

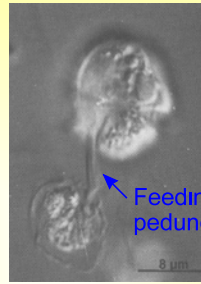
<div> <div>Measuring phytoplankton biomass, specific growth rate & Primary Production</div> <div>Class 16, 10/23/08</div> <div>EEOS630</div> </div>	<div>Slide 1 Measuring phytoplankton biomass, specific growth rate & Primary Production</div> <div>NOTES:</div>
<div> <div>Wimba Sessions</div> <ul style="list-style-type: none"> Quantitative community analysis using Matlab <ul style="list-style-type: none"> 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 <div>EEOS630</div> </div>	<div>Slide 2 Wimba Sessions</div> <div>NOTES:</div>
<div> <div>Phytoplankton Readings</div> <ul style="list-style-type: none"> My chapters: <ul style="list-style-type: none"> Chapter 7 (μ, B, & P), 8 (C14 method), 9 (Light effects) Readings (on UMB E- Reserve) <ul style="list-style-type: none"> μ, B, & P: <ul style="list-style-type: none"> Eppeley, 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 <i>in vivo</i> 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: <ul style="list-style-type: none"> Peterson, B. 1980. Aquatic primary productivity and the ^{14}C-CO₂ method: a history of the productivity problem. Ann. Rev. Ecol. Syst. 11: 359-385. [Just skim for now] Light <ul style="list-style-type: none"> 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.] </div>	<div>Slide 3 Phytoplankton Readings</div> <div>NOTES:</div>

<div data-bbox="345 168 667 203" data-label="Section-Header"> <h2>Planktonic Size Terms</h2> </div> <div data-bbox="277 218 742 241" data-label="Text"> <p>Sieburth et al. (1978), foodweb from Fenchel (1988)</p> </div> <div data-bbox="250 247 519 510" data-label="List-Group"> <ul style="list-style-type: none"> •Femtoplankton 0.02 to 0.2 μm •Picoplankton (0.2 -2 μm) •Nanoplankton (2 - 20 μm) <ul style="list-style-type: none"> ▸ Heterotrophs (HNAN) & Facultative ▸ Autotrophs •Microplankton (20 - 200 μm) <ul style="list-style-type: none"> ▸ Heterotrophs (Ciliates) & Facultative ▸ Autotrophs •Mesoplankton (200 μm - 20 mm) <ul style="list-style-type: none"> ▸ Heterotrophs ▸ Autotrophs </div> <div data-bbox="537 247 755 518" data-label="Figure"> </div>	<div data-bbox="823 134 1263 168" data-label="Section-Header"> <h2>Slide 4 Planktonic Size Terms</h2> </div> <div data-bbox="823 258 940 294" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="308 657 717 695" data-label="Section-Header"> <h2>Planktonic size composition</h2> </div> <div data-bbox="332 701 680 728" data-label="Text"> <p>Not a simple linear grazing food chain</p> </div> <div data-bbox="220 753 561 919" data-label="Figure"> </div> <div data-bbox="581 747 773 942" data-label="Image"> </div> <div data-bbox="282 926 444 963" data-label="Text"> <p>Azam 1998</p> </div> <div data-bbox="656 999 766 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="823 619 1338 657" data-label="Section-Header"> <h2>Slide 5 Planktonic size composition</h2> </div> <div data-bbox="823 804 940 840" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="332 1140 680 1209" data-label="Section-Header"> <h2>Some actors: Diatoms & Dinoflagellates</h2> </div> <div data-bbox="271 1211 755 1260" data-label="Text"> <p>Large enough to determine cells dividing visually (10 μm to several hundred μm)</p> </div> <div data-bbox="233 1264 370 1354" data-label="Image"> </div> <div data-bbox="383 1264 544 1354" data-label="Image"> </div> <div data-bbox="574 1264 730 1354" data-label="Image"> </div> <div data-bbox="227 1362 383 1491" data-label="Text"> <p>Diatoms have silica tests, often form chains, usually large</p> </div> <div data-bbox="383 1354 605 1512" data-label="Image"> </div> <div data-bbox="618 1400 717 1476" data-label="Image"> </div> <div data-bbox="656 1491 766 1520" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="823 1110 1287 1184" data-label="Section-Header"> <h2>Slide 6 Some actors: Diatoms & Dinoflagellates</h2> </div> <div data-bbox="823 1270 940 1306" data-label="Text"> <p>NOTES:</p> </div>

<div data-bbox="381 168 630 203" data-label="Section-Header"> <h2>Diatom frustules</h2> </div> <div data-bbox="342 214 665 243" data-label="Text"> <p>Miller (2004) Fig. 2.1, <i>Thalassiosira</i></p> </div> <div data-bbox="224 247 774 497" data-label="Image"> </div> <div data-bbox="652 512 771 543" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 132 1187 170" data-label="Section-Header"> <h2>Slide 7 Diatom frustules</h2> </div> <div data-bbox="815 256 940 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="250 651 756 722" data-label="Section-Header"> <h2>Diatom cell division, can be used to estimate μ specific growth rate</h2> </div> <div data-bbox="370 726 628 756" data-label="Text"> <p>Miller (2004) Figs. 2.4 & 2.6</p> </div> <div data-bbox="243 741 579 1016" data-label="Image"> </div> <div data-bbox="592 760 740 1024" data-label="Text"> <p>Frequency of dividing cells can be used to estimate μ (McDuff & Chisholm's [1982] equations: See Gallagher Chapter 7 & Slide 27 today)</p> </div>	<div data-bbox="815 621 1409 699" data-label="Section-Header"> <h2>Slide 8 Diatom cell division, can be used to estimate μ specific growth rate</h2> </div> <div data-bbox="815 781 940 816" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="391 1180 617 1220" data-label="Section-Header"> <h2>Dinoflagellates</h2> </div> <div data-bbox="248 1234 602 1541" data-label="Image"> </div> <div data-bbox="240 1459 423 1541" data-label="Caption"> <p>Fig. 2.7 Variation of form among dinoflagellates. (a) Gonyaulax polyedra, a box-like dinoflagellate, ~100 μm long. (b) Dinophysis, a spindle-shaped dinoflagellate with a "tail" ~100 μm long. (c) Prorocentrum, a large, round, pear-shaped dinoflagellate. The structure extending from the surface is a "tail" ~100 μm long. (d) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (e) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (f) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (g) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (h) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (i) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (j) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (k) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (l) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (m) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (n) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (o) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (p) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (q) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (r) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (s) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (t) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (u) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (v) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (w) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (x) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (y) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long. (z) Prorocentrum, a pear-shaped dinoflagellate, ~100 μm long.</p> </div> <div data-bbox="652 1524 771 1556" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 1148 1162 1186" data-label="Section-Header"> <h2>Slide 9 Dinoflagellates</h2> </div> <div data-bbox="815 1268 940 1304" data-label="Text"> <p>NOTES:</p> </div>

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

Table 2.1 Select features of taxonomic groups of microflagellate algae. Several groups that are seldom abundant in marine habitats are left out. Flagellates and Raphidophytes are not included.

	Flagellae	Cell wall	Main auxiliary pigments
Prasinophytes	1	Mucous	Phycocyanin
Cryptophytes	0	Mucous	Chlorophyll <i>b</i>
Rhodophytes	0	Cellulose	Phycocyanin
Chlorophyceae & volvocales ¹	2, unequal posterior short, smooth anterior long	Naked or scales (some rigid)	Chlorophyll <i>a</i> , <i>b</i> , <i>c</i> , fucoxanthin
Rhodophyceae (Rhodospirillum)	1 or 2, equal, hairy, no microtubules	Naked gametes	Chlorophyll <i>a</i> , <i>b</i> , <i>c</i> , fucoxanthin, diadinoxanthin
Phaeocystophyceae			
Pavlovales (syn. Phaeophyceae)	2, equal or not, hairy - haptonemes emerging between	Organic scales	β -carotene
Pavlovales	2, unequal hairy, haptonemes ventral	Organic or calcareous scales	
Cryptophytes	2, equal, equal, sometimes hairy	Naked	Chlorophyll <i>a</i> , <i>b</i> , <i>c</i> , β -carotene, diadinoxanthin
Pyrenophytes or Dinophytes	2, one grading, one posterior	Cellulose plates or others naked	Chlorophyll <i>a</i> , peridinin, β -carotene
Prasinophytes	1 or 2 unequal, or 4 equal and scaly	Organic scales or naked	Chlorophyll <i>b</i> , β -carotene
Chlorophytes	2 (or 4) equal, equal, smooth	Naked or with cellulose sheath, sometimes calcified	Chlorophyll <i>a</i> , <i>b</i> , <i>c</i> , and β -carotene

¹ A number of green algal families Chlorophyceae have recently been separated into a new phylum Rhodophyceae. These include Scenedesmus, Chlorella, and other genera. The Rhodophyceae (including the Rhodospirillum or Rhodospirillum) that bear equal scales and the very rare Rhodospirillum are the principal calcareous microflagellates. Rhodospirillum are characterized by flagella of unequal length (anterior "long" and posterior smooth chlorophyll) and chrysolaminarin as a storage product. The Chlorophyceae and Rhodospirillum (Rhodospirillum) are the brown algae Phaeophyceae and Rhodophyceae.

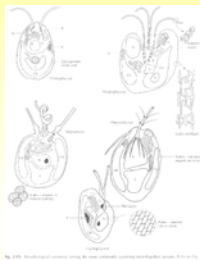
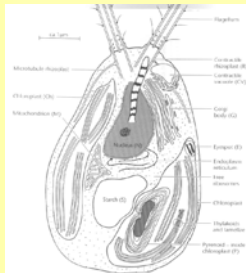
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Slide 11 Microflagellates (2-30 μm)

NOTES:

Microflagellates

Miller (2004) Figs. 2.10 & 2.11

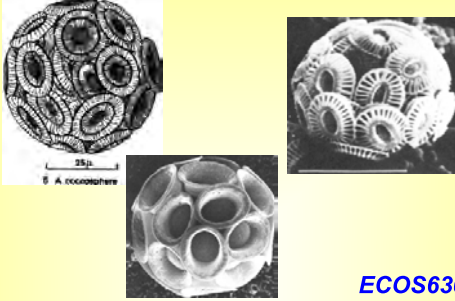


Slide 12 Microflagellates

NOTES:

Haptophyta: Coccolithophorids

From Newell & Newell (1973) & Valiella (1984, p. 1,4)



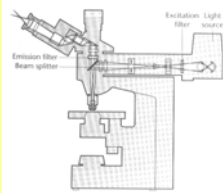
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Slide 13 Haptophyta: Coccolithophorids

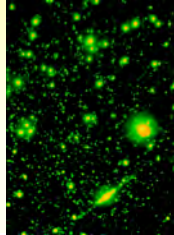
NOTES:

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

Chl a fluorescence used to determine biomass & abundance: Viral fluorescence (right)



Box Fig. 2.2.1 Schematic of an epifluorescence microscope.



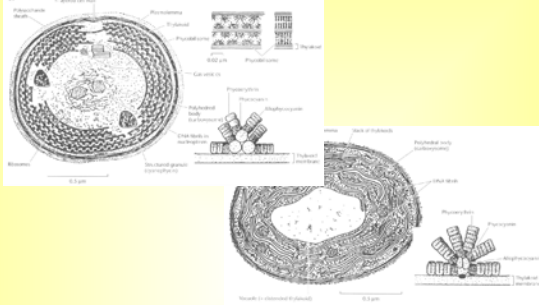
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Slide 14 Most phytoplankton biomass in the oceans is made up of small cells (< 2 μm), the picoplankton

NOTES:

Cyanobacteria & Prochlorococcus

Miller (2004) Fig. 2.12



Slide 15 Cyanobacteria & Prochlorococcus

NOTES:

<div data-bbox="389 168 620 207" data-label="Section-Header"> <h2>Flow cytometry</h2> </div> <div data-bbox="240 210 617 541" data-label="Diagram"> <p>Flow cytometer operating principle and signal processing</p> <p>Standard cytometers: Analog pulse wave or pulse integration (area), then ADC. (EUROPA cytometers) ADC of raw signals, then hardware digital signal processing: pulse lengths and area. Cytometer electronics</p> <p>Box Fig. 2.3.1 Flow cytometer system layout. (Courtesy of Dr George Dehler, Cynbaan, The Netherlands.)</p> </div> <div data-bbox="654 514 771 543" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 134 1188 174" data-label="Section-Header"> <h2>Slide 16 Flow cytometry</h2> </div> <div data-bbox="816 258 940 294" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="389 655 620 695" data-label="Section-Header"> <h2>Flow cytometry</h2> </div> <div data-bbox="425 701 573 730" data-label="Text"> <p>Miller Box 2.3.2</p> </div> <div data-bbox="230 787 734 997" data-label="Figure"> <p>Box Fig. 2.3.2 Scatter plots of fluorescence vs. forward light scatter. (After Olsen et al., 1990.)</p> </div>	<div data-bbox="816 623 1188 663" data-label="Section-Header"> <h2>Slide 17 Flow cytometry</h2> </div> <div data-bbox="816 745 940 781" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="280 1173 721 1293" data-label="Section-Header"> <h2>Temperature effects on specific growth rate and production</h2> </div> <div data-bbox="235 1297 649 1512" data-label="Complex-Block"> <p>Mathematics, Grade 10</p> <p>Session 3, Open-response Questions</p> <p>41. The number of bacteria in a sample doubles every four hours. At the end of 24 hours there are 30,720 bacteria present in a sample.</p> <ol style="list-style-type: none"> How many bacteria were present initially? Show your work. During which four-hour period will 1 million bacteria first be present? Show your work. Write a mathematical expression to determine the number of bacteria present at the end of any four-hour period. </div> <div data-bbox="654 1488 771 1518" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 1113 1408 1188" data-label="Section-Header"> <h2>Slide 18 Temperature effects on specific growth rate and production</h2> </div> <div data-bbox="816 1270 940 1306" data-label="Text"> <p>NOTES:</p> </div>

Why isn't the ocean filled with phytoplankton?

For Tuesday 10/28/08

Estimate how long it would take for a *Synechococcus* (the dominant genus of cyanobacteria), obeying exponential growth at 20° C, to fill the world's oceans. Use the following facts: *Synechococcus* has a diameter of about 1 micrometer, the distance from the equator to the pole is 10,000 km, the mean depth of the ocean is 4200m and 75% of the world's surface area is ocean.

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

NOTES:

'mu' μ and little 'r'

μ is per capita growth rate; μ_{\max} is max growth rate, intrinsic growth rate, Malthusian parameter

$$\begin{aligned}\frac{dN}{dt} &= \mu N. \\ \mu &= \frac{1}{N} \frac{dN}{dt}. \\ \frac{dN}{dt} &= \mu_{\max} N, \text{ with no resource limitation.} \\ \mu_{\max} &= \frac{1}{N} \frac{dN}{dt}.\end{aligned}$$

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Slide 20 'mu' μ and little 'r'

NOTES:

The Malthusian parameter: r_{\max}

Maximum growth rate, no density-dependent limitation

$$\begin{aligned}\frac{dN}{dt} &= r N. \\ \frac{dN}{dt} &= r N, \text{ with no resource limitation.} \\ N_t &= N_0 e^{r_{\max} t}. \\ N_t &= N_0 e^{r_{\max} t}. \\ \frac{d}{dt} \left(\frac{N}{N_0} \right) &= \mu_{\max} \frac{N}{N_0}. \\ \frac{d}{dt} \left(\frac{N}{N_0} \right) &= r_{\max} \frac{N}{N_0}.\end{aligned}$$

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Slide 21 The Malthusian parameter: r_{\max}

NOTES:

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

μ : Units of inverse time

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

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

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

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

$$\begin{aligned} \mu &= \frac{\text{specific production}}{\text{biomass}} = \frac{P}{B} \\ &= \frac{\frac{dC}{dt}}{B} \end{aligned}$$

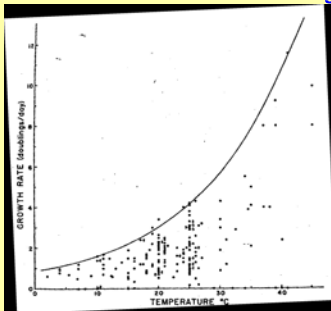
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Slide 23 Biomass-specific production, μ

NOTES:

Eppley (1972)

Note the archaic 'doublings/day' ordinate

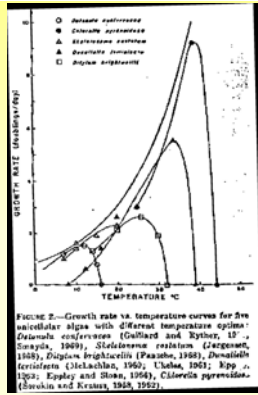


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Slide 24 Eppley (1972)

NOTES:

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



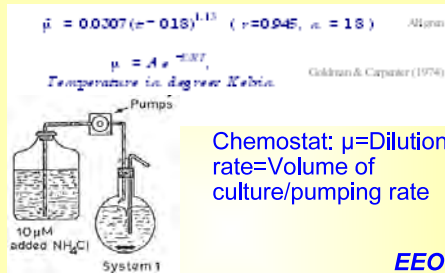
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Slide 25 Equations describing growth

NOTES:

Modifications to Eppley's Temperature equation

Goldman & Carpenter, chemostats, not Temp in Kelvin

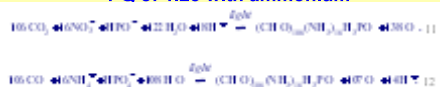


Slide 26 Modifications to Eppley's Temperature equation

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:

<div data-bbox="266 163 756 231"> <h3>The relationship between μ/μ_{\max} & the Redfield ratio</h3> </div> <div data-bbox="306 239 695 266"> <p>Goldman (1980), replotted by Harris (1986)</p> </div> <div data-bbox="280 281 435 543"> </div> <div data-bbox="490 275 725 480"> <ul style="list-style-type: none"> Redfield ratios only attained at $\mu/\mu'_{\max} \approx 1$ C:Chl a ratio is a reasonable predictor of relative growth rate <ul style="list-style-type: none"> Affected by shade adaptation </div> <div data-bbox="469 487 596 512"> <p>Redfield's 106</p> </div> <div data-bbox="654 514 769 541"> <p>EEOS630</p> </div>	<div data-bbox="816 132 1320 210"> <h3>Slide 28 The relationship between μ/μ_{\max} & the Redfield ratio</h3> </div> <div data-bbox="816 294 938 327"> <p>NOTES:</p> </div>
<div data-bbox="323 693 678 772"> <h3>The ecological (and evolutionary) Stage</h3> </div> <div data-bbox="274 762 756 812"> <p>From Hutchinson's 'The ecological play on the evolutionary stage'</p> </div> <div data-bbox="217 810 609 1005"> </div> <div data-bbox="609 909 773 1012"> <p>SeaWiFS Image of Chl a concentration</p> </div> <div data-bbox="654 1037 769 1064"> <p>EEOS630</p> </div>	<div data-bbox="816 657 1239 735"> <h3>Slide 29 The ecological (and evolutionary) Stage</h3> </div> <div data-bbox="816 819 938 852"> <p>NOTES:</p> </div>
<div data-bbox="402 1218 604 1251"> <h3>Redfield ratio</h3> </div> <div data-bbox="420 1264 573 1289"> <p>106 C: 16 N: 1 P</p> </div> <div data-bbox="280 1302 729 1373"> $(CH_2O)_{106} (NH_3)_{16} H_3PO_4 + 138 O_2 \rightleftharpoons 106 CO_2 + 16 HNO_3 + H_3PO_4 + 122 H_2O.$ </div> <div data-bbox="238 1383 719 1579"> <ul style="list-style-type: none"> 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 </div>	<div data-bbox="816 1182 1164 1218"> <h3>Slide 30 Redfield ratio</h3> </div> <div data-bbox="816 1304 938 1339"> <p>NOTES:</p> </div>

Frequency of Dividing Cells

McDuff & Chisholm's (1982) equation

$$\mu = t_{\text{div}}^{-1} \ln(1 + f)$$

where, t_{div} = 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 μ and C:Chl a ratio

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

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

$$\Delta C = 1.05 \frac{A^*}{I^* \varepsilon} \quad 14$$

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

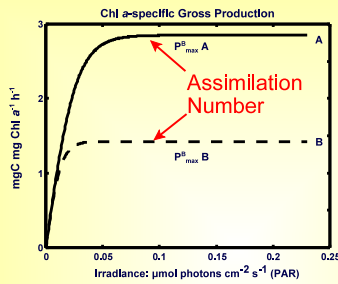
$$\mu = -\ln \left(1 - \left(\frac{1.05 R^*}{I^* \varepsilon} \right) \right) \times 12 \quad 16$$

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

NOTES:

Estimating μ from Assimilation Number



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Slide 34 Estimating μ from Assimilation Number

NOTES:

Assimilation number, C:Chl a, and μ

$$\mu_{\text{max}} = \frac{\text{Assimilation number}}{\text{C:Chl } a} - \text{specific respiration.}$$

$$\mu = \frac{\text{Chl } a\text{-specific prod.}}{\text{C:Chl } a} - \text{specific respiration.}$$

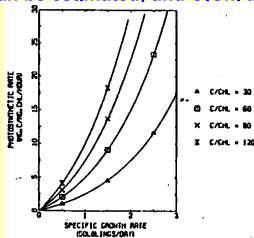
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Slide 35 Assimilation number, C:Chl a, and μ

NOTES:

Assimilation number, μ & temperature

If C:Chl a is known & constant, μ can be determined from assimilation number, BUT, it is neither known (but can be estimated) and C:Chl a ratio is not constant (10



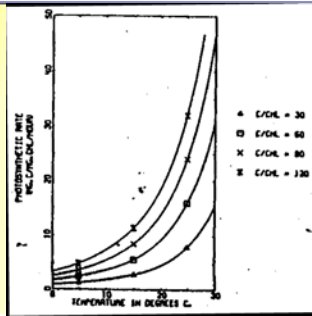
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Slide 36 Assimilation number, μ & temperature

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.

change in biomass
time = net primary production - grazing - other losses

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

where, C = biomass [gCm^{-3} or gCm^{-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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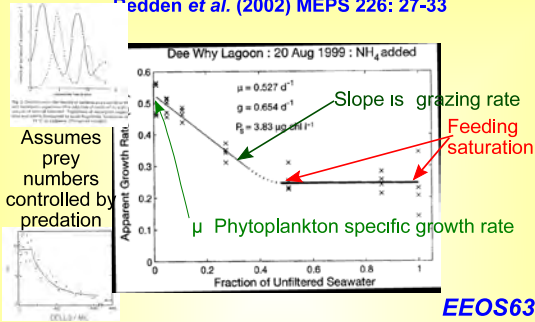
Slide 39 Excursis on grazing & the dilution method

NOTES:

<div data-bbox="357 168 656 203" data-label="Section-Header"> <h3>The dilution method</h3> </div> <div data-bbox="271 214 751 262" data-label="Text"> <p>The most widely used way to estimate μ and grazing rate.</p> </div> <div data-bbox="251 256 756 470" data-label="Equation-Block"> <p>change in biomass = net primary production - grazing - other losses</p> $\frac{dC}{dt} = C(\mu - G - m)$ <p>where, C = biomass [gCm^{-3} or gCm^{-2}].</p> <p>μ = specific growth rate [$\frac{1}{time}$].</p> <p>G = specific grazing rate [$\frac{1}{time}$].</p> <p>m = specific non-grazing loss (eg, DOM loss sinking) [$\frac{1}{time}$].</p> </div> <div data-bbox="613 510 732 539" data-label="Text"> <p>ECOS630</p> </div>	<div data-bbox="815 132 1255 170" data-label="Section-Header"> <h3>Slide 40 The dilution method</h3> </div> <div data-bbox="815 256 940 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="271 651 751 722" data-label="Section-Header"> <h3>Nano- and microzooplankton are the dominant grazers</h3> </div> <div data-bbox="274 724 751 753" data-label="Text"> <p>Protozoan grazing (and juvenile macrozooplankton)</p> </div> <div data-bbox="287 751 656 1026" data-label="Diagram"> <p>The diagram illustrates the microbial loop. It shows phytoplankton being consumed by microzooplankton (indicated by a large red arrow). Microzooplankton are then consumed by higher trophic levels. The diagram also shows the flow of inorganic C, N, and P, phytoplankton, dissolved organic matter, bacteria, and suspended particulates. A label 'fecal fallout' points to the bottom of the diagram.</p> </div> <div data-bbox="654 1001 771 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 621 1378 699" data-label="Section-Header"> <h3>Slide 41 Nano- and microzooplankton are the dominant grazers</h3> </div> <div data-bbox="815 781 940 816" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="246 1176 768 1247" data-label="Section-Header"> <h3>Reduced zooplankton ingestion of phytoplankton at low prey density</h3> </div> <div data-bbox="436 1249 555 1278" data-label="Text"> <p>Frost (1980)</p> </div> <div data-bbox="319 1289 576 1551" data-label="Figure"> <p>The figure consists of two graphs. The top graph is for <i>Calanus</i> and the bottom graph is for <i>Pseudocalanus</i>. Both graphs show the relationship between zooplankton ingestion (y-axis) and phytoplankton density (x-axis). The data points are fitted with a curve that shows a sharp increase in ingestion at low prey density, followed by a plateau at higher densities.</p> </div> <div data-bbox="654 1526 771 1554" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 1146 1408 1224" data-label="Section-Header"> <h3>Slide 42 Reduced zooplankton ingestion of phytoplankton at low prey density</h3> </div> <div data-bbox="815 1306 940 1341" data-label="Text"> <p>NOTES:</p> </div>

Landry-Hassett dilution method

Redden *et al.* (2002) MEPS 226: 27-33

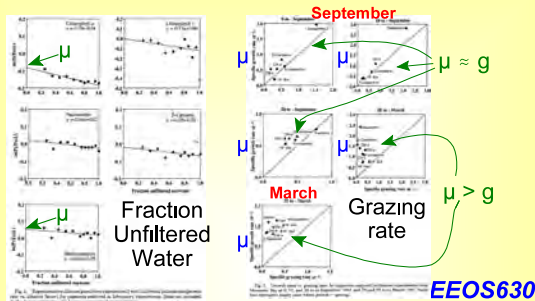


Slide 43 Landry-Hassett dilution method

NOTES:

Taxon-specific dilution method

Waterhouse & Welschmeyer (1995)

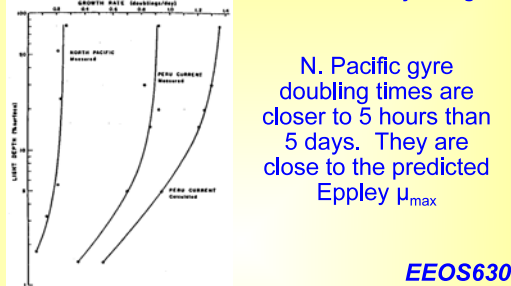


Slide 44 Taxon-specific dilution method

NOTES:

Specific growth rates in the field

Eppeley (1972) Figure 5. Note the low N. Pacific rate, This 5-d doubling time later shown to be very wrong



Slide 45 Specific growth rates in the field

NOTES:

Typical growth rates

Gyre μ underestimated by Eppley (1972)

Area	Doubling time
Oligotrophic	
Sargasso sea	0.26
Fla. strait	0.45
CMF Caribbean	0.37
CMF Mexican	0.35
CMF S. California (July 1970)	0.25-0.4
S. California (April-Sept. 67)	0.7 avg
Eutrophic	
Formosa est.	0.7
Agulh.	0.67
Buen.	0.75
CMF NW Africa	1.0
Western Australia Sea	>1.0

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Slide 46 Typical growth rates

NOTES:

In situ fluorescence

Lorenzen (1966)

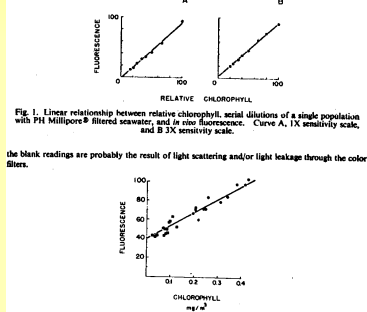
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Slide 47 In situ fluorescence

NOTES:

Lorenzen (1966)

Linear relation between Chl *a* & fluorescence

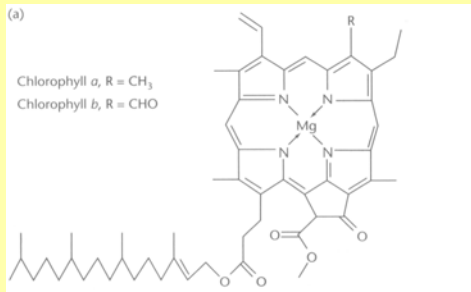


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Slide 48 Lorenzen (1966)

NOTES:

Chlorophyll a



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Slide 49 Chlorophyll a

NOTES:

All phytoplankton have Chl a

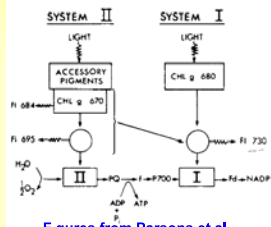
Miller Table 2.2

Table 2.2 Principal pigments in different phytoplankton groups adapted from Van den Hurk et al. (1995)

	Cryptophytes	Prochlorophytes	Neochlorophytes	Chlorophytes	Kryptophytes	Phaeophytes	Cryptophytes	Phaeophytes	Chlorophytes	Phaeophytes
Chlorophyll										
a	+	+	+	+	+	+	+	+	+	+
b										
c										
d										
e										
f										
g										
h										
i										
j										
k										
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t										
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fk										
fl										
fm										
fn										
fo										
fp										
fq										
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fx										
fy										
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ga										
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hp										
hq										
hr										

Photosystem II is the source of most fluorescence

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



Figures from Parsons et al. (1984)

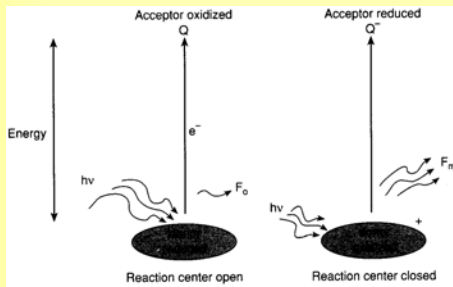
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Slide 52 Photosystem II is the source of most fluorescence

NOTES:

Fluorescence yield not constant: open & closed reaction centers

Falkowski & Raven (1997) Figure 3.11

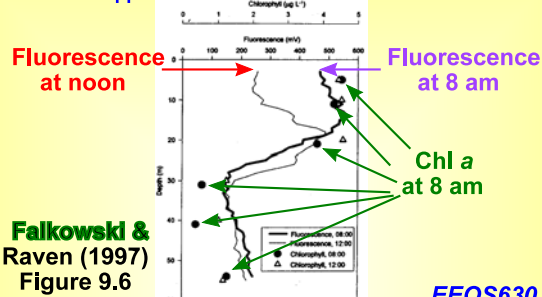


Slide 53 Fluorescence yield not constant: open & closed reaction centers

NOTES:

Fluorescence yield

An 'apparent' noon subsurface Chl a maximum



Falkowski & Raven (1997) Figure 9.6

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Slide 54 Fluorescence yield

NOTES:

<div data-bbox="233 163 776 541"> <h3>How do you measure production?</h3> <p>See Harrison & Platt; Choose a model</p> <ul style="list-style-type: none"> • <i>In situ</i> or simulated <i>in situ</i> incubations <ul style="list-style-type: none"> ▸ <i>In situ</i> incubations account for light-quality effects, but not vertical mixing ▸ Simulated <i>in situ</i> <ul style="list-style-type: none"> ▪ Natural light ▪ Artificial light source (photosynthetron) • Model P vs. I approach <ul style="list-style-type: none"> ▪ 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 <p>EEOS630</p> </div>	<div data-bbox="820 134 1419 212"> <h3>Slide 55 How do you measure production?</h3> </div> <div data-bbox="820 289 1419 331"> <p>NOTES:</p> </div>
<div data-bbox="233 695 776 1066"> <h3>Productivity methods</h3> <p>Choose a method</p> <ul style="list-style-type: none"> • ^{14}C vs. O_2 method <ul style="list-style-type: none"> ▸ Sensitivity & variability in photosynthetic quotient pose problems for the O_2 method • ^{18}O primary production • Incubations: short vs. Long <ul style="list-style-type: none"> ▸ Eppley used 24-h incubations ▸ Most authors recommend short incubations, but <ul style="list-style-type: none"> ◦ Photoacclimation a problem ◦ Redalje: Sum of multiple short incubations < long incubation ▸ Large vs. Small incubation bottles <ul style="list-style-type: none"> ▪ Bottle effects ▪ Noted especially by Gieskes & Kraay (1979) <p>EEOS630</p> </div>	<div data-bbox="820 667 1419 699"> <h3>Slide 56 Productivity methods</h3> </div> <div data-bbox="820 777 1419 819"> <p>NOTES:</p> </div>
<div data-bbox="233 1178 776 1556"> <h3>C-14 method</h3> <p>See Chapter 2 & references for details</p> <ul style="list-style-type: none"> • Prepare a $\text{H}^{14}\text{CO}_3^-$ 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 <p>EEOS630</p> </div>	<div data-bbox="820 1150 1419 1192"> <h3>Slide 57 C-14 method</h3> </div> <div data-bbox="820 1270 1419 1312"> <p>NOTES:</p> </div>

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:

Estimating ^{14}C productivity

Note the isotopic discrimination factor (1.05)

$$\frac{\Delta C}{\Delta t} = 1.05 \frac{A^*}{I^* T}$$

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

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

T = incubation time [h].

1.05 = isotopic discrimination factor.

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Slide 60 Estimating ^{14}C 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>



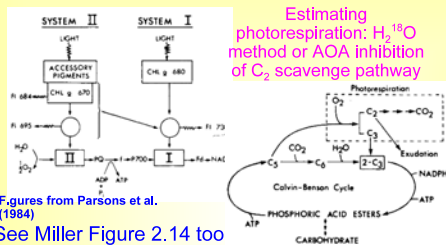
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Slide 62 Hawaii Ocean Time-Series (HOT)

NOTES:

Gross primary Productivity

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



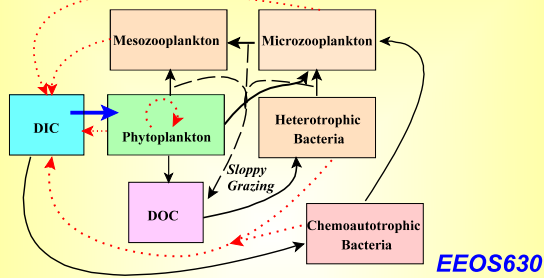
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Slide 63 Gross primary Productivity

NOTES:

Carbon flow in bottles (& the sea)

Are short incubations the best solution?
Photoacclimation a problem



Slide 64 Carbon flow in bottles (& the sea)

NOTES:

The oxygen method

Separating Gross vs. Net production.

- Use light and dark bottles
- Dark bottle measures respiration (but not photorespiration)
 - Photorespiration may not be too important
 - In the absence of grazers, light bottle measures net production.
 - In the absence of grazers, light-Dark measures gross production.
- Photorespiration and heterotrophs create large problems

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Slide 65 The oxygen method

NOTES:

O₂ vs. ¹⁴C

$n \text{ CO}_2 \xrightarrow{\text{light}} \text{Particulate organic C}_1 + \text{Dissolved organic C}_2 + n \text{ O}_2_3$

O₂ method measures O₂ production, = measuring 1 + 2.
¹⁴C method measures only 1 if only filtered POC is counted.

- In theory, the O₂ method can estimate gross and net production
 - Increase in light bottle is net
 - Dark bottle decrease is respiration
 - Light-dark = gross production
- The ¹⁴C activity of dissolved organic matter should be determined

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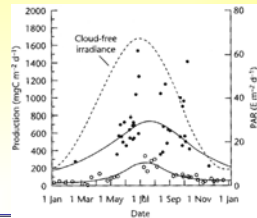
Slide 66 O₂ vs. ¹⁴C

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)



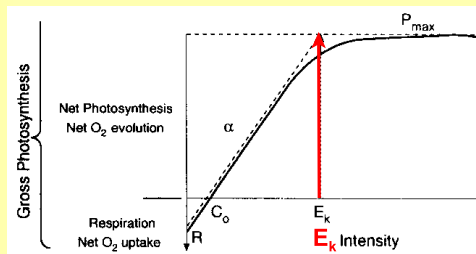
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Slide 67 Primary production underestimated

NOTES:

Falkowski & Raven P vs. E curves

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



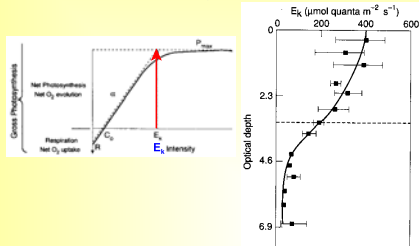
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Slide 68 Falkowski & Raven P vs. E curves

NOTES:

Photoacclimation: to light intensity & light quality

Falkowski & Raven Fig. 9.8;
Light intensity: $I_z = I_0 \cdot \exp(-K_d \cdot z)$; $\xi = K_d z$ = 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

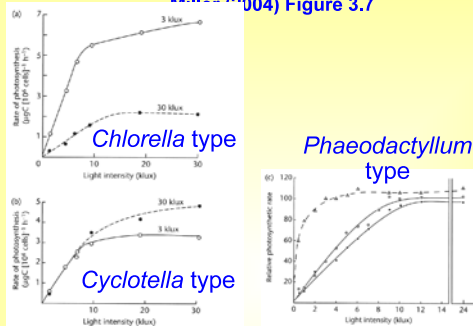
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Slide 71 Shade acclimation (adaptation)

NOTES:

Types of shade acclimation

BRUNNEN (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://docutec.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).

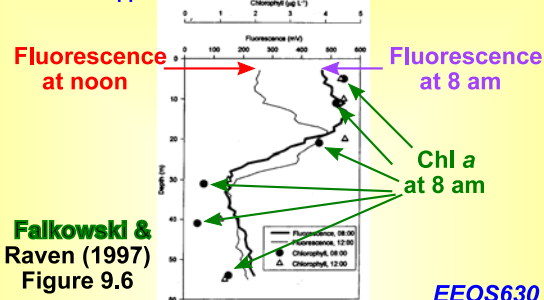
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- To convert to energy, 550nm light assumed

Slide 73 PAR & units of light intensity

NOTES:

Fluorescence yield

An 'apparent' noon subsurface Chl a maximum



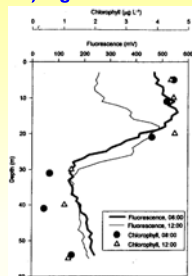
Slide 74 Fluorescence yield

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



Slide 75 Measuring the Chl a profile

NOTES:

Quenching

Refers to both scintillation counting and fluorescence yield

Quenching and quantum yield for fluorescence

$$\Phi_F = \frac{k_F}{(k_F + k_A + k_P)} \text{ where}$$

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

k_F = de-excitation of singlet to fluorescence

k_A = heat.

k_P = photochemistry.

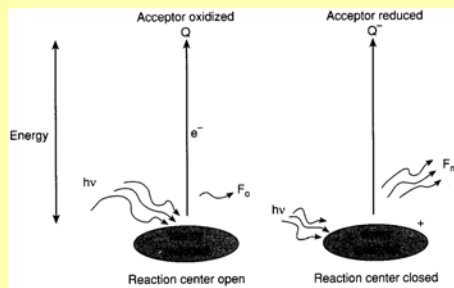
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Slide 76 Quenching

NOTES:

Fluorescence yield & open & closed reaction centers

Falkowski & Raven (1997) Figure 3.11

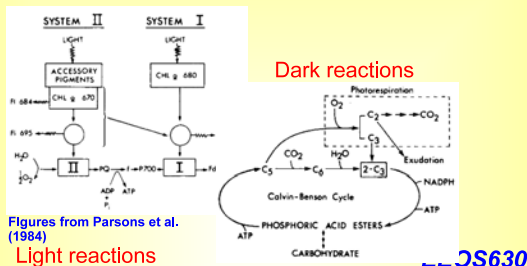


Slide 77 Fluorescence yield & open & closed reaction centers

NOTES:

Gross primary productivity

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



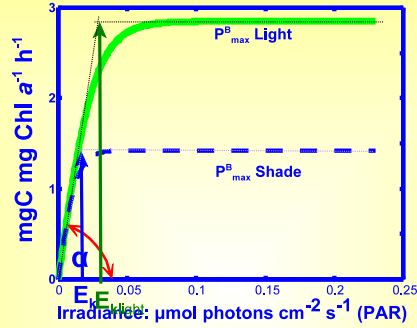
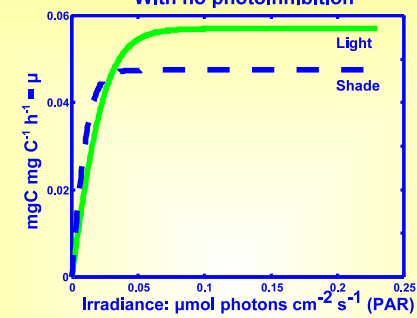
Figures from Parsons et al. (1984)

Light reactions

Dark reactions

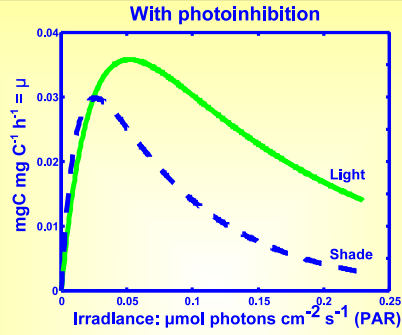
Slide 78 Gross primary productivity

NOTES:

<p>Chl a-specific gross productivity</p> 	<p>Slide 79</p> <p>NOTES:</p>
<p>Jassby & Platt's (1976) Equation</p> <p>Without photoinhibition</p> $P^B = P_{B_{\max}}^B \tanh\left(\frac{\alpha I}{P_{B_{\max}}^B}\right)$ <p>where P^B = Chl a-specific production $\left[\frac{\text{mg C}}{\text{mg Chl a} \cdot \text{h}}\right]$ $P_{B_{\max}}^B$ = Max. rate at light saturation. α = Assimilation number α = the maximum photosynthetic rate at light saturation. α = initial slope of the P vs. I curve. $\alpha = \left[\frac{\text{mg C}}{\text{mg Chl a} \cdot \text{h} \cdot (\text{W m}^{-2})}\right]$ or $\left[\frac{\text{mg C}}{\text{mg Chl a} \cdot \text{h} \cdot (\text{Einstein m}^{-2} \cdot \text{s}^{-1})}\right]$ I = the light intensity of PAR $[\text{Watt m}^{-2}]$ or $[\text{Einstein m}^{-2} \cdot \text{s}^{-1}]$.</p>	<p>Slide 80 Jassby & Platt's (1976) Equation</p> <p>NOTES:</p>
<p>Carbon-specific gross production</p> <p>With no photoinhibition</p> 	<p>Slide 81 Carbon-specific gross production</p> <p>NOTES:</p>

<div data-bbox="207 134 794 575"> <h3>Carbon-specific Production</h3> <p>Shade adaption \Rightarrow lower compensation light intensity</p> <p>mgC mg C⁻¹ h⁻¹ = μ</p> <p>Irradiance: $\mu\text{mol photons cm}^{-2} \text{s}^{-1}$ (PAR)</p> <p>Light gross Shade gross Light net Shade net</p> <p>Shade acclimation produces higher μ at low light</p> <p>Compensation Light Intensity</p> </div>	<div data-bbox="824 134 1412 170"> <h4>Slide 82 Carbon-specific Production</h4> </div> <div data-bbox="824 260 938 291"> <p>NOTES:</p> </div>
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Carbon-specific gross production



Slide 85 Carbon-specific gross production

NOTES:

Vertical profiles of photosynthesis

Miller (2004) Fig. 3.9, May (●) & Sept (○)

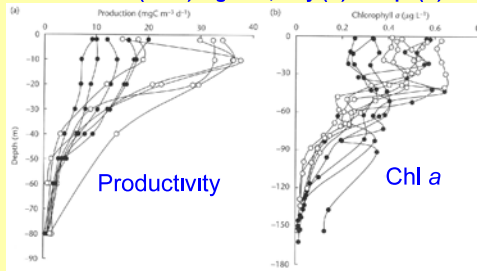
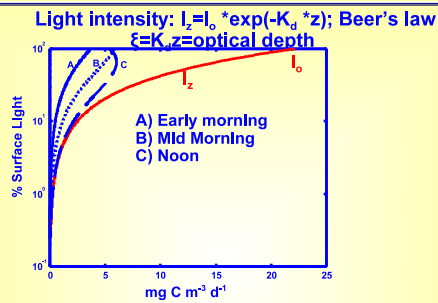


Fig. 3.9 (a) May (closed circles) and September (open circles) profiles of primary productivity m^{-3} in the Gulf of Alaska (19°N, 143°W). (b) Chlorophyll profiles from the same site at various times in the same months (same symbols are always maximal near the surface, then taper off below 50m. (After Weisheimer 1993.)

Slide 86 Vertical profiles of photosynthesis

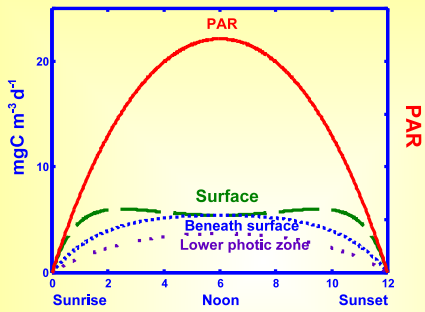
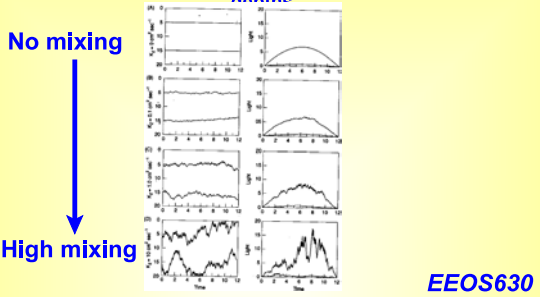
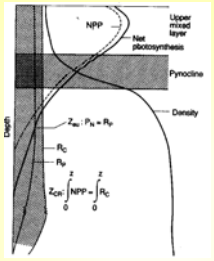
NOTES:

Hourly Gross Productivity vs. Depth



Slide 87 Hourly Gross Productivity vs. Depth

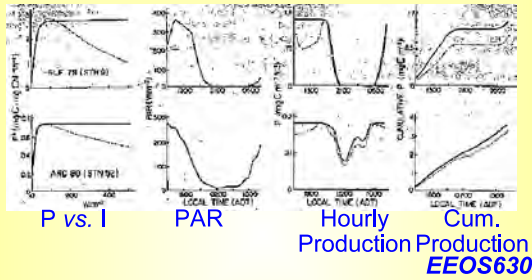
NOTES:

<p>Hourly Gross Productivity</p> <p>With photoinhibition</p> 	<p>Slide 88 Hourly Gross Productivity</p> <p>NOTES:</p>
<p>Cells are not stationary!</p> <p>Left: position of cell; right: light history of cells at 2 depths</p> <p>No mixing</p> <p>High mixing</p>  <p>EEOS630</p>	<p>Slide 89 Cells are not stationary!</p> <p>NOTES:</p>
<p>Euphotic zone ($\approx 1\%$ light depth), mixed layer depth, and critical depth</p>  <p>EEOS630</p>	<p>Slide 90 Euphotic zone ($\approx 1\%$ light depth), mixed layer depth, and critical depth</p> <p>NOTES:</p>

<div data-bbox="303 168 724 205" data-label="Section-Header"> <h3>Non-dimensional production</h3> </div> <div data-bbox="276 214 742 262" data-label="Text"> <p>Behrenfeld & Falkowski (1997), Falkowski & Raven (1997)</p> </div> <div data-bbox="279 300 474 384" data-label="Text"> <p>Production vs. Depth Meters</p> </div> <div data-bbox="279 426 480 531" data-label="Text"> <p>Chl-specific P vs. Depth Optical depth</p> </div> <div data-bbox="485 239 643 537" data-label="Figure"> </div> <div data-bbox="654 512 771 541" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 132 1369 172" data-label="Section-Header"> <h3>Slide 91 Non-dimensional production</h3> </div> <div data-bbox="816 256 940 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="250 653 774 693" data-label="Section-Header"> <h3>The model P vs I approach vs. SIS</h3> </div> <div data-bbox="397 699 609 728" data-label="Text"> <p>Harrison et al. (1985)</p> </div> <div data-bbox="238 728 725 1022" data-label="List-Group"> <ul style="list-style-type: none"> • Light & Chl a profiles determined • SIS <ul style="list-style-type: none"> ▶ 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 <ul style="list-style-type: none"> ▶ Water collected at 50% and 1% Light depths ▶ 30-50 100-ml incubations ▶ Artificial light ▶ Time-zero or dark-bottle blanks </div> <div data-bbox="654 1001 771 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 619 1390 693" data-label="Section-Header"> <h3>Slide 92 The model P vs I approach vs. SIS</h3> </div> <div data-bbox="816 779 940 814" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="289 1180 737 1218" data-label="Section-Header"> <h3>Model estimates of production</h3> </div> <div data-bbox="345 1226 670 1255" data-label="Text"> <p>Requires profiles of light and Chl a</p> </div> <div data-bbox="241 1257 508 1505" data-label="List-Group"> <ul style="list-style-type: none"> • 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^S and α • Sum 24-h estimates to obtain daily production • Compare with SIS profiles </div> <div data-bbox="506 1253 665 1444" data-label="Figure"> </div> <div data-bbox="552 1442 760 1528" data-label="Equation-Block"> $P(t) = P^S(I(t)) \cdot E.$ $P_d = \sum_{i=1}^{24} P(t).$ </div>	<div data-bbox="816 1148 1395 1186" data-label="Section-Header"> <h3>Slide 93 Model estimates of production</h3> </div> <div data-bbox="816 1268 940 1304" data-label="Text"> <p>NOTES:</p> </div>

Model P vs. I approach

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

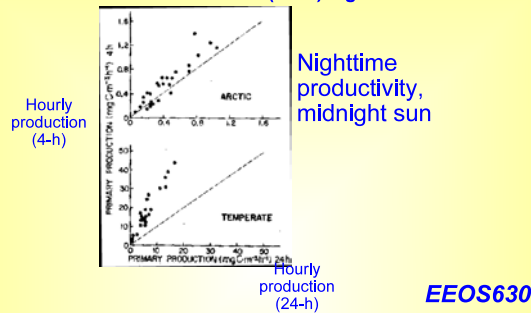


Slide 94 Model P vs. I approach

NOTES:

4- vs. 24-h incubations

Harrison *et al.* (1985) Figure 2

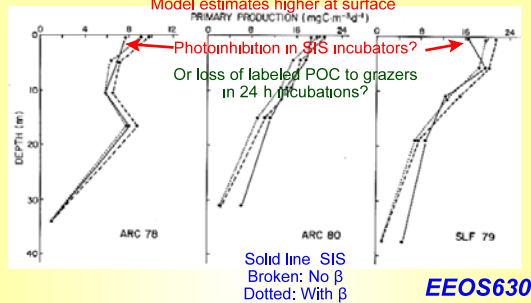


Slide 95 4- vs. 24-h incubations

NOTES:

Harrison *et al.* (1985)

Fig. 3, P vs. I parameters from 50% Light Depth
Model estimates higher at surface



Slide 96 Harrison *et al.* (1985)

NOTES:

<div data-bbox="224 195 256 451" data-label="Text"> <p>Model P vs. I approach</p> </div> <div data-bbox="256 157 560 520" data-label="Figure"> </div> <div data-bbox="535 247 792 304" data-label="Text"> <p>Model estimates Not significantly different from SIS at high light intensities</p> </div> <div data-bbox="535 457 792 514" data-label="Text"> <p>Model estimates LOWER at Low Light Levels: Photoacclimation??</p> </div> <div data-bbox="324 520 771 546" data-label="Text"> <p>SIS approach EEOS630</p> </div>	<div data-bbox="824 136 933 168" data-label="Section-Header"> <p>Slide 97</p> </div> <div data-bbox="824 262 938 294" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="284 661 755 693" data-label="Section-Header"> <p>Problems at low light intensities</p> </div> <div data-bbox="316 703 706 730" data-label="Text"> <p>The model underestimates SIS production.</p> </div> <div data-bbox="224 787 256 934" data-label="Text"> <p>Model P vs. I</p> </div> <div data-bbox="256 756 600 955" data-label="Figure"> </div> <div data-bbox="535 871 792 1008" data-label="Text"> <p>Model estimates LOWER at Low Light Levels: Photoacclimation or light quality effects? Using P vs. I parameters from the 1% light depth produced an even worse fit to the SIS estimates (p. 870)</p> </div> <div data-bbox="373 945 527 997" data-label="Text"> <p>SIS More blue light</p> </div> <div data-bbox="657 1003 771 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="824 630 1404 661" data-label="Section-Header"> <p>Slide 98 Problems at low light intensities</p> </div> <div data-bbox="824 745 938 777" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="316 1144 706 1176" data-label="Section-Header"> <p>Areal production accurate</p> </div> <div data-bbox="373 1186 633 1213" data-label="Text"> <p>Harrison et al. (1985) Fig. 5</p> </div> <div data-bbox="256 1291 289 1449" data-label="Text"> <p>Model P vs. I</p> </div> <div data-bbox="289 1291 738 1438" data-label="Figure"> </div> <div data-bbox="519 1449 568 1474" data-label="Text"> <p>SIS</p> </div> <div data-bbox="657 1491 771 1516" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="824 1117 1331 1148" data-label="Section-Header"> <p>Slide 99 Areal production accurate</p> </div> <div data-bbox="824 1232 938 1264" data-label="Text"> <p>NOTES:</p> </div>

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, f (\pm SE)			
			P_s	P_{10}	α	β
ARC 78	13	50	1.50 (0.16)	1.42 (0.15)**	0.052 (0.003)**	0.0005 (0.0004)**
	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)
SLF 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)	0.0083 (0.0023)

Shade acclimation

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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



Figure 94. The outfall tunnel is located in the Cape Cod Bay area.



Figure 95. The outfall tunnel is located in the Cape Cod Bay area.

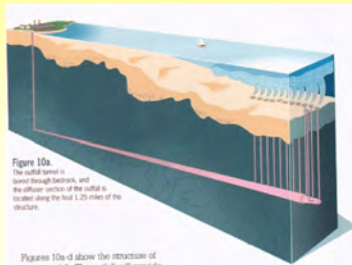


Figure 10a. The outfall tunnel is located in the Cape Cod Bay area, and the outfall section of the outfall is located along the first 1.25 miles of the structure.

Figures 10b-d show the structure of the outfall. The outfall will provide

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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

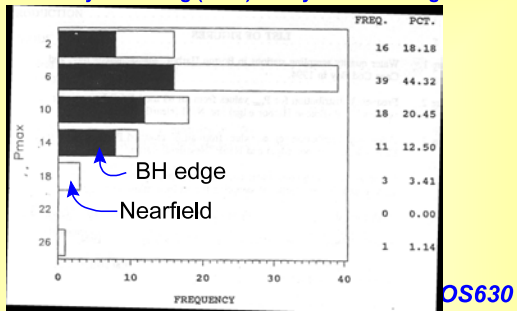
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Slide 103 Realistic P vs. I parameters

NOTES:

MA Bay P vs. I parameters

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



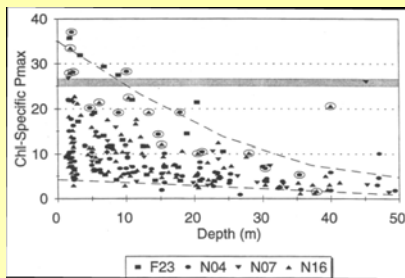
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Slide 104 MA Bay P vs. I parameters

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 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?

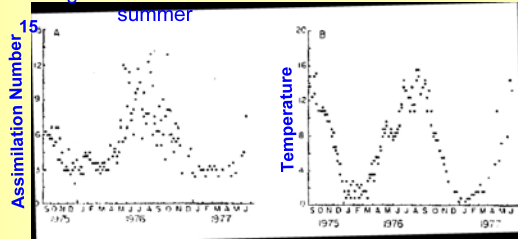
NOTES:

Seasonal variation in A.N.

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

Higher C:Chl *a* ratios in

summer



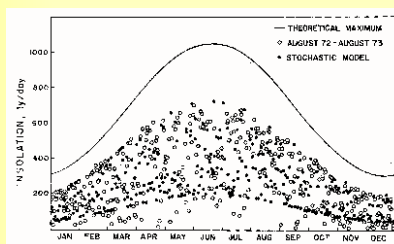
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Slide 107 Seasonal variation in A.N.

NOTES:

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

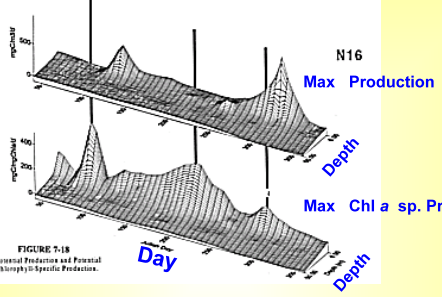
Rhode Island solar irradiance (from Kremer & Nixon)



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

NOTES:

<div data-bbox="240 163 760 541"> <h3>1995 MA Bay Production</h3> <p>Craig Taylor (WHOI) Model P vs. I approach</p>  <p>FIGURE 5-18 Potential Production and Potential Chlorophyll Specific Production.</p> </div>	<div data-bbox="824 132 1339 174"> <h3>Slide 109 1995 MA Bay Production</h3> </div> <div data-bbox="824 258 941 300"> <p>NOTES:</p> </div>
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<div data-bbox="285 170 734 214" data-label="Section-Header"> <h2>Pearson & Rosenberg vs. Hubbell</h2> </div> <div data-bbox="285 216 743 268" data-label="Text"> <p>Directional succession vs. Hubbell's neutral theory/ecological drift</p> </div> <div data-bbox="232 285 695 512" data-label="Image"> </div> <div data-bbox="654 514 769 541" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 134 1334 207" data-label="Section-Header"> <h2>Slide 112 Pearson & Rosenberg vs. Hubbell</h2> </div> <div data-bbox="816 296 940 327" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="302 693 714 732" data-label="Section-Header"> <h2>Pollution Case Study: EMAP</h2> </div> <div data-bbox="292 741 735 770" data-label="Text"> <p>Environmental monitoring and assessment</p> </div> <div data-bbox="280 770 659 1058" data-label="Figure"> </div> <div data-bbox="654 1039 769 1066" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 659 1395 699" data-label="Section-Header"> <h2>Slide 113 Pollution Case Study: EMAP</h2> </div> <div data-bbox="816 783 940 816" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="388 1182 612 1218" data-label="Section-Header"> <h2>Goals of EMAP</h2> </div> <div data-bbox="337 1228 670 1255" data-label="Text"> <p>>1918 benthic samples over 4 years</p> </div> <div data-bbox="245 1255 524 1619" data-label="List-Group"> <ul style="list-style-type: none"> Estimate the current status and trends in the condition of the nation's ecological resources with known confidence; Seek associations between human-induced stresses and ecological condition Provide periodic statistical summaries and interpretive reports on ecological status and trends </div> <div data-bbox="521 1318 766 1537" data-label="Figure"> </div>	<div data-bbox="816 1148 1206 1184" data-label="Section-Header"> <h2>Slide 114 Goals of EMAP</h2> </div> <div data-bbox="816 1270 940 1304" data-label="Text"> <p>NOTES:</p> </div>

Virginian province

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

[illegible]***EEOS630***

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

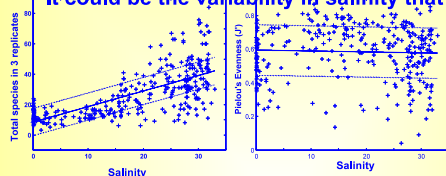
Slide 116 EMAP Methods used to create degradation indices

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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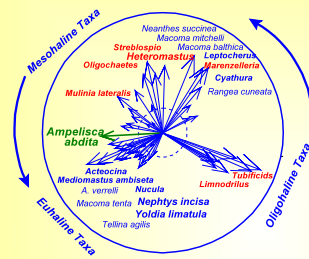
Slide 117 Salinity & diversity

NOTES:

<div data-bbox="276 168 764 212" data-label="Section-Header"> <h2>Trying to control for salinity</h2> </div> <div data-bbox="308 216 709 243" data-label="Text"> <p>Richness calculated on a relative scale</p> </div> <div data-bbox="258 241 769 543" data-label="Figure"> <p>A scatter plot showing Gleason's D (y-axis, 0 to 14) versus Salinity (x-axis, 0 to 35). The data points are represented by blue plus signs. A solid blue curve is fitted to the data, showing an initial increase in Gleason's D with salinity, followed by a plateau and then a slight decrease at higher salinities. The text 'EEOS630' is in the bottom right corner.</p> </div>	<div data-bbox="815 132 1386 172" data-label="Section-Header"> <h3>Slide 118 Trying to control for salinity</h3> </div> <div data-bbox="815 256 940 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="266 655 751 699" data-label="Section-Header"> <h2>Strobel et al. (1994) Benthic Index</h2> </div> <div data-bbox="319 701 698 745" data-label="Text"> <p>Gleason's D, Index, and spionids</p> </div> <div data-bbox="258 743 649 1001" data-label="Equation-Block"> $BI = \frac{1.389 + \% \text{ expected Gleason's D} + 41.5}{26.4}$ $- 0.651 \frac{\text{Normalized tubicol abundance} + 28.2}{119.5}$ $- 0.375 \frac{\text{Spionid abundance} + 20.0}{40.4}$ <p>where,</p> $\% \text{ expected Gleason's D} = \frac{\text{Gleason's D}}{\ln N}$ $(4.283 - 0.498 \ln \text{salinity} + 0.0542 \ln \text{salinity}^2 - 0.00103 \ln \text{salinity}^3) + 100$ <p>N = Number of species N = Number of individuals Normalized tubicol abundance = $\frac{\text{Tubicolids}}{5000} \times 10^6$</p> <p>BI < 0 INDICATES DEGRADED</p> <p>OS630</p> </div>	<div data-bbox="815 621 1375 693" data-label="Section-Header"> <h3>Slide 119 Strobel et al. (1994) Benthic Index</h3> </div> <div data-bbox="815 779 940 814" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="306 1180 693 1222" data-label="Section-Header"> <h2>The 1994 EMAP Index</h2> </div> <div data-bbox="241 1226 753 1346" data-label="Text"> <p>All of MA Bay would be degraded, which is not the case. Few spionid species indicate pollution; spionids are one of the most species-rich families of polychaetes, found at all depths in the ocean!</p> </div> <div data-bbox="282 1325 574 1526" data-label="Figure"> <p>A 3D surface plot showing the relationship between Spionids per m² (z-axis, 0 to 7000), Tubicolid oligochaetes per m² x 10³ (x-axis, 0 to 2), and Salinity (y-axis, 0 to 40). The surface is colored with a gradient from blue (low values) to red (high values). The text 'EEOS630' is in the bottom right corner.</p> </div>	<div data-bbox="815 1146 1305 1182" data-label="Section-Header"> <h3>Slide 120 The 1994 EMAP Index</h3> </div> <div data-bbox="815 1268 940 1304" data-label="Text"> <p>NOTES:</p> </div>

Salinity & species composition

Salinity confounds toxicity for toxic effects



Pollution indicators in red:
pollution indicators might just indicate low or variable salinity

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Slide 121 Salinity & species composition

NOTES:

Classification of EMAP sites

Using fits to log series (Gallagher's non-dimensional diversity)

Expected Number (E)	Corrected Observed Number (O)	Neutral Model Number (N)
1	3	7
2	10	10
3	2	4
4	6	6
5	4	1
6	5	5
7	1	1
8	1	1
9	1	1
10	1	1

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Slide 122 Classification of EMAP sites

NOTES:

Gallagher's conclusions from EMAP

- Salinity appears to be a major determinant of community structure in the Virginian province
- Salinity confounds the effects of sediment toxicity
- Departures from log-series (or Hubbell neutral model) expectation is a good indicator of toxicity or low dissolved oxygen in euhaline portions of estuaries. Species evenness underestimates or the EMAP biotic indices overestimate degradation in the oligo-and mesohaline portions of estuaries

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Slide 123 Gallagher's conclusions from EMAP

NOTES:

Benthic pollution indices

Being proposed worldwide

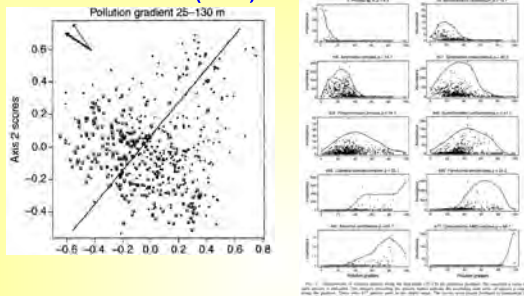
- EMAP approach: multivariate analysis based on impacted and reference areas
 - Impacted areas based on Long & Morgan ER-M, low O₂, or amphipod toxicity
 - Circular logic
- Infaunal benthic index, Chesapeake Bay, Community variables scaled on a 1, 2, 3 basis and a weighted average taken
- Borjas European 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

Table 2. Actual species positions (P's) using the pollution gradient for a selected subset of species.

Species	Shallow	Middle	Deep
<i>Amphipoda</i>	50.4	4.0	2.3
<i>Caprellidae</i>	48.7	8.9	12.2
<i>Corophiidae</i>	129.0	147.0	185.5
<i>Hydrulidae</i>	18.1	0.1	18.4
<i>Isopoda</i>	89.7	21.0	40.4
<i>Polychaeta</i>	2.9	1.1	18.9
<i>Scudidae</i>	47.1	1.8	89.5
<i>Amphipoda</i>	11.1	50.5	42.9
<i>Caprellidae</i>	4.1	36.8	1.0
<i>Corophiidae</i>	11.9	8.4	22.7
<i>Hydrulidae</i>	42.9	39.6	47.7
<i>Isopoda</i>	109.0	115.9	76.7
<i>Polychaeta</i>	18.7	70.9	91.7
<i>Scudidae</i>	36.3	29.5	20.5
<i>Amphipoda</i>	18.7	36.8	1.0
<i>Caprellidae</i>	4.1	36.8	1.0
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Southern California Benthic Response Index

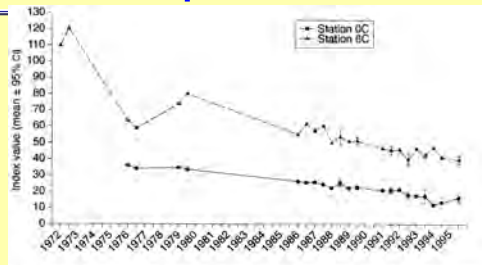


Fig. 7. Benthic Response Index values for stations on the Palos Verdes Shelf during 1972-1995.

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NOTES: