

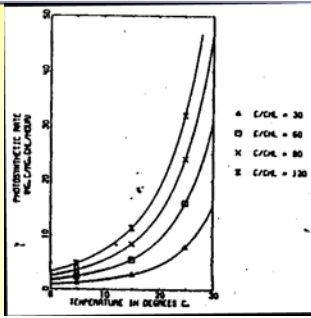
<div data-bbox="256 170 743 329" data-label="Section-Header"> <h2>Measuring Primary Production, P vs. I curves, shade acclimation, Model P vs. I approach, SSCM</h2> </div> <div data-bbox="402 344 594 371" data-label="Text"> <p>Class 17, 10/28/08</p> </div> <div data-bbox="656 516 769 543" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 134 1409 247" data-label="Section-Header"> <h3>Slide 1 Measuring Primary Production, P vs. I curves, shade acclimation, Model P vs. I approach, SSCM</h3> </div> <div data-bbox="816 331 938 365" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="376 732 634 768" data-label="Section-Header"> <h2>Wimba Sessions</h2> </div> <div data-bbox="365 777 646 806" data-label="Text"> <p>Tonight, Tuesday 10/28, 7 pm</p> </div> <div data-bbox="232 806 751 995" data-label="List-Group"> <ul style="list-style-type: none"> Quantitative community analysis using Matlab <ul style="list-style-type: none"> I've had to do rewriting of my Matlab m.files. 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. </div> <div data-bbox="656 1079 769 1104" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 699 1164 735" data-label="Section-Header"> <h3>Slide 2 Wimba Sessions</h3> </div> <div data-bbox="816 821 938 854" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="324 1220 699 1257" data-label="Section-Header"> <h2>Phytoplankton Readings</h2> </div> <div data-bbox="232 1287 769 1577" data-label="List-Group"> <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. <i>Fish. Bull.</i> 70: 1063-1085. Lorenzen, C. J. 1966. A method for the continuous measurement of <i>in vivo</i> chlorophyll concentration. <i>Deep-Sea Res.</i> 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. <i>Ann. Rev. Ecol. Syst.</i> 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. <i>Can. J. Fish. Aquat. Sci.</i> 42: 864-872. Falkowski, P. G. and J. A. Raven. 1997. <i>Aquatic Photosynthesis</i>. 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 data-bbox="816 1186 1279 1224" data-label="Section-Header"> <h3>Slide 3 Phytoplankton Readings</h3> </div> <div data-bbox="816 1308 938 1341" data-label="Text"> <p>NOTES:</p> </div>

<div data-bbox="324 165 701 207" data-label="Section-Header"> <h2>Phytoplankton Readings</h2> </div> <div data-bbox="360 214 662 239" data-label="Section-Header"> <h3>Nutrients and the spring bloom</h3> </div> <div data-bbox="233 233 753 504" data-label="List-Group"> <ul style="list-style-type: none"> • Nutrient effects: <ul style="list-style-type: none"> ▸ Chapter 10: Nitrogen cycle, nutrient limitation & chemostats ▸ Howarth, R. W. 1988. Nutrient limitation of net primary production in marine ecosystems. <i>Ann. Rev. Ecol. Syst.</i> 19: 89-110. • Spring bloom <ul style="list-style-type: none"> ▸ Chapter 11: Sverdrup's critical depth concept & the vernal phytoplankton ▸ Sverdrup, H. U. 1953. On conditions for the vernal blooming of phytoplankton. <i>J. Conseil perm. int. Explor. Mer.</i> 18: 287-295. ▸ Parsons, T. R., M. Takahashi, and B. Hargrave. 1984. <i>Biological Oceanographic Processes</i>. 3rd Edition. Pergamon Press, Oxford & New York. Pages 87-100. ▸ Townsend, D. W. and R. W. Spinrad. 1986. Early phytoplankton blooms in the Gulf of Maine. <i>Cont. Shelf Res.</i> 6: 515-529. </div>	<div data-bbox="815 132 1282 172" data-label="Section-Header"> <h2>Slide 4 Phytoplankton Readings</h2> </div> <div data-bbox="815 256 941 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="365 653 638 684" data-label="Section-Header"> <h2>The Gulf of Maine bloom</h2> </div> <div data-bbox="258 699 758 747" data-label="Text"> <p>Bill Hanlon (UMB M.Sc.): CZCS images, pre-bloom and bloom</p> </div> <div data-bbox="233 762 742 984" data-label="Image"> </div> <div data-bbox="652 999 773 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 621 1292 657" data-label="Section-Header"> <h2>Slide 5 The Gulf of Maine bloom</h2> </div> <div data-bbox="815 741 941 777" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="313 1142 709 1180" data-label="Section-Header"> <h2>Global Primary Production</h2> </div> <div data-bbox="246 1188 747 1255" data-label="Text"> <p>VGPM Estimates of Global Primary Production http://marine.rutgers.edu/opp/Production/Production1.html</p> </div> <div data-bbox="251 1251 719 1484" data-label="Figure"> </div> <div data-bbox="243 1482 456 1512" data-label="Text"> <p>October-December</p> </div> <div data-bbox="652 1486 773 1516" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 1108 1320 1148" data-label="Section-Header"> <h2>Slide 6 Global Primary Production</h2> </div> <div data-bbox="815 1230 941 1266" data-label="Text"> <p>NOTES:</p> </div>

<div data-bbox="292 163 743 231" data-label="Section-Header"> <h3>Estimating μ from Assimilation Number</h3> </div> <div data-bbox="261 243 599 546" data-label="Figure"> <p>P vs. I curves</p> <p>Chl a-specific Gross Production</p> <p>α, initial slope</p> <p>$P^0_{max} A$</p> <p>Assimilation Number</p> <p>$P^0_{max} B$</p> </div> <div data-bbox="618 512 730 537" data-label="Text"> <p>ECOS630</p> </div>	<div data-bbox="821 134 1370 205" data-label="Section-Header"> <h3>Slide 7 Estimating μ from Assimilation Number</h3> </div> <div data-bbox="821 296 940 327" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="264 688 763 758" data-label="Section-Header"> <h3>Assimilation number, C:Chl a, and μ</h3> </div> <div data-bbox="277 806 719 953" data-label="Equation-Block"> $\mu_{max} = \frac{\text{Assimilation number}}{C:Chl a} - \text{specific respiration.}$ $\mu = \frac{Chl a\text{-specific prod.}}{C:Chl a} - \text{specific respiration.}$ </div> <div data-bbox="657 1039 771 1066" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="821 659 1360 735" data-label="Section-Header"> <h3>Slide 8 Assimilation number, C:Chl a, and μ</h3> </div> <div data-bbox="821 821 940 852" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="324 1213 698 1283" data-label="Section-Header"> <h3>Assimilation number, μ & temperature</h3> </div> <div data-bbox="250 1291 756 1358" data-label="Text"> <p>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</p> </div> <div data-bbox="272 1354 526 1591" data-label="Figure"> <p>Specific Growth Rate (μ)</p> <p>Specific Assimilation Rate (P^0)</p> <p>Legend:</p> <ul style="list-style-type: none"> A C:Chl a = 30 B C:Chl a = 60 X C:Chl a = 90 E C:Chl a = 120 </div> <div data-bbox="618 1562 732 1589" data-label="Text"> <p>ECOS630</p> </div>	<div data-bbox="821 1184 1297 1260" data-label="Section-Header"> <h3>Slide 9 Assimilation number, μ & temperature</h3> </div> <div data-bbox="821 1346 940 1377" data-label="Text"> <p>NOTES:</p> </div>

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

Assimilation Number



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Slide 10 Maximum Chl-specific production, per hour, vs. Temperature

NOTES:

Excursis on grazing & the dilution method

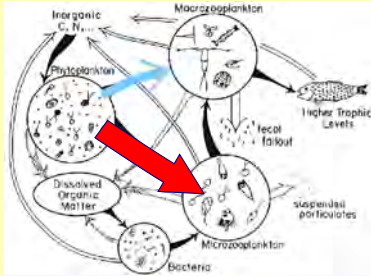
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Slide 11 Excursis on grazing & the dilution method

NOTES:

Nano- and microzooplankton are usually the dominant grazers

Protozoan grazing (and juvenile macrozooplankton)



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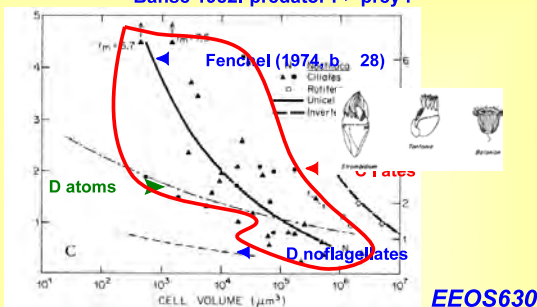
Slide 12 Nano- and microzooplankton are usually the dominant grazers

NOTES:

<div data-bbox="311 168 714 207" data-label="Section-Header"> <h3>Ciliates (microzooplankton)</h3> </div> <div data-bbox="266 216 764 302" data-label="Text"> <p>Aloricate & loricate (Tintinnid ciliates), Pierce & Turner Major predators on heterotrophic & autotrophic nanoplankton; usually not the major predators on picoplankton</p> </div> <div data-bbox="228 296 727 537" data-label="Image"> </div>	<div data-bbox="818 134 1341 174" data-label="Section-Header"> <h3>Slide 13 Ciliates (microzooplankton)</h3> </div> <div data-bbox="818 258 940 294" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="344 655 669 697" data-label="Section-Header"> <h3>Allometry of r_{\max} (μ_{\max})</h3> </div> <div data-bbox="428 703 568 730" data-label="Text"> <p>Fenchel (1974)</p> </div> <div data-bbox="311 724 672 808" data-label="Text"> <p>$\log_{10} r_{\max} = a - 0.275 \times \log_{10} \text{Weight}$ where a = -1.9367 for unicellular organisms = -1.6391 for heterotrophic organisms = -1.4 for heterotrophic organisms</p> </div> <div data-bbox="228 800 596 1029" data-label="Figure"> </div> <div data-bbox="574 816 758 947" data-label="Text"> <p>This relationship does not work well for phytoplankton, see Banse</p> </div> <div data-bbox="656 1003 771 1031" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="818 623 1320 663" data-label="Section-Header"> <h3>Slide 14 Allometry of r_{\max} (μ_{\max})</h3> </div> <div data-bbox="818 745 940 781" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="272 1144 755 1184" data-label="Section-Header"> <h3>Weak allometry in phytoplankton</h3> </div> <div data-bbox="328 1190 682 1220" data-label="Text"> <p>Banse (1982) Fig. 1. Slopes nearly flat</p> </div> <div data-bbox="311 1220 626 1514" data-label="Figure"> </div> <div data-bbox="656 1491 771 1518" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="818 1110 1213 1188" data-label="Section-Header"> <h3>Slide 15 Weak allometry in phytoplankton</h3> </div> <div data-bbox="818 1331 940 1367" data-label="Text"> <p>NOTES:</p> </div>

Ciliate $\mu \approx$ Phytoplankton μ

Banase 1982: predator $r >$ prey r

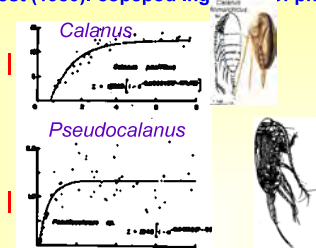


Slide 16 Ciliate $\mu \approx$ Phytoplankton μ

NOTES:

Reduced zooplankton ingestion of phytoplankton at low prey density

Frost (1980): copepod ingestion of phytoplankton



Phytoplankton concentration

EEOS630

Slide 17 Reduced zooplankton ingestion of phytoplankton at low prey density

NOTES:

Holling's (1959) Ingestion curves

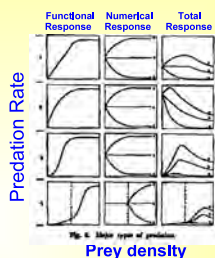
Type 1 (rectilinear), 2 (concave down), and 3 (S-shaped)
All have little predation at low prey density

• **Functional response:** How individual predators respond to increasing prey density

- 1 & 2 are usually statistically indistinguishable.
- Type 3 functional response: it has major evolutionary & ecological implications!

• **Numerical:** Increase in predator numbers in response to increasing prey

• **Total response:** combined effects of functional & numerical response



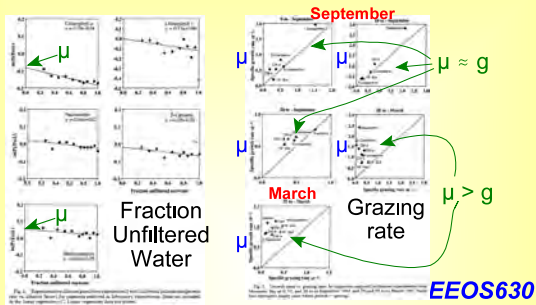
Slide 18 Holling's (1959) Ingestion curves

NOTES:

<div data-bbox="240 163 760 541"> <h3>Calanus pacificus ingestion</h3> <p>Frost (1972) fit rectilinear or Holling Type I curves</p> <p>Prey density EEOS630</p> </div>	<div data-bbox="824 132 1331 174"> <h3>Slide 19 Calanus pacificus ingestion</h3> </div> <div data-bbox="824 258 938 300"> <p>NOTES:</p> </div>
<div data-bbox="240 653 760 1031"> <h3>The dilution method</h3> <p>The most widely used way to estimate μ and grazing rate.</p> <p> $\frac{dC}{dt} = C(\mu - C - m)$ where, C = biomass [$gC m^{-3}$ or $gC m^{-2}$] μ = phytoplankton growth rate [$\frac{1}{time}$] C = phytoplankton grazing rate [$\frac{1}{time}$] m = phytoplankton mortality rate (eg., DQM loss, sinking) [$\frac{1}{time}$]. </p> <p>ECOS630</p> </div>	<div data-bbox="824 621 1237 663"> <h3>Slide 20 The dilution method</h3> </div> <div data-bbox="824 747 938 789"> <p>NOTES:</p> </div>
<div data-bbox="240 1142 760 1520"> <h3>Landry-Hassett dilution method</h3> <p>Redden et al. (2002) MEPS 226: 27-33</p> <p> $\mu = 0.527 d^{-1}$ $g = 0.654 d^{-1}$ $R_0 = 3.83 \mu g chl a l^{-1} d^{-1}$ </p> <p>Slope is grazing rate Feeding saturation μ Phytoplankton specific growth rate</p> <p>EEOS630</p> </div>	<div data-bbox="824 1110 1399 1152"> <h3>Slide 21 Landry-Hassett dilution method</h3> </div> <div data-bbox="824 1236 938 1278"> <p>NOTES:</p> </div>

Taxon-specific dilution method

Waterhouse & Welschmeyer (1995)

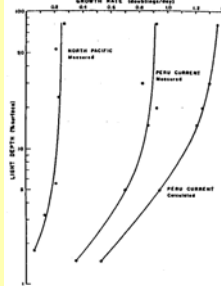


Slide 22 Taxon-specific dilution method

NOTES:

Specific growth rates in the field

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



N. Pacific gyre doubling times are closer to 5 hours than 5 days. They are close to the predicted Eppley μ_{max}

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Slide 23 Specific growth rates in the field

NOTES:

Typical growth rates

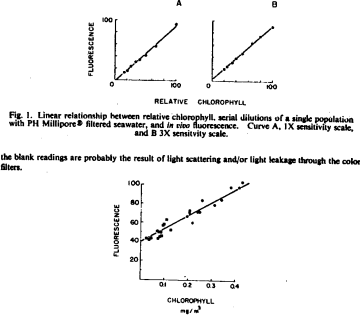
Gyre μ underestimated by Eppley (1972)

Area	Doubling time
Oligotrophic	
Sargasso sea	0.26
Blue water	0.45
Off California	0.37
Off Mexico	0.55
Off S. California July 1970	0.25-0.4
S. California (April-Sept. 67)	0.7-0.9
Eutrophic	
Peru current	0.7
Agulhas	0.67
Japan	0.75
Off NW Africa	1.0
Western Australia Sea	>1.0

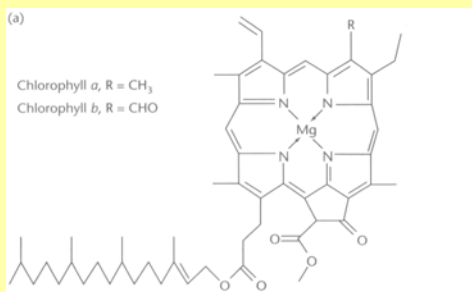
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Slide 24 Typical growth rates

NOTES:

<div> <div></div> <div> <div>In situ fluorescence, fluorescence yield & shade acclimation</div> <div>Lorenzen (1966)</div> </div> <div>EEOS630</div> </div>	<div>Slide 25 Typical growth rates</div> <div>NOTES:</div>																												
<div> <div></div> <div> <div>Typical growth rates</div> <div>Gyre μ underestimated by Eppley (1972)</div> <div> <table border="1"> <thead> <tr> <th>Area</th><th>Doubling time</th></tr> </thead> <tbody> <tr> <td colspan="2">Oligotrophic</td> </tr> <tr> <td>Sargasso sea</td><td>0.26</td></tr> <tr> <td>W. med.</td><td>0.45</td></tr> <tr> <td>CMF Caribbean</td><td>0.37</td></tr> <tr> <td>CMF Mexico</td><td>0.35</td></tr> <tr> <td>CMF S. California (July 1970)</td><td>0.25-0.4</td></tr> <tr> <td>S. California (April-Sept. 67)</td><td>0.7-1.0</td></tr> <tr> <td colspan="2">Fertile-rich</td> </tr> <tr> <td>Bay of Bengal</td><td>0.7</td></tr> <tr> <td>Agulh.</td><td>0.67</td></tr> <tr> <td>Java</td><td>0.75</td></tr> <tr> <td>CMF NW Africa</td><td>1.0</td></tr> <tr> <td>Western Australian</td><td>>1.0</td></tr> </tbody> </table> </div> <div>DS630</div> </div> </div>	Area	Doubling time	Oligotrophic		Sargasso sea	0.26	W. med.	0.45	CMF Caribbean	0.37	CMF Mexico	0.35	CMF S. California (July 1970)	0.25-0.4	S. California (April-Sept. 67)	0.7-1.0	Fertile-rich		Bay of Bengal	0.7	Agulh.	0.67	Java	0.75	CMF NW Africa	1.0	Western Australian	>1.0	<div>Slide 26 In situ fluorescence, fluorescence yield & shade acclimation</div> <div>NOTES:</div>
Area	Doubling time																												
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Western Australian	>1.0																												
<div> <div></div> <div> <div>Lorenzen (1966)</div> <div>Linear relation between Chl a & fluorescence</div> <div>  <p>Fig. 1. Linear relationship between relative chlorophyll <i>a</i> serial dilutions of a single population with PH Millipore filtered seawater, and in situ fluorescence. Curve A, IX sensitivity scale, and B, IX sensitivity scale.</p> <p>the blank readings are probably the result of light scattering and/or light leakage through the color filter.</p> </div> <div>DS630</div> </div> </div>	<div>Slide 27 Lorenzen (1966)</div> <div>NOTES:</div>																												

Chlorophyll *a*

**EEOS630**

Slide 28 Chlorophyll a

NOTES:

All phytoplankton have Chl a

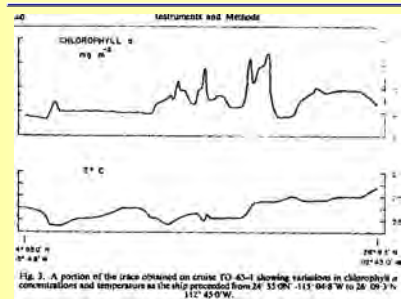
Miller Table 2.2

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Slide 29 All phytoplankton have Chl a

NOTES:

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

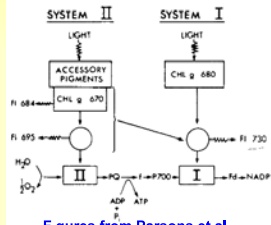
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Slide 30 In situ fluorometry allows an analysis of fine scale pattern in phytoplankton biomass, in real time

NOTES:

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)

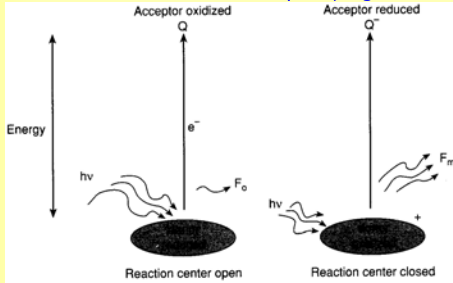
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Slide 31 Photosystem II is the source of most fluorescence

NOTES:

Fluorescence yield not constant: open & closed reaction centers

Falkowski & Raven (1997) Figure 3.11

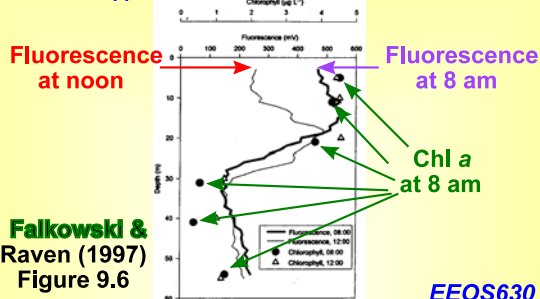


Slide 32 Fluorescence yield not constant: open & closed reaction centers

NOTES:

Fluorescence yield

An 'apparent' noon subsurface Chl a maximum



Falkowski & Raven (1997) Figure 9.6

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Slide 33 Fluorescence yield

NOTES:

<div data-bbox="235 163 776 541"> <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="824 134 1247 210"> <h3>Slide 34 How do you measure production?</h3> </div> <div data-bbox="824 294 938 327"> <p>NOTES:</p> </div>
<div data-bbox="235 695 776 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="824 665 1252 699"> <h3>Slide 35 Productivity methods</h3> </div> <div data-bbox="824 783 938 816"> <p>NOTES:</p> </div>
<div data-bbox="235 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="824 1148 1133 1182"> <h3>Slide 36 C-14 method</h3> </div> <div data-bbox="824 1266 938 1299"> <p>NOTES:</p> </div>

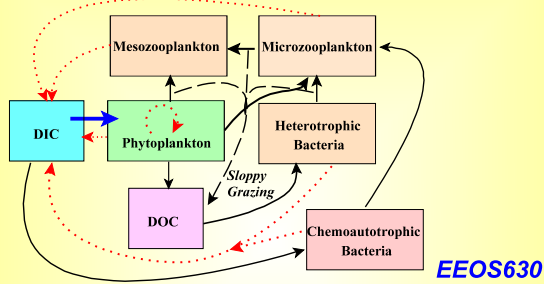
<div data-bbox="347 168 691 205" data-label="Section-Header"> <h3>Estimating productivity</h3> </div> <div data-bbox="245 243 753 443" data-label="List-Group"> <ul style="list-style-type: none"> • Incubate using <i>in situ</i> (preferred, but not possible with many licenses for ^{14}C) or simulated <i>in situ</i> 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. </div> <div data-bbox="664 514 769 541" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="826 132 1282 170" data-label="Section-Header"> <h3>Slide 37 Estimating productivity</h3> </div> <div data-bbox="826 256 938 289" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="347 657 691 695" data-label="Section-Header"> <h3>Estimating productivity</h3> </div> <div data-bbox="418 701 602 726" data-label="Text"> <p>After the Incubation</p> </div> <div data-bbox="245 732 753 1005" data-label="List-Group"> <ul style="list-style-type: none"> • Determine radioactivity of POC (& DOC) and the amount of Chl <i>a</i> in the sample bottles <ul style="list-style-type: none"> ▸ 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. </div> <div data-bbox="664 1003 769 1031" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="826 623 1282 661" data-label="Section-Header"> <h3>Slide 38 Estimating productivity</h3> </div> <div data-bbox="826 745 938 779" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="326 1144 703 1182" data-label="Section-Header"> <h3>Estimating ^{14}C productivity</h3> </div> <div data-bbox="315 1190 714 1218" data-label="Text"> <p>Note the isotopic discrimination factor (1.05)</p> </div> <div data-bbox="224 1234 760 1446" data-label="Equation-Block"> $\frac{\Delta C}{\Delta t} = 1.05 \frac{A^*}{I^* T}$ <p>where, A^* = activity of ^{14}C in sample POC (& DOC) $\left[\frac{\text{dpm}}{\text{sample}} \right]$.</p> <p>$I^*$ = specific activity of DIC in bottle $\left[\frac{\text{dpm}}{\text{g C DIC}} \right]$.</p> <p>$T$ = incubation time [h].</p> <p>1.05 = isotopic discrimination factor.</p> </div> <div data-bbox="664 1491 769 1518" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="826 1110 1334 1148" data-label="Section-Header"> <h3>Slide 39 Estimating ^{14}C productivity</h3> </div> <div data-bbox="826 1234 938 1268" data-label="Text"> <p>NOTES:</p> </div>



<div data-bbox="355 165 662 201" data-label="Section-Header"> <h3>C-14 method blanks</h3> </div> <div data-bbox="360 212 657 237" data-label="Text"> <p>What do the blanks represent?</p> </div> <div data-bbox="238 241 737 493" data-label="List-Group"> <ul style="list-style-type: none"> • The control ^{14}C uptake (time 0, DCMU control (stops electron transport in photosystem II, dark bottle) should be subtracted from A* • Chl <i>a</i> concentration to estimate of Chl <i>a</i>-specific production should be determined from the time-0 and ^{14}C-spiked bottle to obtain initial and final estimates of Chl <i>a</i> <ul style="list-style-type: none"> ▸ Rarely done on both initial & final </div> <div data-bbox="656 512 773 537" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="818 132 1235 165" data-label="Section-Header"> <h3>Slide 40 C-14 method blanks</h3> </div> <div data-bbox="818 254 941 287" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="266 653 745 690" data-label="Section-Header"> <h3>Hawaii Ocean Time-Series (HOT)</h3> </div> <div data-bbox="263 699 769 743" data-label="Text"> <p>http://hahana.soest.hawaii.edu/hot/protocols/protocols.html</p> </div> <div data-bbox="464 760 550 810" data-label="Image"> </div> <div data-bbox="464 861 550 919" data-label="Image"> </div> <div data-bbox="656 1001 773 1026" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="818 621 1323 693" data-label="Section-Header"> <h3>Slide 41 Hawaii Ocean Time-Series (HOT)</h3> </div> <div data-bbox="818 779 941 812" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="266 1180 745 1218" data-label="Section-Header"> <h3>Hawaii Ocean Time-Series (HOT)</h3> </div> <div data-bbox="263 1226 769 1270" data-label="Text"> <p>http://hahana.soest.hawaii.edu/hot/protocols/protocols.html</p> </div> <div data-bbox="464 1287 550 1337" data-label="Image"> </div> <div data-bbox="464 1388 550 1446" data-label="Image"> </div>	<div data-bbox="818 1146 1339 1182" data-label="Section-Header"> <h3>Slide 42 Gross primary Productivity</h3> </div> <div data-bbox="818 1268 941 1302" data-label="Text"> <p>NOTES:</p> </div>

Carbon flow in bottles (& the sea)

Are short incubations the best solution?
Photoacclimation a problem



Slide 43 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 44 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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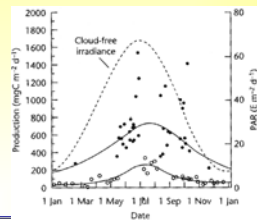
Slide 45 O₂ vs. ¹⁴C

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)



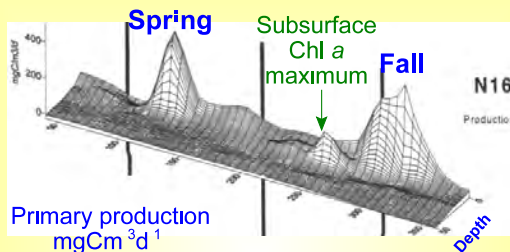
ECOS630

Slide 46 Primary production underestimated

NOTES:

1995 MA Bay seasonal production

Craig Taylor's data in MWRA 1995 water-column report



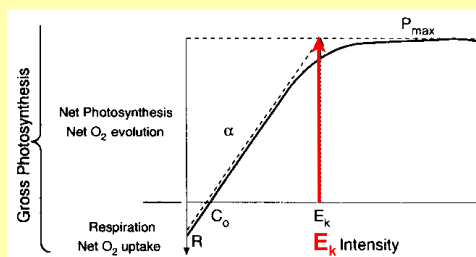
EEOS630

Slide 47 1995 MA Bay seasonal production

NOTES:

Falkowski & Raven P vs. E curves

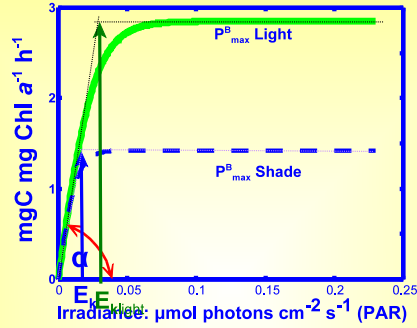
Falkowski & Raven (1997, p. 196, Fig 7.2)



EEOS630

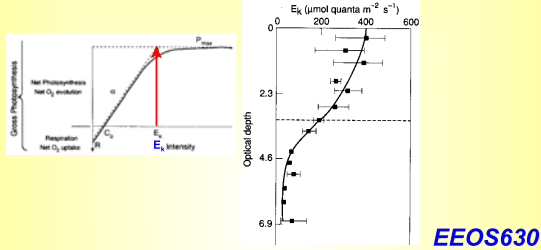
Slide 48 Falkowski & Raven P vs. E curves

NOTES:

<p>Chl a-specific gross productivity</p> 	<p>Slide 49</p> <p>NOTES:</p>
<p>PAR & units of light intensity</p> <ul style="list-style-type: none"> Parsons, Takahashi & Hargrave (1984) <ul style="list-style-type: none"> Parsons_1984.pdf on ereserve <ul style="list-style-type: none"> the direct link the ECOS630 reserves is: http://docutec.lib.umb.edu/eres/coursepass.aspx?cid=65 Password: deep 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). To convert to energy, 550nm light assumed <p><i>EEOS630</i></p>	<p>Slide 50 PAR & units of light intensity</p> <p>NOTES:</p>
<p>Converting units of light intensity</p> <ul style="list-style-type: none"> Ein=mol photon <ul style="list-style-type: none"> so the units of light should be in terms of a flux <ul style="list-style-type: none"> μEin cm⁻²s⁻¹ in the PAR PSR<PUR<PAR (Photosynthetically active radiation or Photo. available radiation wavelengths from 300 to 720 nm) Ein=6.02 * 10²³ quanta=2.86 x 10⁹/Angstroms g cal where Angstrom= 10⁻¹⁰ m 1 g cal =4.185 x 10⁷ ergs=4.185 watt*sec 1 g cal/cm² =1 langley For average wavelength of visible light 550 nm, 1 Ein=(2.86 x 10⁹/5500)g cal=52 x 10³ g cal <ul style="list-style-type: none"> note that Harrison and Platt use watts/m² <p><i>EEOS630</i></p>	<p>Slide 51 Converting units of light intensity</p> <p>NOTES:</p>

Photoacclimation: to light intensity & light quality

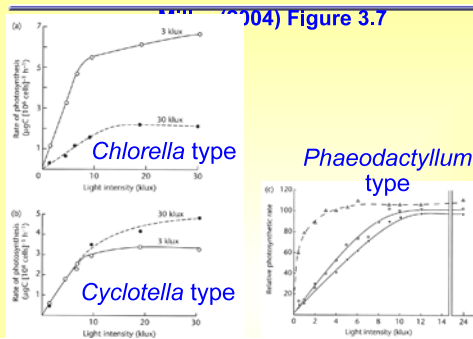
Falkowski & Raven Fig. 9.8;
Light intensity: $I_z = I_0 \cdot \exp(-K_d \cdot z)$; $\xi = K_d \cdot z = \text{optical depth}$



Slide 52 Photoacclimation: to light intensity & light quality

NOTES:

Types of shade acclimation

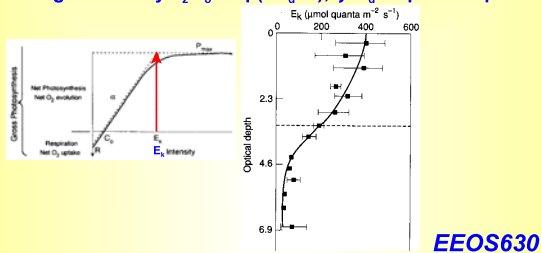


Slide 53 Photoacclimation: to light intensity & light quality

NOTES:

Photoacclimation: to light intensity & light quality

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



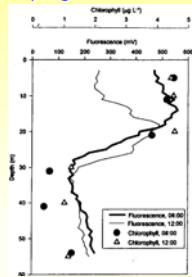
Slide 54 Types of shade acclimation

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 55 Measuring the Chl a profile

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 56 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 57 Shade acclimation (adaptation)

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.

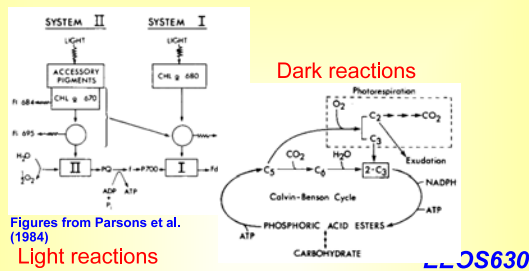
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Slide 58 Quenching

NOTES:

Gross primary productivity

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



Slide 59 Gross primary productivity

NOTES:

Jassby & Platt's (1976) Equation

Without photoinhibition

$$P^II = P_{II}^{max} \tanh\left(\frac{aI}{P_{II}^{max}}\right)$$

where P^II = C_{H_2O} -specific production $\left[\frac{mg C}{mg Chla \cdot h} \right]$

P_{II}^{max} = Max. rate at light saturation.

= Assimilation number

= the maximum photosynthetic rate at light saturation.

a = initial slope of the P vs. I curve.

= $\left[\frac{mg C}{mg Chla \cdot h \cdot (W m^{-2})} \right]$ or

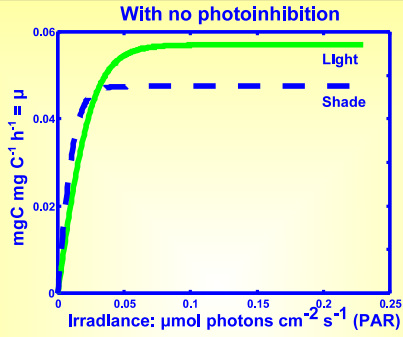
= $\left[\frac{mg C}{mg Chla \cdot h \cdot (E m^{-2} h^{-1})} \right]$

I = the light intensity of PAR $[W m^{-2}]$ or $[Einstein m^{-2} h^{-1}]$.

Slide 60 Jassby & Platt's (1976) Equation

NOTES:

Carbon-specific gross production

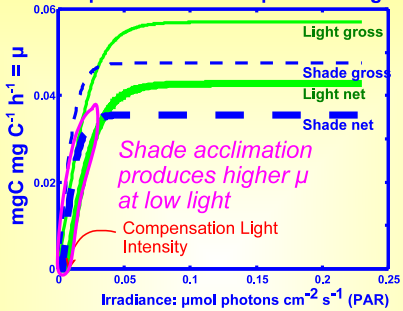


Slide 61 Carbon-specific gross production

NOTES:

Carbon-specific Production

Shade adaption \Rightarrow lower compensation light intensity

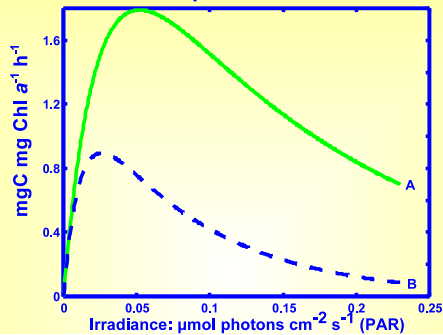


Slide 62 Carbon-specific Production

NOTES:

Chl a - specific Production

With photoinhibition



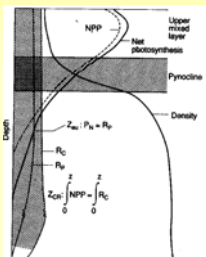
Slide 63 Chl a - specific Production

NOTES:

<div data-bbox="235 163 760 451"> <h3>Photoinhibition Equation</h3> <p>Jassby & Platt (1976)</p> $P^B = P_r^B \left(1 - e^{\left(\frac{-\alpha I}{P_r^B} \right)} \right) e^{\frac{-\beta I}{P_r^B}}$ <ul style="list-style-type: none"> α - Initial slope of P vs. I curve. β - Photoinhibition parameter. - Negative slope at high light intensity. P_r^B - Max. photo. rate without photoinhibition. </div> <div data-bbox="662 514 771 541"> <p>EEOS630</p> </div>	<div data-bbox="824 134 1305 170"> <h3>Slide 64 Photoinhibition Equation</h3> </div> <div data-bbox="824 258 938 289"> <p>NOTES:</p> </div>
<div data-bbox="235 653 776 1031"> <h3>Carbon-specific gross production</h3> <p>With photoinhibition</p> </div>	<div data-bbox="824 625 1414 661"> <h3>Slide 65 Carbon-specific gross production</h3> </div> <div data-bbox="824 745 938 777"> <p>NOTES:</p> </div>
<div data-bbox="235 1144 776 1522"> <h3>Vertical profiles of photosynthesis</h3> <p>Miller (2004) Fig. 3.9, May (●) & Sept (○)</p> </div>	<div data-bbox="824 1117 1218 1186"> <h3>Slide 66 Vertical profiles of photosynthesis</h3> </div> <div data-bbox="824 1270 938 1302"> <p>NOTES:</p> </div>

<div data-bbox="207 134 779 562"> <h3>Hourly Gross Productivity vs. Depth</h3> <p>Light Intensity: $I_z = I_o \cdot \exp(-K_d \cdot z)$; Beer's law $\xi = K_d \cdot z = \text{optical depth}$</p> <p>A) Early morning B) Mid Morning C) Noon</p> </div>	<div data-bbox="813 134 1414 212"> <h3>Slide 67 Hourly Gross Productivity vs. Depth</h3> </div> <div data-bbox="813 289 1414 331"> <p>NOTES:</p> </div>
<div data-bbox="207 667 779 1087"> <h3>Hourly Gross Productivity</h3> <p>With photoinhibition</p> <p>PAR Surface Beneath surface Lower photic zone</p> </div>	<div data-bbox="813 667 1414 709"> <h3>Slide 68 Hourly Gross Productivity</h3> </div> <div data-bbox="813 787 1414 829"> <p>NOTES:</p> </div>
<div data-bbox="207 1150 779 1591"> <h3>Cells are not stationary!</h3> <p>Left: position of cell; right: light history of cells at 2 depths</p> <p>No mixing ↓ High mixing</p> <p>EEOS630</p> </div>	<div data-bbox="813 1150 1414 1192"> <h3>Slide 69 Cells are not stationary!</h3> </div> <div data-bbox="813 1270 1414 1312"> <p>NOTES:</p> </div>

Euphotic zone ($\approx 1\%$ light depth), mixed layer depth, and critical depth



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Slide 70 Euphotic zone ($\approx 1\%$ light depth), mixed layer depth, and critical depth

NOTES:

Non-dimensional production

Behrenfeld & Falkowski (1997), Falkowski & Raven

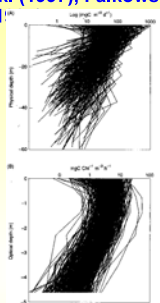
(1)

Production
vs. Depth

Meters

Chl-specific
P vs. Depth

Optical depth



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Slide 71 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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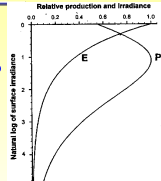
Slide 72 The model P vs I approach vs. SIS

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 estimates to obtain daily production
- Compare with SIS profiles



$$P(t) = P_B(I(t)) \cdot E$$

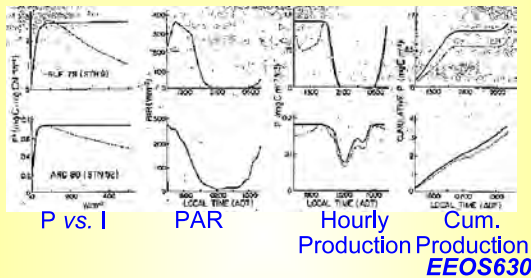
$$P_d = \sum_{i=1}^{24} P(t_i)$$

Slide 73 Model estimates of production

NOTES:

Model P vs. I approach

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

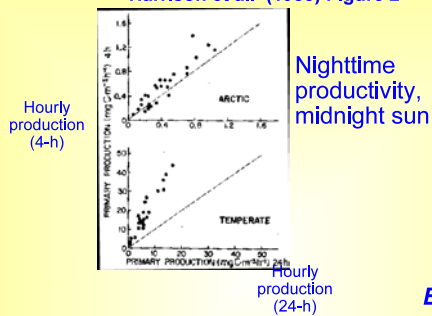


Slide 74 Model P vs. I approach

NOTES:

4- vs. 24-h incubations

Harrison *et al.* (1985) Figure 2



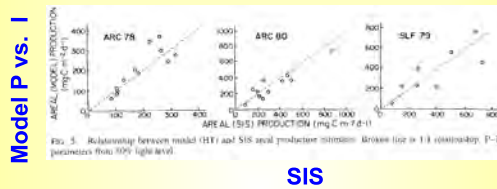
Slide 75 4- vs. 24-h incubations

NOTES:

<div data-bbox="240 163 760 548"> <h3>Harrison et al. (1985)</h3> <p>Fig. 3. P vs. I parameters from 50% Light Depth</p> <p>Model estimates higher at surface Photoinhibition in SIS incubators? Or loss of labeled POC to grazers in 24 h incubations?</p> <p>Solid line: SIS Broken: No β Dotted: With β</p> <p>EEOS630</p> </div>	<div data-bbox="824 132 1250 170"> <h3>Slide 76 Harrison et al. (1985)</h3> </div> <div data-bbox="824 254 938 291"> <p>NOTES:</p> </div>
<div data-bbox="240 646 792 1031"> <h3>Model P vs. I approach</h3> <p>Model estimates Not significantly different from SIS at high light intensities</p> <p>Model estimates LOWER at Low Light Levels: Photoacclimation??</p> <p>SIS approach</p> <p>EEOS630</p> </div>	<div data-bbox="824 621 935 659"> <h3>Slide 77</h3> </div> <div data-bbox="824 743 938 781"> <p>NOTES:</p> </div>
<div data-bbox="240 1136 792 1520"> <h3>Problems at low light intensities</h3> <p>The model underestimates SIS production.</p> <p>Model estimates LOWER at Low Light Levels: Photoacclimation or light quality effects?</p> <p>Using P vs. I parameters from the 1% light depth produced an even worse fit to the SIS estimates (p. 870)</p> <p>SIS More blue light</p> <p>EEOS630</p> </div>	<div data-bbox="824 1110 1393 1148"> <h3>Slide 78 Problems at low light intensities</h3> </div> <div data-bbox="824 1232 938 1270"> <p>NOTES:</p> </div>

Areal production accurate

Harrison et al. (1985) Fig. 5



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Slide 79 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: \bar{x} (\pm 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 (0.0003)
	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)	0.0063 (0.0023)

Shade acclimation

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Slide 80 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


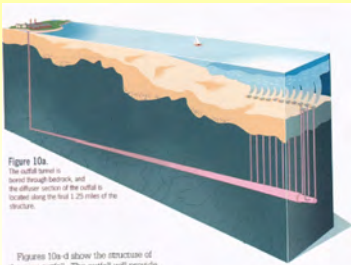
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Slide 81 Applications

NOTES:

The MA Bay Outfall

From MWRA State of the Harbor Report

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Slide 82 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

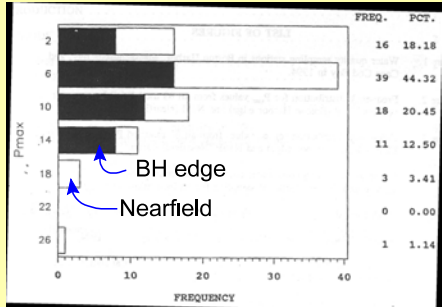
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Slide 83 Realistic P vs. I parameters

NOTES:

MA Bay P vs. I parameters

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



FREQ.	PCT.
16	10.18
39	44.32
18	20.45
11	12.50
3	3.41
0	0.00
1	1.14

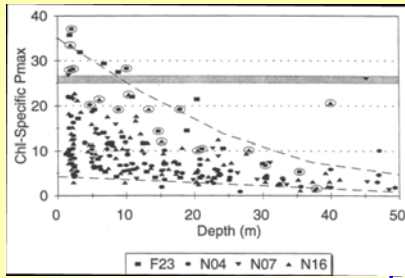
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Slide 84 MA Bay P vs. I parameters

NOTES:

MA Bay assimilation numbers

Including Falkowski's theoretical maximum= 25



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Slide 85 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 86 Why might assimilation numbers be too high?

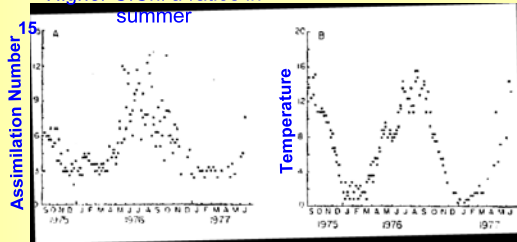
NOTES:

Seasonal variation in A.N.

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

Higher C:Chl *a* ratios in

summer



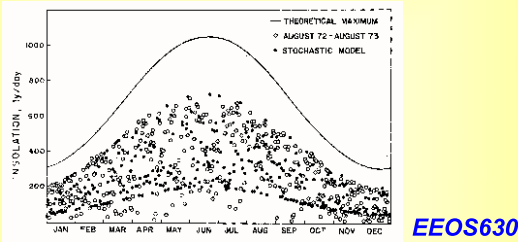
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Slide 87 Seasonal variation in A.N.

NOTES:

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

Rhode Island solar irradiance (from Kremer & Nixon)

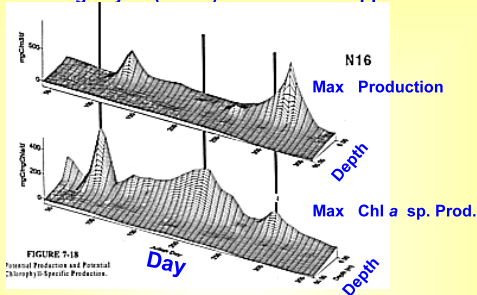


Slide 88 Model P vs. I approach: can account for differences in irradiance (due to clouds)

NOTES:

1995 MA Bay Production

Craig Taylor (WHOI) Model P vs. I approach

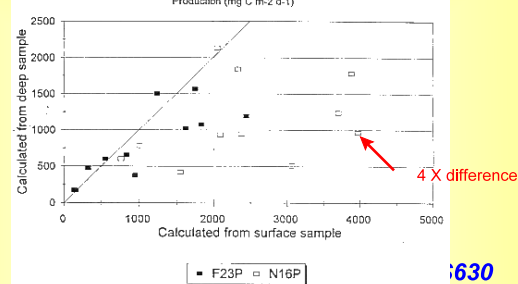


Slide 89 1995 MA Bay Production

NOTES:

2 different production estimates

Using deep vs. surface P vs. I parameter estimates
(Kelly & Doering MWRA 95-19)



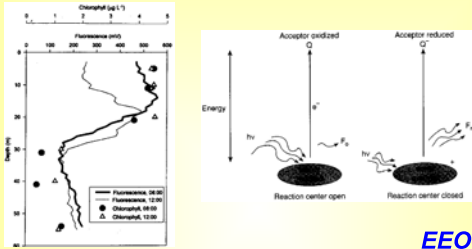
Slide 90 2 different production estimates

NOTES:

<div data-bbox="269 233 768 315" data-label="Section-Header"> <h2>Excursis on the Subsurface Chlorophyll maxima</h2> </div> <div data-bbox="248 323 753 447" data-label="Text"> <p>Prevalent in Gulf of Maine (and MA Bay) from April through early September, many coastal zones (including the Washington-Oregon-California shelf) & oligotrophic gyres (called the Typical Tropical Structure)</p> </div> <div data-bbox="654 512 773 541" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 132 1396 172" data-label="Section-Header"> <h3>Slide 91 2 different production estimates</h3> </div> <div data-bbox="816 256 941 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="280 653 751 693" data-label="Section-Header"> <h2>2 different production estimates</h2> </div> <div data-bbox="280 701 740 749" data-label="Text"> <p>Using deep vs. surface P vs. I paramter estimates (Kelly & Doering MWRA 95-19)</p> </div> <div data-bbox="285 739 794 1029" data-label="Figure"> </div> <div data-bbox="719 1003 773 1029" data-label="Text"> <p>630</p> </div>	<div data-bbox="816 621 1331 699" data-label="Section-Header"> <h3>Slide 92 Excursis on the Subsurface Chlorophyll maxima</h3> </div> <div data-bbox="816 781 941 816" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="264 1180 758 1220" data-label="Section-Header"> <h2>MA Bay subsurface Chl a maxima</h2> </div> <div data-bbox="410 1228 586 1255" data-label="Text"> <p>Haury et al. (1983)</p> </div> <div data-bbox="248 1228 703 1549" data-label="Figure"> </div> <div data-bbox="696 1526 773 1554" data-label="Text"> <p>JS630</p> </div>	<div data-bbox="816 1148 1312 1220" data-label="Section-Header"> <h3>Slide 93 MA Bay subsurface Chl a maxima</h3> </div> <div data-bbox="816 1304 941 1341" data-label="Text"> <p>NOTES:</p> </div>

As noted by Cullen, SSFluorescence not necessarily a SSChl max nor SSCarbon max

Falkowski & Raven Figure 9.6



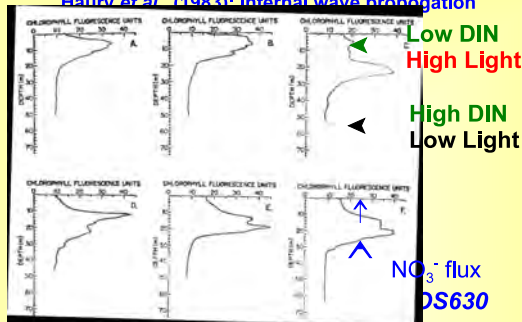
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Slide 94 As noted by Cullen, SSFluorescence not necessarily a SSChl max nor SSCarbon max

NOTES:

Internal waves and MA Bay SSCM

Haury et al. (1983): internal wave propagation

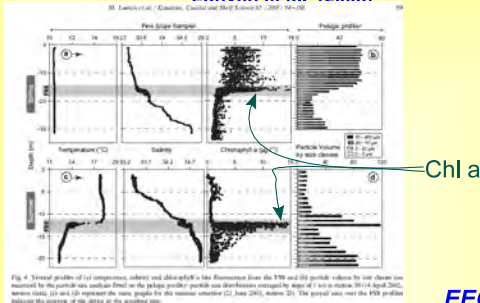


Slide 95 Internal waves and MA Bay SSCM

NOTES:

Fine structure of the SSCM

Lunven et al. (2005)



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Slide 96 Fine structure of the SSCM

NOTES:

Fine structure of the SSCM

Lunven et al. (2005)

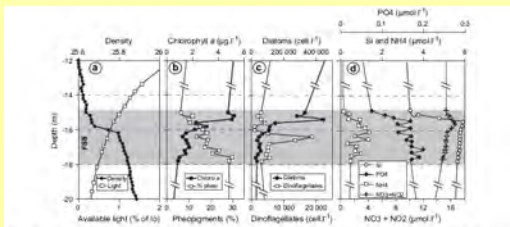


Fig. 5. Vertical profiles of (a) density and available light, (b) chlorophyll *a* and phaeopigment, (c) diatoms and dinoflagellates, (d) dissolved inorganic Si, NO₃⁻, NH₄⁺, NO₂⁻ (summed the density gradient on 14 April 2003). (a) – vertical density; (b) (c) and (d) – chemical and biological analyses on the samples obtained by the FSS.

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Slide 97 Fine structure of the SSCM

NOTES:

Fine structure of the SSCM

Lunven et al. (2005)

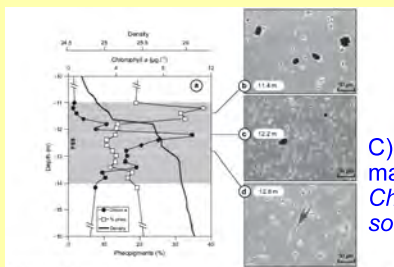


Fig. 7. Vertical profiles of density, chlorophyll *a* and phaeopigment (a) around the pycnocline and examples of microscopic observation from samples taken around the pycnocline peak (b) (c) (d) on 27 June 2003. The blue lines are isopycnals; the pycnocline and was diagnosed by collapse of Chaetoceros count (b). The water above the pycnocline mostly contained individual diatoms and the maximum number of Chaetoceros was observed in the layer (b). Shaded regions, surface diatoms and dinoflagellates were observed below the maximum of chlorophyll *a* (b).

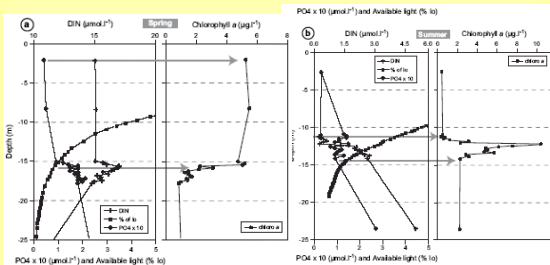
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Slide 98 Fine structure of the SSCM

NOTES:

Fine structure of the SSCM

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



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Slide 99 Fine structure of the SSCM

NOTES: