Measuring phytoplankton biomass, specific growth rate & Primary Production

Class 16, 10/23/08

EEOS630

Slide 1 Measuring phytoplankton biomass, specific growth rate & Primary Production

NOTES:

Wimba Sessions

- Quantitative community analysis using Matlab
  - Run the tutorial at the Mathworks site
  - I'll be logged on at 7 pm tonight to demonstrate community analysis using the West Falmouth oilspill data as an example using Matlab
- Due date: papers due 4 weeks after projects posted – today I hope

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Slide 2 Wimba Sessions

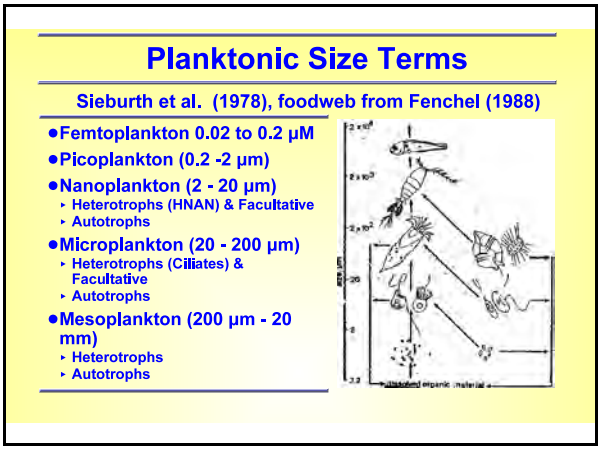
NOTES:

Phytoplankton Readings

- My chapters:
  - Chapter 7 (μ, B, & P), 8 (C14 method), 9 (Light effects)
- Readings (on UMB E- Reserve)
  - μ, B, & P:
    - Eppley, R. W. 1972. Temperature and phytoplankton growth in the sea. Fish. Bull. *70*: 1063-1085.
    - Lorenzen, C. J. 1966. A method for the continuous measurement of *in vivo* chlorophyll concentration. Deep-Sea Res. *13*: 223-227.*[The classic paper describing the use of pumped water through a Turner Model III fluorometer with excitation peak at 445 nm and emission peak at >645 nm*
  - C14:
    - Peterson, B. 1980. Aquatic primary productivity and the ^{14}C-CO_2 method: a history of the productivity problem. Ann. Rev. Ecol Syst. 11: 359-385. [Just skim for now]
  - Light
    - Harrison, W. G,. T. Platt, and M. K. Lewis. 1985. The utility of light-saturation models for estimating marine primary productivity in the field: a comparison with conventional "simulated: in situ" methods. Can J. Fish. Aquat. Sci. *42*: 864-872.
    - Falkowski, P. G. and J. A. Raven. 1997. Aquatic Photosynthesis. Blackwell Science, Malden MA. 375 pp. *[Read Chapter 9. Read pp. 263-276, 282-288 on fast repetition rate fluorescence and nonphotochemical quenching; skim the rest of the chapter.]*

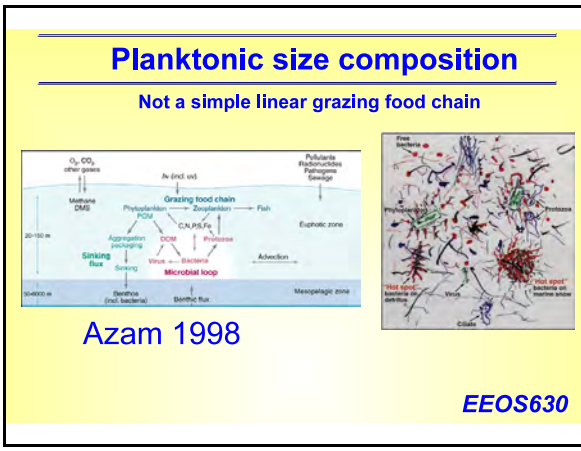
Slide 3 Phytoplankton Readings

NOTES:



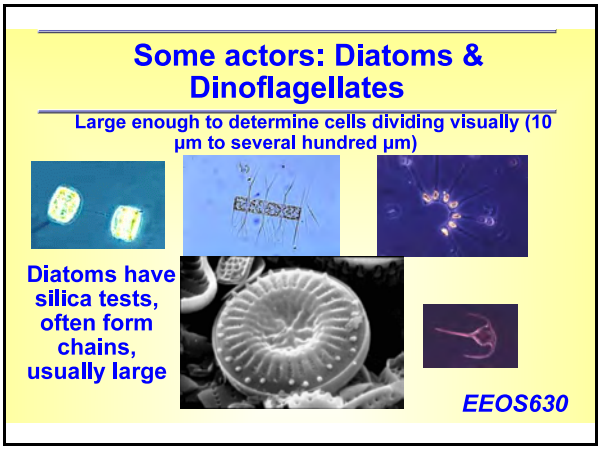
Slide 4 Planktonic Size Terms

NOTES:



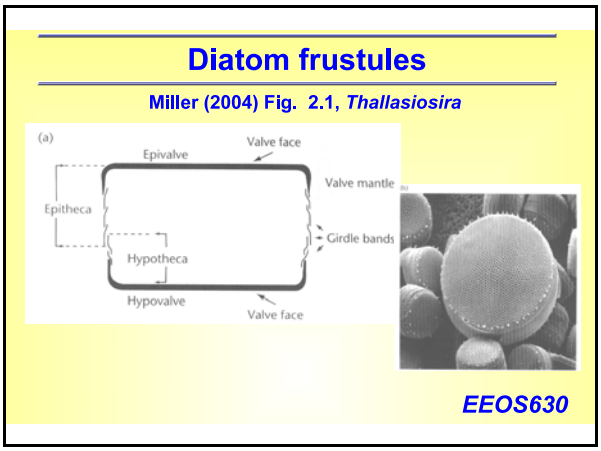
Slide 5 Planktonic size composition

NOTES:



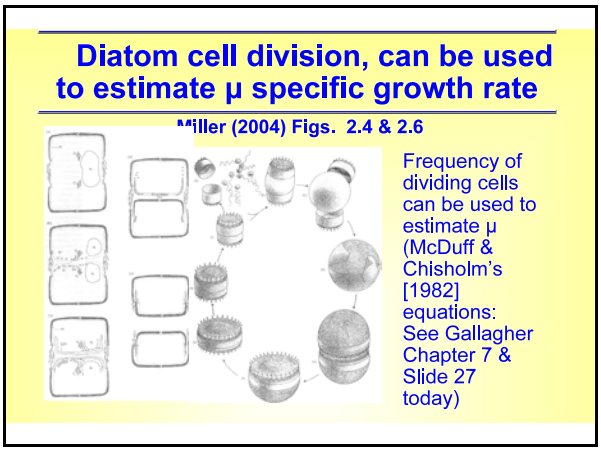
Slide 6 Some actors: Diatoms & Dinoflagellates

NOTES:



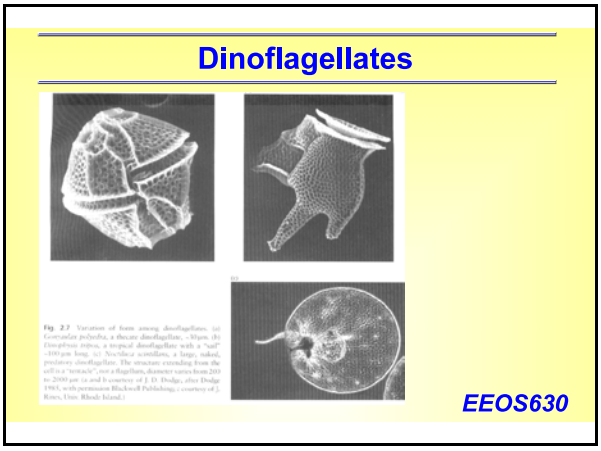
Slide 7 Diatom frustules

NOTES:



Slide 8 Diatom cell division, can be used to estimate μ specific growth rate

NOTES:

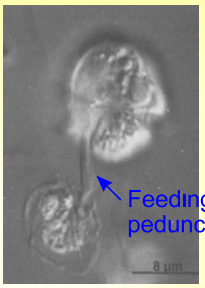


Slide 9 Dinoflagellates

NOTES:

Predatory dinoflagellates

Miller (2004) Figs. 2.8 & 2.9



Slide 10 Predatory dinoflagellates

NOTES:

Microflagellates (2-30 µm)

Miller (Table 2.1): a diverse array of phyla

	Flagellae	Cell wall	Main auxiliary pigments
Prokaryotes			
Cyanophyta	1	Murein	Phycocyanin
Prochlorophyta	0	Murein	Chlorophyll *b*
Rhodophyta	0	Cellulose	Phycoerythrin
Chrysophyceae & relatives*	2, unequal posterior short, smooth anterior long	Naked or scales (some opal)	Chlorophylls c_1+c_2, fucoxanthin
Bacillariophyceae (diatoms)	1 in male gamete, hairs, no microtubules	Naked gametes	Chlorophylls c_1+c_2, fucoxanthin, diatoxanthin
Prymnesiophyta			
Pavlovales (= Haptophyta)	2, equal or not, hairy – haptonema emerging between	Organic scales	β-carotene
Prymnesiales	2, unequal, hairy, haptonema vestigial	Organic or calcite scales	
Cryptophyta	2, apical, equal, sometimes hairy	Naked	Chlorophyll c_2, α-carotene, diatoxanthin
Pyrrophyta or Dinophyta	2, one girdling, one posterior	Cellulose plates or often naked	Chlorophyll c_2, peridinin, β-carotene
Prasinophyta	1 or 2 unequal, or 4 equal and scaly	Organic scales or naked	Chlorophyll *b*, β-carotene
Chlorophyta	2 (or 4) apical, equal, smooth	Naked or with cellulose sheath, sometimes calcified	Chlorophyll *b*, α-, β-, and γ-carotene

*A number of groups related to the Chrysophyceae have recently been separated within a new phylum Heterokontophyta. These include Xanthophyceae, Dictyochophyceae (including the Pelagophyceae or Silicoflagellates that bear equal scales and the very rare Pelagophyceae (the principal eukaryotic picoplankton). Heterokontophyta are characterized by flagellae of unequal length, anterior "tinsel" and posterior smooth, chlorophyll *c*, and chrysolaminarin as a storage product. The Chrysophyceae and Bacillariophyceae (listed above) are Heterokontophyta as are the brown algae Phaeophyceae and Xanthophyceae.

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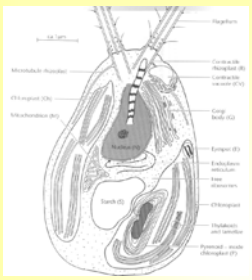
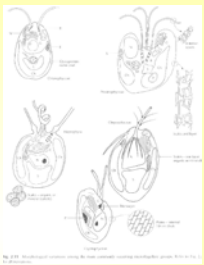
Slide 11 Microflagellates (2-30 µm)

NOTES:

Microflagellates

Miller (2004) Figs. 2.10 & 2.11





Slide 12 Microflagellates

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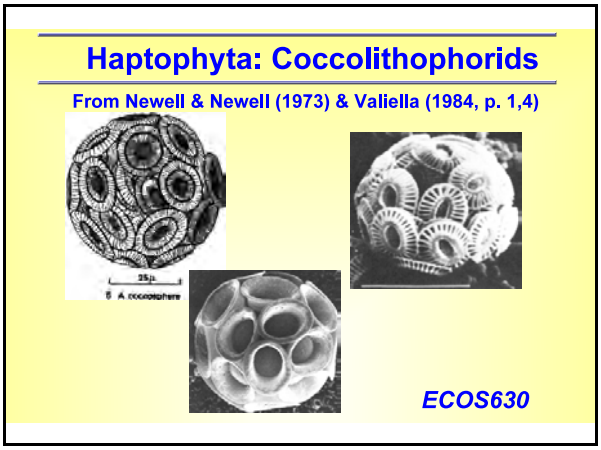
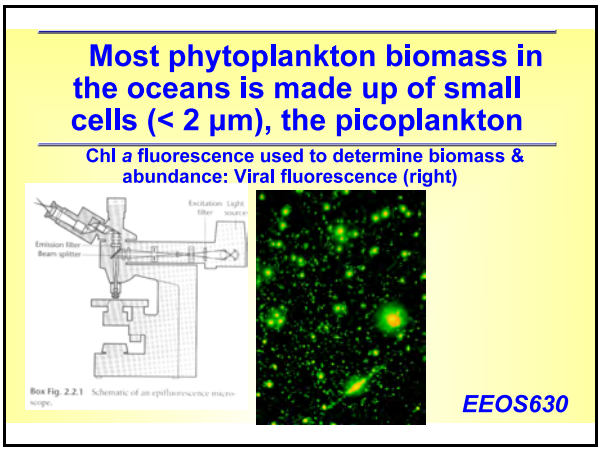


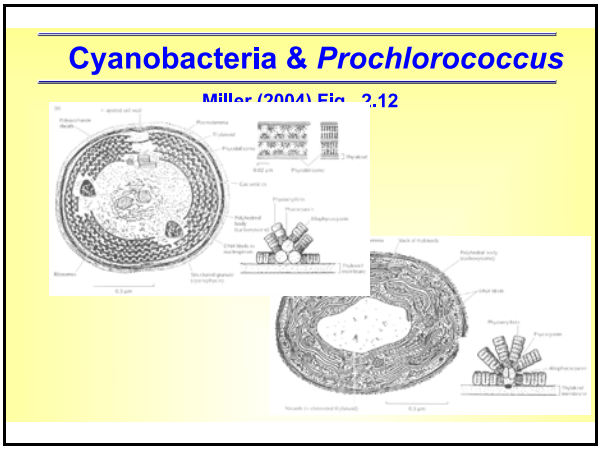
Slide 13 Haptophyta: Coccolithophorids

NOTES:



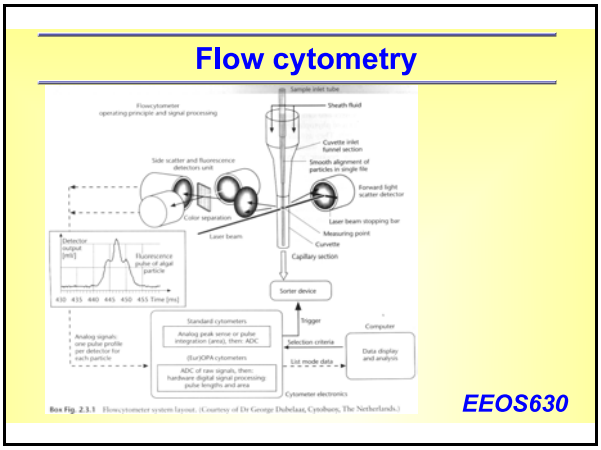
Slide 14 Most phytoplankton biomass in the oceans is made up of small cells (< 2 µm), the picoplankton

NOTES:



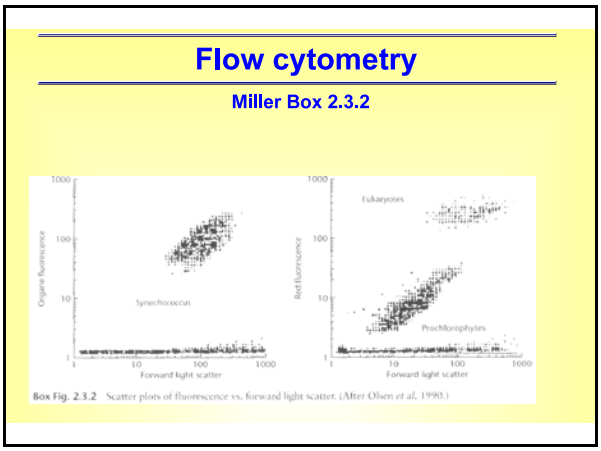
Slide 15 Cyanobacteria & Prochlorococcus

NOTES:



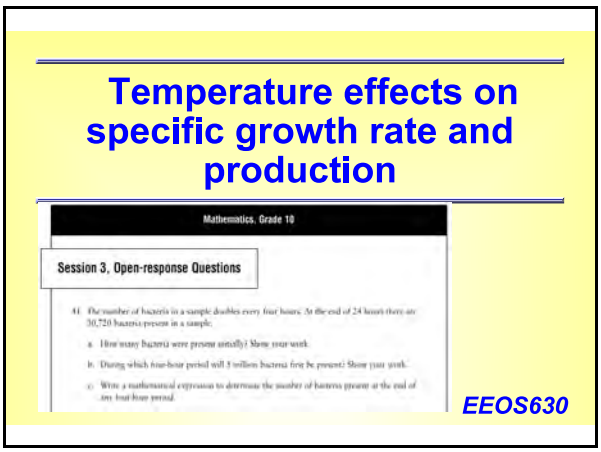
Slide 16 Flow cytometry

NOTES:



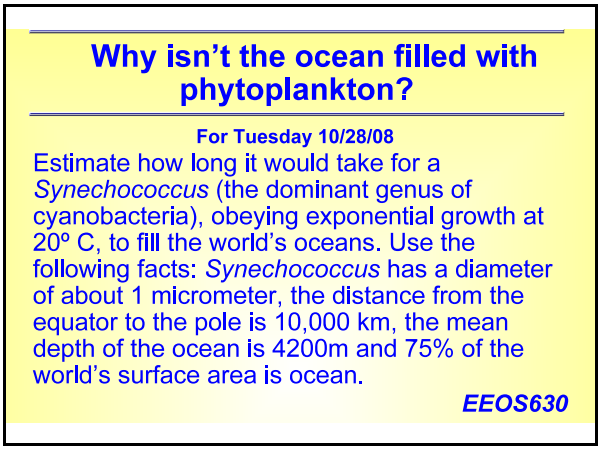
Slide 17 Flow cytometry

NOTES:



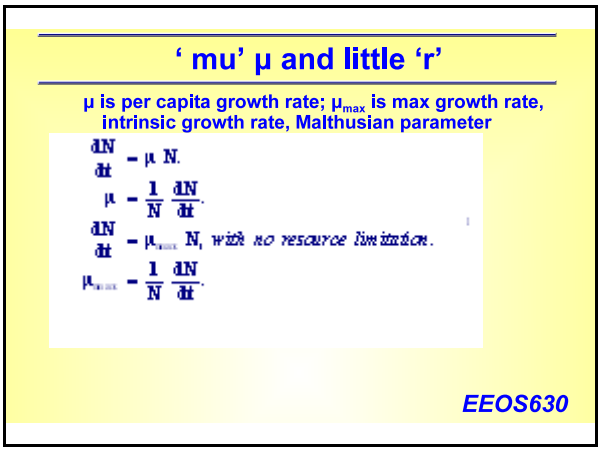
Slide 18 Temperature effects on specific growth rate and production

NOTES:



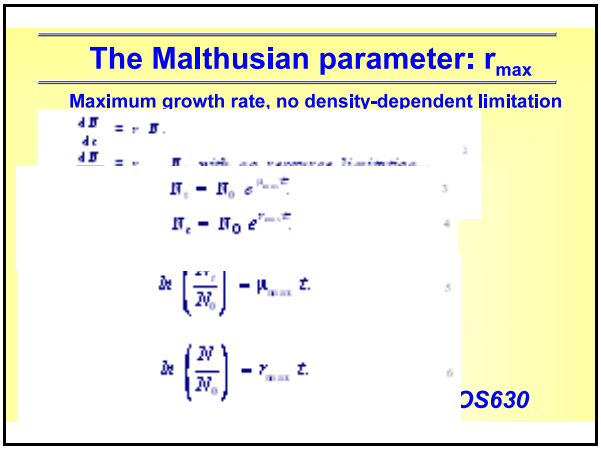
Slide 19 Why isn't the ocean filled with phytoplankton?

NOTES:



Slide 20 ' mu' μ and little 'r'

NOTES:



Slide 21 The Malthusian parameter: rmax

NOTES:

Specific growth rate, μ, and doublings per day (archaic)

μ: Units of inverse time

$$\ln\left(\frac{N_t}{N_0}\right) = \ln(2) = \mu\, t_d$$

$$t_d = \frac{\ln(2)}{\mu} \approx \frac{0.693}{\mu}$$

$$\text{Specific growth rate}\left[\frac{\text{doublings}}{\text{day}}\right] = \frac{1}{t_d} = \frac{\mu}{\ln(2)} \approx \frac{\mu}{0.693}$$

Slide 22 Specific growth rate, μ, and doublings per day (archaic)

NOTES:

Biomass-specific production, μ

Estimating biomass, in Carbon, the key problem in estimating μ

$$\mu = \text{specific production} = \frac{\text{production}}{\text{biomass}} = \frac{P}{B} = \frac{\frac{dC}{dt}}{B}$$

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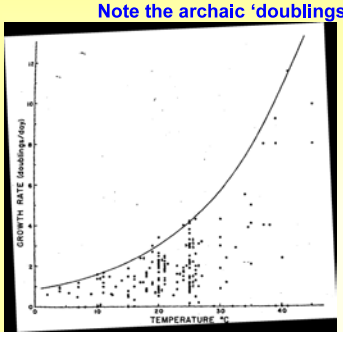
Slide 23 Biomass-specific production, μ

NOTES:

Eppley (1972)

Note the archaic 'doublings/day' ordinate



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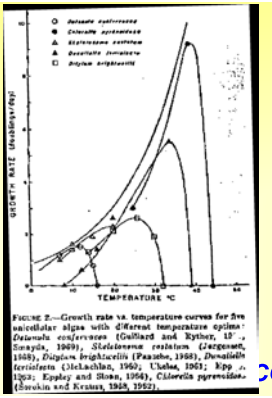
Slide 24 Eppley (1972)

NOTES:

Individual phytoplankton species have different temperature optima. The previous figure was an envelope to predict maximal specific growth rates



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Slide 25 Equations describing growth

NOTES:

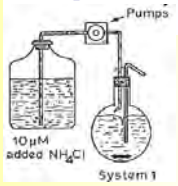
Modifications to Eppley's Temperature equation

Goldman & Carpenter, chemostats, not Temp in Kelvin

$\mu = 0.0307(e^{-0.18})^{1.15}$ (r=0.945, n = 18) Algae

$\mu = A e^{-BT}$, Goldman & Carpenter (1974)

Temperature in degrees Kelvin



Chemostat: µ=Dilution rate=Volume of culture/pumping rate

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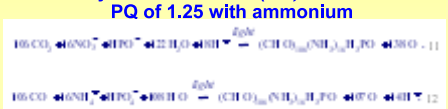
Slide 26 Modifications to Eppley's Temperature equation

NOTES:

Redfield Ratio

Photosynthetic Quotient (PQ) of 2.0 with nitrate PQ of 1.25 with ammonium



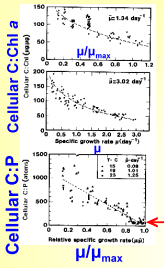
- The Redfield ratio describes the major elemental ratios of C N O in phytoplankton
- While it is 'relatively' easy to estimate production using N or C uptake or O_2 production, it is difficult to estimate µ since we don't know the biomass

Slide 27 Redfield Ratio

NOTES:

The relationship between μ/μ_{max} & the Redfield ratio

Goldman (1980), replotted by Harris (1986)



- Redfield ratios only attained at $\mu/\mu'_{max} \approx 1$
- C:Chl *a* ratio is a reasonable predictor of relative growth rate
  - Affected by shade adaptation

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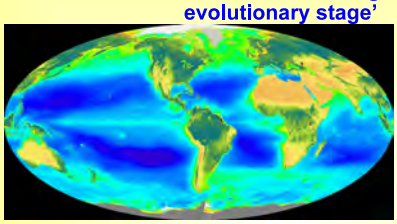
Slide 28 The relationship between μ/μmax & the Redfield ratio

NOTES:

The ecological (and evolutionary) Stage

From Hutchinson's 'The ecological play on the evolutionary stage'



SeaWIFs Image of Chl *a* concentration

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Slide 29 The ecological (and evolutionary) Stage

NOTES:

Redfield ratio

106 C: 16 N: 1 P

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138\,O_2 \rightarrow 106\,CO_2 + 16\,HNO_3 + H_3PO_4 + 122\,H_2O.$$

- The 'Redfield' ratio was first determined approximately by Harvey in the 20s, grinding up seaweeds
- Only phytoplankton growing near μ'_{max} have Redfield ratios
- The Redfield ratio predicts the rate of regeneration on C:N:P in deep water

Slide 30 Redfield ratio

NOTES:

Frequency of Dividing Cells

McDuff & Chisholm's (1982) equation

$$\mu = t_{ec}^{-1} \ln(1 + f).$$

where, t_{ec} = time division is evident (e.g., mitosis time).

f = frequency of ind. in pop. dividing.

- Can work for known phytoplankton species, for example, diatoms or dinoflagellates
- It is not routinely used
- Is being used to estimate *Alexandrium* μ using molecular markers

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Slide 31 Frequency of Dividing Cells

NOTES:

Redalje-Laws Chl-a labeling

Estimates P, μ and C:Chl a ratio

Table 1. Definitions and variables used in applying the Redalje-Laws approach (from Gould & Gallagher 1990)

Variable	Units	Description
ΔC	$\frac{\mu g\ C}{sample \cdot time}$	C fixed during incubation
ρ	–	specific growth rate
1.05	Dimensionless	Factor to account for isotope discrimination
A^*	$\frac{dpm}{sample}$	^{14}C activity of total particulate matter
C_p	$\frac{\mu g\ C}{sample}$	Microalgal C at the end of the incubation
I^*	$\frac{dpm}{\mu g\ C}$	Specific activity of DIC
R^*_{chl}	$\frac{dpm}{\mu g\ C}$	Specific activity of C in Chl a molecule
t		duration of incubation in hours

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Slide 32 Redalje-Laws Chl-a labeling

NOTES:

Increased labeling of Chl *a* per unit time used to estimate μ

$$\Delta C = \frac{1.05\ A^*}{I^* t} \quad (14)$$

$$C_p = \frac{A^*}{R^*} \quad (15)$$

$$\mu = \frac{-\ln\left(1 - \left(\frac{1.05\ R^*}{I^*}\right)\right)}{t} \times 12. \quad (16)$$

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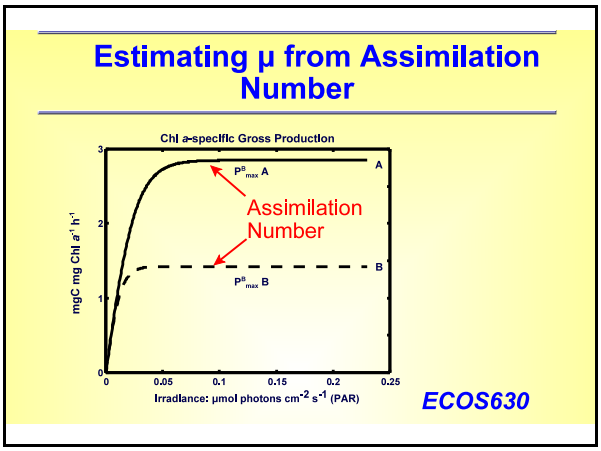
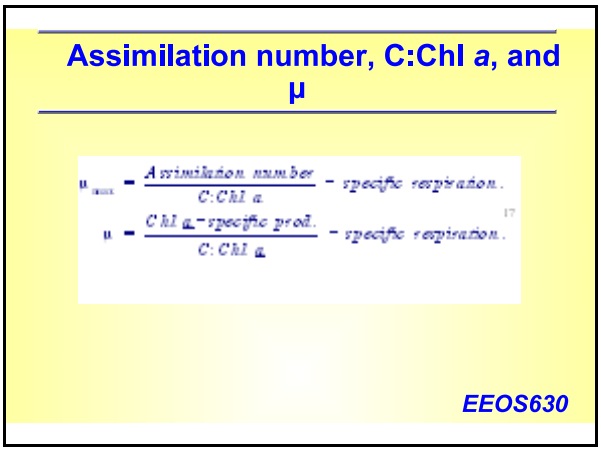
Slide 33 Increased labeling of Chl a per unit time used to estimate μ

NOTES:



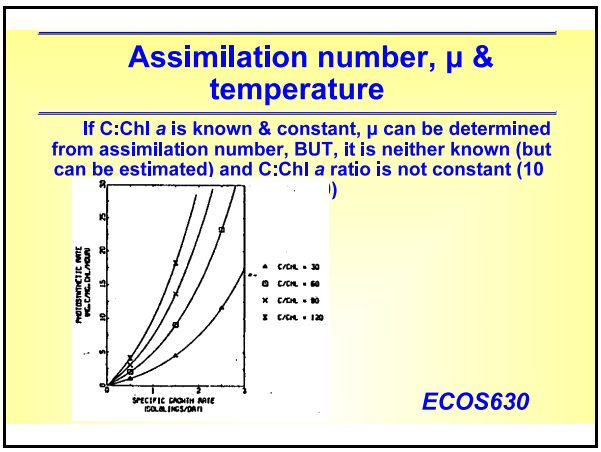
Slide 34 Estimating μ from Assimilation Number

NOTES:



Slide 35 Assimilation number, C:Chl a, and μ

NOTES:

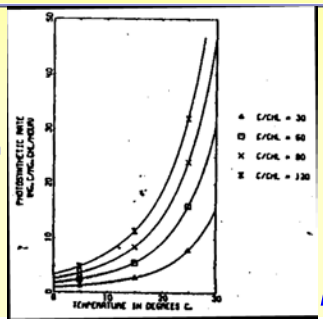


Slide 36 Assimilation number, μ & temperature

NOTES:

Maximum Chl-specific production, per hour, *vs.* Temperature

Assimilation Number



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Slide 37 Maximum Chl-specific production, per hour, vs. Temperature

NOTES:

The dilution method

The most widely used way to estimate μ and grazing rate.

$$\frac{\text{change in biomass}}{\text{time}} = \text{net primary production} - \text{grazing} - \text{other losses}$$

$$\frac{dC}{dt} = C(\mu - G - m).$$

where, C = biomass [$gC\,m^{-3}$ or $gC\,m^{-2}$].

μ = specific growth rate [$\frac{1}{time}$]

G = specific grazing rate [$\frac{1}{time}$].

m = specific nongrazing loss (e.g., DOM loss, sinking) [$\frac{1}{time}$].

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Slide 38 The dilution method

NOTES:

Excursis on grazing & the dilution method

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Slide 39 Excursis on grazing & the dilution method

NOTES:

The dilution method

The most widely used way to estimate μ and grazing rate.

$$\frac{\text{change in biomass}}{\text{time}} = \text{autotrophic production} - \text{grazing} - \text{other losses}$$

$$\frac{dC}{dt} = C(\mu - G - m).$$

where, C = biomass [$gC\,m^{-3}$ or $gC\,m^{-2}$],

μ = specific growth rate [$\frac{1}{time}$],

G = specific grazing rate [$\frac{1}{time}$],

m = specific non-grazing loss (e.g., DOM loss, sinking) [$\frac{1}{time}$].

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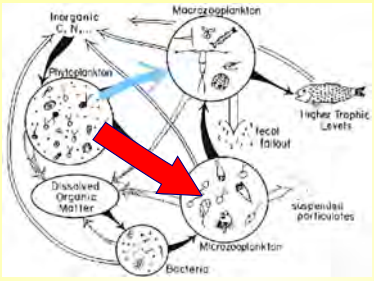
Slide 40 The dilution method

NOTES:

Nano- and microzooplankton are the dominant grazers

Protozoan grazing (and juvenile macrozooplankton)



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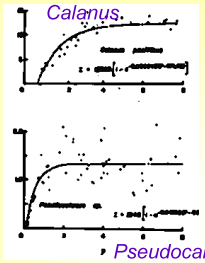
Slide 41 Nano- and microzooplankton are the dominant grazers

NOTES:

Reduced zooplankton ingestion of phytoplankton at low prey density

Frost (1980)



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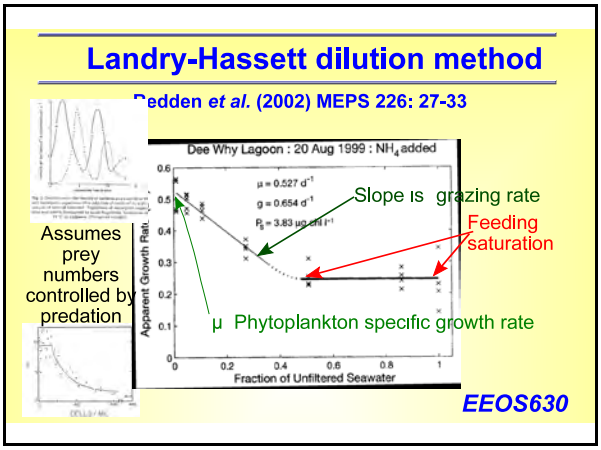
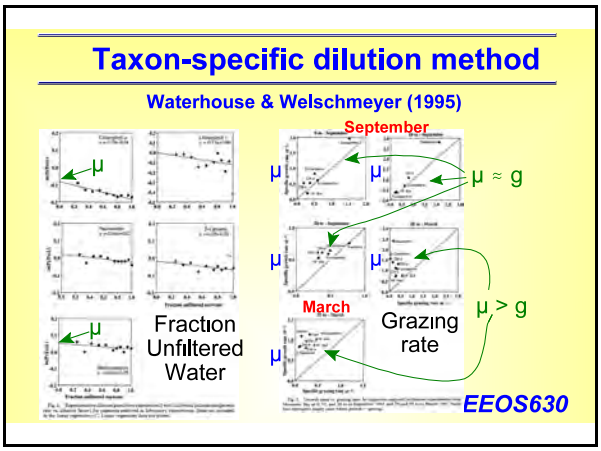
Slide 42 Reduced zooplankton ingestion of phytoplankton at low prey density

NOTES:



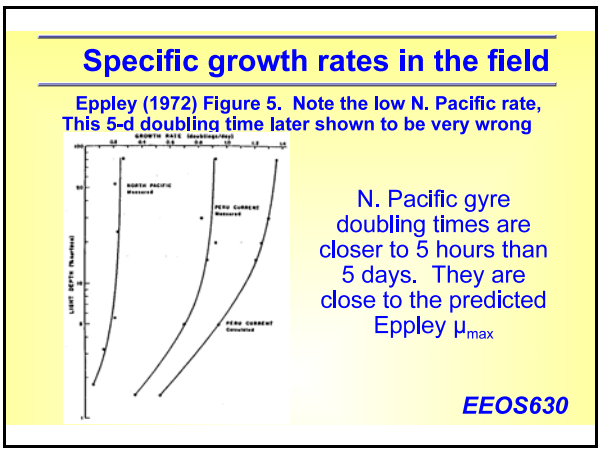
Slide 43 Landry-Hassett dilution method

NOTES:



Slide 44 Taxon-specific dilution method

NOTES:



Slide 45 Specific growth rates in the field

NOTES:

Typical growth rates

Gyre μ underestimated by Eppley (1972)

Area	Doublings/day
Oligotrophic	
Sargasso Sea	0.26
Ha. strait	0.45
Off Carolinas	0.37
Off Monterey	0.35
Off S.California (July 1970)	0.25-0.4
S. California (April-Sept. 67)	0.7 avg
Fluorescence-rich	
Pera current	0.7
April	0.67
June	0.75
Off SW Africa	1.0
Western Arabian Sea	>1.0

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Slide 46 Typical growth rates

NOTES:

In situ fluorescence

Lorenzen (1966)

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Slide 47 In situ fluorescence

NOTES:

Lorenzen (1966)

Linear relation between Chl a & fluorescence

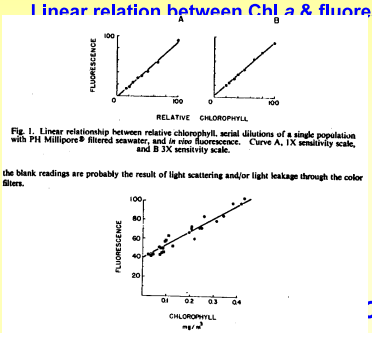

Fig. 1. Linear relationship between relative chlorophyll, serial dilutions of a single population with PH Millipore® filtered seawater, and *in vivo* fluorescence. Curve A, 1X sensitivity scale, and B 3X sensitivity scale.

the blank readings are probably the result of light scattering and/or light leakage through the color filters.

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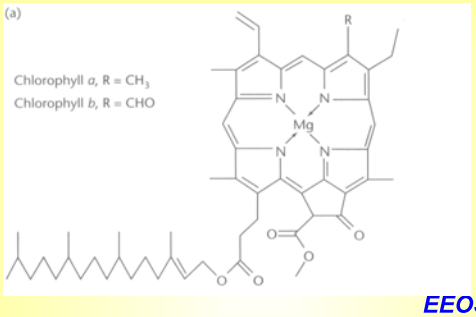
Slide 48 Lorenzen (1966)

NOTES:

Chlorophyll *a*



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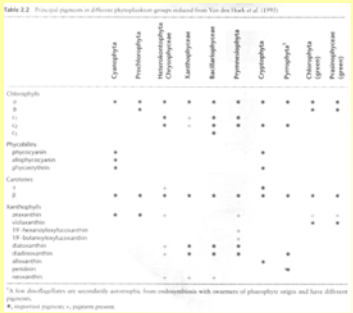
Slide 49 Chlorophyll a

NOTES:

All phytoplankton have Chl *a*

Miller Table 2.2



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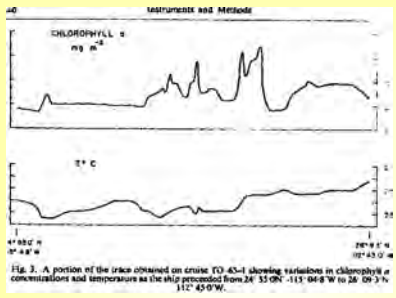
Slide 50 All phytoplankton have Chl a

NOTES:

In situ fluorometry allows an analysis of fine scale pattern in phytoplankton biomass, in real time



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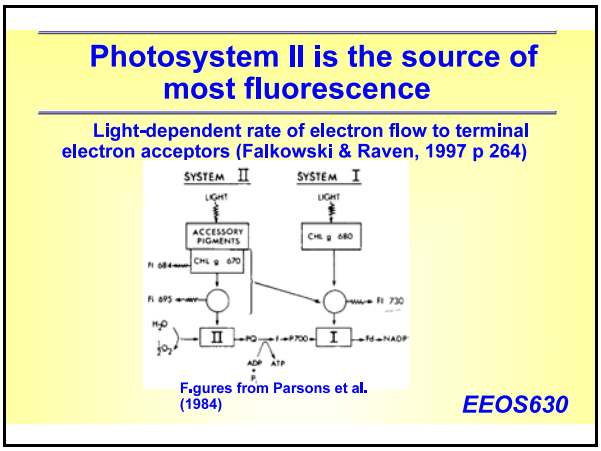
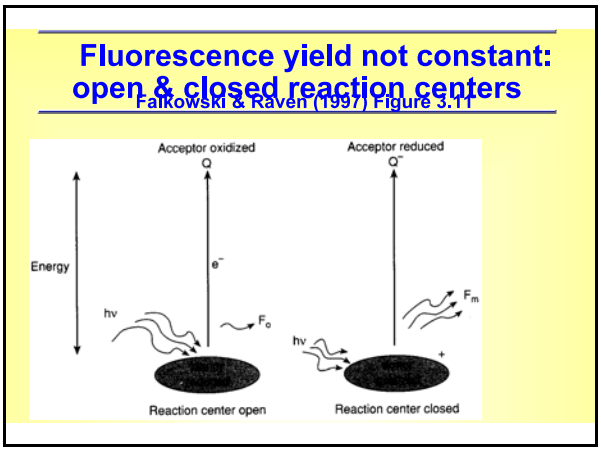
Slide 51 In situ fluorometry allows an analysis of fine scale pattern in phytoplankton biomass, in real time

NOTES:



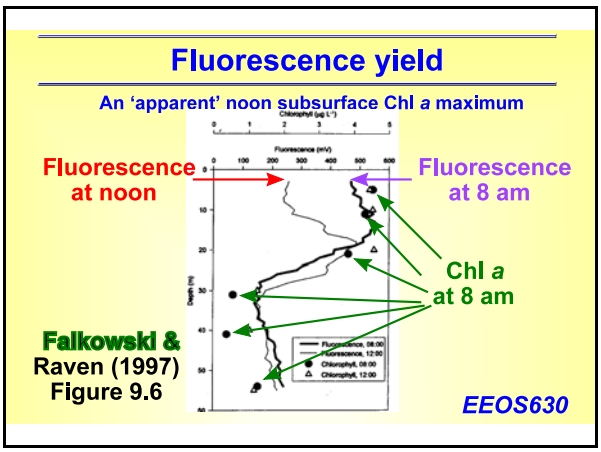
Slide 52 Photosystem II is the source of most fluorescence

NOTES:



Slide 53 Fluorescence yield not constant: open & closed reaction centers

NOTES:



Slide 54 Fluorescence yield

NOTES:

How do you measure production?

See Harrison & Platt; Choose a model

- *In situ* or simulated *in situ* incubations
  - *In situ* incubations account for light-quality effects, but not vertical mixing
  - Simulated *in situ*
    - Natural light
    - Artificial light source (photosynthetron)
- Model P vs. I approach
  - Obtain accurate estimates of initial slope of P vs. I curve, α, and the assimilation number
  - If the light field & **Chl *a* profiles** are known, primary production throughout the water column can be estimated from the P vs. I parameters

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Slide 55 How do you measure production?

NOTES:

Productivity methods

Choose a method

- ^{14}C *vs.* O_2 method
  - Sensitivity & variability in photosynthetic quotient pose problems for the O_2 method
- ^{18}O primary production
- Incubations: short vs. Long
  - Eppley used 24-h incubations
  - Most authors recommend short incubations, but
    - Photoacclimation a problem
    - Redalje: Sum of multiple short incubations < long incubation
  - Large *vs.* Small incubation bottles
    - Bottle effects
    - Noted especially by Gieskes & Kraay (1979)

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Slide 56 Productivity methods

NOTES:

C-14 method

See Chapter 2 & references for details

- Prepare a $H^{14}CO_3^-$ solution of known activity
- Obtain samples from the appropriate depth and light conditions. Don't expose samples to direct sunlight.
- Split samples between experimental and control bottles. Add ^{14}C spike to both experimental and control bottles.
- Controls: A variety have been used: Time-0, dark-bottle, DCMU, DCMU & dark-bottle

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Slide 57 C-14 method

NOTES:

Estimating productivity

- Incubate using *in situ* (preferred, but not possible with many licenses for ^{14}C) or simulated *in situ* methods for 2 to 24 hours
- Gently filter the particulate matter for later laboratory analysis (a 0.4-µm filter is now common). A sample of the medium can be obtained to estimate DOC production.

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Slide 58 Estimating productivity

NOTES:

Estimating productivity

After the Incubation

- Determine radioactivity of POC (& DOC) and the amount of Chl *a* in the sample bottles
  - Estimate or measure the specific activity of the DIC in the incubation bottle [dpm/ g DIC].
  - Measure the ^{14}C activity in the particulate (and dissolved) organic phases. The filtered samples or liquid samples (for DOC) are first acidified to drive off unfixed ^{14}C, then the sample's radioactivity is determined by liquid scintillation counting.

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Slide 59 Estimating productivity

NOTES:

Esimating ^{14}C productivity

Note the isotopic discrimination factor (1.05)

$$\frac{dC}{dt} = 1.05 \, A^* \, I^* \, T$$

where, A^* = activity of ^{14}C in sample POC (& DOC) $\left[\frac{dpm}{sample}\right]$.

I^* = specific activity of DIC in bottle $\left[\frac{dpm}{g\,C\,DIC}\right]$.

T = Incubation time [h].

1.05 = Isotopic discrimination factor.

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Slide 60 Esimating 14C productivity

NOTES:

C-14 method blanks

What do the blanks represent?

- The control ^{14}C uptake (time 0, DCMU control (stops electron transport in photosystem II, dark bottle) should be subtracted from A*
- Chl *a* concentration to estimate of Chl *a*-specific production should be determined from the time-0 and ^{14}C-spiked bottle to obtain initial and final estimates of Chl *a*
  - Rarely done on both initial & final

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Slide 61 C-14 method blanks

NOTES:

Hawaii Ocean Time-Series (HOT)

http://hahana.soest.hawaii.edu/hot/protocols/protocols.html

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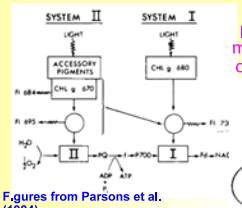
Slide 62 Hawaii Ocean Time-Series (HOT)

NOTES:

Gross primary Productivity

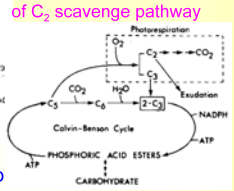
Light-dependent rate of electron flow to terminal electron acceptors (Falkowski & Raven, 1997 p 264)



F.gures from Parsons et al. (1984)

See Miller Figure 2.14 too

Estimating photorespiration: $H_2{}^{18}O$ method or AOA inhibition of C_2 scavenge pathway



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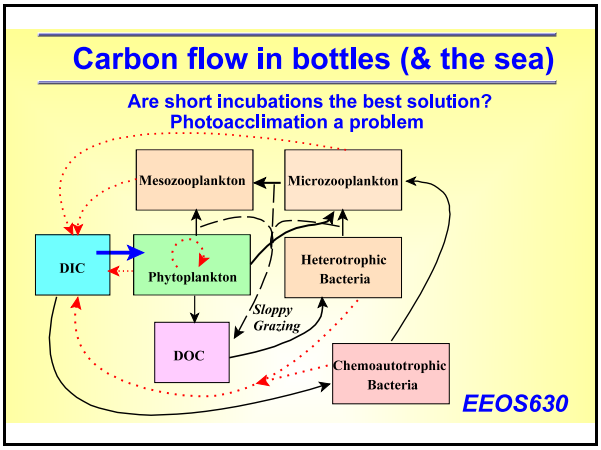
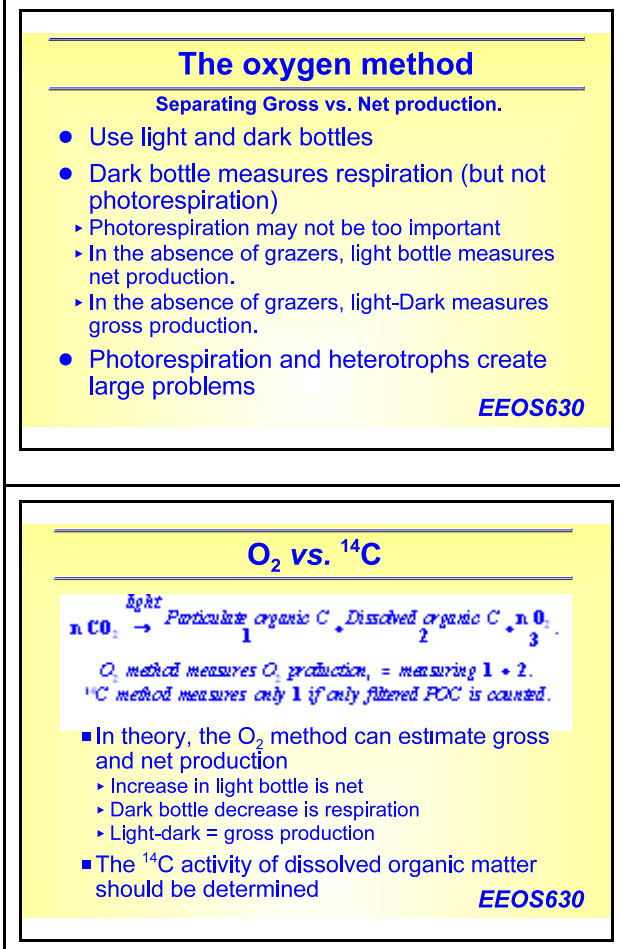
Slide 63 Gross primary Productivity

NOTES:



Slide 64 Carbon flow in bottles (& the sea)

NOTES:



Slide 65 The oxygen method

NOTES:

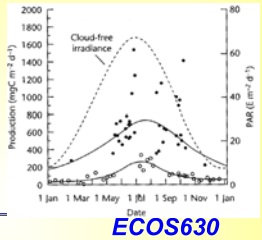
Slide 66 O2 vs. 14C

NOTES:

Primary production underestimated

Miller (2004) Fig. 3.4, Welschmeyer *et al.* 1993

- Open circles: data collected before 1980
- Filled circles 1980-1984, Trace-metal clean conditions
- 2-fold difference
- There may have also been interannual variability: the Pacific Interdecadal oscillation (first discovered after Welschmeyer's 1993 paper)



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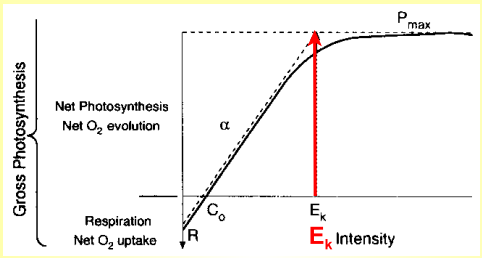
Slide 67 Primary production underestimated

NOTES:

Falkowski & Raven P *vs.* E curves

Falkowski & Raven (1997, p. 196, Fig 7.2)



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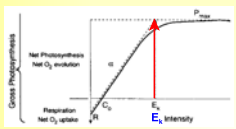
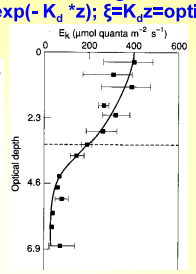
Slide 68 Falkowski & Raven P vs. E curves

NOTES:

Photoacclimation: to light intensity & light quality

Falkowski & Raven Fig. 9.8;
Light intensity: $I_z = I_o * \exp(-K_d * z)$; $\xi = K_d z$ = optical depth





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Slide 69 Photoacclimation: to light intensity & light quality

NOTES:

Shade acclimation (adaptation)

Phytoplankton can adapt to both the intensity and quality of light by:

- Changes in the amount of photosynthetic pigment per cell (*e.g.*, changes in C:Chl *a* ratio)
- Changes in the ratios of photosynthetic pigments
- Changes in the size and number of photosynthetic units (Chl *a*:P700 size)
- Changes in chloroplast size & orientation
- Changes in the enzyme activities of both the light and dark reactions

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Slide 70 Shade acclimation (adaptation)

NOTES:

Shade acclimation (adaptation)

Phytoplankton can adapt to both the intensity and quality of light by:

- Changes in the amount of photosynthetic pigment per cell (*e.g.*, changes in C:Chl *a* ratio)
- Changes in the ratios of photosynthetic pigments
- Changes in the size and number of photosynthetic units (measured by the Chl *a*:P700 size, Perry *et al.* 1981)
- Changes in chloroplast size & orientation
- Changes in the enzyme activities of both the light and dark reactions

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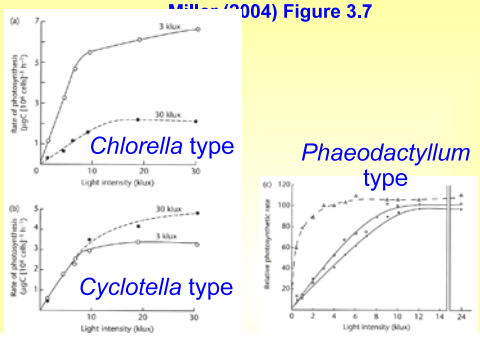
Slide 71 Shade acclimation (adaptation)

NOTES:

Types of shade acclimation

Miller (2004) Figure 3.7



Slide 72 Types of shade acclimation

NOTES:

PAR & units of light intensity

- Parsons, Takahashi & Hargrave (1984)
  - Parsons_1984.pdf on ereserve
    - the direct link the ECOS630 reserves is:
    - http://docutek.lib.umb.edu/coursepage.asp?cid=65
    - Password: ocean
- Photosynthetically available radiation [PAR] The quantity of light in those wavelengths that can be utilized for photosynthesis (400 to 700 nm, Behrenfeld & Falkowski (1997), some earlier papers listed PAR from 300 to 720 nm).

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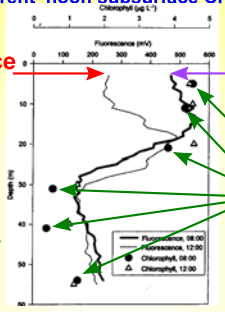
- To convert to energy, 550nm light assumed

Slide 73 PAR & units of light intensity

NOTES:

Fluorescence yield

An 'apparent' noon subsurface Chl *a* maximum



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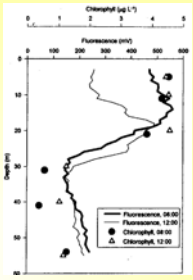
Slide 74 Fluorescence yield

NOTES:

Measuring the Chl *a* profile

Falkowski & Raven (1997) Figure 9.6

- **Fluorescence yield reduced by:**
  - Photochemical quenching: can occur with a diel cycle
  - Shade acclimation & increase in PSII activity
  - Increase in the physiological status of the cells
- **Fluorescence yield increased by:**
  - Reduction in PSII activity
  - Toxic effects (used to estimate Cu contamination)
  - Nutrient stress
  - Senescence



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Slide 75 Measuring the Chl a profile

NOTES:

Quenching

Refers to both scintillation counting and fluorescence yield

Quenching and quantum yield for fluorescence

$$\Phi_F = \frac{k_F}{(k_F + k_d + k_p)}, \text{ where}$$

Φ_F = ratio of light emitted as fluorescence to light absorbed.

k_F = de-excitation of singlet to fluorescence

k_d = heat.

k_p = photochemistry.

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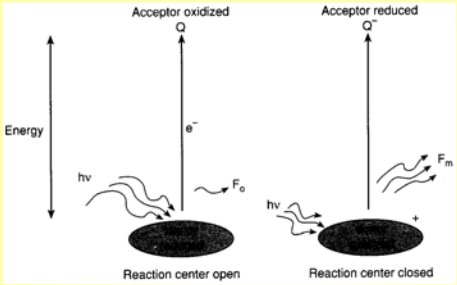
Slide 76 Quenching

NOTES:

Fluorescence yield & open & closed reaction centers

Falkowski & Raven (1997) Figure 3.11

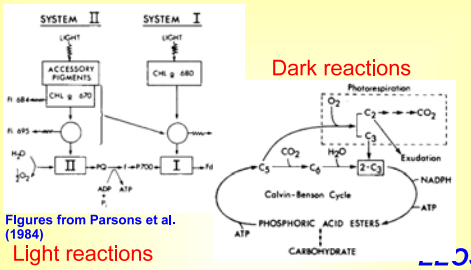


Slide 77 Fluorescence yield & open & closed reaction centers

NOTES:

Gross primary productivity

Light-dependent rate of electron flow to terminal electron acceptors (Falkowski & Raven, 1997 p 264)



Figures from Parsons et al. (1984)

Light reactions

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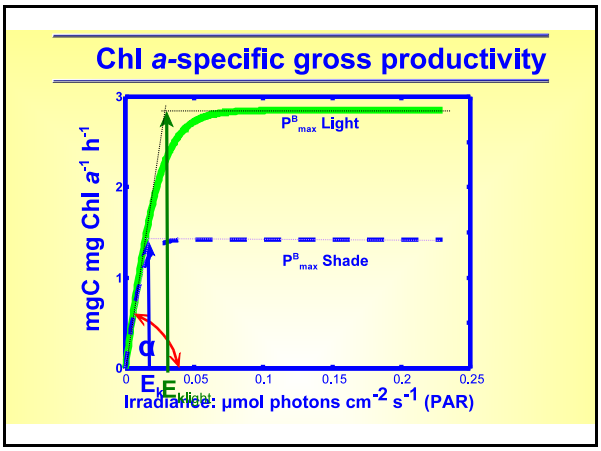
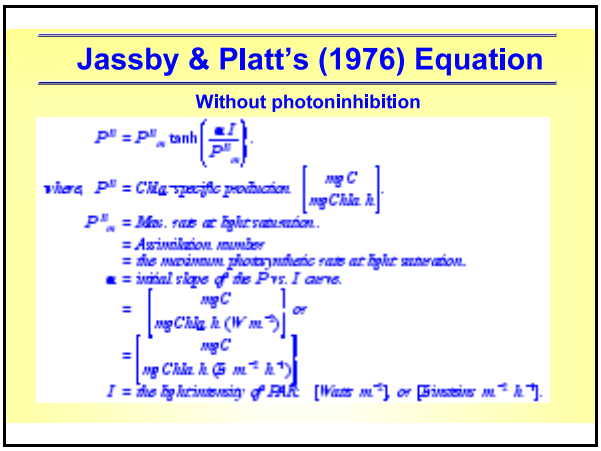
Slide 78 Gross primary productivity

NOTES:



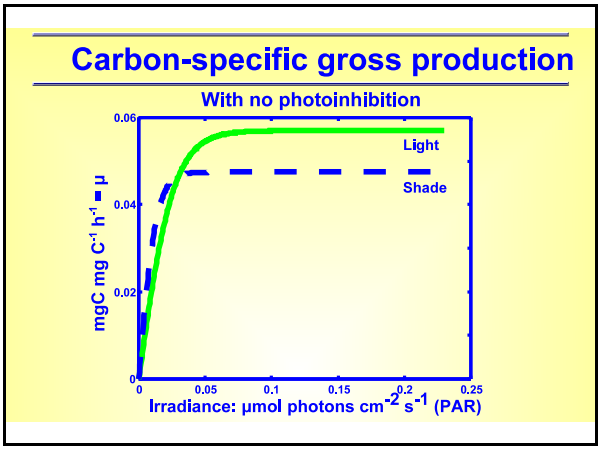
Slide 79

NOTES:



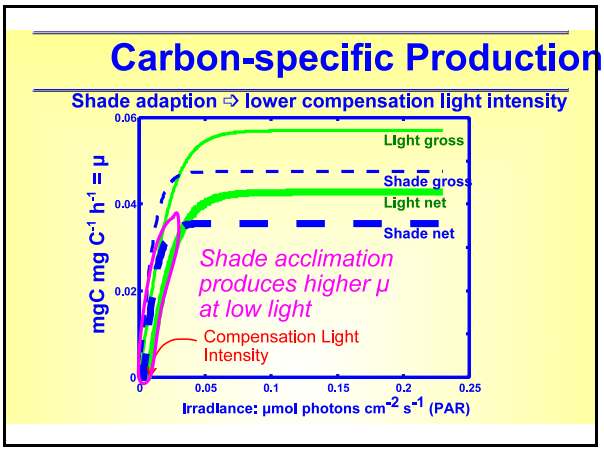
Slide 80 Jassby & Platt's (1976) Equation

NOTES:



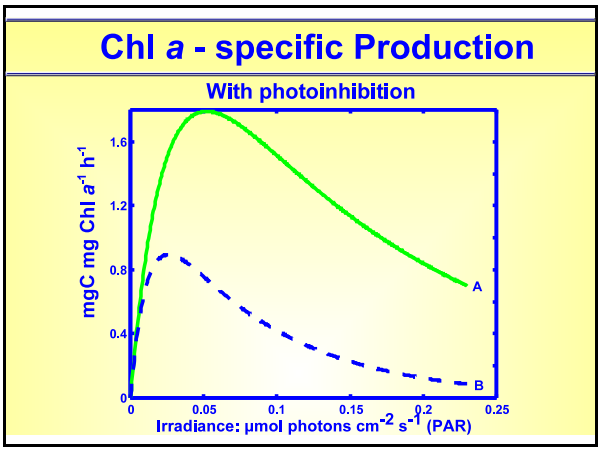
Slide 81 Carbon-specific gross production

NOTES:



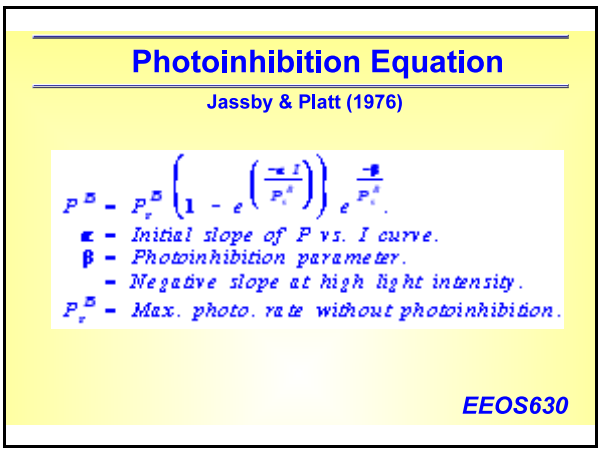
Slide 82 Carbon-specific Production

NOTES:



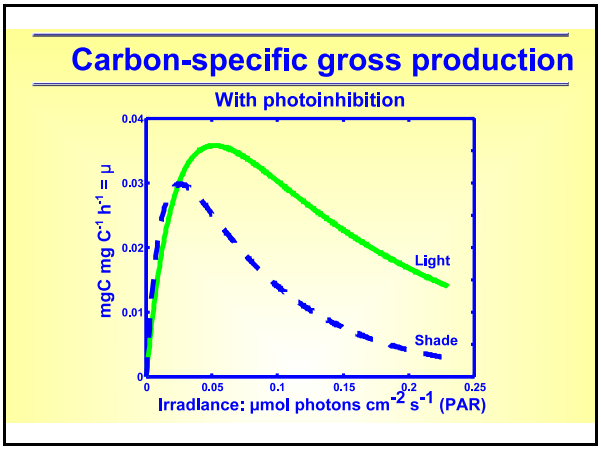
Slide 83 Chl a - specific Production

NOTES:



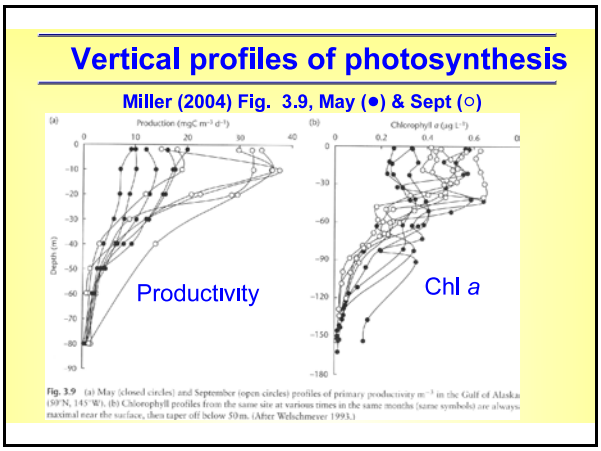
Slide 84 Photoinhibition Equation

NOTES:



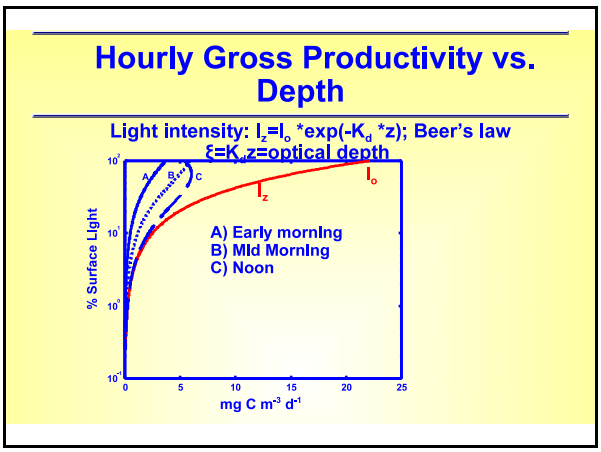
Slide 85 Carbon-specific gross production

NOTES:



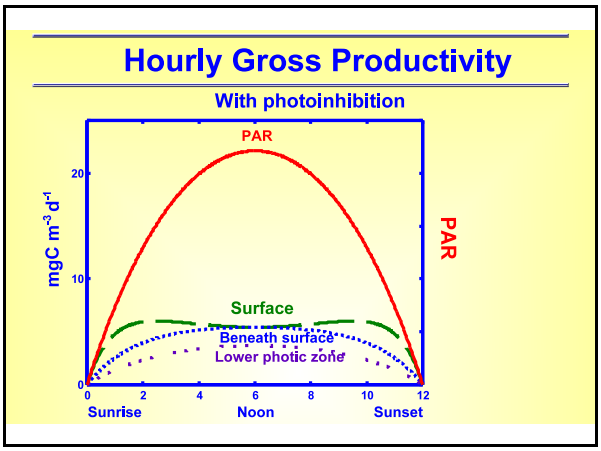
Slide 86 Vertical profiles of photosynthesis

NOTES:



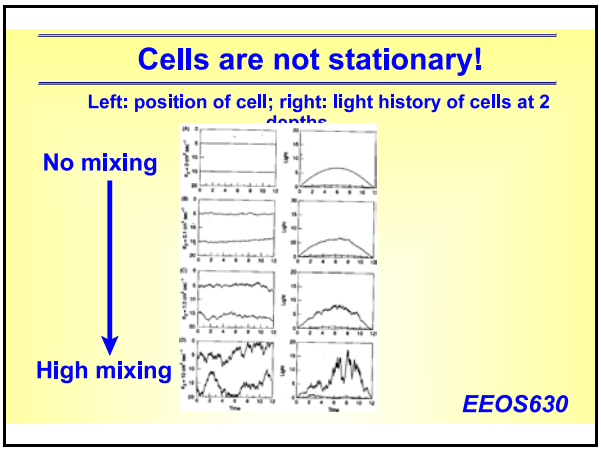
Slide 87 Hourly Gross Productivity vs. Depth

NOTES:



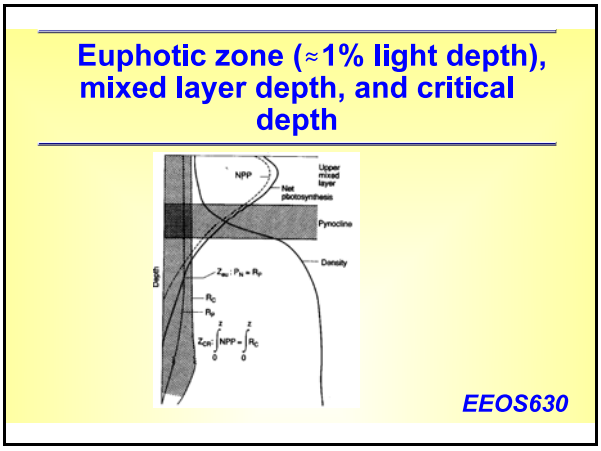
Slide 88 Hourly Gross Productivity

NOTES:



Slide 89 Cells are not stationary!

NOTES:



Slide 90 Euphotic zone (≈1% light depth), mixed layer depth, and critical depth

NOTES:

Non-dimensional production

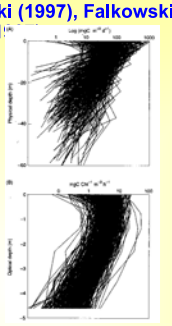
Behrenfeld & Falkowski (1997), Falkowski & Raven (1

Production vs. Depth

Meters

Chl-specific P vs. Depth

Optical depth



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Slide 91 Non-dimensional production

NOTES:

The model P vs I approach vs. SIS

Harrison et al. (1985)

- Light & Chl a profiles determined
- SIS
  - 30-L Niskin bottles from 100, 50, 25, 10, and 1% light depths
  - 24 h 200-ml incubations on board deck
  - natural sunlight & neutral density filters
  - Trapezoidal integration over depth interval
- Model P vs. I approach
  - Water collected at 50% and 1% Light depths
  - 30-50 100-ml incubations
  - Artificial light
  - Time-zero or dark-bottle blanks

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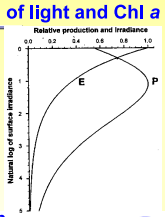
Slide 92 The model P vs I approach vs. SIS

NOTES:

Model estimates of production

Requires profiles of light and Chl *a*

- Profile light over a 24-h day and chl a
- Estimate α and AN at the 1% and 50% light depth only using 30-50 P vs. I incubations
- Calculate hourly production using Chl *a*, I, P^B and α
- Sum 24-h est mates to obta n daily product on
- Compare with SIS prof les



$$P(t) = P^B(I(t)) \cdot B.$$

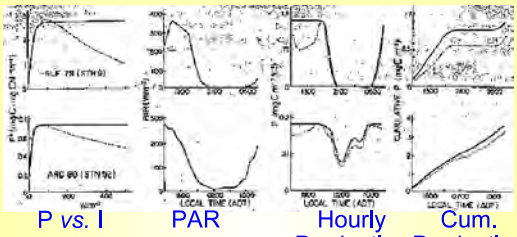
$$P_z = \sum_{t=1}^{24} P(t).$$

Slide 93 Model estimates of production

NOTES:

Model P vs. I approach

Fig 1 (dotted=photoinhibition) Harrison *et al.* (1985)



P *vs.* I | PAR | Hourly Production | Cum. Production

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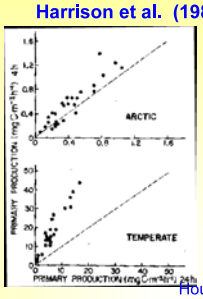
Slide 94 Model P vs. I approach

NOTES:

4- *vs.* 24-h incubations

Harrison et al. (1985) Figure 2



Hourly production (4-h)

Nighttime productivity, midnight sun

Hourly production (24-h)

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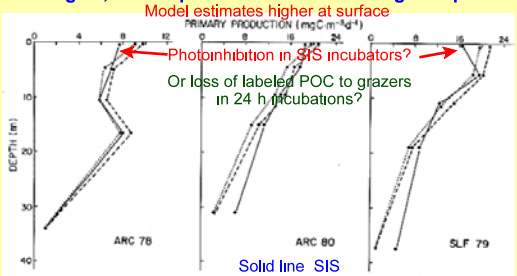
Slide 95 4- vs. 24-h incubations

NOTES:

Harrison *et al.* (1985)

Fig. 3, P vs. I parameters from 50% Light Depth



Solid line SIS
Broken: No β
Dotted: With β

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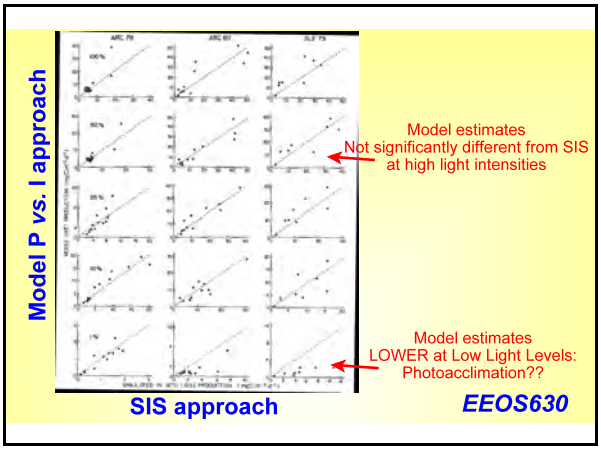
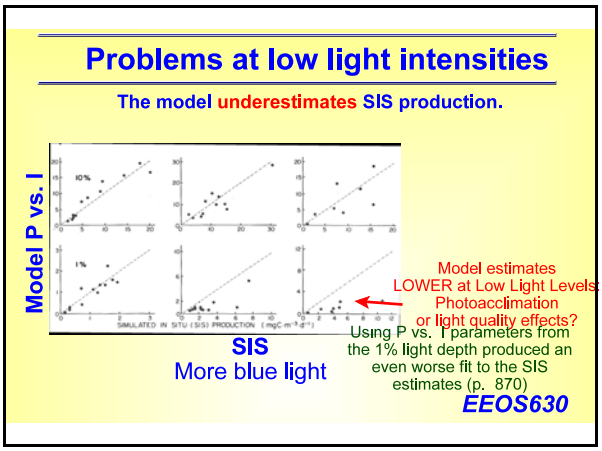
Slide 96 Harrison et al. (1985)

NOTES:



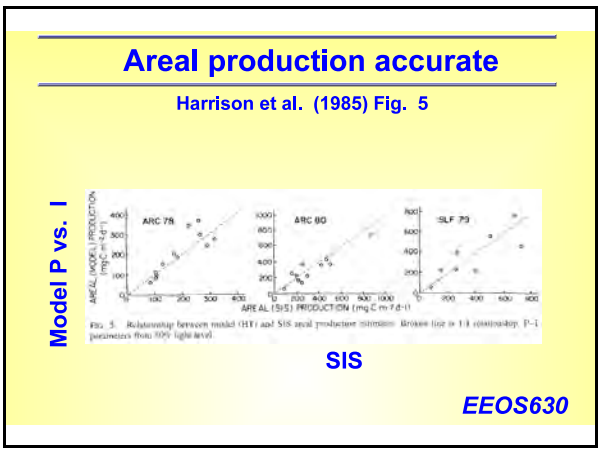
Slide 97

NOTES:



Slide 98 Problems at low light intensities

NOTES:



Slide 99 Areal production accurate

NOTES:

P vs. I parameters indicate shade adaptation/stratification

50% Light depth chosen for P *vs.* I parameters

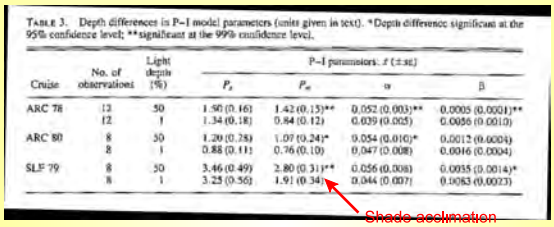


TABLE 3. Depth differences in P–I model parameters (units given in text). *Depth difference significant at the 95% confidence level; **significant at the 99% confidence level.

Cruise	No. of observations	Light depth (%)	P–I parameters: x (±SE) P_s	P_m	α	β
ARC 78	12	50	1.50 (0.16)	1.42 (0.15)**	0.052 (0.003)**	0.0005 (0.0001)**
	12	1	1.34 (0.18)	0.84 (0.12)	0.039 (0.005)	0.0056 (0.0010)
ARC 80	8	50	1.20 (0.28)	1.07 (0.24)*	0.054 (0.010)*	0.0012 (0.0004)
	8	1	0.88 (0.11)	0.76 (0.10)	0.047 (0.008)	0.0046 (0.0004)
SLE 79	8	50	3.46 (0.49)	2.80 (0.31)**	0.056 (0.008)	0.0035 (0.0014)*
	8	1	3.25 (0.56)	1.91 (0.34)	0.044 (0.007)	0.0063 (0.0023)

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Slide 100 P vs. I parameters indicate shade adaptation/stratification

NOTES:

Applications

- Application to MA Bay monitoring
  - Measuring Chl *a*
  - Measuring production
    - O_2
    - Model approach introduced by Craig Taylor
    - Incubation method
  - Problems with the model approach
    - Assimilation numbers too high

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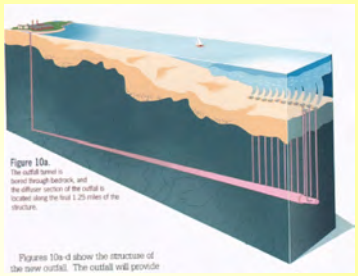
Slide 101 Applications

NOTES:

The MA Bay Outfall

From MWRA State of the Harbor Report



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Slide 102 The MA Bay Outfall

NOTES:

Realistic P vs. I parameters

Many published assimilation numbers and α's are too high

- There **are** theoretical limits for α and A.N.
  - Maximum α set by the quantum efficiency of photosynthesis
  - A.N. is set by the maximum specific growth rate (assuming balanced growth)
  - Falkowski published a theoretical maximum of about 20-25
  - Harris: 6-8 mg C mg Chl *a* h^{-1}

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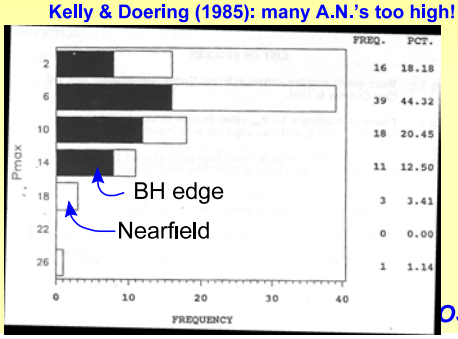
Slide 103 Realistic P vs. I parameters

NOTES:

MA Bay P vs. I parameters

Kelly & Doering (1985): many A.N.'s too high!



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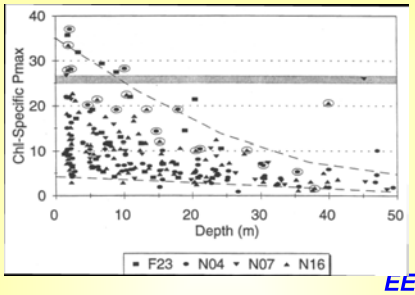
Slide 104 MA Bay P vs. I parameters

NOTES:

MA Bay assimilation numbers

Including Falkowski's theoretical maximum= 25



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Slide 105 MA Bay assimilation numbers

NOTES:

Why might assimilation numbers be too high?

- Theoretical maximum assimilation numbers are are often exceeded, due to:
  - Improper methods
    - Filters not retaining phytoplankton
    - Improper estimate of Chl *a*
  - Unbalanced growth
  - Failure to subtract controls

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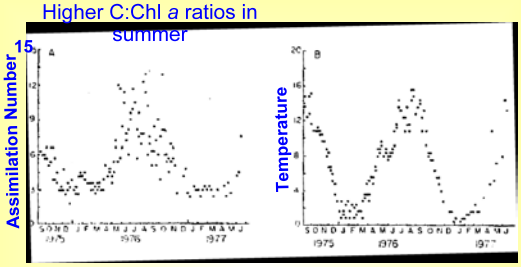
Slide 106 Why might assimilation numbers be too high?

NOTES:

Seasonal variation in A.N.

Harrison & Platt (1980), max. AN < 15

Higher C:Chl *a* ratios in summer



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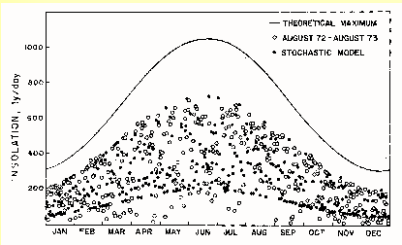
Slide 107 Seasonal variation in A.N.

NOTES:

Model P *vs.* I approach: can account for differences in irradiance (due to clouds)

Rhode Island solar irradiance (from Kremer & Nixon)



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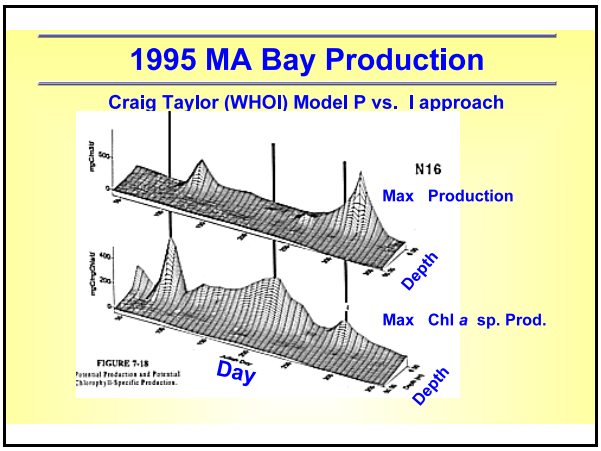
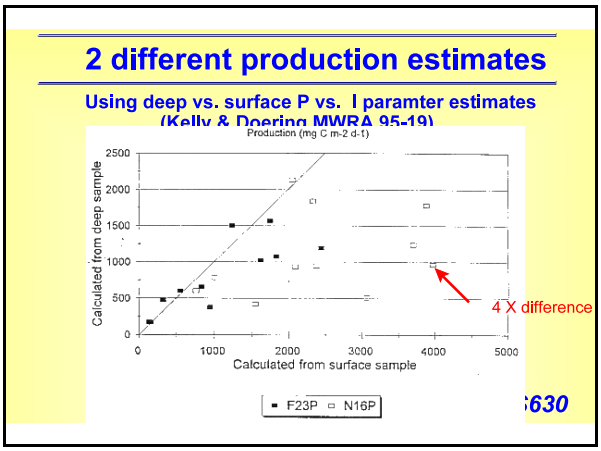
Slide 108 Model P vs. I approach: can account for differences in irradiance (due to clouds)

NOTES:



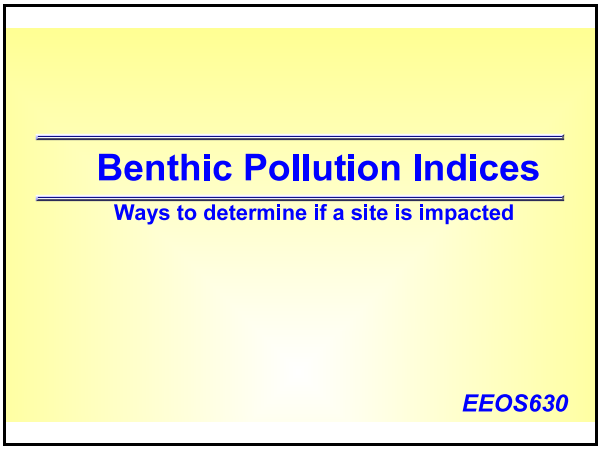
Slide 109 1995 MA Bay Production

NOTES:



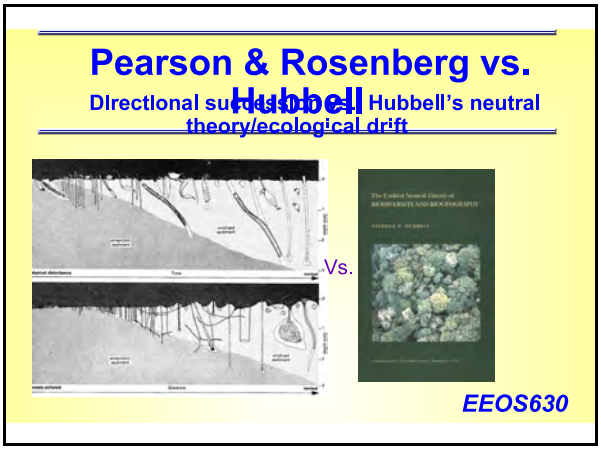
Slide 110 2 different production estimates

NOTES:



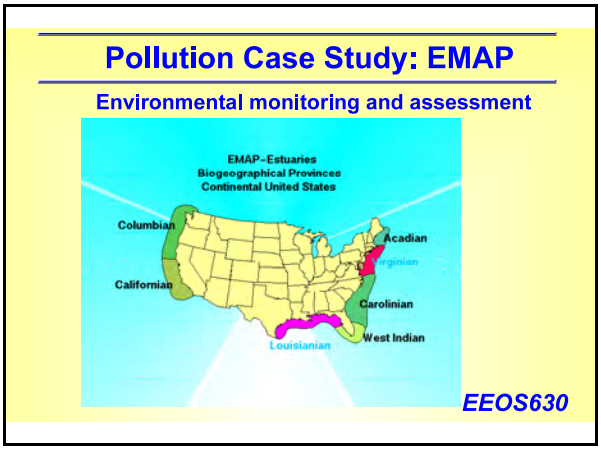
Slide 111 Benthic Pollution Indices

NOTES:



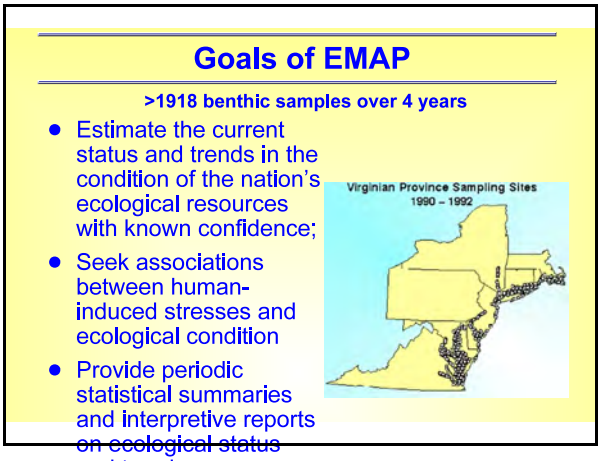
Slide 112 Pearson & Rosenberg vs. Hubbell

NOTES:



Slide 113 Pollution Case Study: EMAP

NOTES:

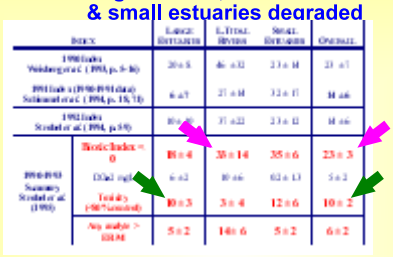


Slide 114 Goals of EMAP

NOTES:

Virginian province degradation

1995 Index degraded (Shannon, Gleason's D), spionids & oligochaetes; 1/3 of area of tidal rivers & small estuaries degraded



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Slide 115 Virginian province degradation

NOTES:

EMAP Methods used to create degradation indices

- Identify degraded and non-degraded stations
  - Based on the Long & Morgan (1990) and Long et al. (1995) ERM & ERL approaches.
  - Amphipod toxicity
  - Low dissolved oxygen
- Identify approximately 30 degraded and 30 nondegraded samples
- Used linear discriminant analysis to classify stations as degraded or non-degraded

Slide 116 EMAP Methods used to create degradation indices

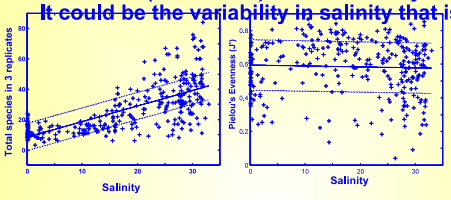
NOTES:

Salinity & diversity

1 species added per salinity psu in Virginian Province

Evenness (Pielou's J') not affected by salinity

It could be the variability in salinity that is key



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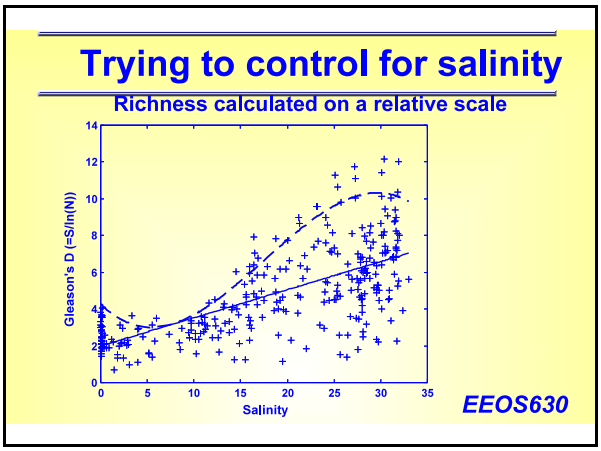
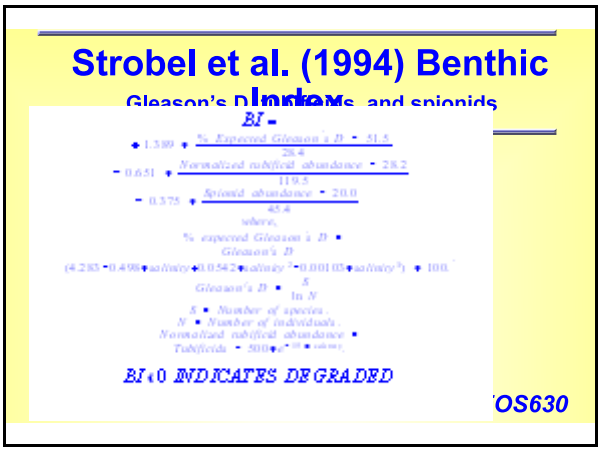
Slide 117 Salinity & diversity

NOTES:



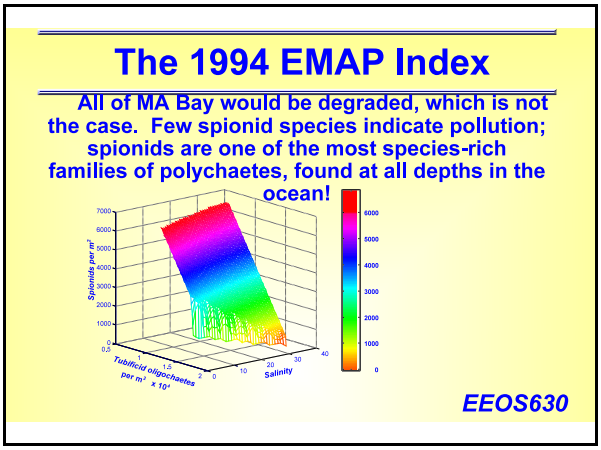
Slide 118 Trying to control for salinity

NOTES:



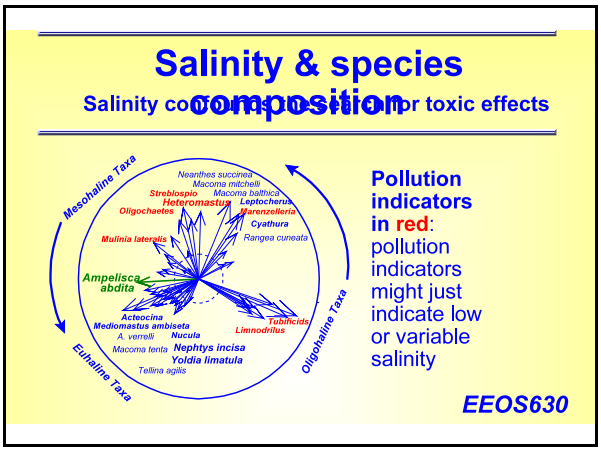
Slide 119 Strobel et al. (1994) Benthic Index

NOTES:



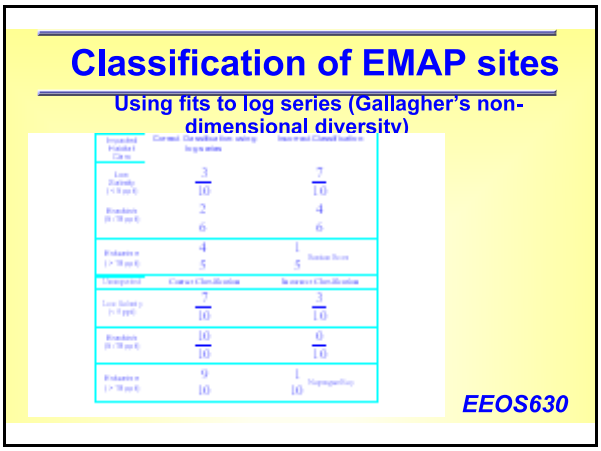
Slide 120 The 1994 EMAP Index

NOTES:



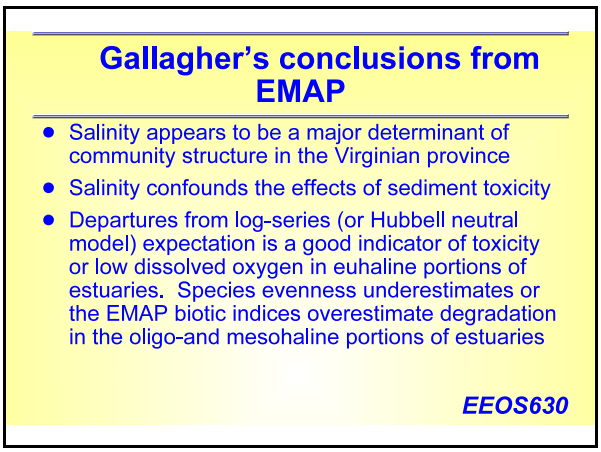
Slide 121 Salinity & species composition

NOTES:



Slide 122 Classification of EMAP sites

NOTES:



Slide 123 Gallagher's conclusions from EMAP

NOTES:

Benthic pollution indices

Being proposed worldwide

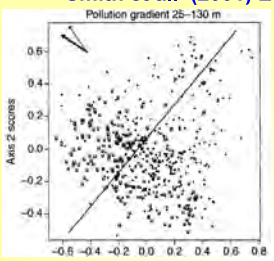
- EMAP approach: multivariate analysis based on impacted and reference areas
  - Impacted areas based on Long & Morgan ER-M, low O_2 or amphipod toxicity
  - Circular logic
- Infaunal benthic index, Chesapeake Bay, Community variables scaled on a 1, 2, 3 basis and a weighted average taken
- Borjas European AMBI (AZTI's Marine Biotic Index). More than 4000 European species assigned to 6 Ecological Groupings based on their response to pollution. A benthic index (1 to 7) is developed for each sample based on the relative abundance of Groups I to VI
- Southern California Benthic Response Index (Smith et al. 2001, Ecol. Applications)
  - A weighted average method based on a large multivariate analysis
  - A weight assigned to each of thousands of Southern California species
- Other approaches: Word's Infaunal trophic index, ABC, Nematode:harpacticoid ratio, Variability in space & time
- My non-dimensional diversity analysis shares features with Gray's departure from lognormal & Caswell's neutral model

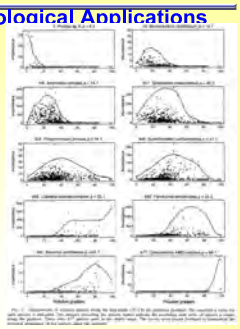
Slide 124 Benthic pollution indices

NOTES:

Benthic Response Index

Smith et al. (2001) Ecological Applications





Slide 125 Benthic Response Index

NOTES:

Southern California BRI

Compared to Word's Infaunal Trophic Index

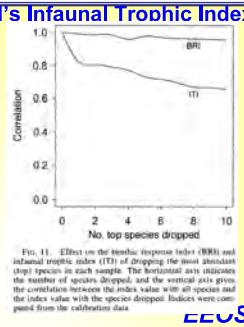


Fig. 11. Effect on the benthic response index (BRI) and infaunal trophic index (IT) of dropping the most abundant (top) species in each sample. The horizontal axis indicates the number of species dropped, and the vertical axis gives the correlation between the index value with all species and the index value with the species dropped. Indices were compared from the calibration data

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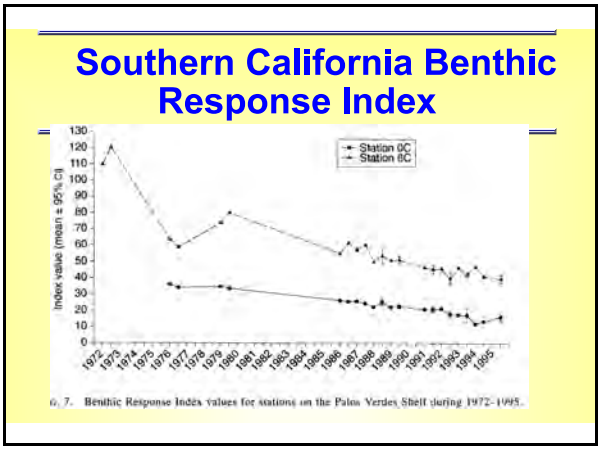
Slide 126 Southern California BRI

NOTES:



6. 7. Benthic Response Index values for stations on the Palos Verdes Shelf during 1972-1995.

Slide 127 Southern California Benthic Response Index
NOTES: