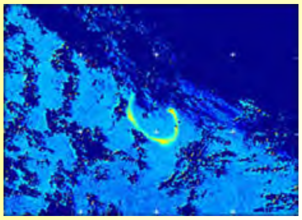
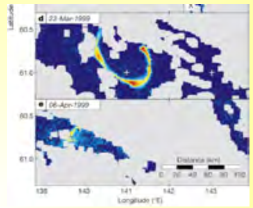
Slide 60 Market-oriented CO2 solution

NOTES:

SOIREE
(Southern Ocean iron release experiment)

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





Abraham *et al.* 2000

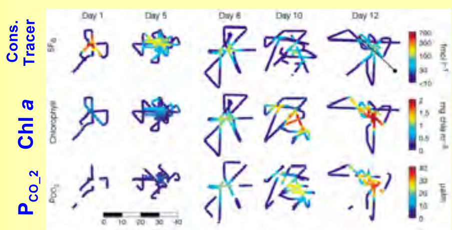
Slide 61 SOIREE

(Southern Ocean iron release experiment)

NOTES:

IRONEX III, SOIREE

Boyd *et al.* (2000) Figure 2



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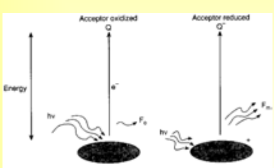
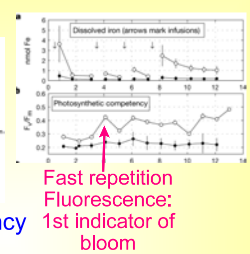
Slide 62 IRONEX III, SOIREE

NOTES:

Variable fluorescence & Fe limitation

Photosynthetic competency = F_v = $(F_m - F_o)/ F_m$,





Photosynthetic competency $=F_v = (F_m - F_o)/ F_m$

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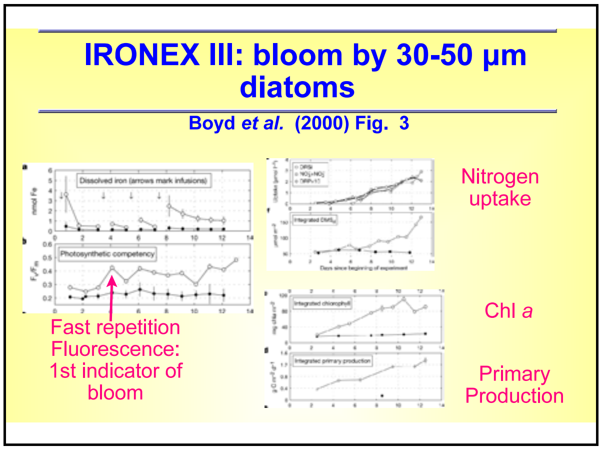
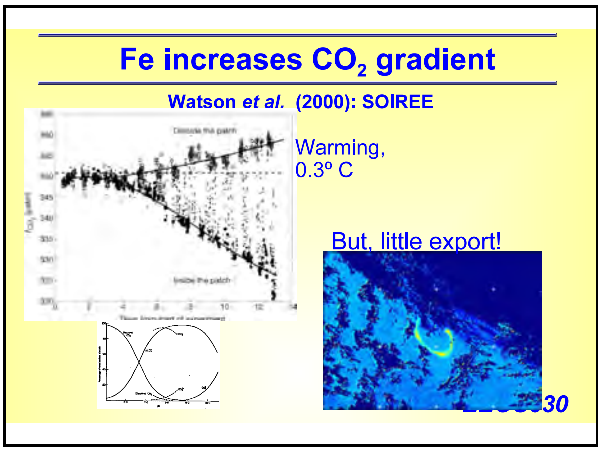
Slide 63 Variable fluorescence & Fe limitation

NOTES:



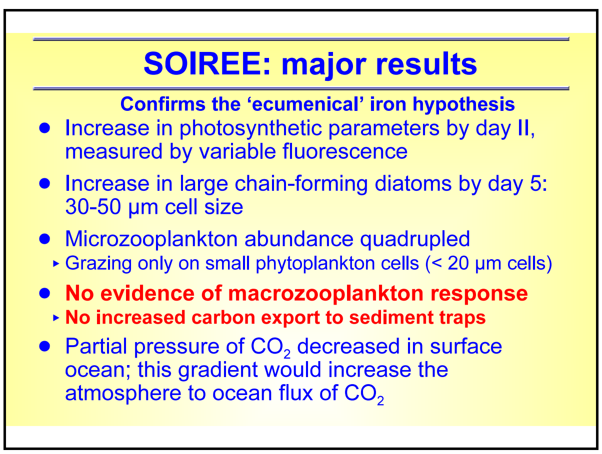
Slide 64 IRONEX III: bloom by 30-50 µm diatoms

NOTES:



Slide 65 Fe increases CO2 gradient

NOTES:



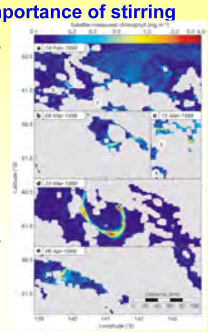
Slide 66 SOIREE: major results

NOTES:

SOIREE

Abraham *et al.* 2000. Importance of stirring

- 150-km long bloom 6 weeks after the Fe fertiliaztion experiment
- 23 March 1999
  - 3 mg Chl *a* m^{-3}
  - In an area where SeaWiFS indicates the mean Chl *a* was 0.2 ±0.06 mg Chl *a* m^{-3} {15X increase}
- Stirring plays a key role
  - Fit growth rates of μ=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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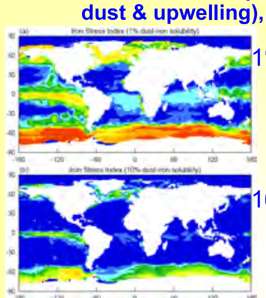
Slide 68 C:N:P:Fe Redfield ratios

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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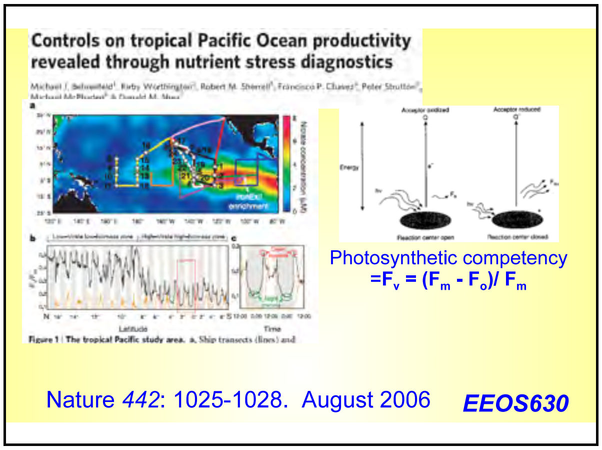
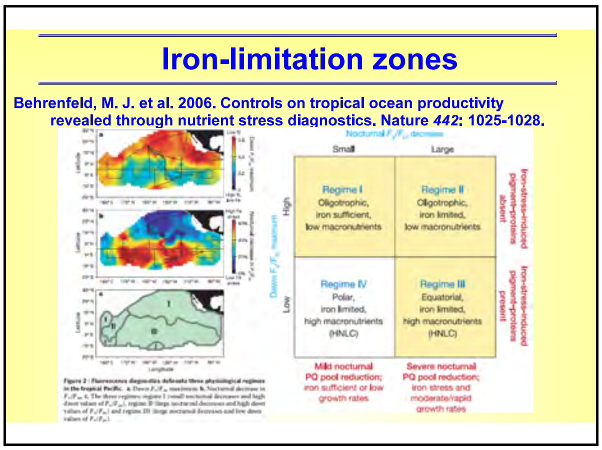
Slide 69 Iron stress in the oceans

NOTES:



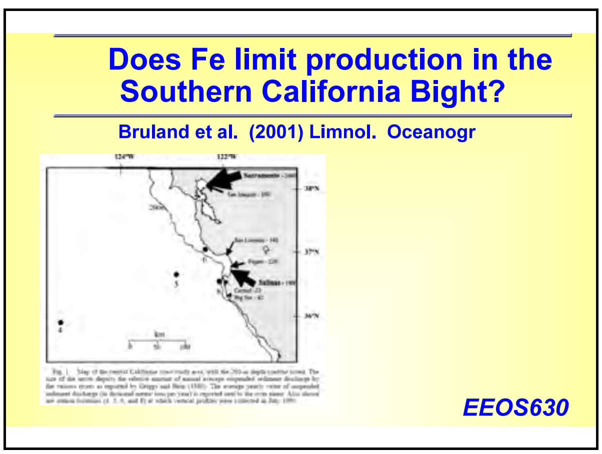
Slide 70 The ecumenical Fe hypothesis

NOTES:



Slide 71 Iron-limitation zones

NOTES:

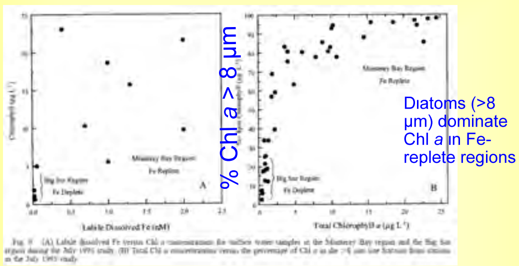


Slide 72 Does Fe limit production in the Southern California Bight?

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: