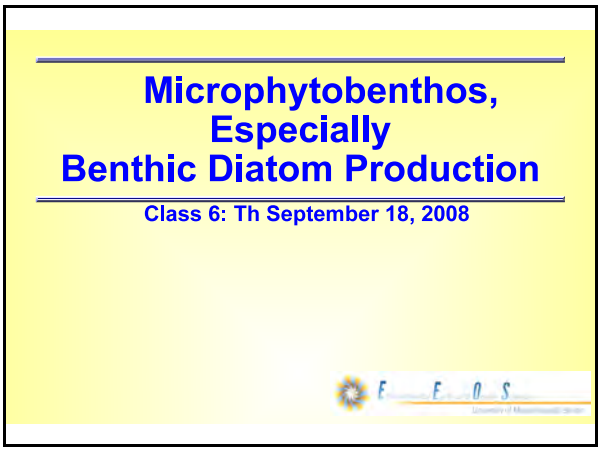
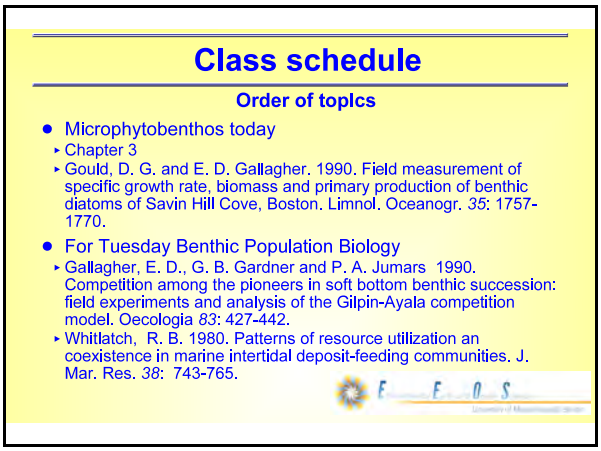


Slide 1 Microphytobenthos, Especially

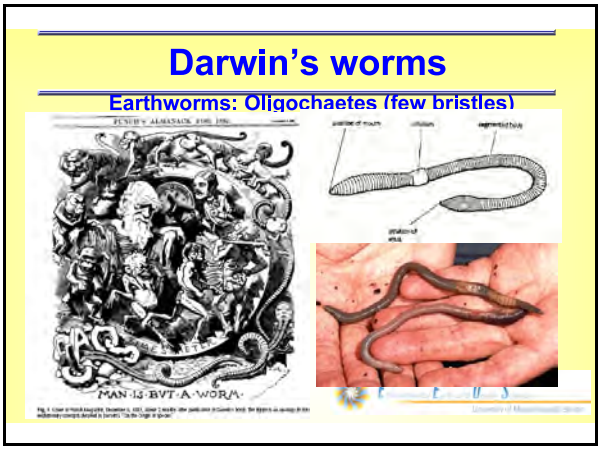
Benthic Diatom Production

NOTES:



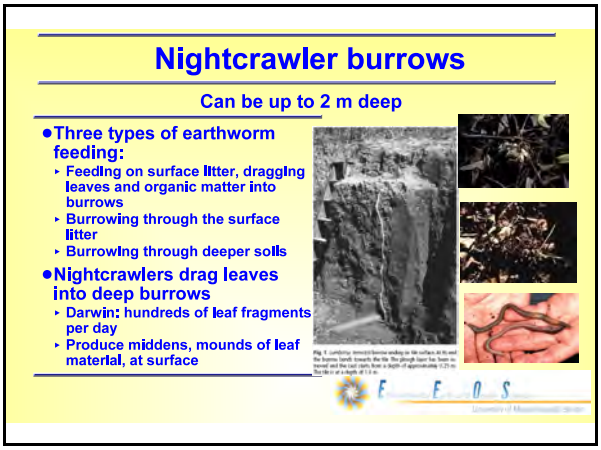
Slide 2 Class schedule

NOTES:



Slide 3 Darwin's worms

NOTES:



Slide 4 Nightcrawler burrows

NOTES:

Slide 5

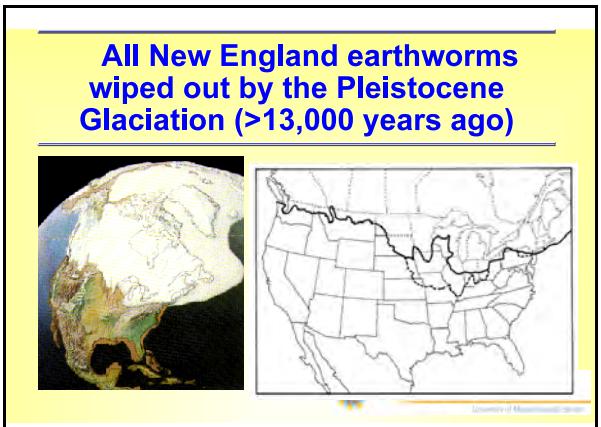
NOTES:

Slide 6 Are earthworms harmful?

NOTES:

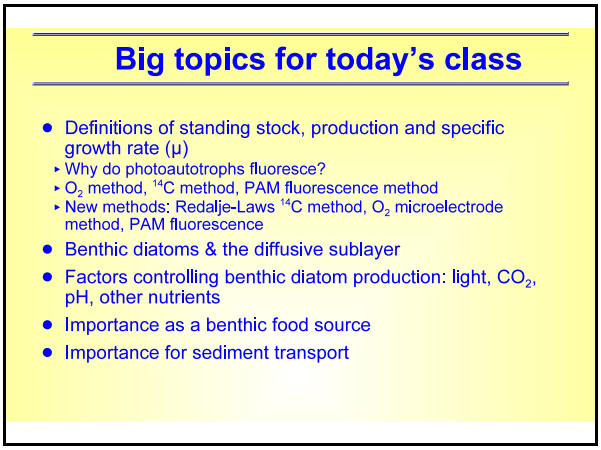
Slide 7 Don't release earthworms into forests!

NOTES:



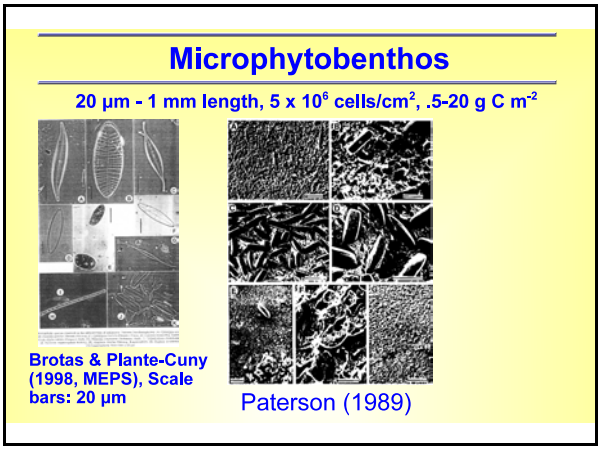
Slide 8 All New England earthworms wiped out by the Pleistocene Glaciation (>13,000 years ago)

NOTES:



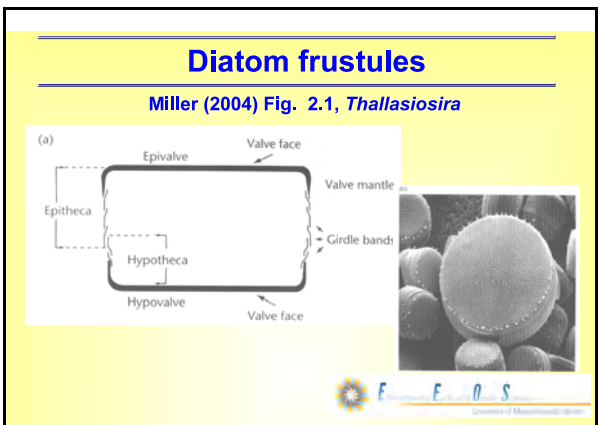
Slide 9 Big topics for today's class

NOTES:



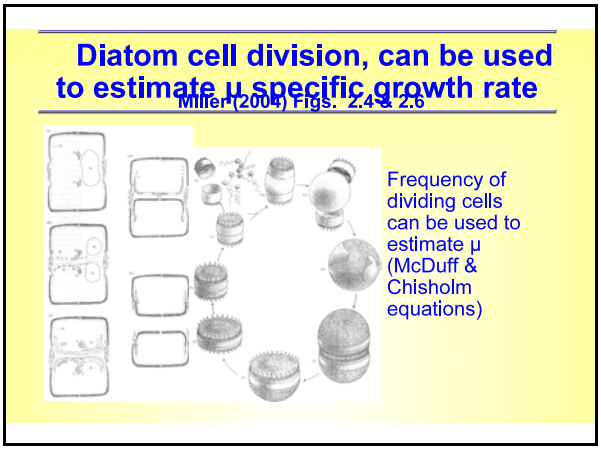
Slide 10 Microphytobenthos

NOTES:



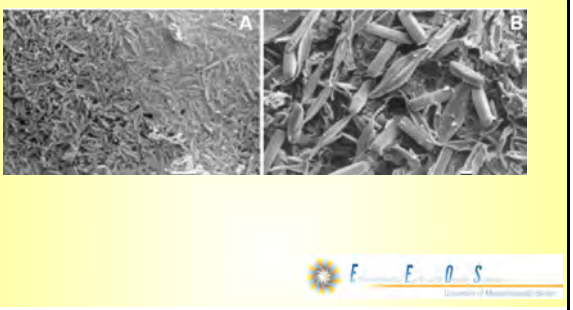
Slide 11 Diatom frustules

NOTES:



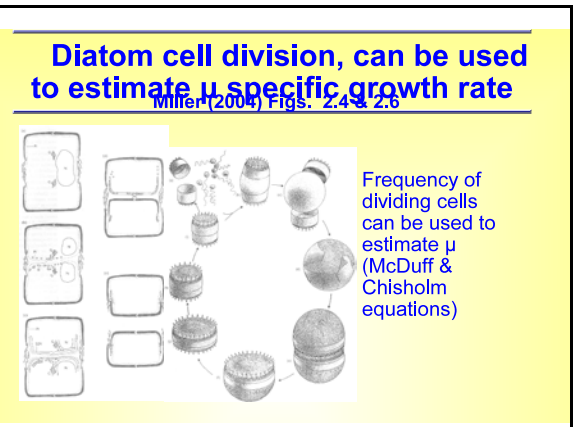
Slide 12 Diatom cell division, can be used to estimate µ specific growth rate

NOTES:



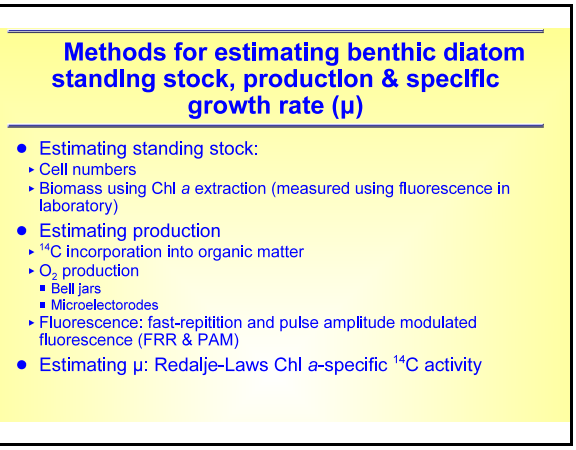
Slide 13 Diatom cell division, can be used to estimate µ specific growth rate

NOTES:



Slide 14 Microphytobenthic motility

NOTES:

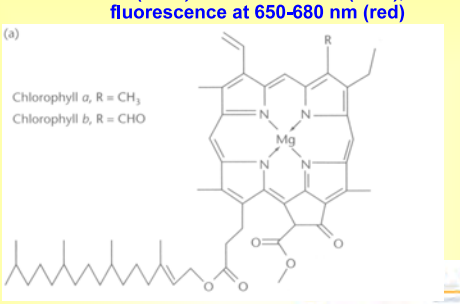


Slide 15 Methods for estimating benthic diatom standing stock, production & specific growth rate (µ)

NOTES:

Chlorophyll *a* fluorescence

Lorenzen (1966) excite at 430 nm (blue), measure fluorescence at 650-680 nm (red)

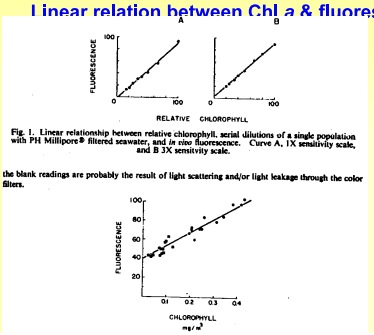


Slide 16 Chlorophyll a fluorescence

NOTES:

Lorenzen (1966)

Linear relation between Chl *a* & fluorescence



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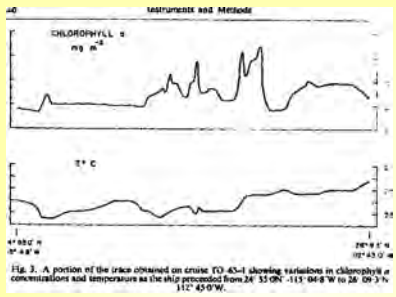
Slide 17 Lorenzen (1966)

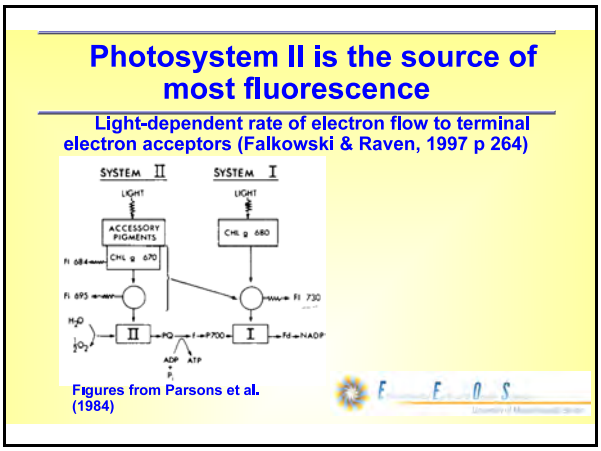
NOTES:

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

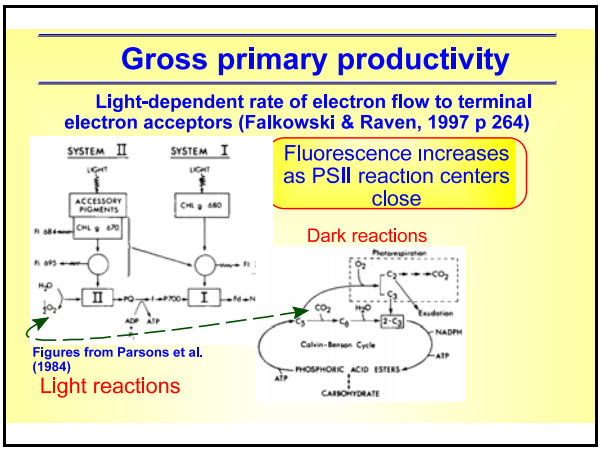


Slide 18 In situ fluorometry allows an analysis of fine scale pattern in phytoplankton biomass, in real time

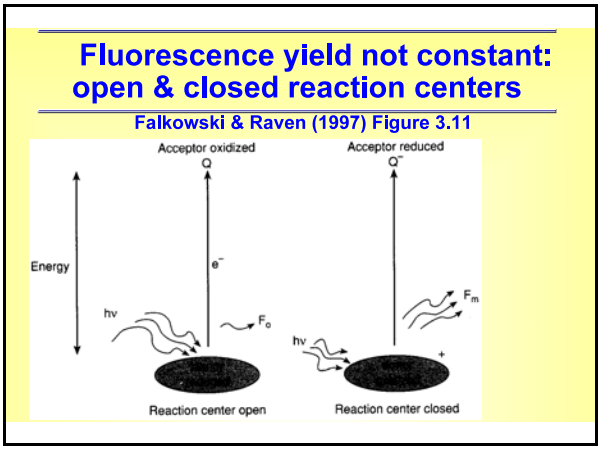
NOTES:



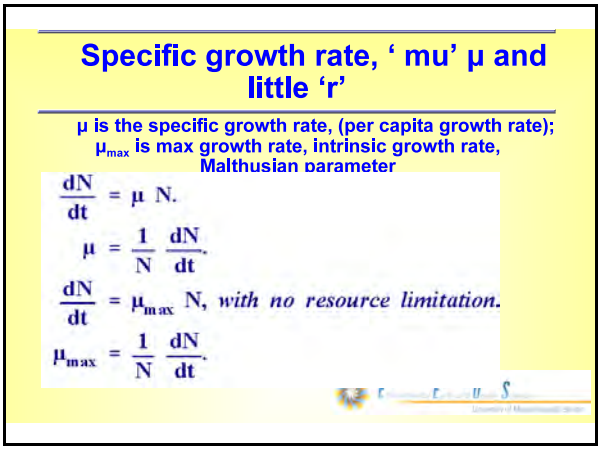
Slide 19 Photosystem II is the source of most fluorescence
NOTES:



Slide 20 Gross primary productivity
NOTES:

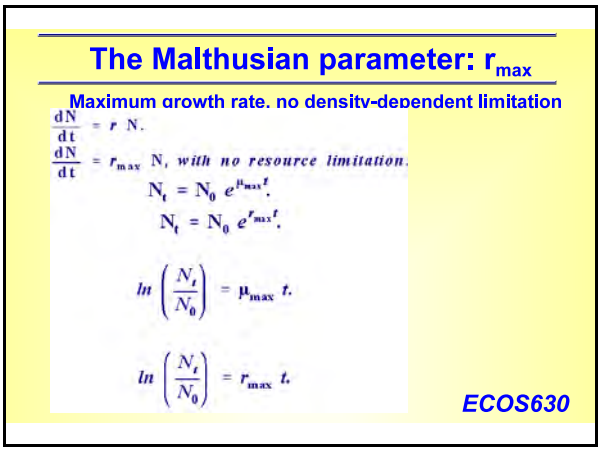


Slide 21 Fluorescence yield not constant: open & closed reaction centers
NOTES:



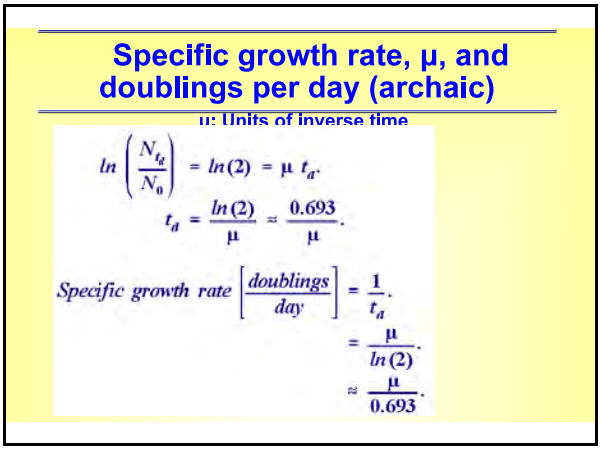
Slide 22 Specific growth rate, ' mu' μ and little 'r'

NOTES:



Slide 23 The Malthusian parameter: rmax

NOTES:



Slide 24 Specific growth rate, μ, and doublings per day (archaic)

NOTES:

Biomass-specific production, μ

Estimating biomass, in carbon, the key problem in estimating μ. Estimating photoautotropic Carbon:Chl *a* ratio difficult

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

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Slide 25 Biomass-specific production, μ

NOTES:

Bell jars used to estimate O_2 flux

Uthicke & Klumpp (1998), MEPS

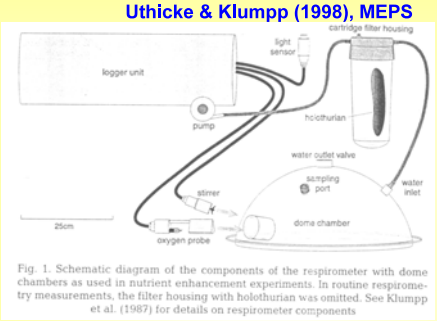


Fig. 1. Schematic diagram of the components of the respirometer with dome chambers as used in nutrient enhancement experiments. In routine respirometry measurements, the filter housing with holothurian was omitted. See Klumpp et al. (1987) for details on respirometer components

Slide 26 Bell jars used to estimate O2 flux

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 heterotrophic respiration create large problems

Slide 27 The oxygen method

NOTES:

O_2 vs. ^{14}C

$$n\,CO_2 \xrightarrow{light} \underset{1}{Particulate\ organic\ C} + \underset{2}{Dissolved\ organic\ C} + \underset{3}{n\,O_2}$$

O_2 method measures O_2 production, = measuring 1 + 2.
^{14}C method measures only 1 if only filtered POC is counted.

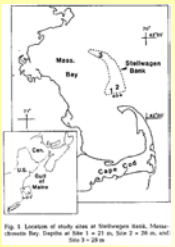
- In theory, the O_2 method can estimate gross and net production
  - Increase in light bottle is net
  - Dark bottle decrease is respiration
  - Light-dark = gross production
- The ^{14}C activity of dissolved organic matter should be determined

Slide 28 O2 vs. 14C

NOTES:

O_2 flux used to measure Stellwagen Bank microphytobenthic production

Cahoon et al. 1993 Figure 1 & Conclusion



The importance of benthic microalgal production at Stellwagen Bank derives from the apparent ability of the distinctly benthic microalgal assemblage there to sustain significant production at light levels consistently below 1 % surface incident PPFD. If this ability is common, benthic microalgae may be widely distributed in continental shelf habitats. Benthic habitats underlying clearer, less productive water columns than at Stellwagen Bank may support relatively higher benthic microalgal production. Benthic microalgal production may therefore be a significant, if infrequently considered, fraction of total production in continental shelf ecosystems.

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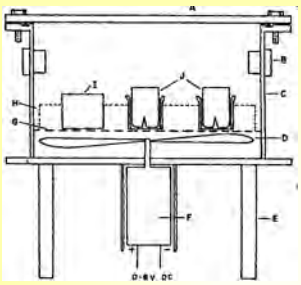
Slide 29 O2 flux used to measure Stellwagen Bank microphytobenthic production

NOTES:

Sub-aerial production

Whitney & Darley's surveys of Georgia Salt marshes



Georgia salt marshes Highest benthic diatom production ever measured! diffusive sublayer thickness < 10 µm

Slide 30 Sub-aerial production

NOTES:

Redalje-Laws Chl *a* labelling

HPLC separation of Chl *a* to determine ^{14}C activity
Gould & Gallagher (1990)

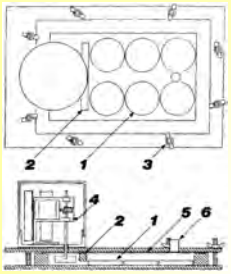


Table 1. Definitions and equations used in the ^{14}C-Chl *a*-labeling technique (adapted for sediments from Redalje and Laws 1981; Redalje 1983; Welschmeyer and Lorenzen 1984).

A^*	Activity of total particulate matter, dpm core^{-1}
R^*	Specific activity of C in Chl *a* molecule, dpm μg^{-1} C
I^*	Specific activity of DIC, dpm μg^{-1} C
ΔC	C fixed during the incubation, μg C core^{-1} incubation^{-1} converted to mg C m^{-2} h^{-1}
Cp	Microalgal C present at the end of the incubation, μg C core^{-1} converted to g C cm^{-3}
μ	Specific growth rate per day assuming 12 h growth per day
1.05	Factor to account for isotope discrimination
t	Duration of incubation in hours

Equations:

$$\Delta C = 1.05[(A^*/I^*) \times (1/t)] \quad (1)$$

$$Cp = A^*/R^* \quad (2)$$

$$\mu = \frac{-\ln[1 - (1.05\,R^* \times I^*)]}{t} \times 12 \quad (3)$$

Slide 31 Redalje-Laws Chl a labelling

NOTES:

Gould & Gallagher (1990)

Estimates of diatom standing stock, μ, and production

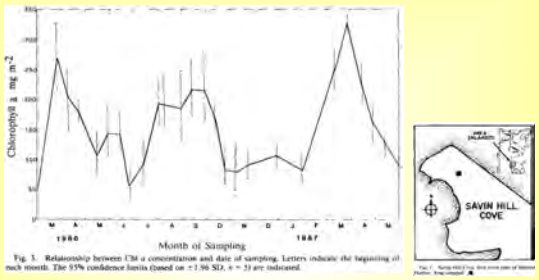


Fig. 3. Relationship between Chl *a* concentration and date of sampling. Letters indicate the beginning of each month. The 95% confidence limits (based on ±1.96 SE, $n = 3$) are indicated.

Slide 32 Gould & Gallagher (1990)

NOTES:

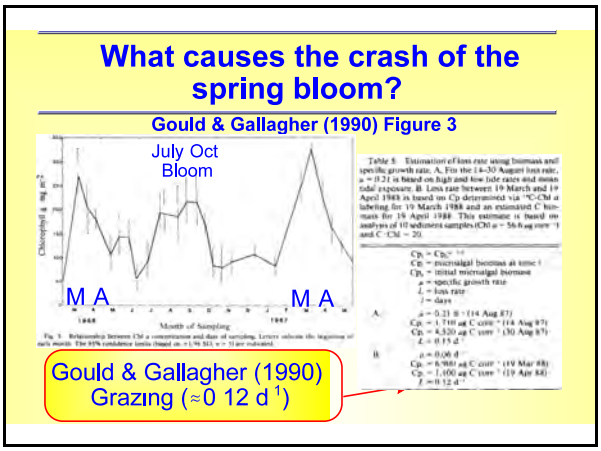
Table 4. Results of field incubations done in Savin Hill Cove and laboratory incubation of Duxbury Beach sediment. C:Chl ratio is based on Cp calculated via ^{14}C-Chl *a* labeling and on fluorometrically determined Chl *a* values. SD in parentheses. Spearman's rank correlation coefficients calculated for Savin Hill Cove data as follows: C:Chl ratio and μ, $r_s = -0.94$, $P < 0.01$; Cp and C:Chl, $r_s = 0.89$, $P < 0.05$; Cp and μ, $r_s = -0.78$, $P < 0.05$. Units given in Table 1. Temperature (°C) in the incubation chamber at the end of the incubation—T; doubling time (d)—DT.

	T	t	I^* (×10^3)	I^* (×10^3)	R^*	ΔC	Cp (×10^3)	μ	DT	C:Chl
Savin Hill Cove										
14 Aug 87										
Low tide	31	2.75	8.35(1.85)	8.56	489(31)	70(15)	3.23(0.98)	0.27(0.02)	2.6	21.3
30 Aug 87										
High tide	20	3.0	15.62(3.42)	7.60	346(11)	136(34)	8.51(2.21)	0.18(0.01)	3.9	32.5
11 Sep 87										
Low tide	28	3.0	3.76(0.41)	5.62	321(20)	44(03)	2.21(0.42)	0.24(0.02)	2.0	18.7
6 Mar 88										
Low/high	5	10.0	48.38(6.95)	8.59	593(06)	112(16)	15.40(0.36)	0.09(0.01)	7.7	54.4
19 Mar 88										
Low/high	7	11.0	28.49(5.43)	7.86	413(27)	65(13)	13.00(3.57)	0.06(0.01)	11.6	60.4
4 Jul 88										
Low tide	30	2.5	7.13(0.56)	5.75	192(08)	98(08)	6.19(0.89)	0.17(0.01)	3.6	42.5
4 Jul 88										
Low/high	20	10.5	18.55(0.20)	5.08	608(100)	69(04)	5.75(1.21)	0.15(0.03)	4.6	
Duxbury Beach										
7 Aug 88										
Lab	26	3.0	5.84(0.81)	7.14	95(09)	54(07)	11.60(3.00)	0.06(0.01)	11.6	55.4

Doubling time = ln(2)/μ≈0.69/μ

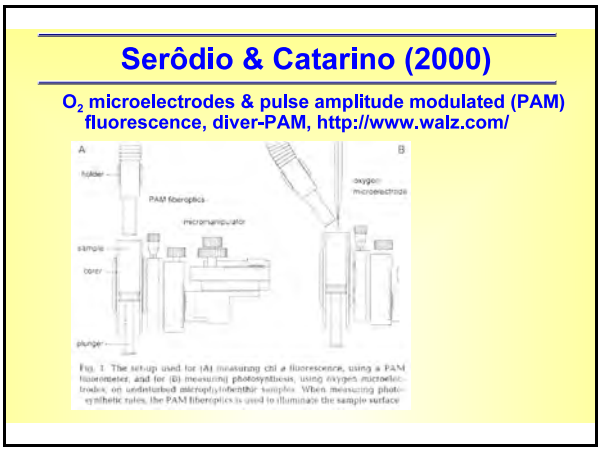
Slide 33

NOTES:



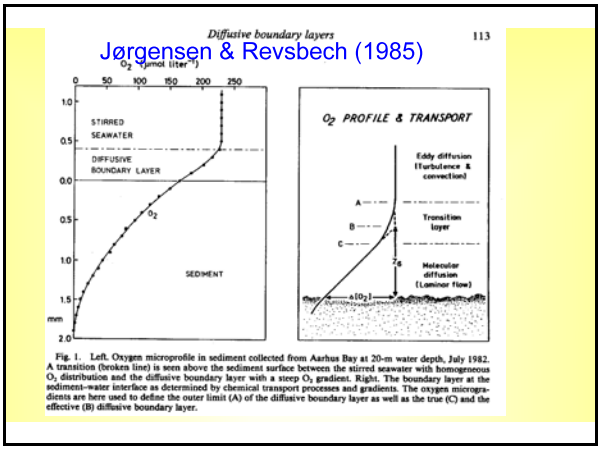
Slide 34 What causes the crash of the spring bloom?

NOTES:



Slide 35 Serôdio & Catarino (2000)

NOTES:



Slide 36

NOTES:

Benthic boundaries

- ***Ekman layer***
- ***Log layer***
- ***Viscous sublayer***
- ***Molecular diffusive sublayers***
- **Ox c zone**
- **Ox d zed zone**
- **Sulfidogenic zone**
- **Methanogenic zone**

Slide 37

NOTES:

Thicknesses of benthic boundaries

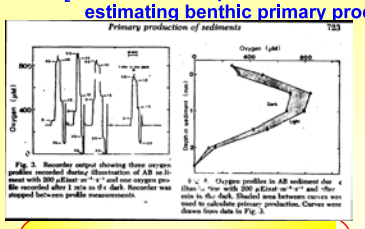
Parameter	Deep-Sea	Shelf	Description
U (cm/s)	3	30	average water velocity
U_* (cm/s), boundary shear velocity	0.1	1	Boundary shear velocity (the square root of boundary shear stress/seawater density)
ν (cm^2/s)	2	200	characteristic eddy viscosity
z_E (cm)	500	5000	Ekman depth
z (cm)	100	1000	log layer thickness
z_ν (cm)	2	0.2 to 1	viscous sublayer thickness
z_δ (cm)	0.2	0.02-0.1	diffusive sublayer thickness $z_\delta = z_\nu / [Sc^{1/3}]$, where Sc=Schmidt number $= \nu / \delta \approx 600$ for O_2 or CO_2 δ = molecular diffusivity

Slide 38 Thicknesses of benthic boundaries

NOTES:

Revsbech & Jørgensen (1983)

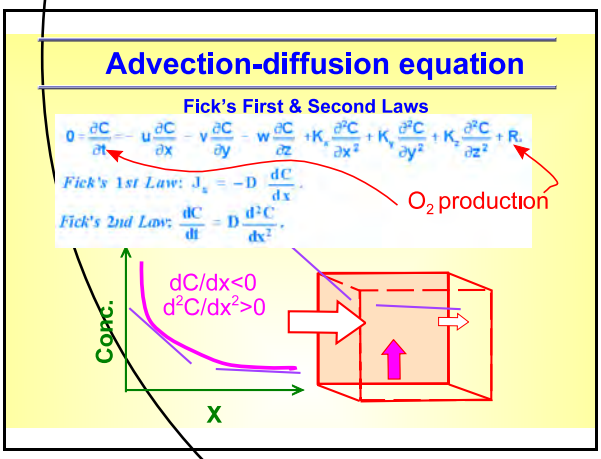
O_2 microelectrode profiles of the best methods for estimating benthic primary production



O_2 primary production obtained by subtracting the integrated light & dark profiles (after 1 min in dark)

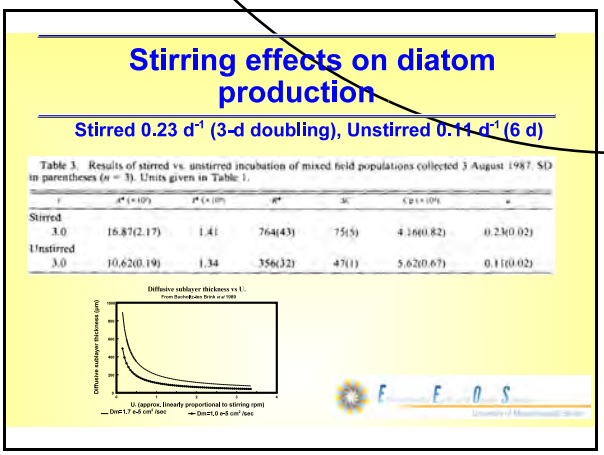
Slide 39 Revsbech & Jørgensen (1983)

NOTES:



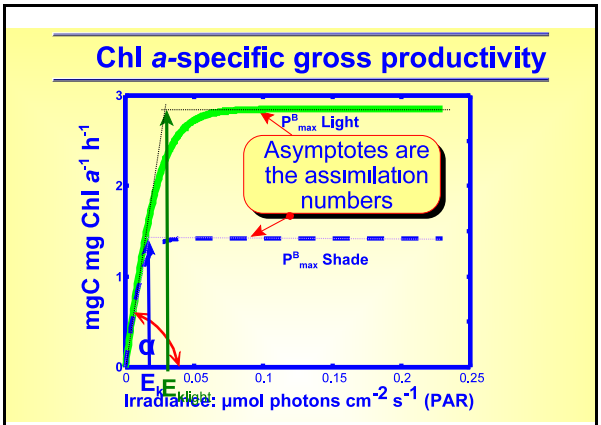
Slide 40 Advection-diffusion equation

NOTES:



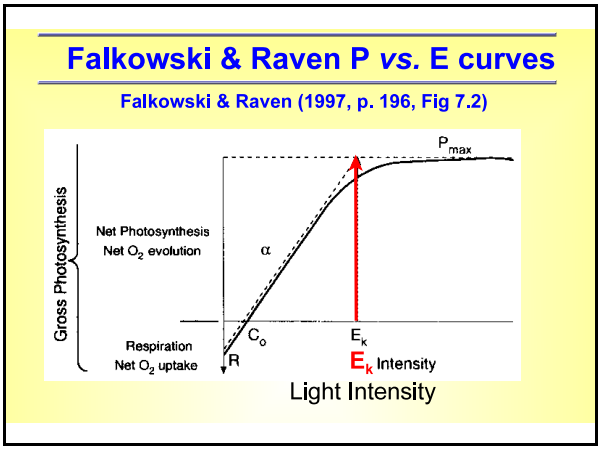
Slide 41 Stirring effects on diatom production

NOTES:



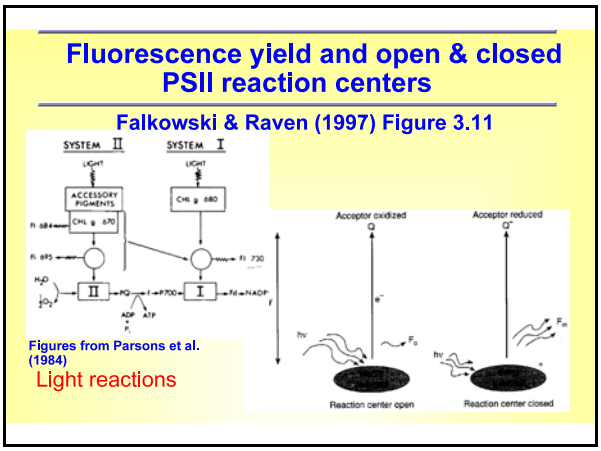
Slide 42

NOTES:



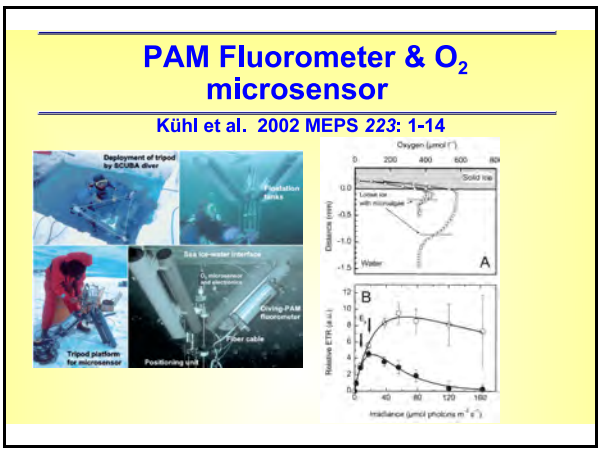
Slide 43 Falkowski & Raven P vs. E curves

NOTES:



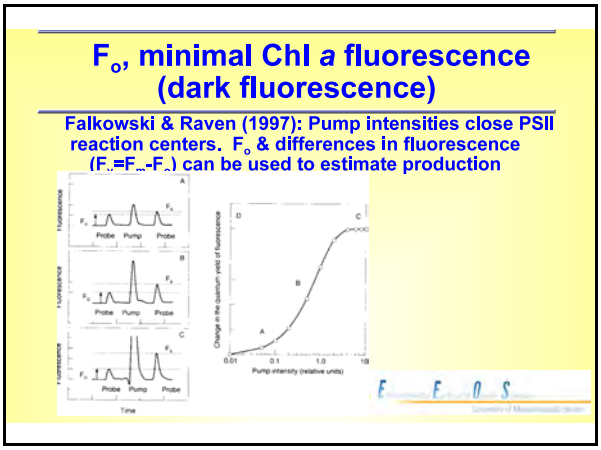
Slide 44 Fluorescence yield and open & closed PSII reaction centers

NOTES:



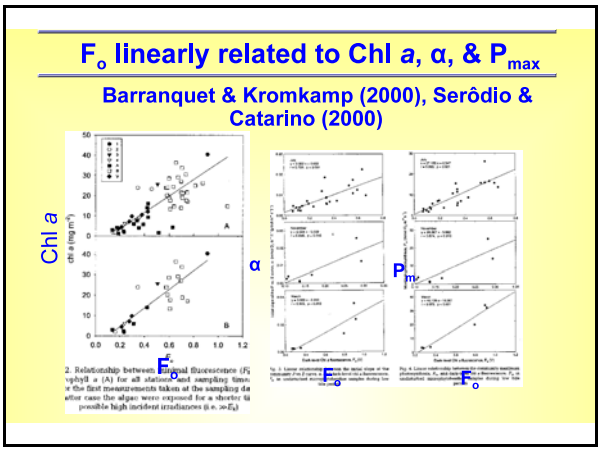
Slide 45 PAM Fluorometer & O2 microsensor

NOTES:



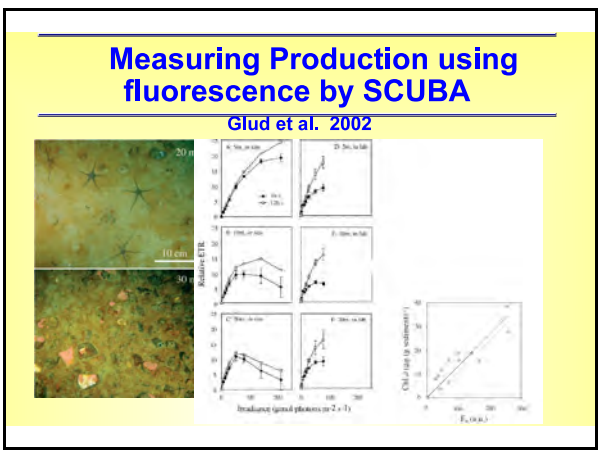
Slide 46 Fo, minimal Chl a fluorescence (dark fluorescence)

NOTES:



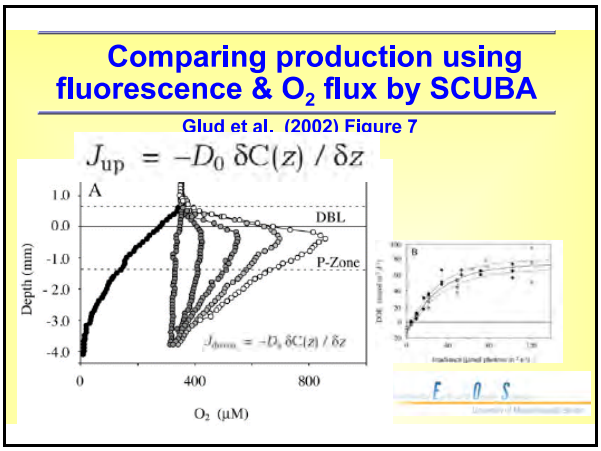
Slide 47 Fo linearly related to Chl a, α, & Pmax

NOTES:



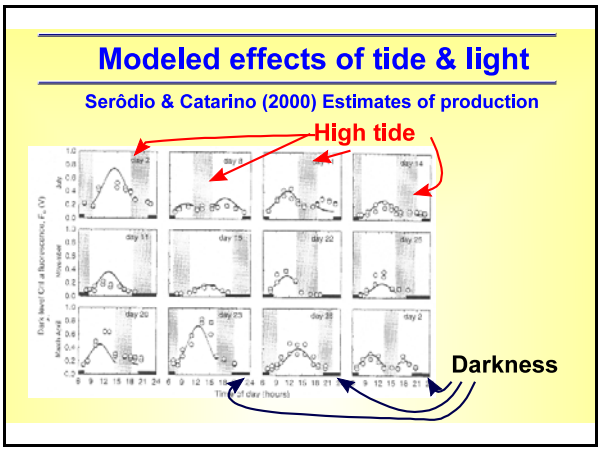
Slide 48 Measuring Production using fluorescence by SCUBA

NOTES:



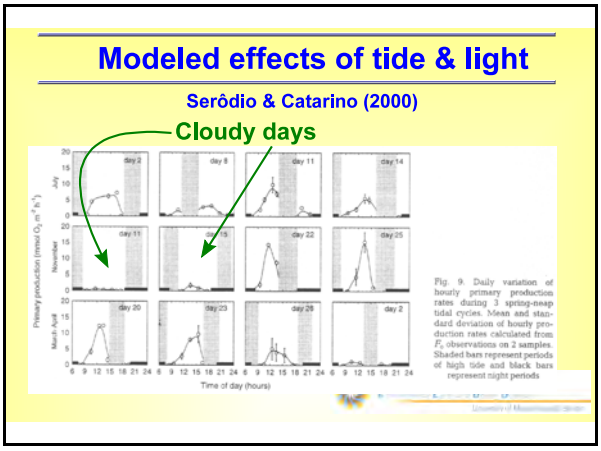
Slide 49 Comparing production using fluorescence & O2 flux by SCUBA

NOTES:



Slide 50 Modeled effects of tide & light

NOTES:



Slide 51 Modeled effects of tide & light

NOTES:

Rates of diatom production

Epipelic: about 100-200 gCm^{-2}y^{-1}

Location/Source	Technique	g C/m²/yr	Author
Benthic microalgae:			
Georgia salt marsh	O_2, CO_2	200	Pomeroy (1959)
Delaware salt marsh	O_2	38–99	Gallagher and Daiber (1973)
California salt marsh	O_2	217–400	Zedler (1980)
Massachusetts salt marsh	^{14}C (shaded)	106	Van Raalte *et al.* (1976)
	(unshaded)	165	
Intertidal sandflat	O_2	143–226	Pamatmat (1968)
Intertidal sandflat	O_2	0–325	Riznyk and Phinney (1972)
Intertidal sandflat	^{14}C	4–9	Steele and Baird (1968)
Intertidal mudflat	^{14}C	51	Leach (1970)
Estuarine subtidal	^{14}C	116	Gronived (1960)
	^{14}C	90	Marshall (1970)
	^{14}C	180	Joint (1978)
Wadden Sea sand flat	^{14}C	58–177	Cadée (1980)
Sea and marsh grasses:			
Thalassia beds	O_2	520–640	Westlake (1963)
Spartina (Georgia)	O_2	257–897	Teal (1962)
(North Carolina to Nova Scotia)	cropping	130–256	Mann (1972b)
(Massachusetts)	cropping	1100–2300[b]	Valiela *et al.* (1976)
Mangrove swamps:			
Florida (net prod.)	O_2 (+ litter)	400	Mann (1972b)
Kelps:			
Laminaria (Nova Scotia)	cropping	1900	Westlake (1963)
(England)	cropping	1225	Bellamy *et al.* (1968)
(Nova Scotia)	blade renewal	1750	Mann (1972b)
Macrocystis	cropping	400–820	Clendenning (1972)
Littoral seaweeds:			
Fucus	O_2	<3000[c]	Knowlsher (1966)

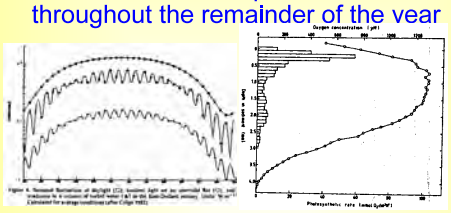
Slide 52 Rates of diatom production

NOTES:

What limits benthic production?

LIght In wInter, DIC In summer

- Production limited by light in winter
- Production may be limited by inorganic carbon in North temperate mudflats throughout the remainder of the year

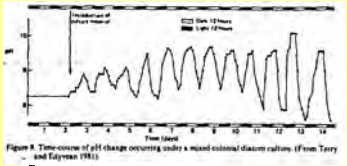


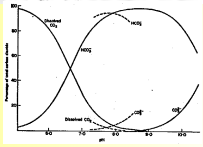
Slide 53 What limits benthic production?

NOTES:

DIC limitation in diatoms mats

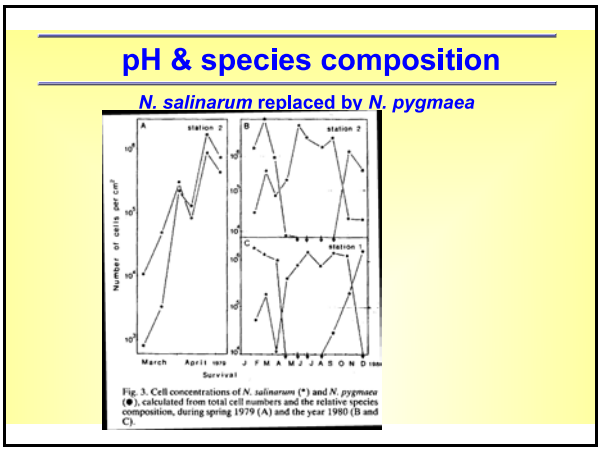
pH from Terry & Edyvean (1981)





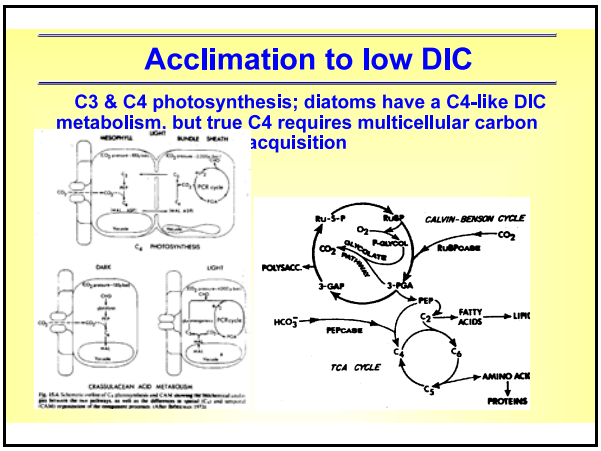
Slide 54 DIC limitation in diatoms mats

NOTES:



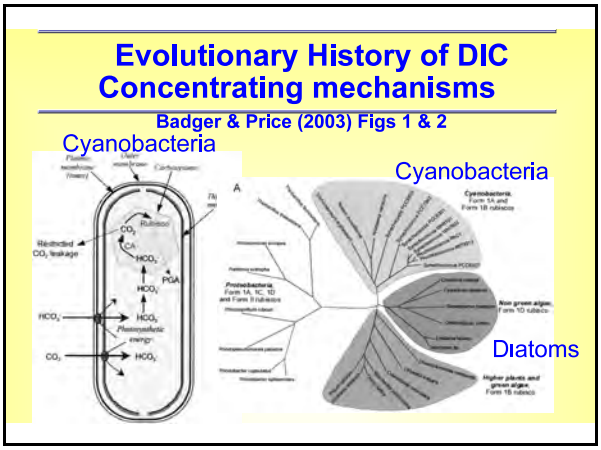
Slide 55 pH & species composition

NOTES:



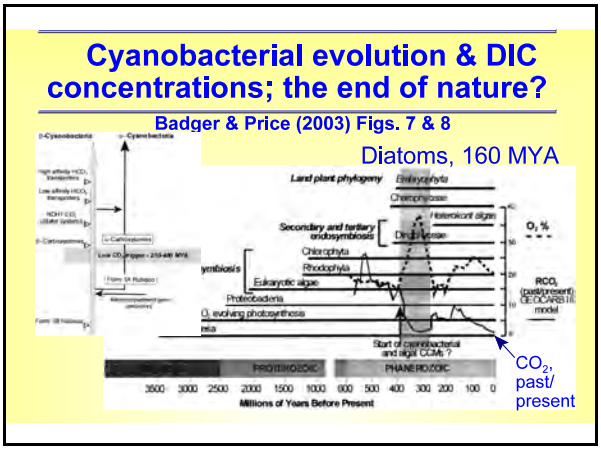
Slide 56 Acclimation to low DIC

NOTES:



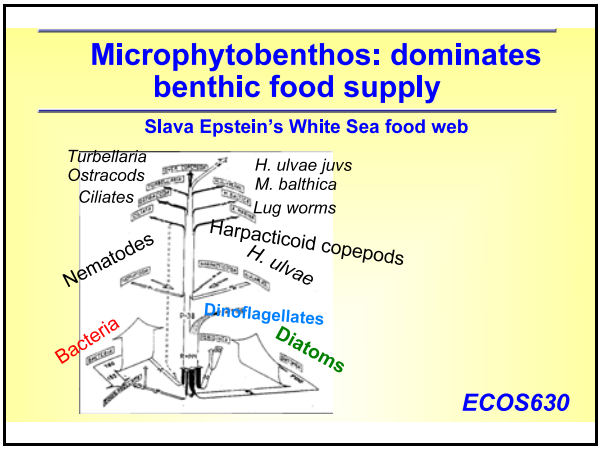
Slide 57 Evolutionary History of DIC Concentrating mechanisms

NOTES:



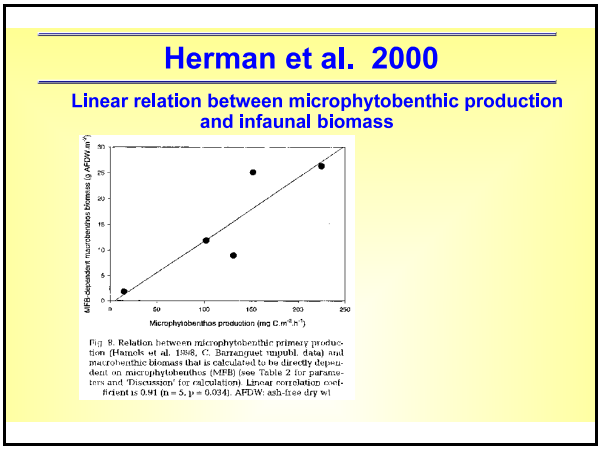
Slide 58 Cyanobacterial evolution & DIC concentrations; the end of nature?

NOTES:



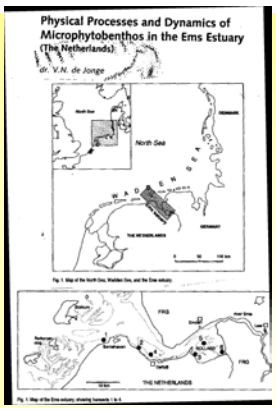
Slide 59 Microphytobenthos: dominates benthic food supply

NOTES:



Slide 60 Herman et al. 2000

NOTES:

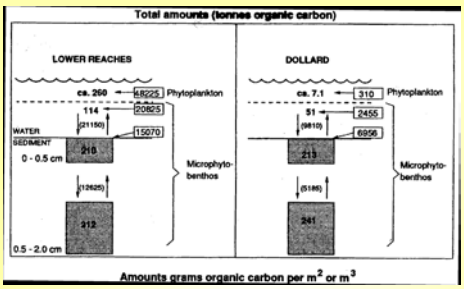


Slide 61

NOTES:

Photoautotrophic standing stock

From de Jonge (1994)

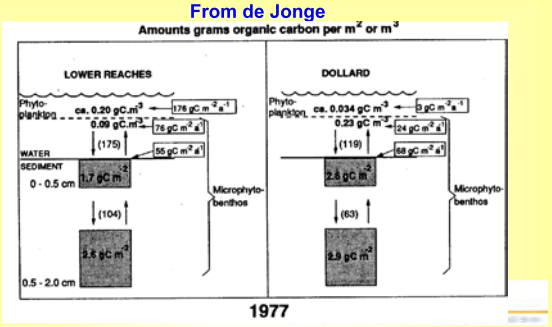


Slide 62 Photoautotrophic standing stock

NOTES:

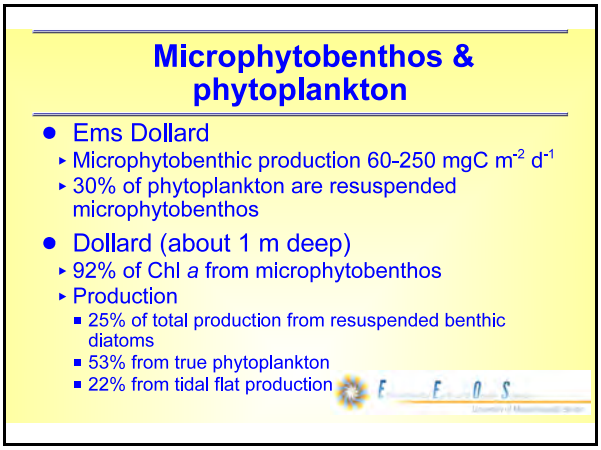
Photoautotrophic production

From de Jonge



Slide 63 Photoautotrophic production

NOTES:



Slide 64 Microphytobenthos & phytoplankton

NOTES: