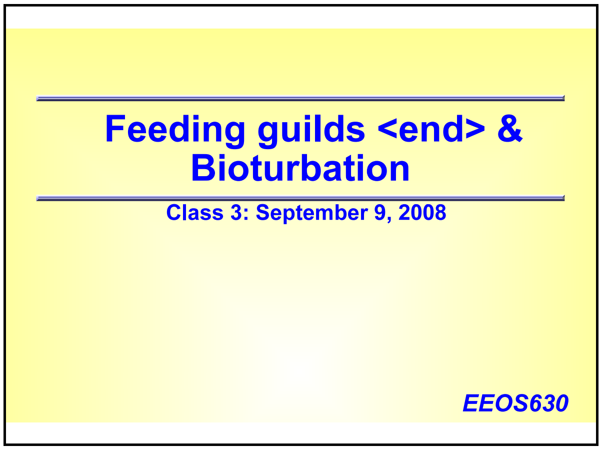

Feeding guilds <end> & Bioturbation

Class 3: September 9, 2008

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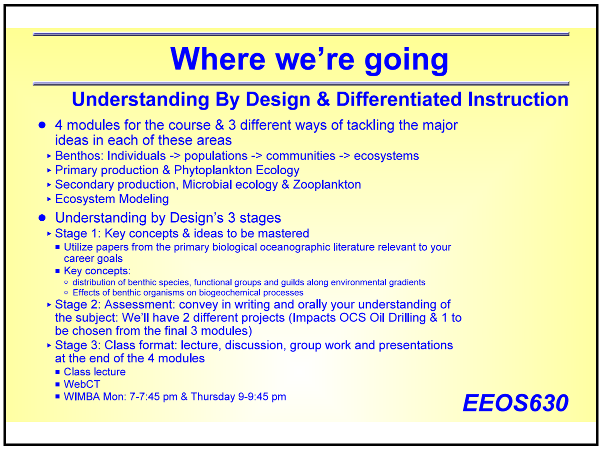
Slide 1 Feeding guilds <end> & Bioturbation

NOTES:



Where we’re going

Understanding By Design & Differentiated Instruction

- 4 modules for the course & 3 different ways of tackling the major ideas in each of these areas
  - Benthos: Individuals -> populations -> communities -> ecosystems
  - Primary production & Phytoplankton Ecology
  - Secondary production, Microbial ecology & Zooplankton
  - Ecosystem Modeling
- Understanding by Design’s 3 stages
  - Stage 1: Key concepts & ideas to be mastered
    - Utilize papers from the primary biological oceanographic literature relevant to your career goals
    - Key concepts:
      - distribution of benthic species, functional groups and guilds along environmental gradients
      - Effects of benthic organisms on biogeochemical processes
  - Stage 2: Assessment: convey in writing and orally your understanding of the subject: We’ll have 2 different projects (Impacts OCS Oil Drilling & 1 to be chosen from the final 3 modules)
  - Stage 3: Class format: lecture, discussion, group work and presentations at the end of the 4 modules
    - Class lecture
    - WebCT
    - WIMBA Mon: 7-7:45 pm & Thursday 9-9:45 pm

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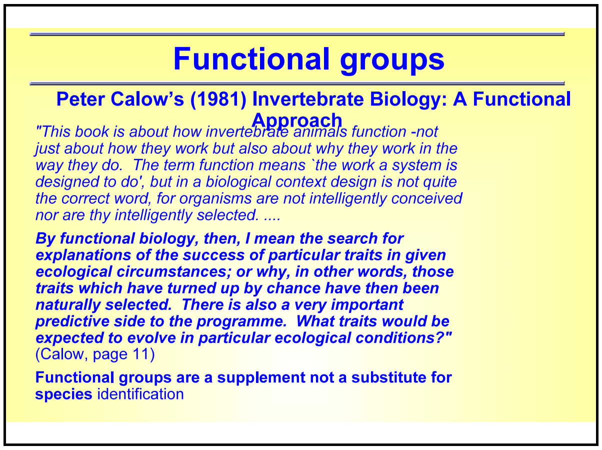
Slide 2 Where we’re going

NOTES:



Functional groups

Peter Calow’s (1981) Invertebrate Biology: A Functional Approach

"This book is about how invertebrate animals function -not just about how they work but also about why they work in the way they do. The term function means `the work a system is designed to do', but in a biological context design is not quite the correct word, for organisms are not intelligently conceived nor are thy intelligently selected. ....

By functional biology, then, I mean the search for explanations of the success of particular traits in given ecological circumstances; or why, in other words, those traits which have turned up by chance have then been naturally selected. There is also a very important predictive side to the programme. What traits would be expected to evolve in particular ecological conditions?" (Calow, page 11)

Functional groups are a supplement not a substitute for species identification

Slide 3 Functional groups

NOTES:

Guilds: arenas for competition

Seed gathering ants & rodents are members of the same guild, Brown *et al.* (1986)

"[A guild is] a group of species that exploit the same class of environmental resources in a similar way. This term groups together species, without regard to taxonomic positions, that overlap significantly in their niche requirements." Root (1967)

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Slide 4 Guilds: arenas for competition

NOTES:

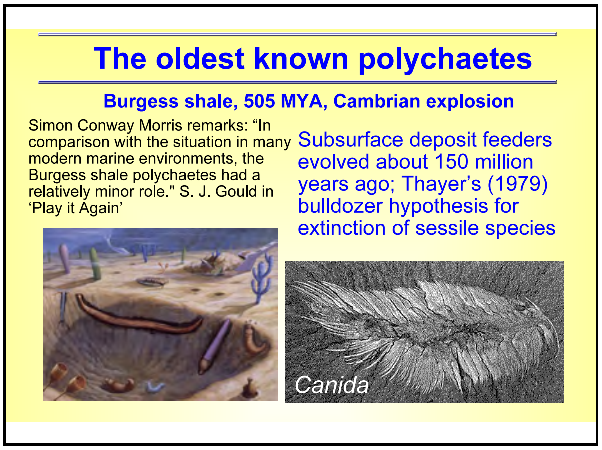
Benthic functional groups

Based on interactions with the sediment; Functional groups are not feeding guilds

- Woodin's (1976) functional groups
  - 1) Tube builders
  - 2) Suspension feeders
  - 3) Burrowers
- Woodin & Jackson's (1979) functional groups
  - 1) Mobile burrowing organisms, a.k.a. Thayer's (1979) bulldozers
  - 2) Destabilizing sedentary organisms (*e.g.*, *Molpadia oolitica*).
  - 3) Sedentary organisms which project above and below the sediment surface (*e.g.*, sea grasses).
  - 4) Tube builders
  - 5) Sedentary organisms which don't destabilize or stabilize sediments

Slide 5 Benthic functional groups

NOTES:



The oldest known polychaetes

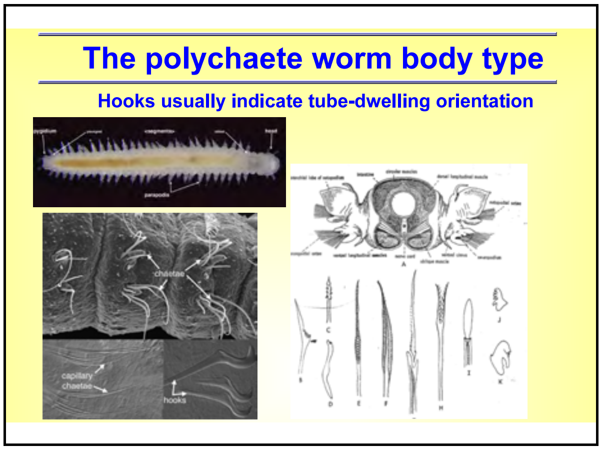
Burgess shale, 505 MYA, Cambrian explosion

Simon Conway Morris remarks: "In comparison with the situation in many modern marine environments, the Burgess shale polychaetes had a relatively minor role." S. J. Gould in 'Play it Again'

Subsurface deposit feeders evolved about 150 million years ago; Thayer's (1979) bulldozer hypothesis for extinction of sessile species

Slide 6 The oldest known polychaetes

NOTES:

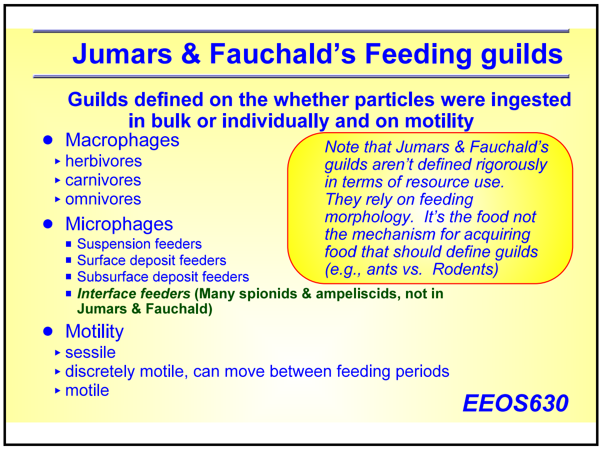


The polychaete worm body type

Hooks usually indicate tube-dwelling orientation

Slide 7 The polychaete worm body type

NOTES:



Jumars & Fauchald's Feeding guilds

Guilds defined on the whether particles were ingested in bulk or individually and on motility

- Macrophages
  - herbivores
  - carnivores
  - omnivores
- Microphages
  - Suspension feeders
  - Surface deposit feeders
  - Subsurface deposit feeders
  - ***Interface feeders*** **(Many spionids & ampeliscids, not in Jumars & Fauchald)**
- Motility
  - sessile
  - discretely motile, can move between feeding periods
  - motile

Note that Jumars & Fauchald's guilds aren't defined rigorously in terms of resource use. They rely on feeding morphology. It's the food not the mechanism for acquiring food that should define guilds (e.g., ants vs. Rodents)

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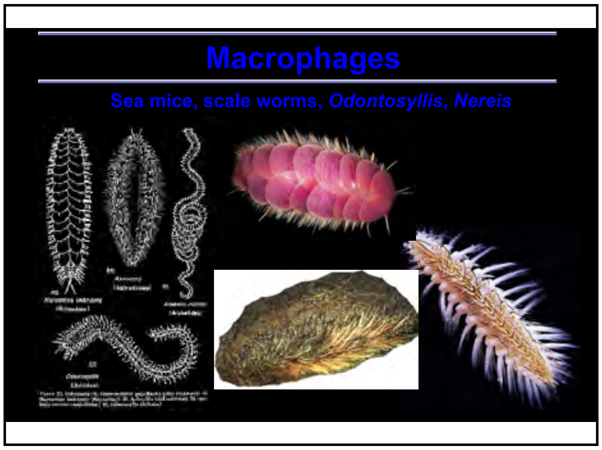
Slide 8 Jumars & Fauchald's Feeding guilds

NOTES:

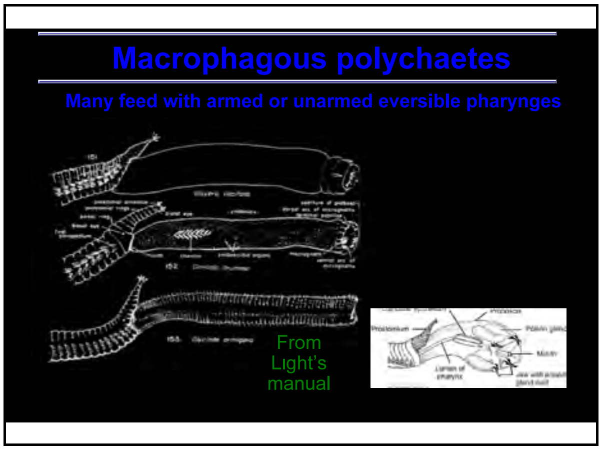


Macrophages

Sea mice, scale worms, *Odontosyllis*, *Nereis*

Slide 9 Macrophages

NOTES:



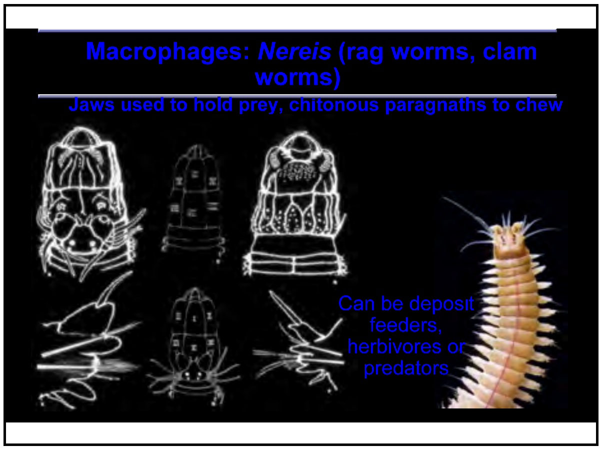
Macrophagous polychaetes

Many feed with armed or unarmed eversible pharynges

From Light's manual

Slide 10 Macrophagous polychaetes

NOTES:



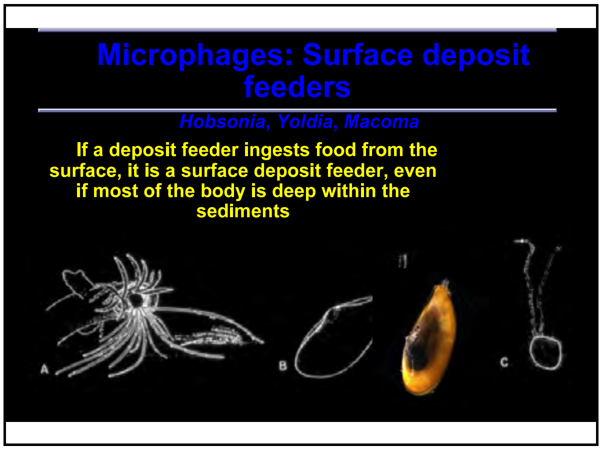
Macrophages: *Nereis* (rag worms, clam worms)

Jaws used to hold prey, chitonous paragnaths to chew

Can be deposit feeders, herbivores or predators

Slide 11 Macrophages: Nereis (rag worms, clam worms)

NOTES:



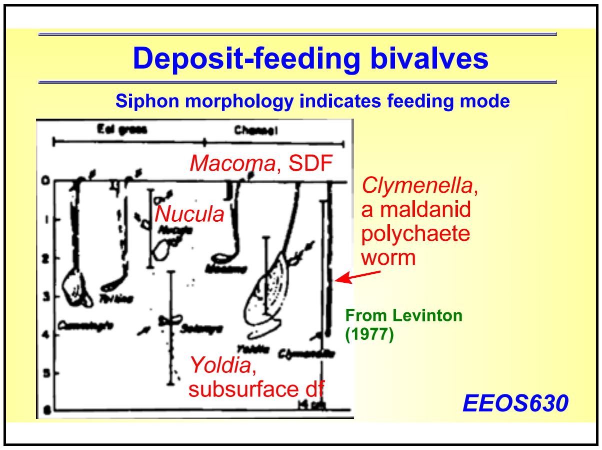
Microphages: Surface deposit feeders

Hobsonia, Yoldia, Macoma

If a deposit feeder ingests food from the surface, it is a surface deposit feeder, even if most of the body is deep within the sediments

Slide 12 Microphages: Surface deposit feeders

NOTES:



Deposit-feeding bivalves

Siphon morphology indicates feeding mode

From Levinton (1977)

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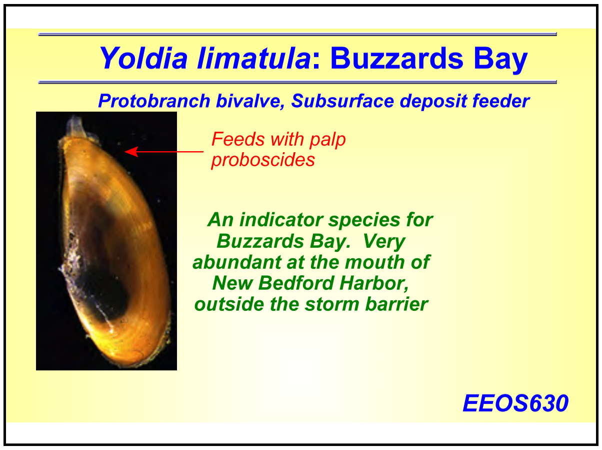
Slide 13 Deposit-feeding bivalves

NOTES:



Yoldia limatula: Buzzards Bay

Protobranch bivalve, Subsurface deposit feeder

An indicator species for Buzzards Bay. Very abundant at the mouth of New Bedford Harbor, outside the storm barrier

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Slide 14 Yoldia limatula: Buzzards Bay

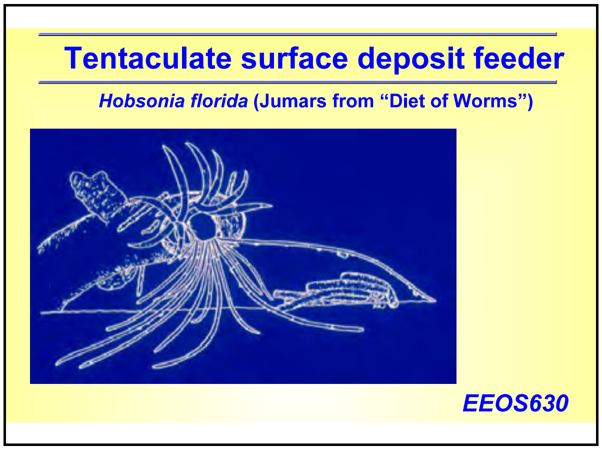
NOTES:

Macoma balthica, a key indicator species worldwide

A shallow-dwelling surface deposit feeder; very thin shell, vulnerable to predation (discussed by Vermeij)

Slide 15 Macoma balthica, a key indicator species worldwide

NOTES:



Tentaculate surface deposit feeder

Hobsonia florida (Jumars from "Diet of Worms")

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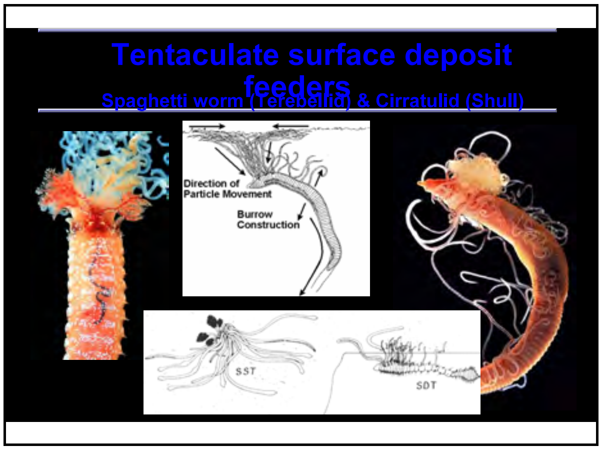
Slide 16 Tentaculate surface deposit feeder

NOTES:

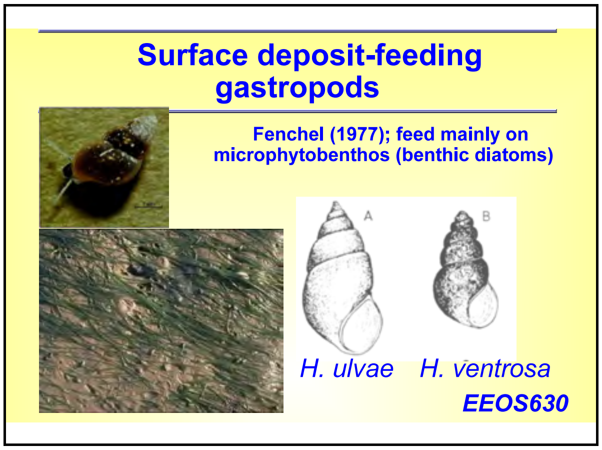


Tentaculate surface deposit feeders

Spaghetti worm (Terebellid) & Cirratulid (Shull)

Slide 17 Tentaculate surface deposit feeders

NOTES:



Surface deposit-feeding gastropods

Fenchel (1977); feed mainly on microphytobenthos (benthic diatoms)

H. ulvae *H. ventrosa*

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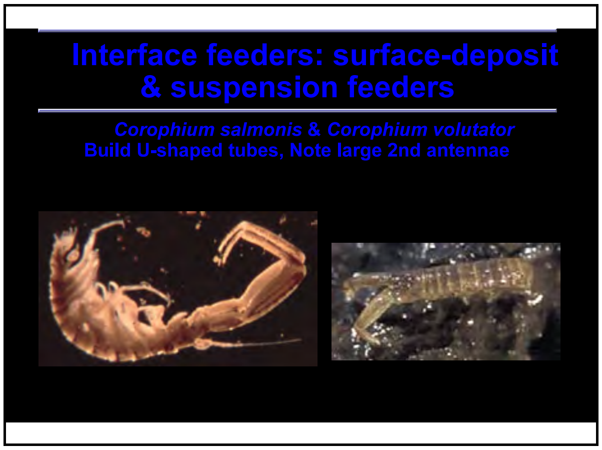
Slide 18 Surface deposit-feeding gastropods

NOTES:

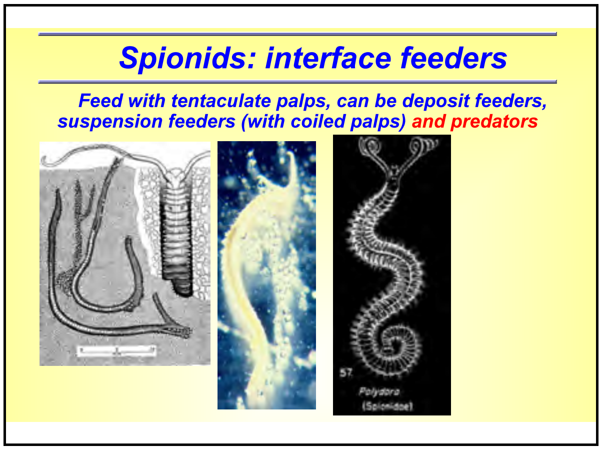


Interface feeders: surface-deposit & suspension feeders

Corophium salmonis & Corophium volutator
Build U-shaped tubes, Note large 2nd antennae

Slide 19 Interface feeders: surface-deposit & suspension feeders

NOTES:

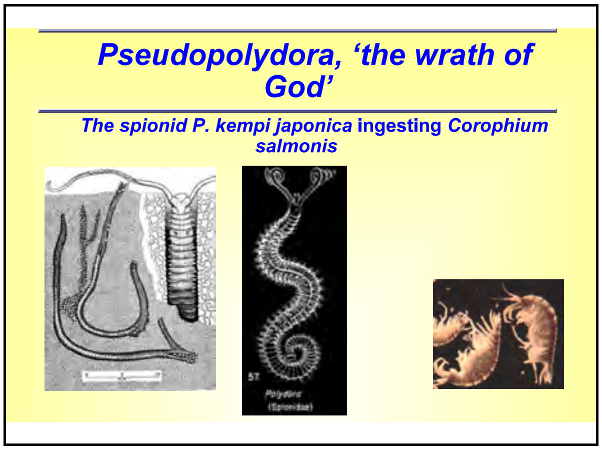


Spionids: interface feeders

Feed with tentaculate palps, can be deposit feeders, suspension feeders (with coiled palps) and predators

Slide 20 Spionids: interface feeders

NOTES:



Pseudopolydora, 'the wrath of God'

The spionid P. kempi japonica ingesting *Corophium salmonis*

Slide 21 Pseudopolydora, 'the wrath of God'

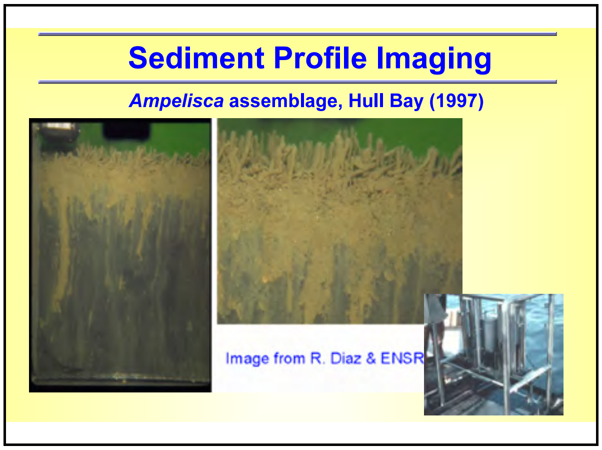
NOTES:

Interface feeders: *Ampelisca abdita*

Near Peddocks Island in Quincy Bay

Slide 22 Interface feeders: Ampelisca abdita

NOTES:



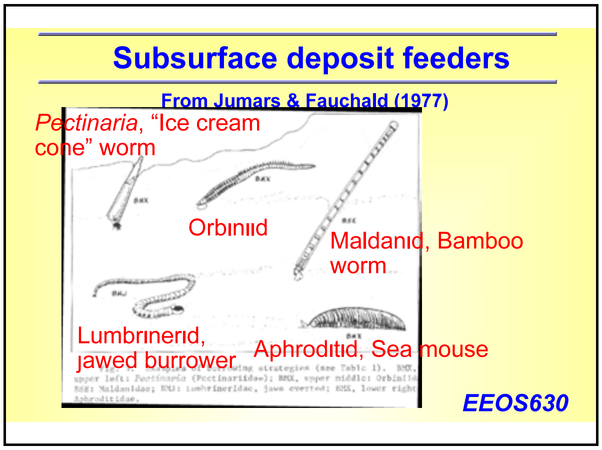
Sediment Profile Imaging

Ampelisca assemblage, Hull Bay (1997)

Image from R. Diaz & ENSR

Slide 23 Sediment Profile Imaging

NOTES:

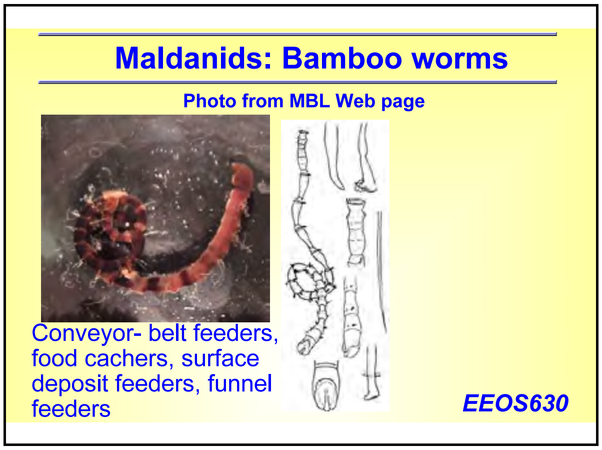


Subsurface deposit feeders

From Jumars & Fauchald (1977)

Slide 24 Subsurface deposit feeders

NOTES:



Maldanids: Bamboo worms

Photo from MBL Web page

Conveyor- belt feeders, food cachers, surface deposit feeders, funnel feeders

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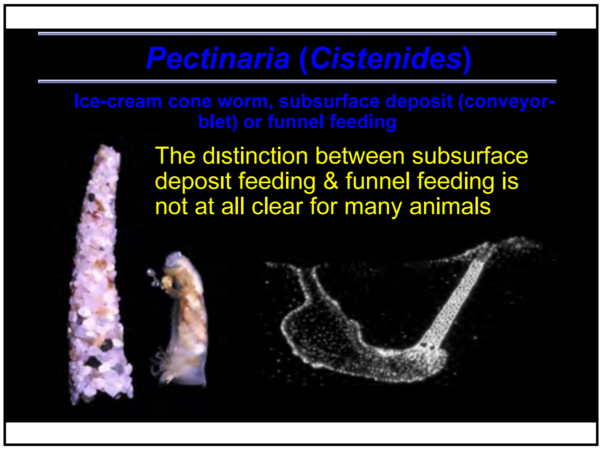
Slide 25 Maldanids: Bamboo worms

NOTES:



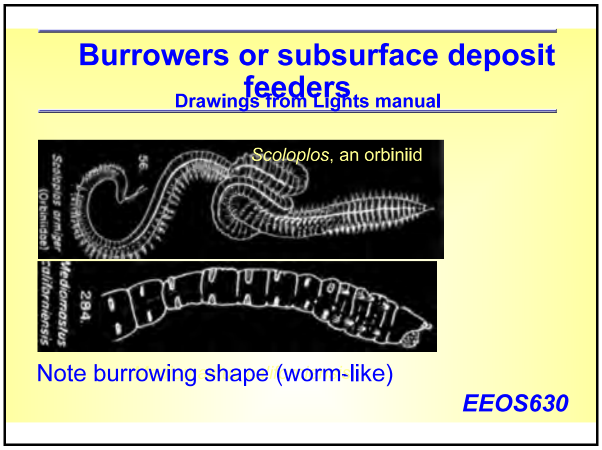
Pectinaria (Cistenides)

Ice-cream cone worm, subsurface deposit (conveyor-blet) or funnel feeding

The distinction between subsurface deposit feeding & funnel feeding is not at all clear for many animals

Slide 26 Pectinaria (Cistenides)

NOTES:



Burrowers or subsurface deposit feeders

Drawings from Lights manual

Scoloplos, an orbiniid

Note burrowing shape (worm-like)

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Slide 27 Burrowers or subsurface deposit feeders

NOTES:

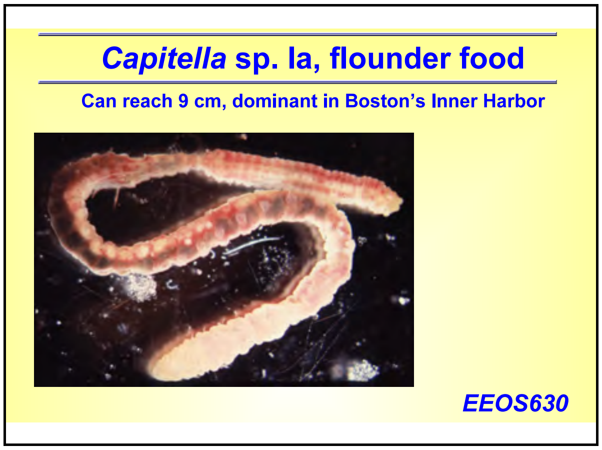
Capitella sp. I

Shallow subsurface deposit feeder & premier pollution indicator, see Gallagher & Keay 1998

Wang, Xu-Chen, Yi-Xian Zhang, and R. F. Chen. 2001. Distribution and partitioning of polycyclic aromatic hydrocarbons (PAHs) in different size fctions in sediments from Boston Harbor, United States. Marine Pollution Bulletin *42*: 1139-1149.

Slide 28 Capitella sp. I

NOTES:



Capitella sp. Ia, flounder food

Can reach 9 cm, dominant in Boston's Inner Harbor

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Slide 29 Capitella sp. Ia, flounder food

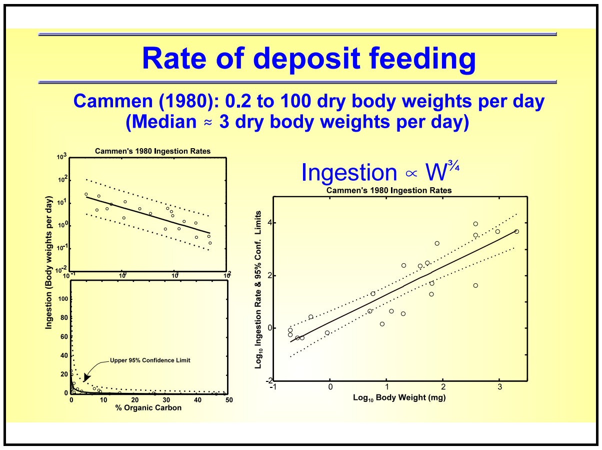
NOTES:

Lug worm feeding (funnel feeding)

Atlantic: *Arenicola*; Pacific: *Abarenicola*

Slide 30 Lug worm feeding (funnel feeding)

NOTES:



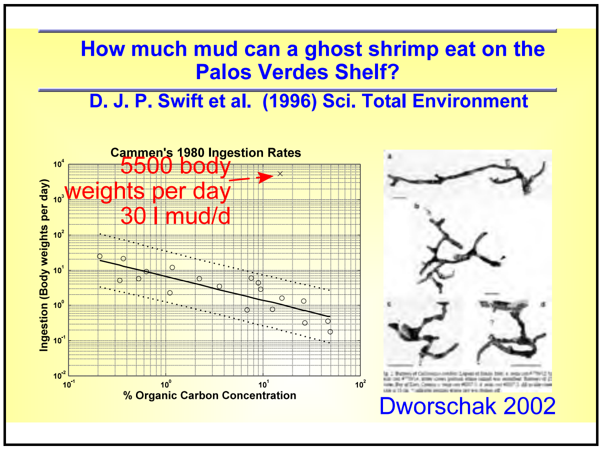
Rate of deposit feeding

Cammen (1980): 0.2 to 100 dry body weights per day (Median ≈ 3 dry body weights per day)

Ingestion ∝ $W^{3/4}$

Slide 31 Rate of deposit feeding

NOTES:



How much mud can a ghost shrimp eat on the Palos Verdes Shelf?

D. J. P. Swift et al. (1996) Sci. Total Environment

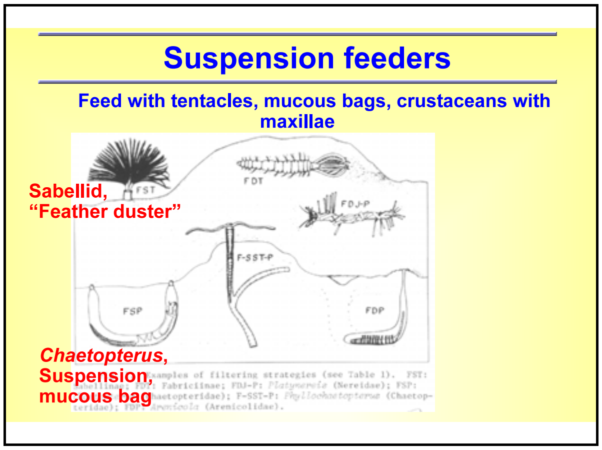
5500 body weights per day

30 l mud/d

Dworschak 2002

Slide 32 How much mud can a ghost shrimp eat on the Palos Verdes Shelf?

NOTES:



Suspension feeders

Feed with tentacles, mucous bags, crustaceans with maxillae

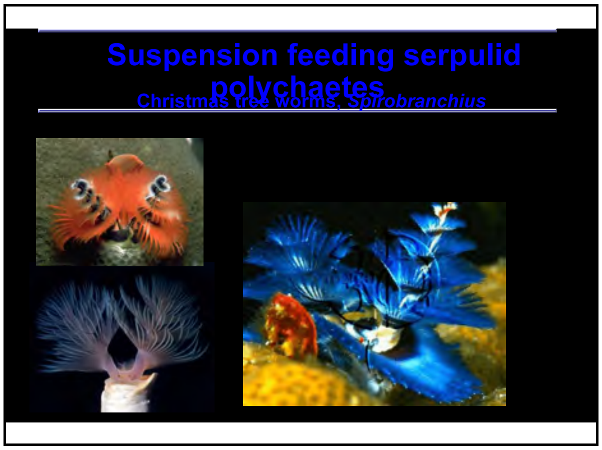
Sabellid, “Feather duster”

Chaetopterus, Suspension, mucous bag

Examples of filtering strategies (see Table 1). FST: Sabellinae; FDT: Fabriciinae; FDJ-P: *Platynereis* (Nereidae); FSP: Chaetopteridae); F-SST-P: *Phyllochaetopterus* (Chaetopteridae); FDP: *Arenicola* (Arenicolidae).

Slide 33 Suspension feeders

NOTES:

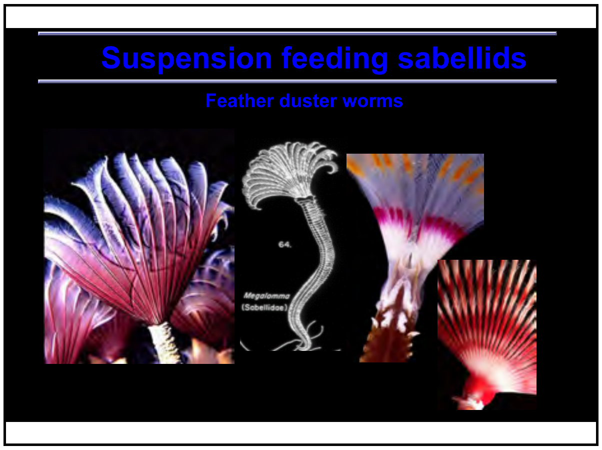


Suspension feeding serpulid polychaetes

Christmas tree worms, *Spirobranchius*

Slide 34 Suspension feeding serpulid polychaetes

NOTES:



Suspension feeding sabellids

Feather duster worms

Slide 35 Suspension feeding sabellids

NOTES:

***Sabellaria* reefs**

***Sabellaria alveolata* studied by D. P. Wilson**

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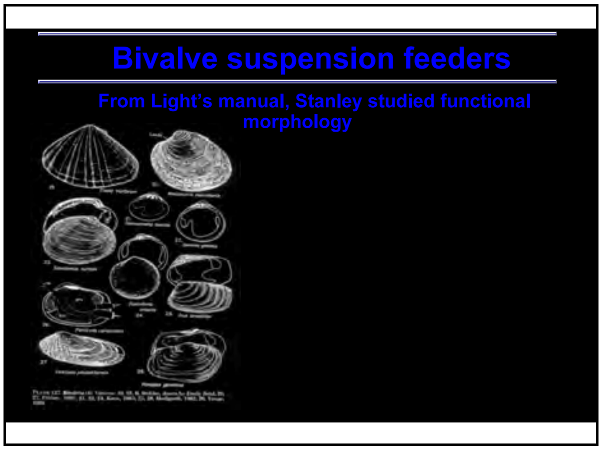
Slide 36 Sabellaria reefs

NOTES:

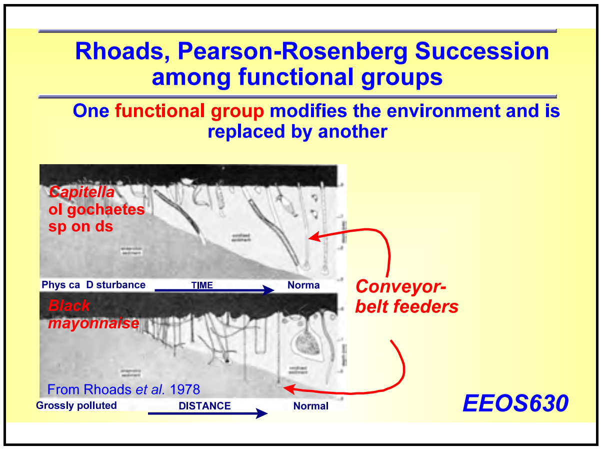


Bivalve suspension feeders

From Light's manual, Stanley studied functional morphology

Slide 37 Bivalve suspension feeders

NOTES:



Rhoads, Pearson-Rosenberg Succession among functional groups

One functional group modifies the environment and is replaced by another

From Rhoads *et al.* 1978

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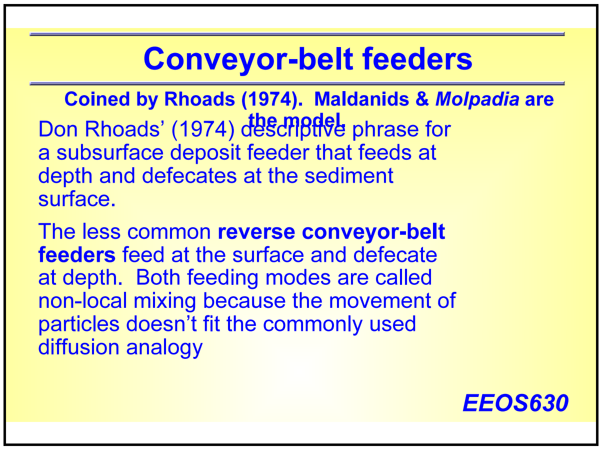
Slide 38 Rhoads, Pearson-Rosenberg Succession among functional groups

NOTES:



Conveyor-belt feeders

Coined by Rhoads (1974). Maldanids & *Molpadia* are the model

Don Rhoads' (1974) descriptive phrase for a subsurface deposit feeder that feeds at depth and defecates at the sediment surface.

The less common **reverse conveyor-belt feeders** feed at the surface and defecate at depth. Both feeding modes are called non-local mixing because the movement of particles doesn't fit the commonly used diffusion analogy

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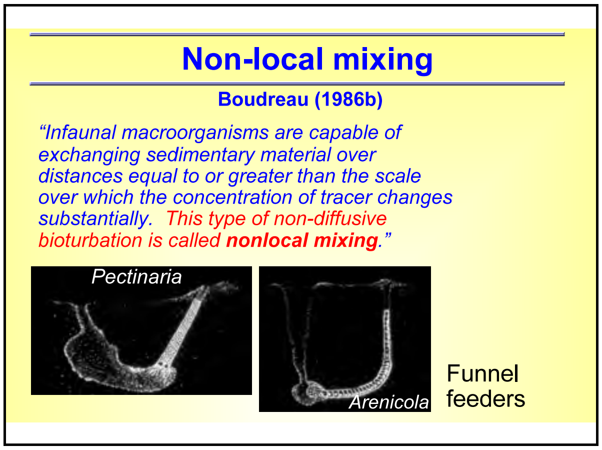
Slide 39 Conveyor-belt feeders

NOTES:



Non-local mixing

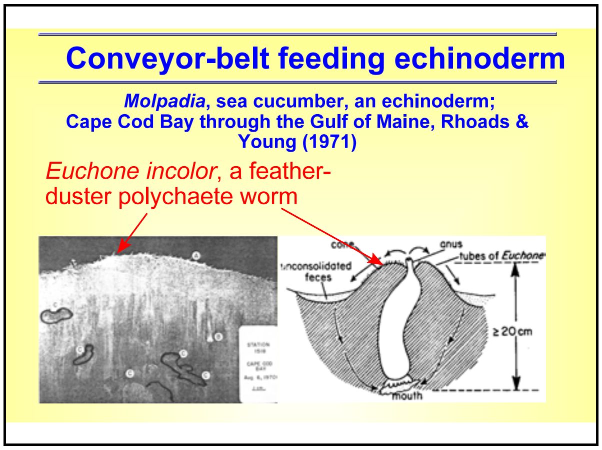
Boudreau (1986b)

*“Infaunal macroorganisms are capable of exchanging sedimentary material over distances equal to or greater than the scale over which the concentration of tracer changes substantially. This type of non-diffusive bioturbation is called **nonlocal mixing**.”*

Funnel feeders

Slide 40 Non-local mixing

NOTES:



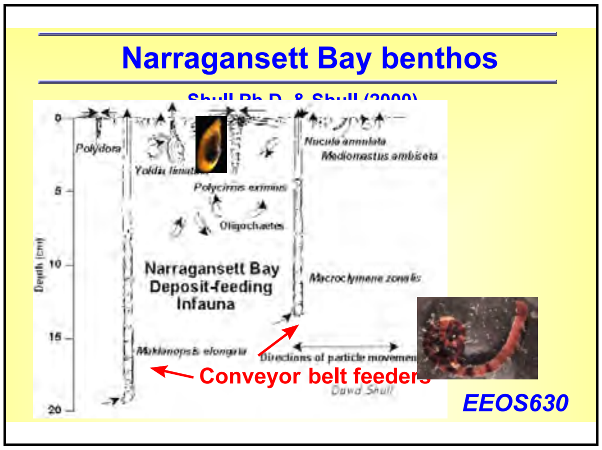
Conveyor-belt feeding echinoderm

***Molpadia*, sea cucumber, an echinoderm; Cape Cod Bay through the Gulf of Maine, Rhoads & Young (1971)**

Euchone incolor, a feather-duster polychaete worm

Slide 41 Conveyor-belt feeding echinoderm

NOTES:



Narragansett Bay benthos

Shull Ph.D. & Shull (2000)

Conveyor belt feeders

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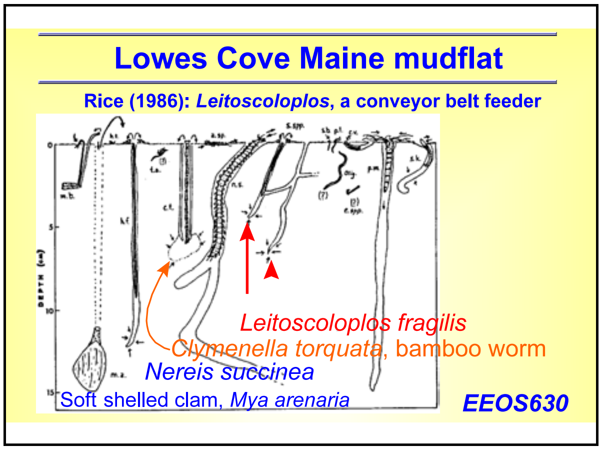
Slide 42 Narragansett Bay benthos

NOTES:



Lowes Cove Maine mudflat

Rice (1986): *Leitoscoloplos*, a conveyor belt feeder

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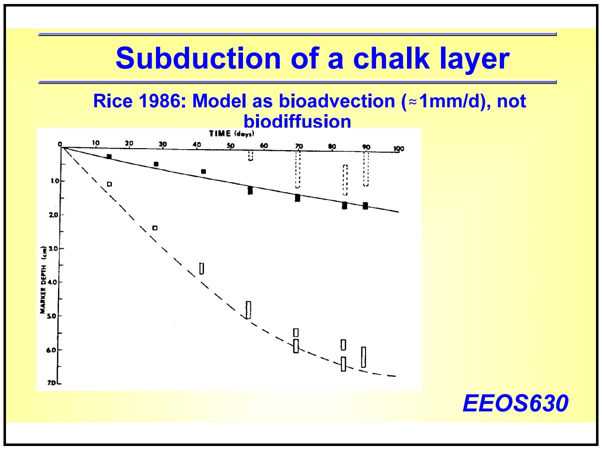
Slide 43 Lowes Cove Maine mudflat

NOTES:



Subduction of a chalk layer

Rice 1986: Model as bioadvection (≈1mm/d), not biodiffusion

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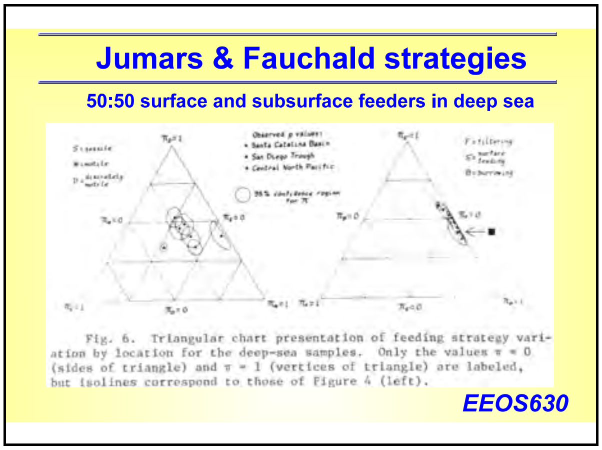
Slide 44 Subduction of a chalk layer

NOTES:



Jumars & Fauchald strategies

50:50 surface and subsurface feeders in deep sea

Fig. 6. Triangular chart presentation of feeding strategy variation by location for the deep-sea samples. Only the values π = 0 (sides of triangle) and π = 1 (vertices of triangle) are labeled, but isolines correspond to those of Figure 4 (left).

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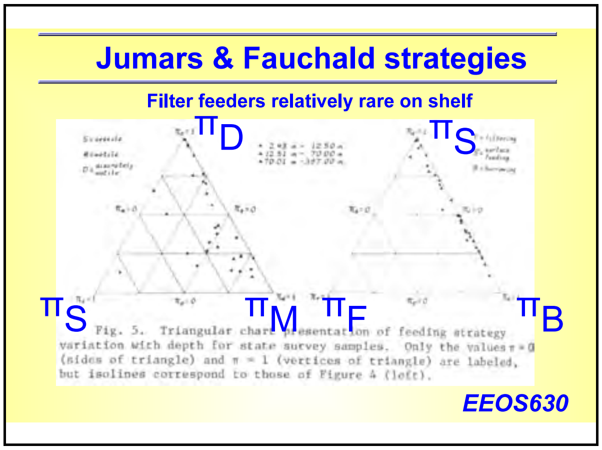
Slide 45 Jumars & Fauchald strategies

NOTES:



Jumars & Fauchald strategies

Filter feeders relatively rare on shelf

Fig. 5. Triangular chart presentation of feeding strategy variation with depth for state survey samples. Only the values π = 0 (sides of triangle) and π = 1 (vertices of triangle) are labeled, but isolines correspond to those of Figure 4 (left).

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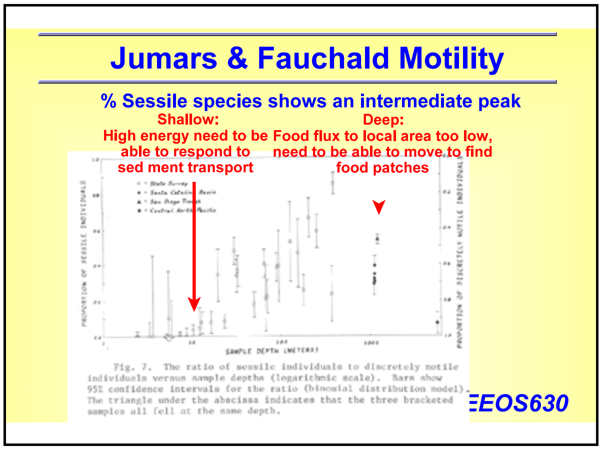
Slide 46 Jumars & Fauchald strategies

NOTES:



Jumars & Fauchald Motility

% Sessile species shows an intermediate peak

Shallow:
High energy need to be able to respond to sed ment transport

Deep:
Food flux to local area too low, need to be able to move to find food patches

Fig. 7. The ratio of sessile individuals to discretely motile individuals versus sample depths (logarithmic scale). Bars show 95% confidence intervals for the ratio (binomial distribution model). The triangle under the abscissa indicates that the three bracketed samples all fell at the same depth.

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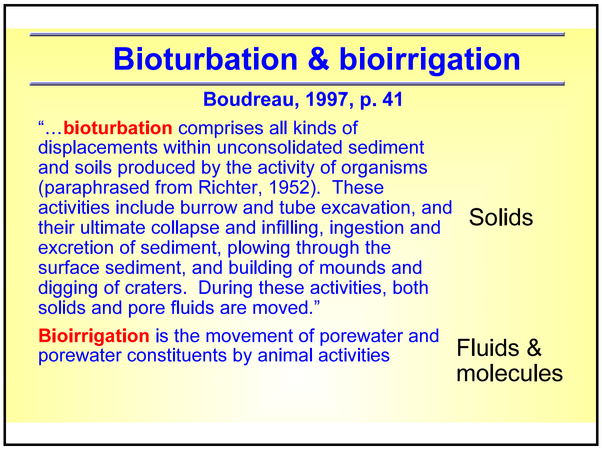
Slide 47 Jumars & Fauchald Motility

NOTES:



Bioturbation & bioirrigation

Boudreau, 1997, p. 41

"…**bioturbation** comprises all kinds of displacements within unconsolidated sediment and soils produced by the activity of organisms (paraphrased from Richter, 1952). These activities include burrow and tube excavation, and their ultimate collapse and infilling, ingestion and excretion of sediment, plowing through the surface sediment, and building of mounds and digging of craters. During these activities, both solids and pore fluids are moved."

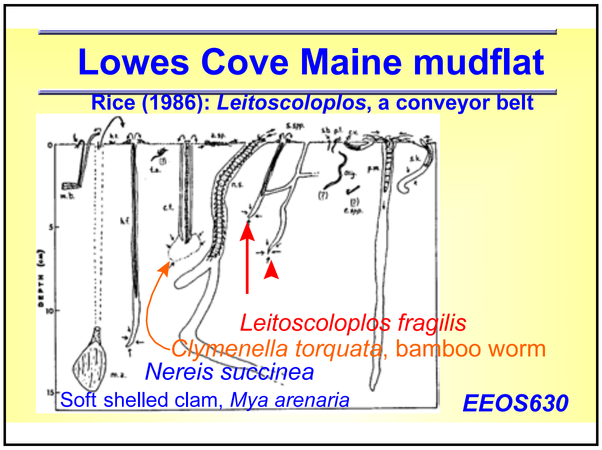
Solids

Bioirrigation is the movement of porewater and porewater constituents by animal activities

Fluids & molecules

Slide 48 Bioturbation & bioirrigation

NOTES:



Lowes Cove Maine mudflat

Rice (1986): *Leitoscoloplos*, a conveyor belt

Leitoscoloplos fragilis

Clymenella torquata, bamboo worm

Nereis succinea

Soft shelled clam, *Mya arenaria*

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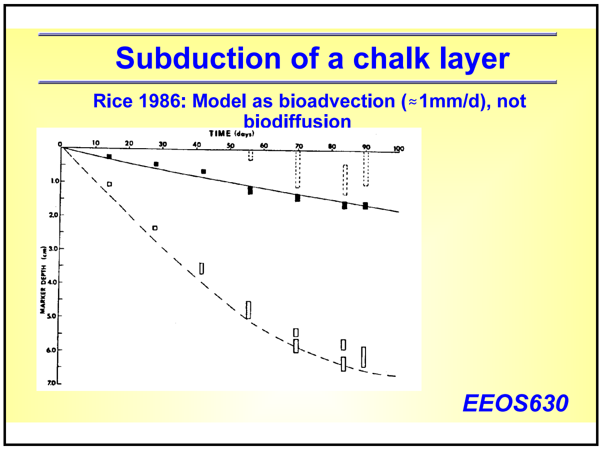
Slide 49 Lowes Cove Maine mudflat

NOTES:



Subduction of a chalk layer

Rice 1986: Model as bioadvection (≈1mm/d), not biodiffusion

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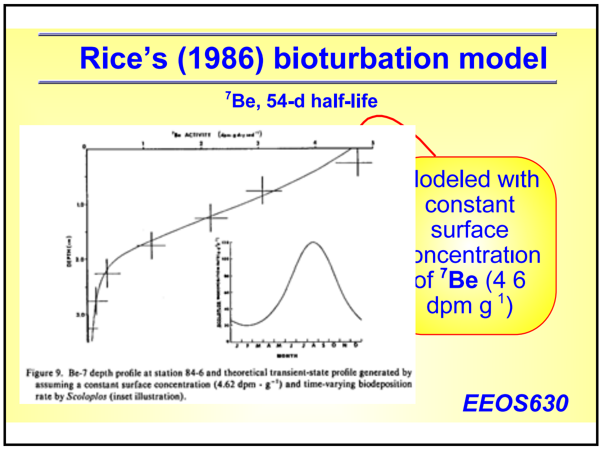
Slide 50 Subduction of a chalk layer

NOTES:



Rice's (1986) bioturbation model

^{7}Be, 54-d half-life

Figure 9. Be-7 depth profile at station 84-6 and theoretical transient-state profile generated by assuming a constant surface concentration (4.62 dpm · g^{-1}) and time-varying biodeposition rate by *Scoloplos* (inset illustration).

lodeled with constant surface oncentration of ^{7}**Be** (4 6 dpm g ^{1})

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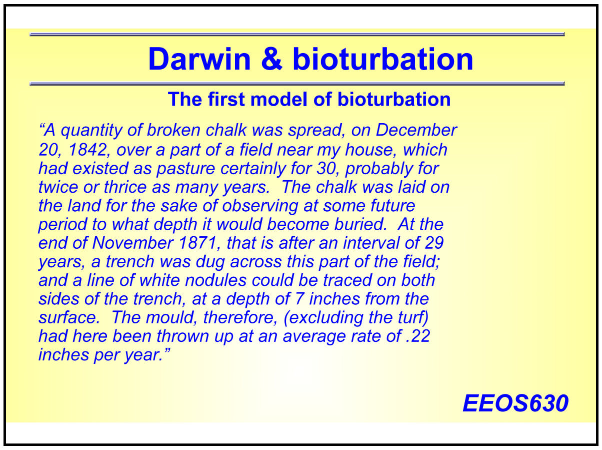
Slide 51 Rice's (1986) bioturbation model

NOTES:



Darwin & bioturbation

The first model of bioturbation

"A quantity of broken chalk was spread, on December 20, 1842, over a part of a field near my house, which had existed as pasture certainly for 30, probably for twice or thrice as many years. The chalk was laid on the land for the sake of observing at some future period to what depth it would become buried. At the end of November 1871, that is after an interval of 29 years, a trench was dug across this part of the field; and a line of white nodules could be traced on both sides of the trench, at a depth of 7 inches from the surface. The mould, therefore, (excluding the turf) had here been thrown up at an average rate of .22 inches per year."

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Slide 52 Darwin & bioturbation

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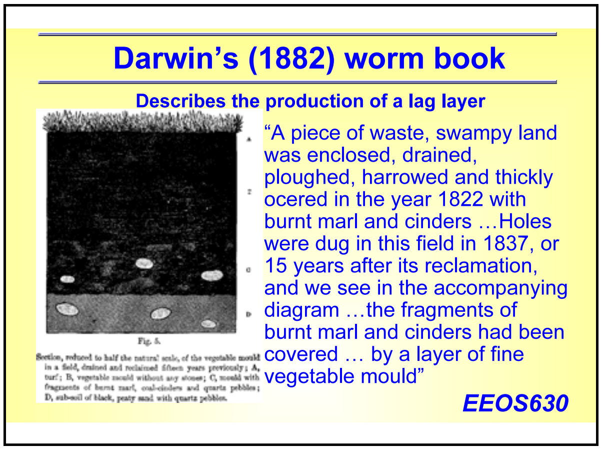

Darwin's (1882) worm book

Describes the production of a lag layer

Fig. 5.

Section, reduced to half the natural scale, of the vegetable mould in a field, drained and reclaimed fifteen years previously; A, turf; B, vegetable mould without any stones; C, mould with fragments of burnt marl, coal-cinders and quartz pebbles; D, sub-soil of black, peaty sand with quartz pebbles.

"A piece of waste, swampy land was enclosed, drained, ploughed, harrowed and thickly ocered in the year 1822 with burnt marl and cinders …Holes were dug in this field in 1837, or 15 years after its reclamation, and we see in the accompanying diagram …the fragments of burnt marl and cinders had been covered … by a layer of fine vegetable mould"

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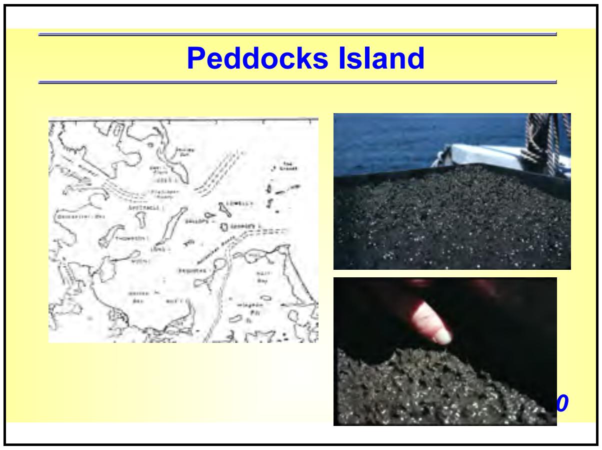
Slide 53 Darwin's (1882) worm book

NOTES:

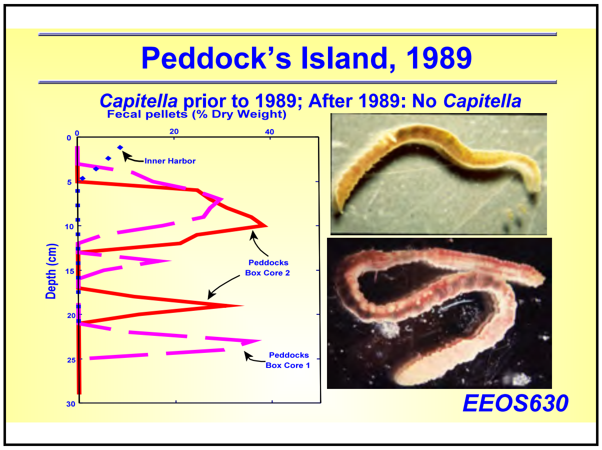


Peddocks Island

0

Slide 54 Peddocks Island

NOTES:



Peddock's Island, 1989

Capitella prior to 1989; After 1989: No *Capitella*

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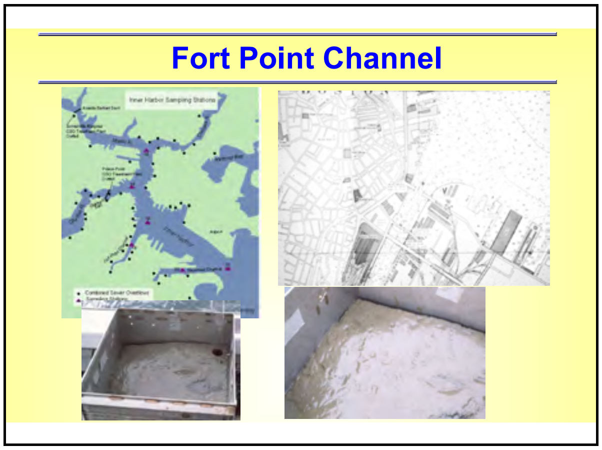
Slide 55 Peddock's Island, 1989

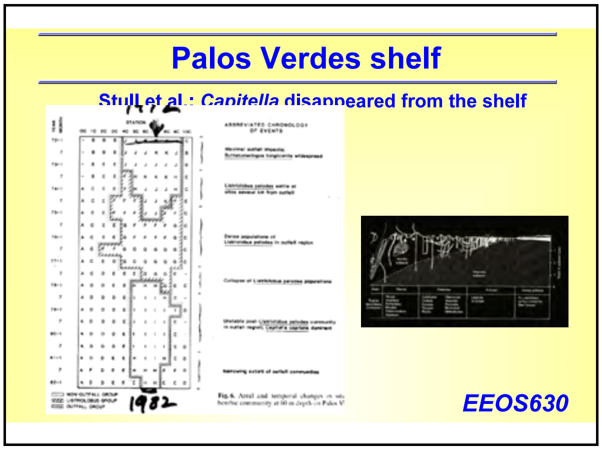
NOTES:



Fort Point Channel

Slide 56 Fort Point Channel

NOTES:



Palos Verdes shelf

Stull et al.: *Capitella* disappeared from the shelf

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Slide 57 Palos Verdes shelf

NOTES:

Benthic ecology & capping

Gallagher & Shull MIT capping workshop

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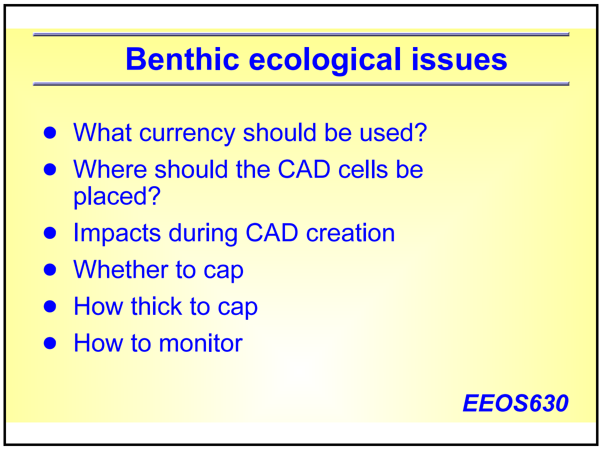
Slide 58 Benthic ecology & capping

NOTES:



Benthic ecological issues

- What currency should be used?
- Where should the CAD cells be placed?
- Impacts during CAD creation
- Whether to cap
- How thick to cap
- How to monitor

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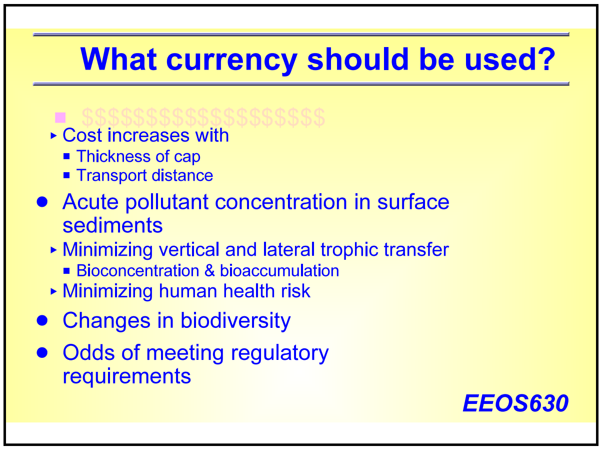
Slide 59 Benthic ecological issues

NOTES:



What currency should be used?

- $$$$$$$$$$$$$$$$$$$
  - Cost increases with
    - Thickness of cap
    - Transport distance
- Acute pollutant concentration in surface sediments
  - Minimizing vertical and lateral trophic transfer
    - Bioconcentration & bioaccumulation
  - Minimizing human health risk
- Changes in biodiversity
- Odds of meeting regulatory requirements

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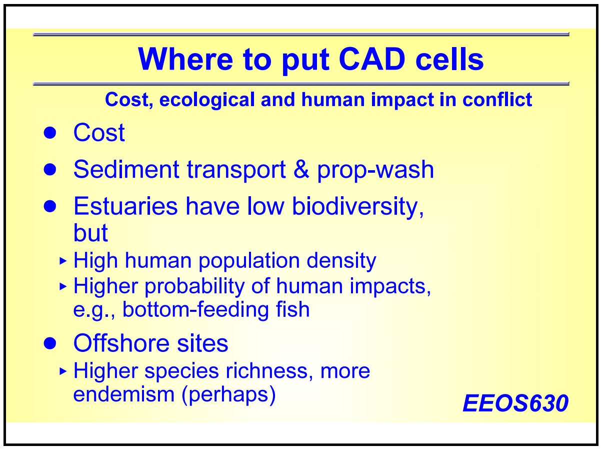
Slide 60 What currency should be used?

NOTES:



Where to put CAD cells

Cost, ecological and human impact in conflict

- Cost
- Sediment transport & prop-wash
- Estuaries have low biodiversity, but
  - High human population density
  - Higher probability of human impacts, e.g., bottom-feeding fish
- Offshore sites
  - Higher species richness, more endemism (perhaps)

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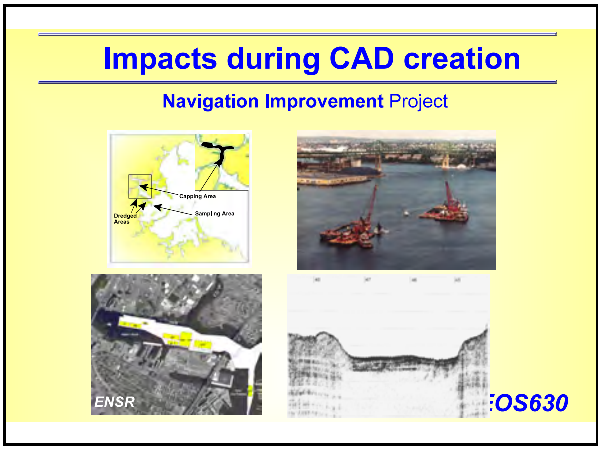
Slide 61 Where to put CAD cells

NOTES:

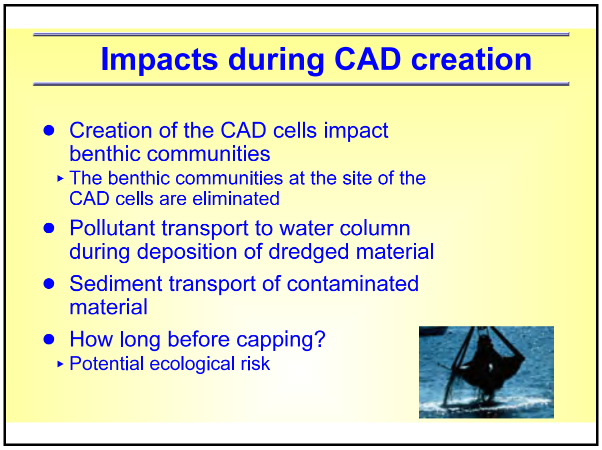


Impacts during CAD creation

Navigation Improvement Project

Slide 62 Impacts during CAD creation

NOTES:

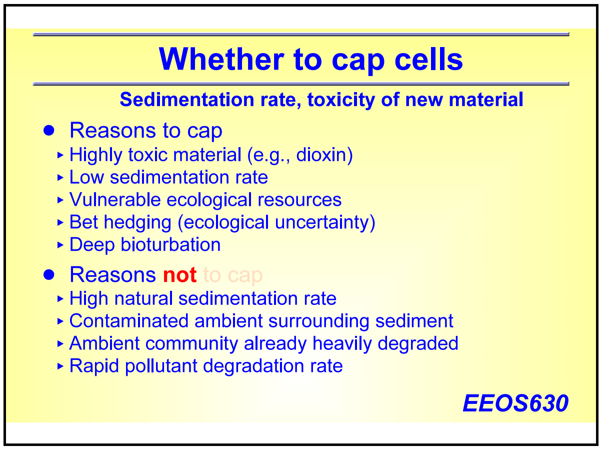


Impacts during CAD creation

- Creation of the CAD cells impact benthic communities
  - The benthic communities at the site of the CAD cells are eliminated
- Pollutant transport to water column during deposition of dredged material
- Sediment transport of contaminated material
- How long before capping?
  - Potential ecological risk

Slide 63 Impacts during CAD creation

NOTES:



Whether to cap cells

Sedimentation rate, toxicity of new material

- Reasons to cap
  - Highly toxic material (e.g., dioxin)
  - Low sedimentation rate
  - Vulnerable ecological resources
  - Bet hedging (ecological uncertainty)
  - Deep bioturbation
- Reasons **not** to cap
  - High natural sedimentation rate
  - Contaminated ambient surrounding sediment
  - Ambient community already heavily degraded
  - Rapid pollutant degradation rate

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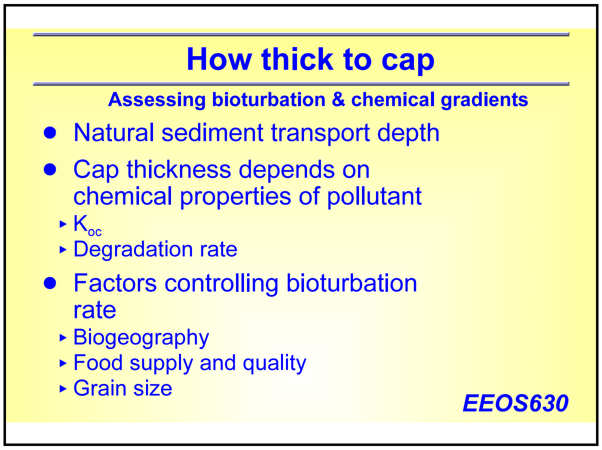
Slide 64 Whether to cap cells

NOTES:



How thick to cap

Assessing bioturbation & chemical gradients

- Natural sediment transport depth
- Cap thickness depends on chemical properties of pollutant
  - K_{oc}
  - Degradation rate
- Factors controlling bioturbation rate
  - Biogeography
  - Food supply and quality
  - Grain size

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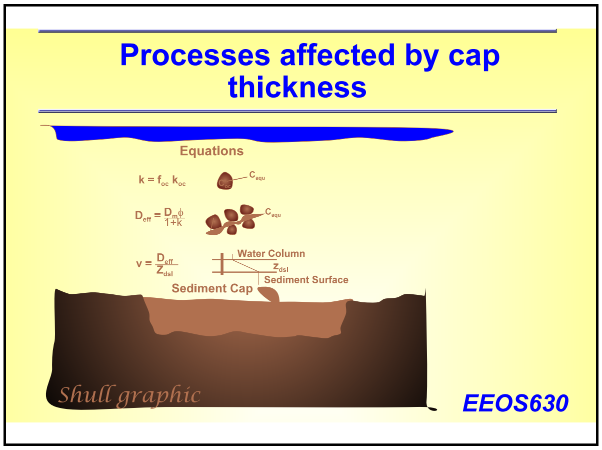
Slide 65 How thick to cap

NOTES:



Processes affected by cap thickness

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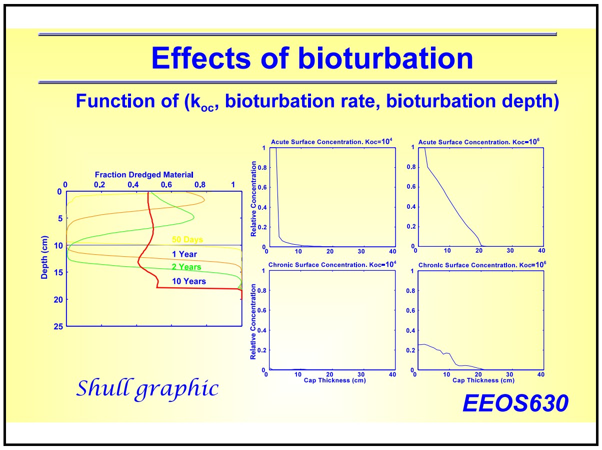
Slide 66 Processes affected by cap thickness

NOTES:



Effects of bioturbation

Function of (k_{oc}, bioturbation rate, bioturbation depth)

Shull graphic

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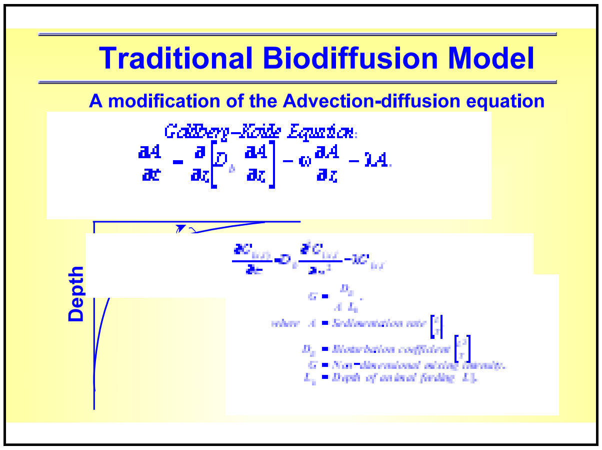
Slide 67 Effects of bioturbation

NOTES:



Traditional Biodiffusion Model

A modification of the Advection-diffusion equation

Goldberg–Koide Equation:

$$\frac{\partial A}{\partial t} = \frac{\partial}{\partial z}\left[D_b \frac{\partial A}{\partial z}\right] - \omega \frac{\partial A}{\partial z} - \lambda A.$$

$$\frac{\partial C_{(z,t)}}{\partial t} = D_b \frac{\partial^2 C_{(z,t)}}{\partial z^2} - \lambda C_{(z,t)}$$

$$G = \frac{D_B}{A\ L_B}.$$

where A = Sedimentation rate $\left[\frac{L}{T}\right]$

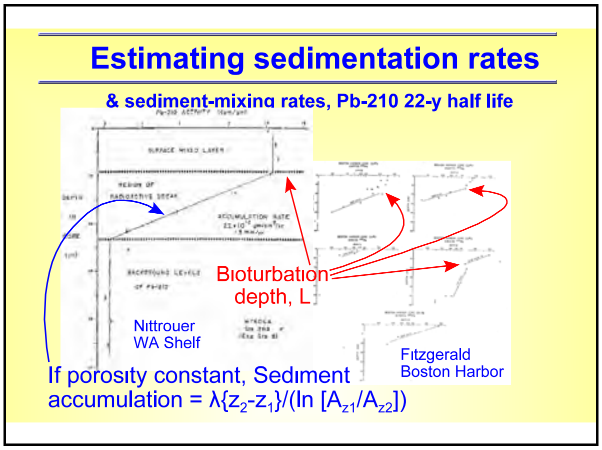
D_B = Bioturbation coefficient $\left[\frac{L^2}{T}\right]$

G = Non-dimensional mixing intensity.

L_B = Depth of animal feeding [L].

Slide 68 Traditional Biodiffusion Model

NOTES:



Estimating sedimentation rates

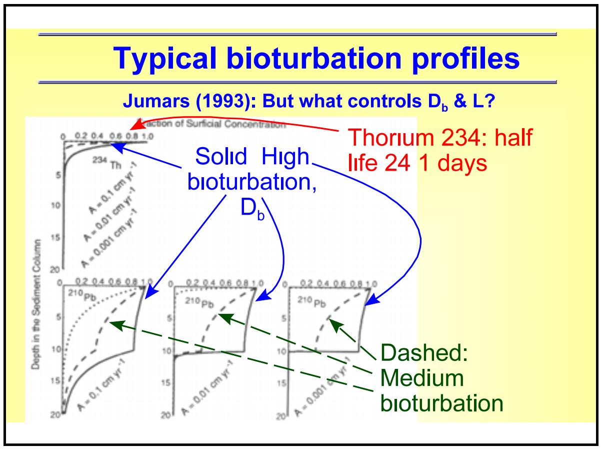
& sediment-mixing rates, Pb-210 22-y half life

If porosity constant, Sediment accumulation = $\lambda\{z_2-z_1\}/(\ln [A_{z1}/A_{z2}])$

Slide 69 Estimating sedimentation rates

NOTES:

Slide 70 Typical bioturbation profiles



Typical bioturbation profiles

Jumars (1993): But what controls D_b & L?

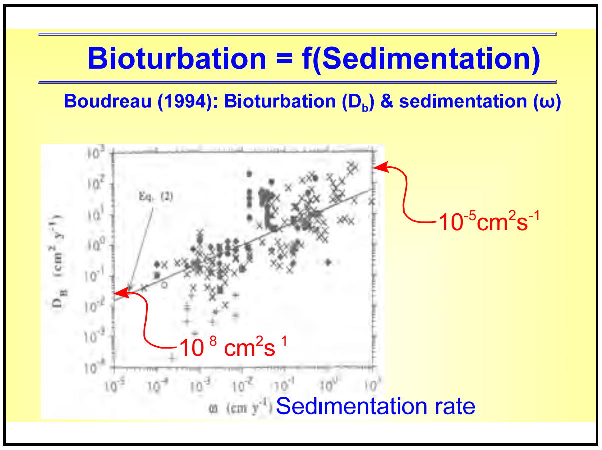
Thorium 234: half life 24 1 days

Solid High bioturbation, D_b

Dashed: Medium bioturbation

NOTES:

Slide 71 Bioturbation = f(Sedimentation)



Bioturbation = f(Sedimentation)

Boudreau (1994): Bioturbation (D_b) & sedimentation (ω)

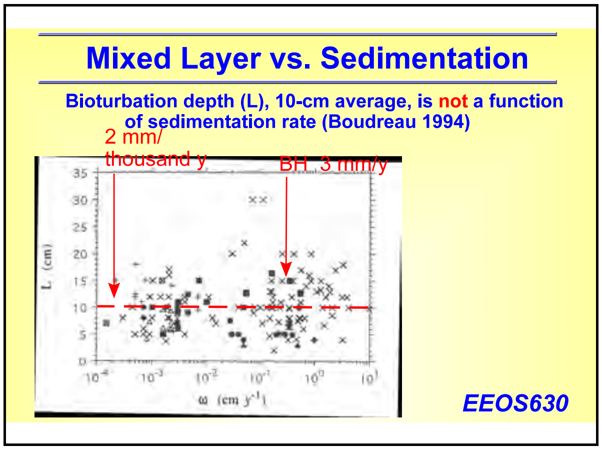
10^{-5}cm^{2}s^{-1}

10 8 cm^{2}s 1

Sedimentation rate

NOTES:

Slide 72 Mixed Layer vs. Sedimentation



Mixed Layer vs. Sedimentation

Bioturbation depth (L), 10-cm average, is not a function of sedimentation rate (Boudreau 1994)

2 mm/ thousand y

BH 3 mm/y

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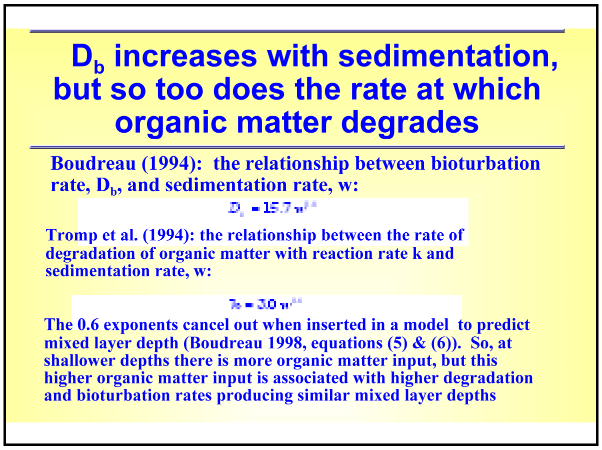
NOTES:



D_b increases with sedimentation, but so too does the rate at which organic matter degrades

Boudreau (1994): the relationship between bioturbation rate, D_b, and sedimentation rate, w:

$$D_b = 15.7 w^{0.6}$$

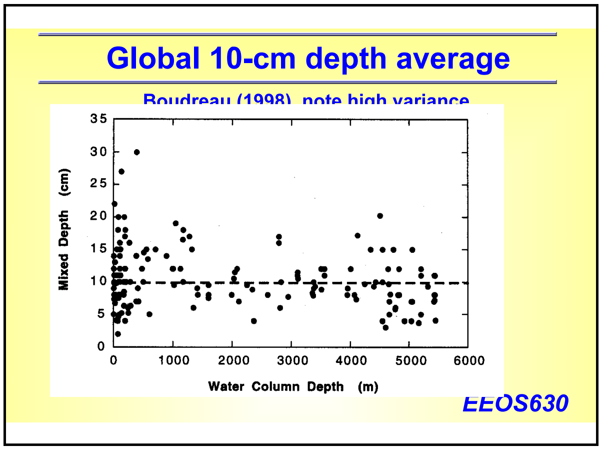
Tromp et al. (1994): the relationship between the rate of degradation of organic matter with reaction rate k and sedimentation rate, w:

$$k = 3.0 w^{0.6}$$

The 0.6 exponents cancel out when inserted in a model to predict mixed layer depth (Boudreau 1998, equations (5) & (6)). So, at shallower depths there is more organic matter input, but this higher organic matter input is associated with higher degradation and bioturbation rates producing similar mixed layer depths

Slide 73 Db increases with sedimentation, but so too does the rate at which organic matter degrades

NOTES:

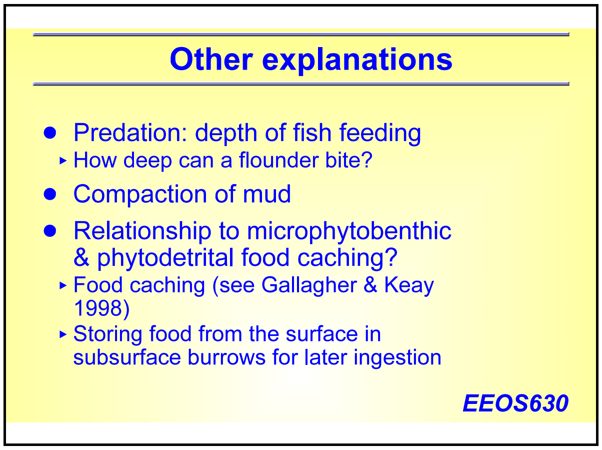


Global 10-cm depth average

Boudreau (1998), note high variance

Slide 74 Global 10-cm depth average

NOTES:



Other explanations

- Predation: depth of fish feeding
  - How deep can a flounder bite?
- Compaction of mud
- Relationship to microphytobenthic & phytodetrital food caching?
  - Food caching (see Gallagher & Keay 1998)
  - Storing food from the surface in subsurface burrows for later ingestion

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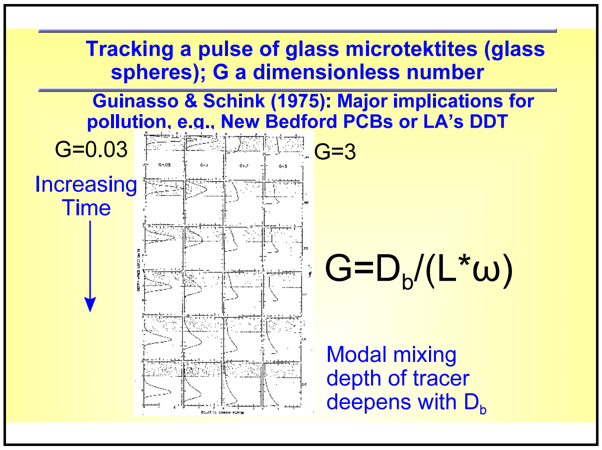
Slide 75 Other explanations

NOTES:



Tracking a pulse of glass microtektites (glass spheres); G a dimensionless number

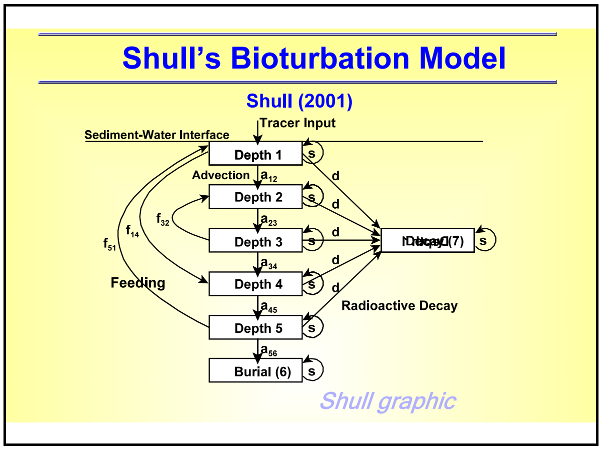
Guinasso & Schink (1975): Major implications for pollution, e.g., New Bedford PCBs or LA's DDT

$G=D_b/(L*\omega)$

Modal mixing depth of tracer deepens with D_b

Slide 76 Tracking a pulse of glass microtektites (glass spheres); G a dimensionless number

NOTES:



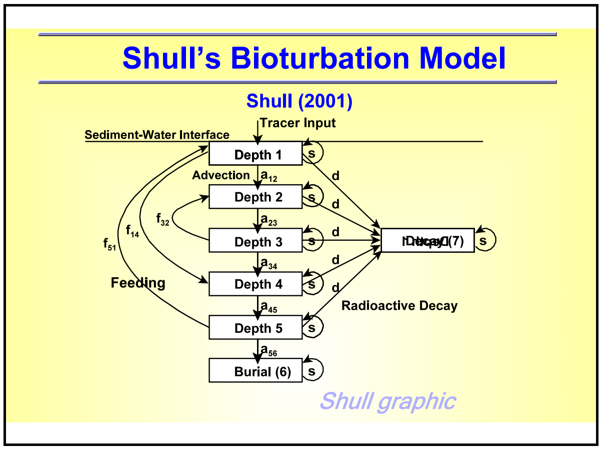
Shull's Bioturbation Model

Shull (2001)

Shull graphic

Slide 77 Shull's Bioturbation Model

NOTES:



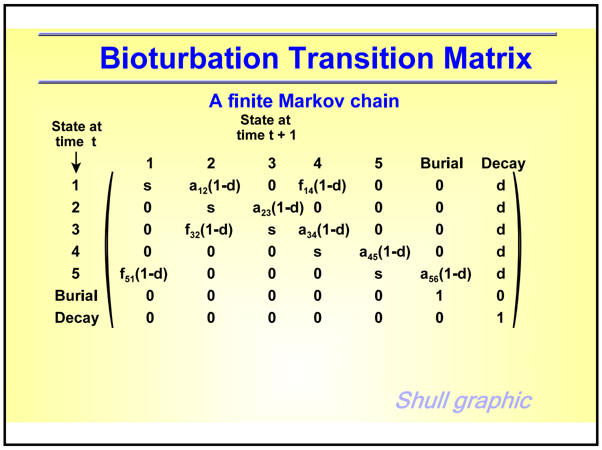
Shull's Bioturbation Model

Shull (2001)

Shull graphic

Slide 78 Shull's Bioturbation Model

NOTES:



Bioturbation Transition Matrix

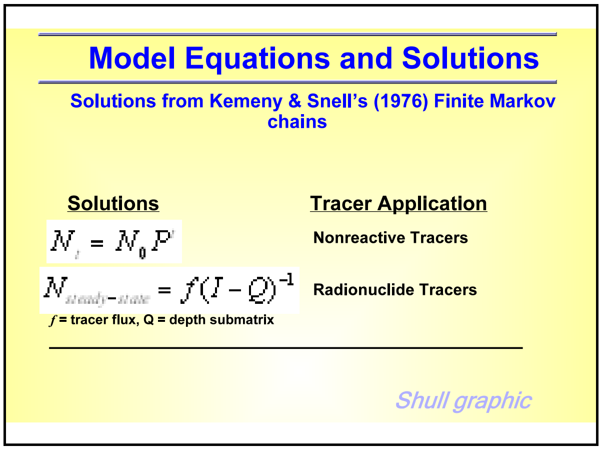
A finite Markov chain

$$\begin{array}{c|ccccccc}
\text{State at time } t \downarrow \;/\; \text{State at time } t+1 & 1 & 2 & 3 & 4 & 5 & \text{Burial} & \text{Decay} \\
\hline
1 & s & a_{12}(1-d) & 0 & f_{14}(1-d) & 0 & 0 & d \\
2 & 0 & s & a_{23}(1-d) & 0 & 0 & 0 & d \\
3 & 0 & f_{32}(1-d) & s & a_{34}(1-d) & 0 & 0 & d \\
4 & 0 & 0 & 0 & s & a_{45}(1-d) & 0 & d \\
5 & f_{51}(1-d) & 0 & 0 & 0 & s & a_{56}(1-d) & d \\
\text{Burial} & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
\text{Decay} & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{array}$$

Shull graphic

Slide 79 Bioturbation Transition Matrix

NOTES:



Model Equations and Solutions

Solutions from Kemeny & Snell's (1976) Finite Markov chains

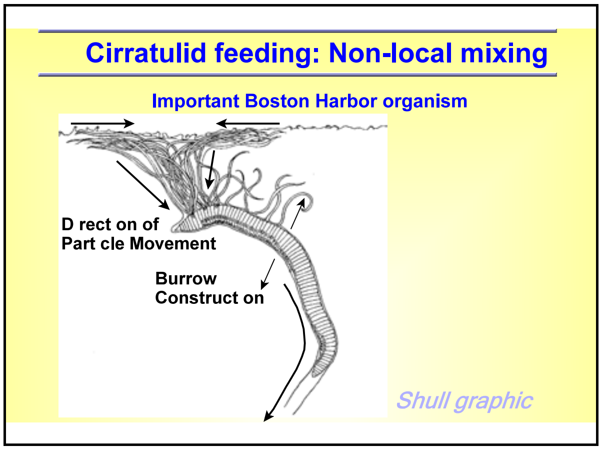
<u>Solutions</u>	<u>Tracer Application</u>
$N_t = N_0 P^t$	Nonreactive Tracers
$N_{steady-state} = f(I-Q)^{-1}$	Radionuclide Tracers

f = tracer flux, Q = depth submatrix

Shull graphic

Slide 80 Model Equations and Solutions

NOTES:



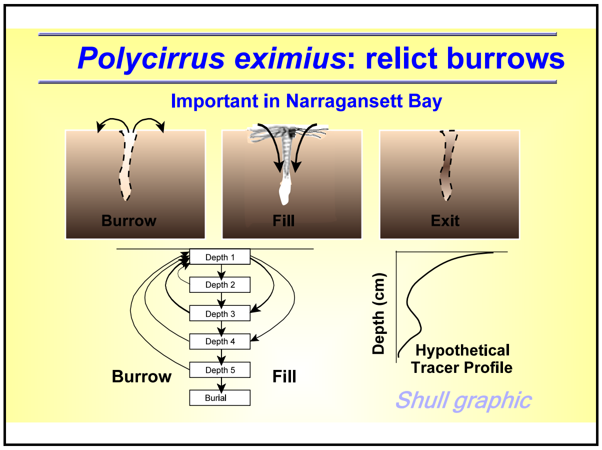
Cirratulid feeding: Non-local mixing

Important Boston Harbor organism

Shull graphic

Slide 81 Cirratulid feeding: Non-local mixing

NOTES:



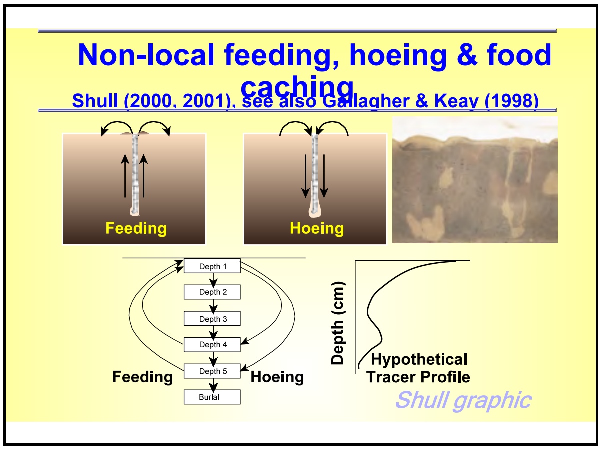
Polycirrus eximius: relict burrows

Important in Narragansett Bay

Shull graphic

Slide 82 Polycirrus eximius: relict burrows

NOTES:



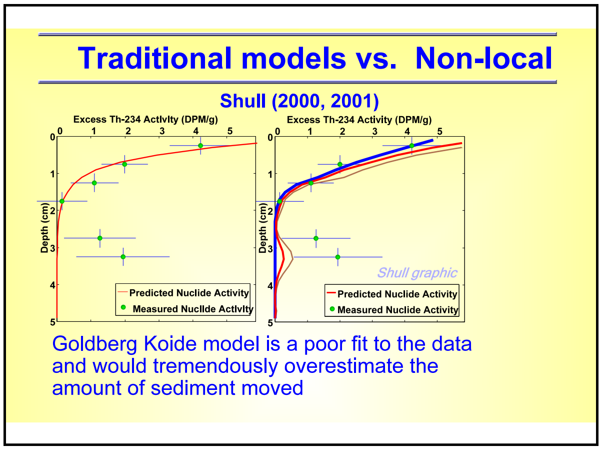
Non-local feeding, hoeing & food caching

Shull (2000, 2001), see also Gallagher & Keay (1998)

Shull graphic

Slide 83 Non-local feeding, hoeing & food caching

NOTES:



Traditional models vs. Non-local

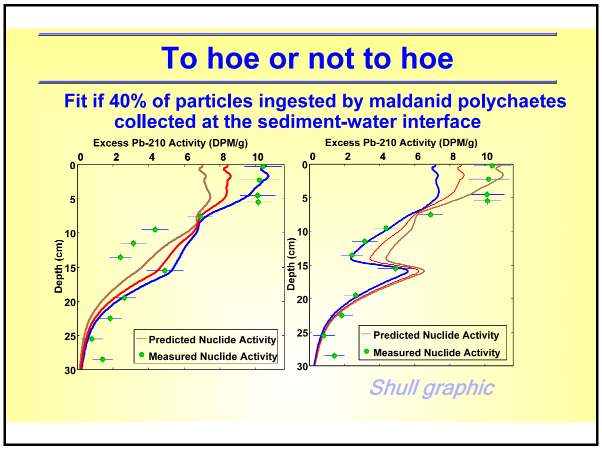
Shull (2000, 2001)

Shull graphic

Goldberg Koide model is a poor fit to the data and would tremendously overestimate the amount of sediment moved

Slide 84 Traditional models vs. Non-local

NOTES:



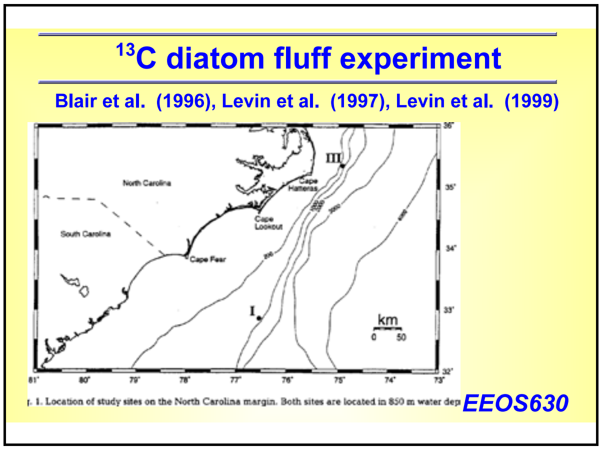
To hoe or not to hoe

Fit if 40% of particles ingested by maldanid polychaetes collected at the sediment-water interface

Shull graphic

Slide 85 To hoe or not to hoe

NOTES:



^{13}C diatom fluff experiment

Blair et al. (1996), Levin et al. (1997), Levin et al. (1999)

1. Location of study sites on the North Carolina margin. Both sites are located in 850 m water dep

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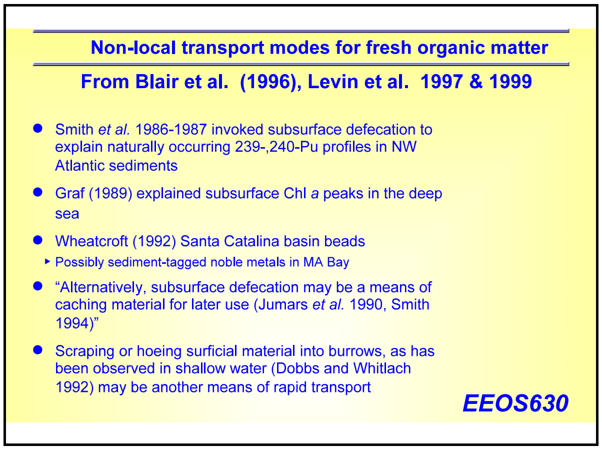
Slide 86 13C diatom fluff experiment

NOTES:



Non-local transport modes for fresh organic matter

From Blair et al. (1996), Levin et al. 1997 & 1999

- Smith *et al.* 1986-1987 invoked subsurface defecation to explain naturally occurring 239-,240-Pu profiles in NW Atlantic sediments
- Graf (1989) explained subsurface Chl *a* peaks in the deep sea
- Wheatcroft (1992) Santa Catalina basin beads
  - Possibly sediment-tagged noble metals in MA Bay
- "Alternatively, subsurface defecation may be a means of caching material for later use (Jumars *et al.* 1990, Smith 1994)"
- Scraping or hoeing surficial material into burrows, as has been observed in shallow water (Dobbs and Whitlach 1992) may be another means of rapid transport

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Slide 87 Non-local transport modes for fresh organic matter

NOTES: