Overview

Definitions

Export flux - deposition to the base of the euphotic zone

Gross and net sedimentation

Sediment trap methods

Design - rotating cups

Problems - hydrodynamics, resuspension

Swimmers

Poisons

Sedimentation

Calibration

Magnitude re primary production

Seasonal dynamics

Particle aggregation and transparent exoplymer particles (TEP)

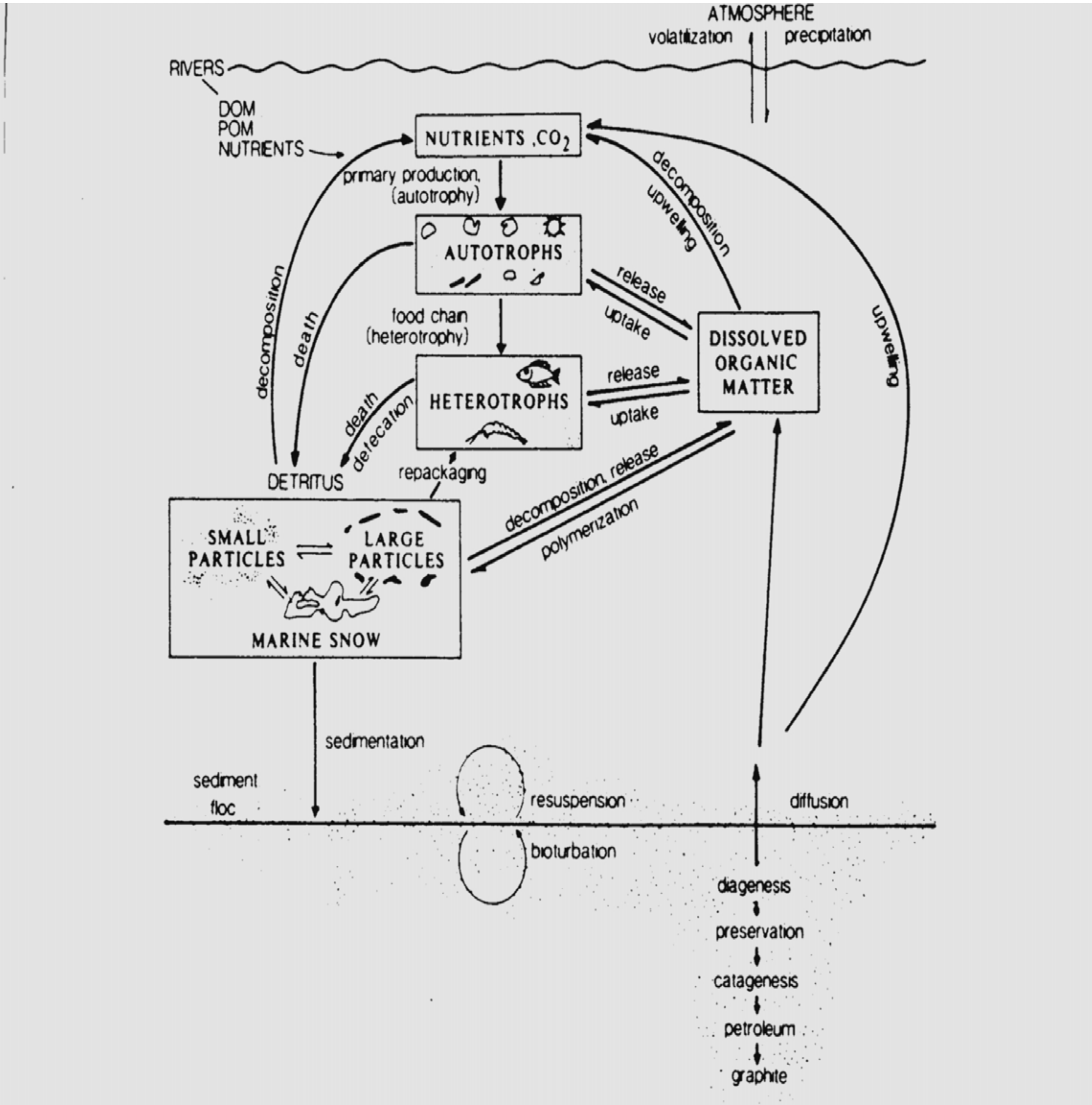
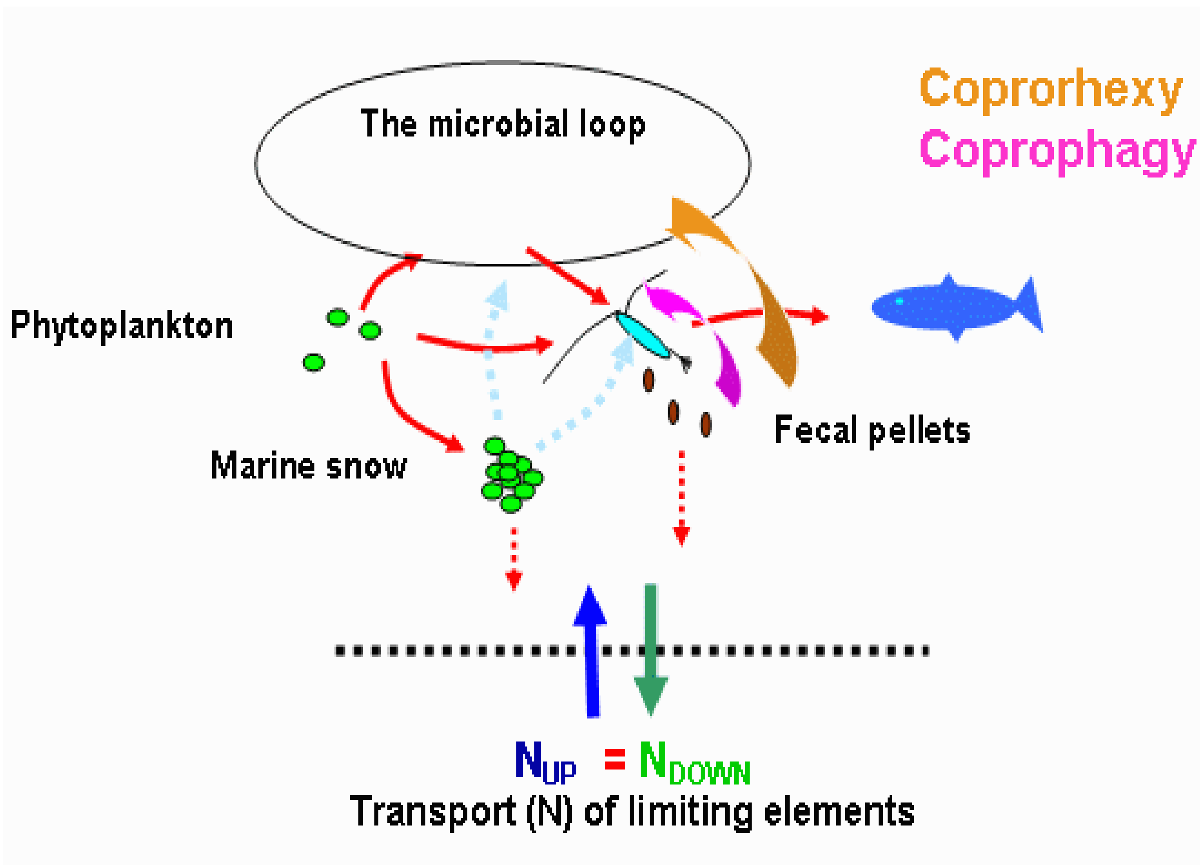


Figure 1. Schematic of the organic matter cycle in the ocean. DOM, Dissolved organic matter; POM, particulate organic matter.


Coprorhexy
Coprophagy
The microbial loop
Phytoplankton
Marine snow
Fecal pellets
N_UP = N_DOWN
Transport (N) of limiting elements

Particle types and definitions

Sources: sediment, algae, bacteria, protozoans, mucus, macrophyte detritus, fecal pellets, other debris

Suspended particulate matter (SPM) = Total PM (TPM) = turbidity, usually mg l^{-1}

POM = Pariculate organic matter = %organic * SPM
PIM = Particulate inorganic matter (ash)
PIM + POM = TPM

POC = Particulate organic carbon
PIC = Particulate inorganic carbon
C/N = Carbon : Nitrogen

Chl = Chlorophyll, μg l^{-1}
CPE = Chloroplastic equivalents = Chl + Phaeo

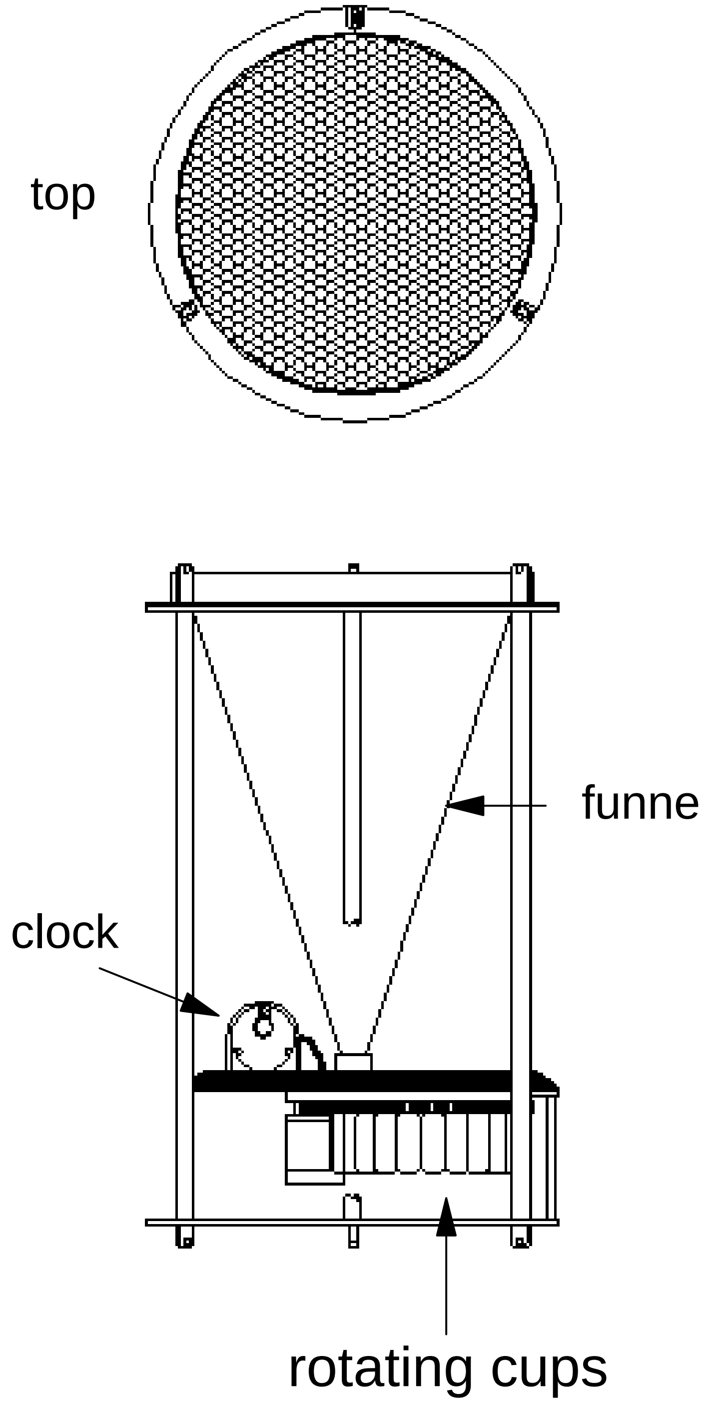
Chl/C - variable, 20-80

Sinking rate (ω_s) for spherical particles according to Stokes Law:

$$\omega_s = [(\rho_p - \rho_w)\, g\, d^2]/18\,\mu$$

where ρ_p is particle ρ_w is fluid density, g is gravity, d is particle diameter, and μ is dynamic viscosity. In natural flocs, particle shape and the composite density that arise from organic and inorganic components makes Stokes settling difficult to apply.

Particles sink at a rate of about 1 m d^{-1} (phytoplankton cells) to 100 m d^{-1} (fecal pellets); blooms can take a long time to reach the seafloor!


top
funnel
clock
rotating cups


U.S.
COAST
GUARD

Devices used for particle concentration and flux

Transmissometer
Optical backscatter
Nephelometer
Fluorometer
Multisizer
Particle imaging
Sediment traps
see review in

http://www-ocean.tamu.edu/Quarterdeck/QD5.1/richardson-5.1.html

Methods are based on inherent optical properties of the medium -

Problems with sediment traps

Undertrapping - flushing from traps

related to aspect ratio - height/mouth width > 5-8
quantified by trap Re, relating trap opening and flow speed to aspect ratio

Overtrapping - dead zones at trap mouth

Resuspension - near-bottom traps, gross vs net sedimentation

Poisons - control decomposition

Swimmers - controlled by poisoning traps and subsequent removal

Trap Errors

Traps are designed to collect only the settling particles. Sources of errors in trap measurements include:

Error Source	Error Magnitude
Swimmers	Up to a factor of 2 depending on techniques
Solubilization of carbon	A few percent per day
Hydrodynamic effects that include:	
Trap geometry	Up to several multiples of change
Flow	Zero to several multiples of change
Wave induced trap motion	Not quantified
Tilt	25-100%
Effects of brine in the trap	0-300% (60% is max seen in surface waters)

System Errors

Error Source	Error Magnitude
Vertical migration of zooplankton	8-70% of trap flux
Vertical mixing of DOC, DIC, and POC	7-25% in two estimates
Advective transport	Undetermined
Gas exchange of carbon dioxide with atmosphere	2% in one estimate

http://www-ocean.tamu.edu/JGOFS/

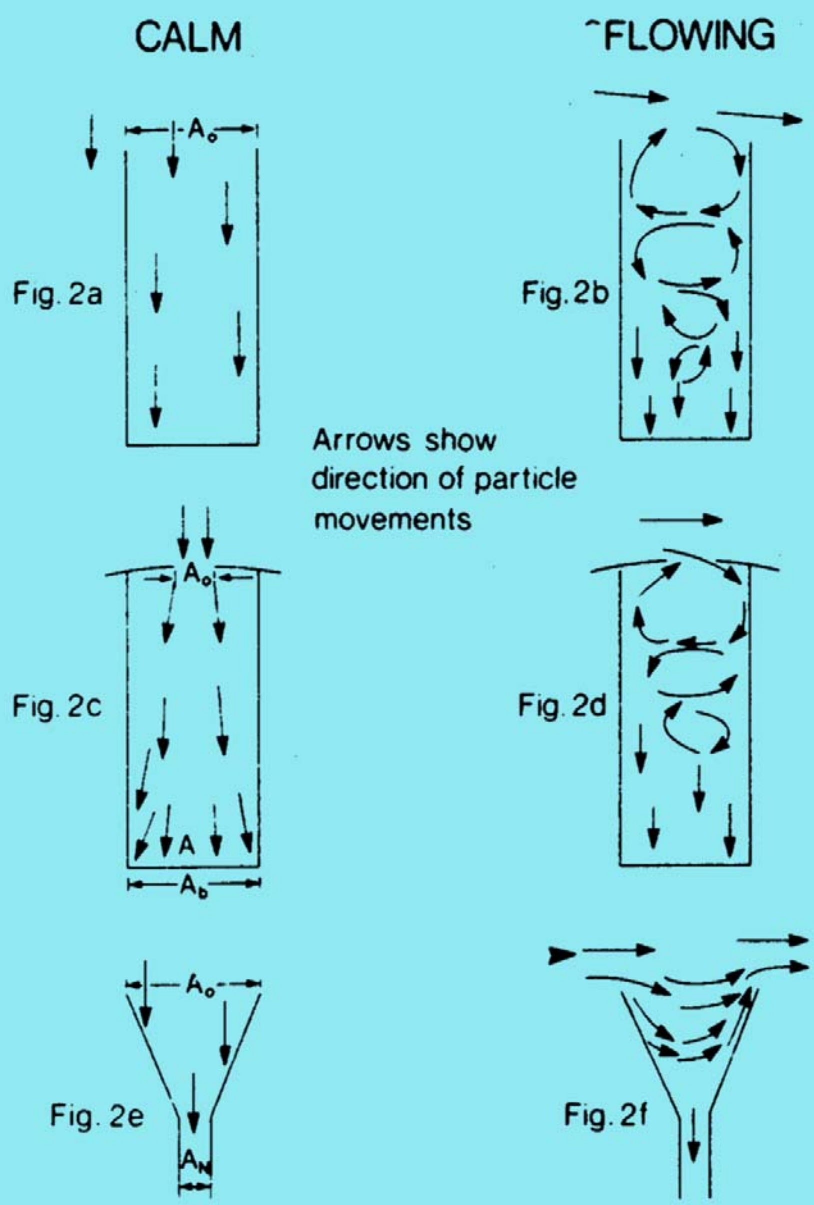


Figure 2. Schematic diagram showing probable paths of some particles.
Abb. 2. Schematische Darstellung von möglichen Wegen (Pfeilrichtungen) sedimentierender Partikel.

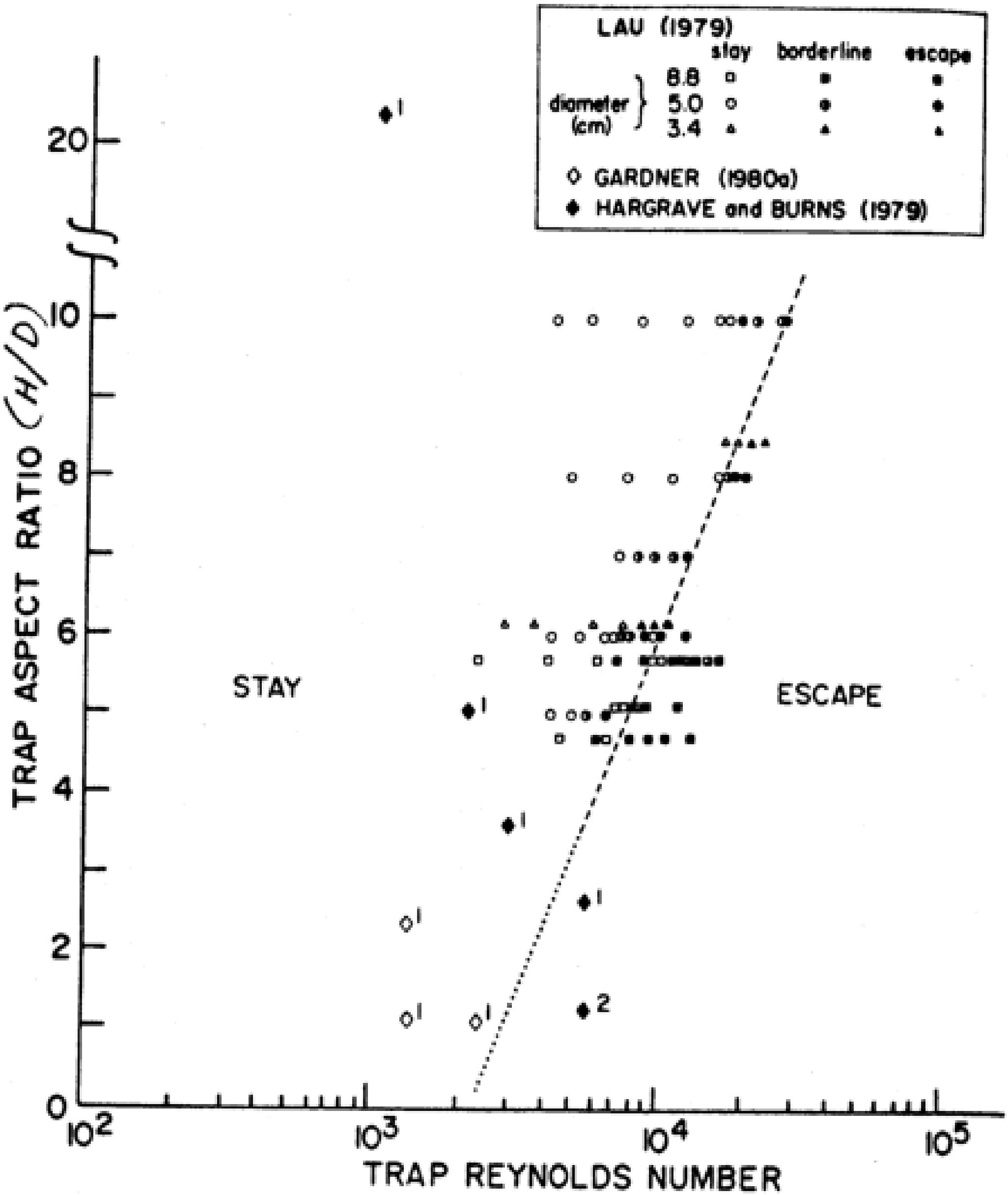


Figure 5. Behavior of oil droplets in the bottom of traps with various aspect ratios and R_t from the study of Lau (1979). "The dashed line indicates approximately the separation between the 'stay' and 'escape' regions" (Lau, 1979). The dotted part is an extension, by the present authors, of Lau's dashed line for lower aspect ratios and R_t. Also plotted on this figure are data from Gardner's (1980a) and Hargrave and Burns' (1979) studies of straight-sided cylinders (see Figs. 4 and 7, respectively). All of the cylinders tested in each of these two studies were ranked (separately for each study) in order of decreasing collection efficiency (where significant differences were demonstrated). Each rank is plotted on this figure by its coordinates for R_t and H/D. Data are plotted only for cylinders where replicates were tested and collection efficiencies are considered significantly different only if the error bars did not overlap (see Figs. 4 and 7).

$$\text{Trap } Re = \frac{UD}{\nu}$$

Reynolds number

Ratio of inertial to viscous forces

Inertia - keep moving

Viscosity - resist moving

Inertial force = ρ A U^2

Viscous force = μ A U / L

Re = ρ L U / μ where $\nu = \mu / \rho$

Re = L U / ν

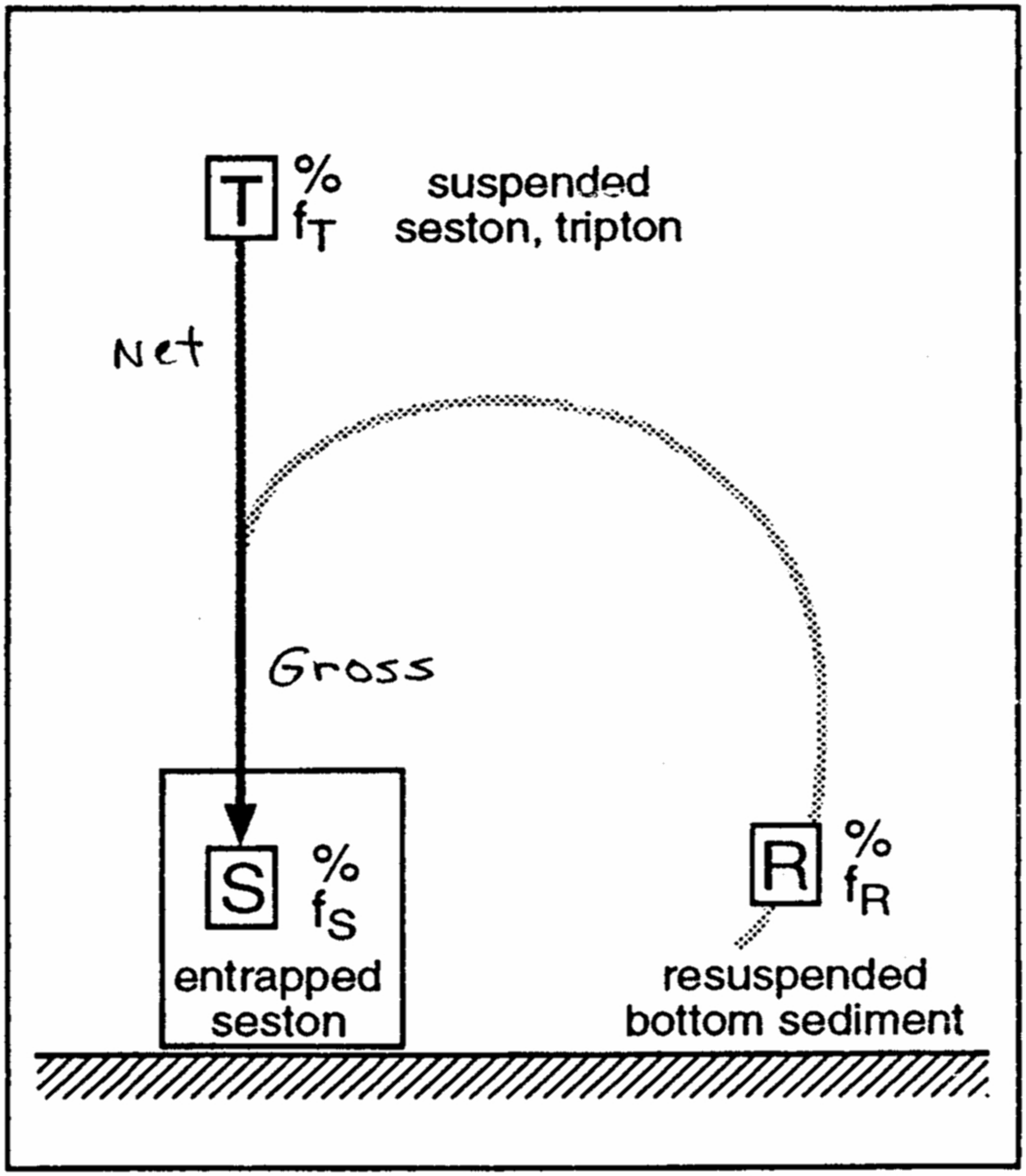


Fig. 1. Schematic view of bottom sediment resuspension measured by sediment traps exposed close to the lake bottom. (Modified from Gasith, 1975). T = suspended tripton [mg dry weight]; f_T = organic fraction of T [%]; R = resuspended bottom sediment [mg dry weight]; f_R = organic fraction of R [%]; S = entrapped settling flux [mg dry weight]; f_S = organic fraction of S [%].

$$(1)\ R = S - T; \quad (2)\ R \cdot f_R = S \cdot f_S - T \cdot f_T$$

$$(3)\ R = S \cdot \frac{(f_S - f_T)}{(f_R - f_T)}$$

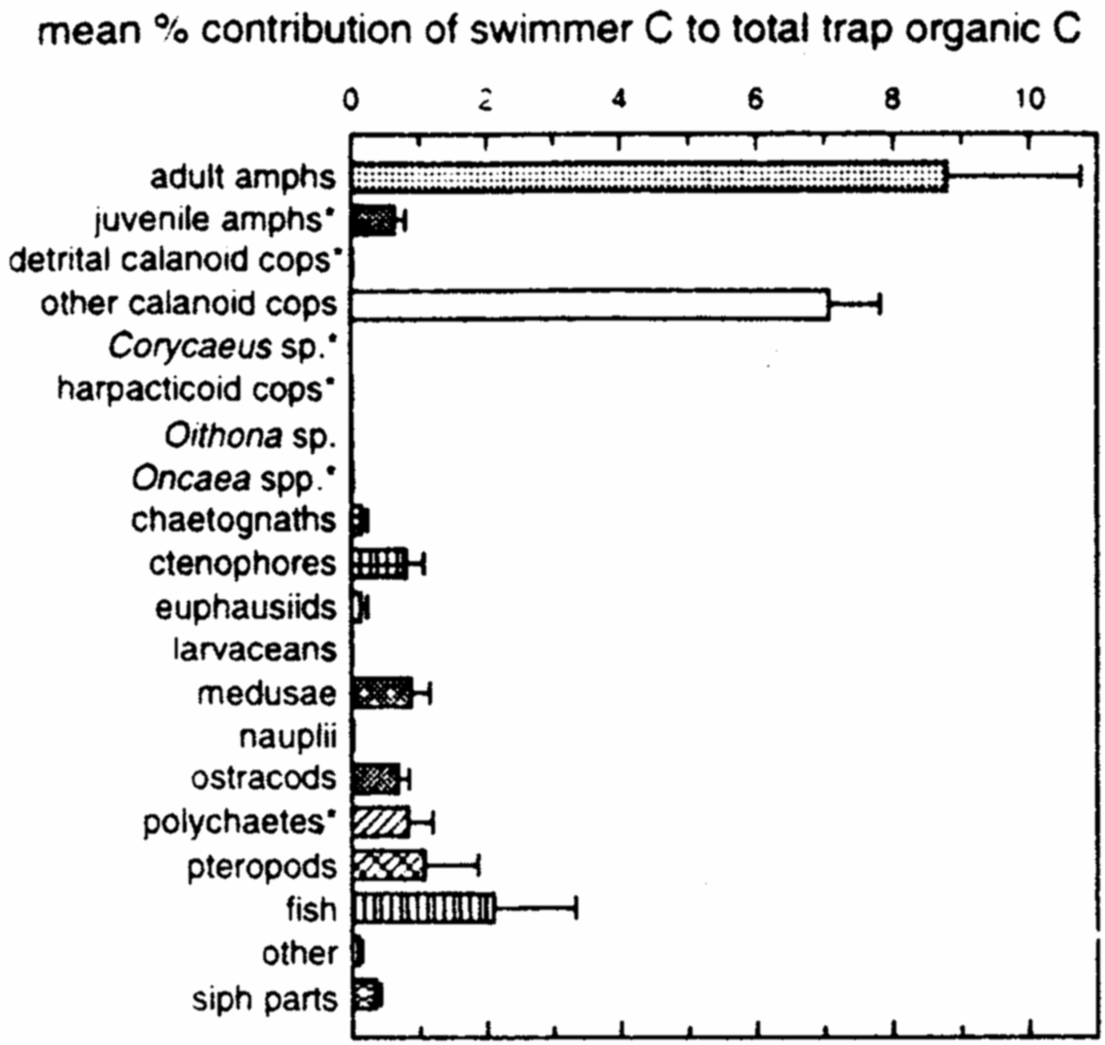


Fig. 3. Mean percent contribution of swimmer C in sediment traps for the major swimmer taxa removed from bi-weekly sediment trap samples. Calculated as (swimmer C/swimmer C + detrital C) × 100 (see text). Asterisk (*) indicates taxa we consider likely detrital associates. Amphs: amphipods; cops: copepods; detrital calanoid cops: includes *Scopalatum vorax*, *Scolecithricella* sp. (see 'Materials and methods'); other: includes juvenile ophioroids, salps, *Poeobious* sp. (worm), and isopods; siph parts: siphonophore parts. n = 29 bi-weekly samples; error bars show +1 SE

Steinberg et al. 1998 Mar. Ecol. Prog. Ser. 164: 157

Trap calibration with thorium isotopes

^{234}Th half-life = 24.1 days (daughter of ^{238}U)
Particle reactive, mostly bound

$$\text{POC flux} = (\text{POC/Th}) * P_{Th}$$

$$P_{Th} = \lambda \left[A_U - \left(A^d_{TH} + A^p_{TH}\right)\right]$$

where λ the ^{234}Th decay constant

A_U is ^{238}U activity

A^d_{TH} is ^{234}Th dissolved activity

A^p_{TH} is ^{234}Th particulate activity

^{234}Th is not in equilibrium with the rate of decay from ^{238}U, i.e. there is a deficit due to sinking of ^{234}Th on particles. Because POC and ^{234}U are both particle-associated, the deficit is an indicator of sinking flux

Bacon
et al 1996
Deep Sea Res. 43:1133

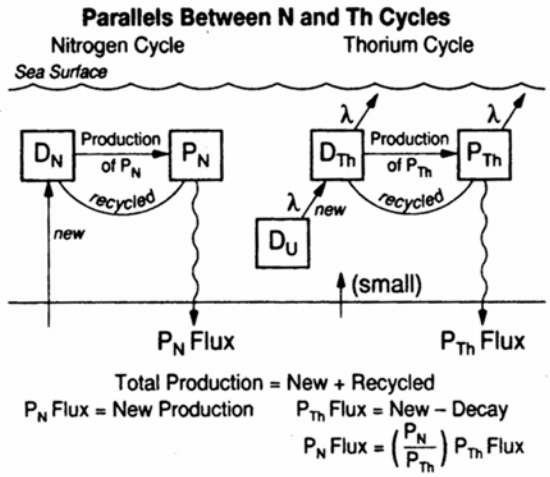
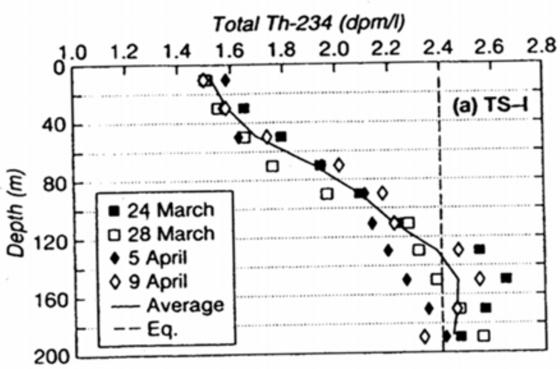
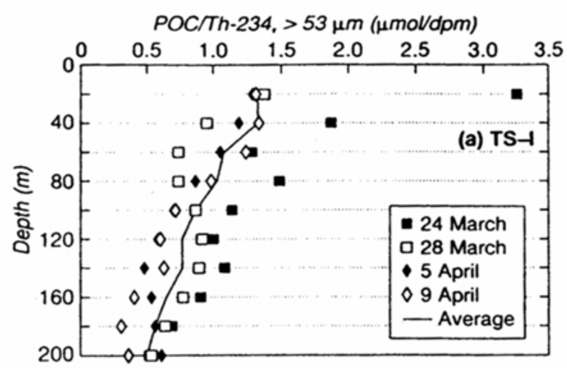


Fig. 7. Parallels between N and Th cycles in the euphotic zone.





Murray
et al.
1996
Deep Sea R
43:109

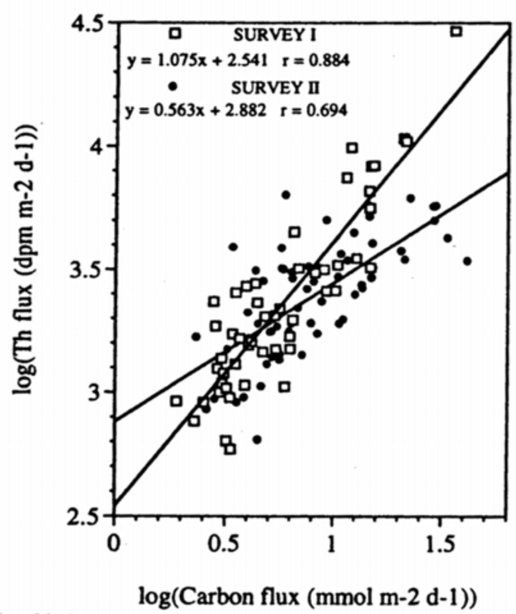


Fig. 6. Relationship between measured trap fluxes of particulate organic carbon and ^{234}Th. Log values are plotted because the histograms of both POC and ^{234}Th flux are skewed toward lower values. There is a good correlation between the particulate organic carbon and ^{234}Th fluxes on each cruise.

Magnitude and seasonal cycles

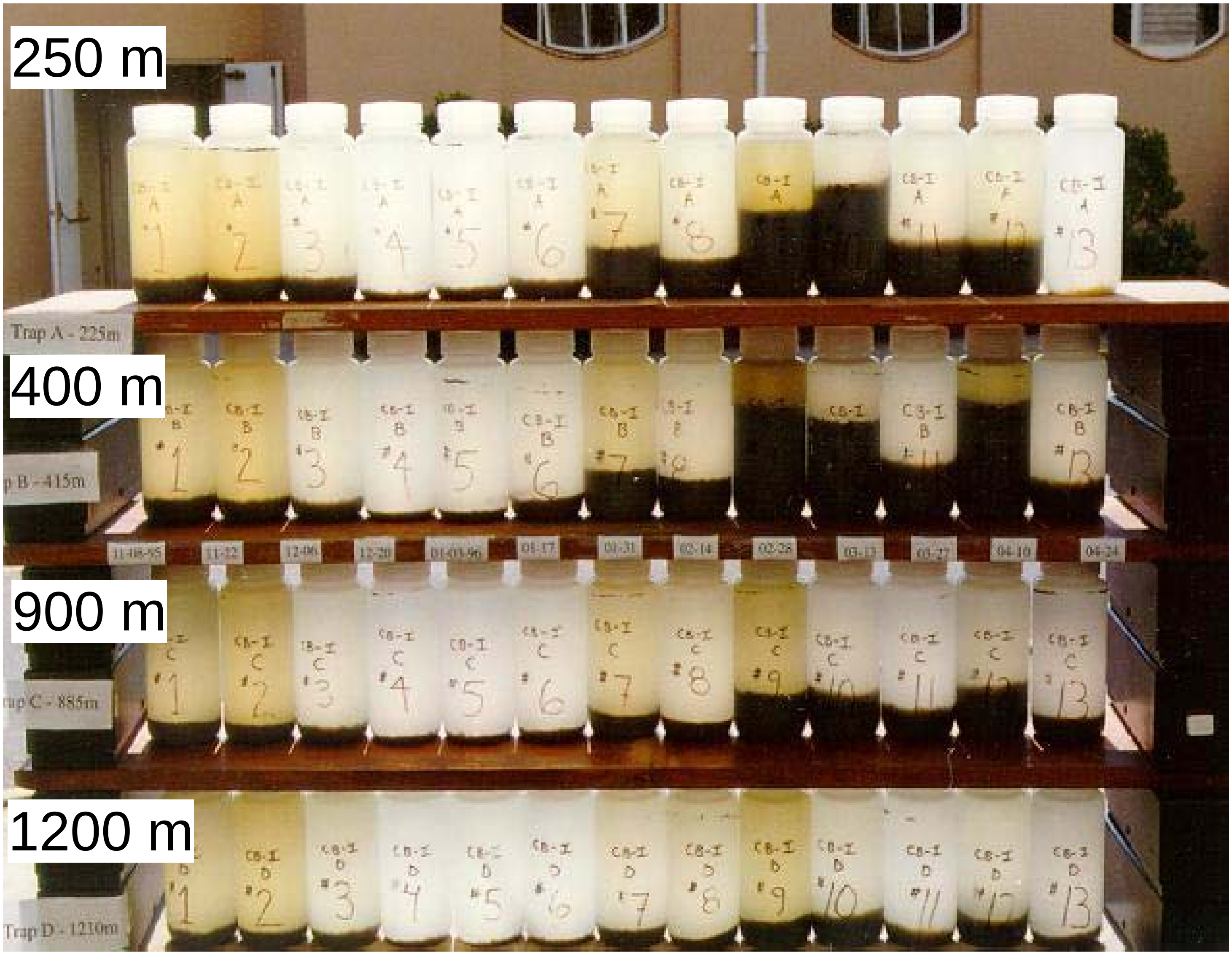
- What is falling?
  Cells, carcasses, feeding structures (salps), fecal pellets, detritus

- How much primary production is exported?
  Carbon sedimentation is proportional to primary production and falls off exponentially with depth

- How much flux is due to fecal pellets?

- Time lag of deposition re bloom periods

- Strong seasonality, especially in polar regions



Magnitude and seasonality attenuate with depth

Many moorings have more than one sediment trap attached to them. Additional traps can be used to provide replicate samples, to permit the use of different preservatives allowing for more types of analyses to be run on the sediments, or to look at the effect of increasing depth on particle flux, particularly organic carbon. In the photo below are cups from four sediment traps located at different depths (250, 400, 900 and 1200 meters) on a single mooring in the Cariaco Basin.

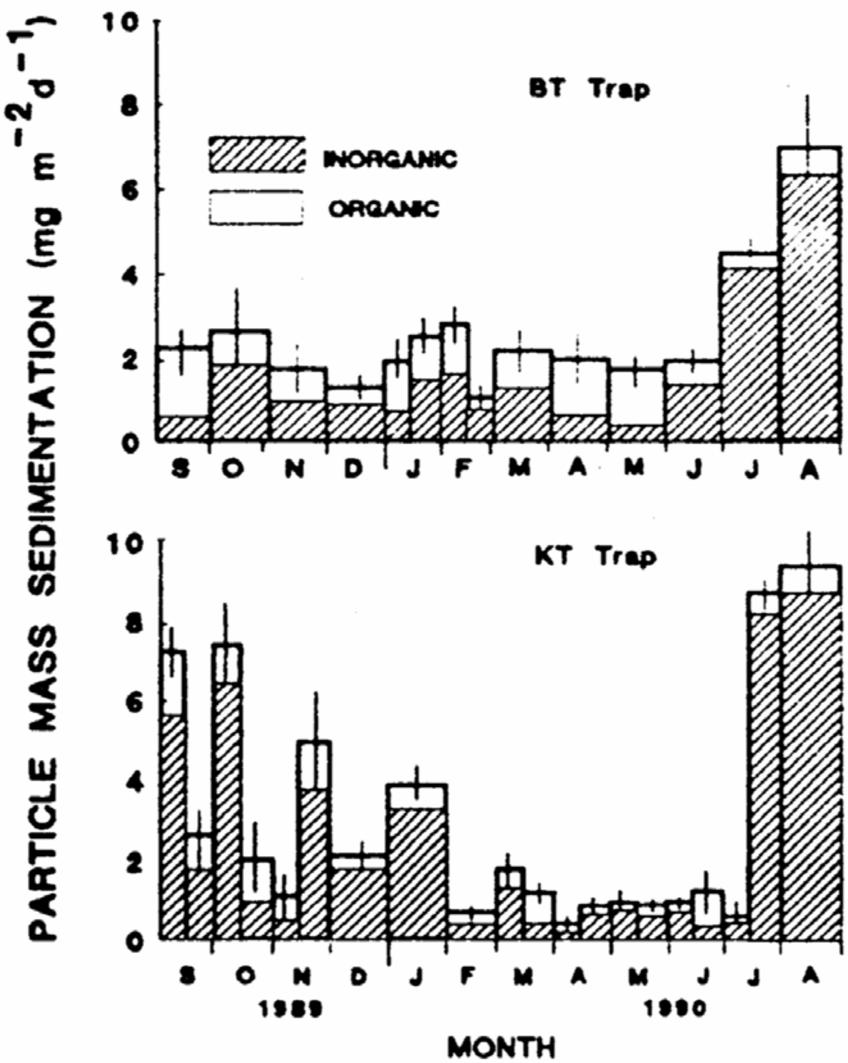


Fig. 1. Seasonal changes in sedimentation of total mass, organic and inorganic matter (unshaded and shaded histograms). Organic (organic C × 2) and inorganic [mass flux − (organic C flux × 2) − (silicon flux × 60/28)] flux was calculated for each collection period determined with two sediment traps suspended under permanent ice cover from the Canadian ice island in the Arctic Ocean in Peary Channel for 1 year. Vertical bars indicate ±1 σ of the mean value determined from dry weights of triplicate subsamples after removal of zooplankton from sedimented material.

Hargrave et al. 1994. Cont. Shelf Res. 14: 279

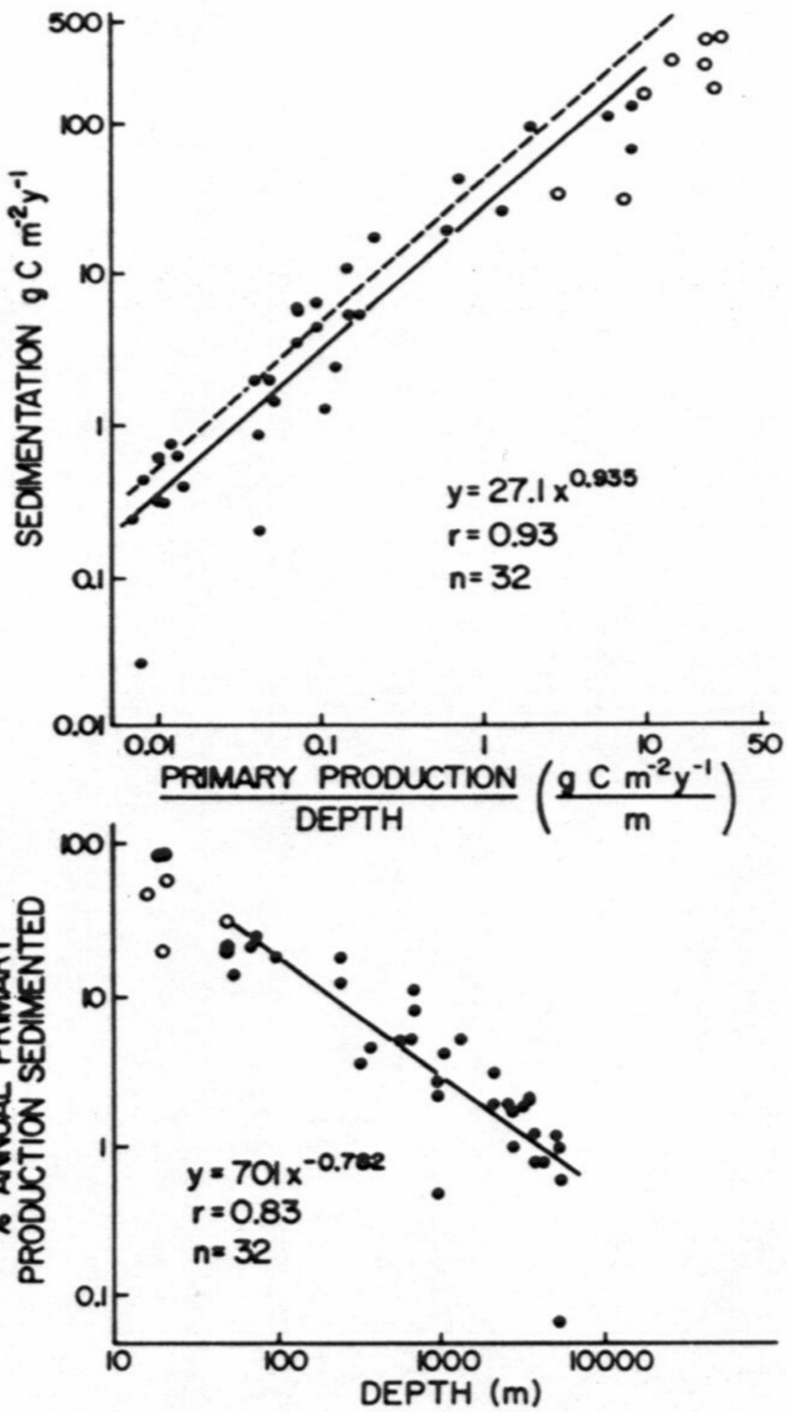


FIG. 101. Comparisons of estimates of annual sedimentation of particulate organic carbon and the ratio of phytoplankton production:water column depth (upper panel) and annual sedimentation expressed as a percentage of annual carbon production plotted against depth (lower panel) from data tabulated in Suess (1980). Measurements in areas where depth was <50 m (open circles) are not included in the regression

Table 2. Percentage contribution of fecal carbon production (FCP) and sedimentation (FCS) of total and primary sedimentation of particulate organic carbon ($POCS_{tot}$ and $POCS_{prim}$) in different seasons and study areas.

Station	Season	FCP : $POCS_{tot}$ (%)	FCP : $POCS_{prim}$ (%)	FCS : $POCS_{tot}$ (%)	FCS : $POCS_{prim}$ (%)
Bay	Spring	12.9	166.1	0.040	0.514
	Summer	8.2	96.3	0.015	0.180
	Autumn	11.3	157.9	0.021	0.301
Archipelago	Spring	3.8	8.7	0.003	0.008
	Summer	3.5	16.1	0.019	0.087
Open sea	Spring	5.0	9.0	0.005	0.009
	Summer	17.3	32.8	0.016	0.031
	Autumn	4.1	22.7	0.010	0.057

Vitasalo et al. 1999. Limnol. Oceanogr. 44: 1388

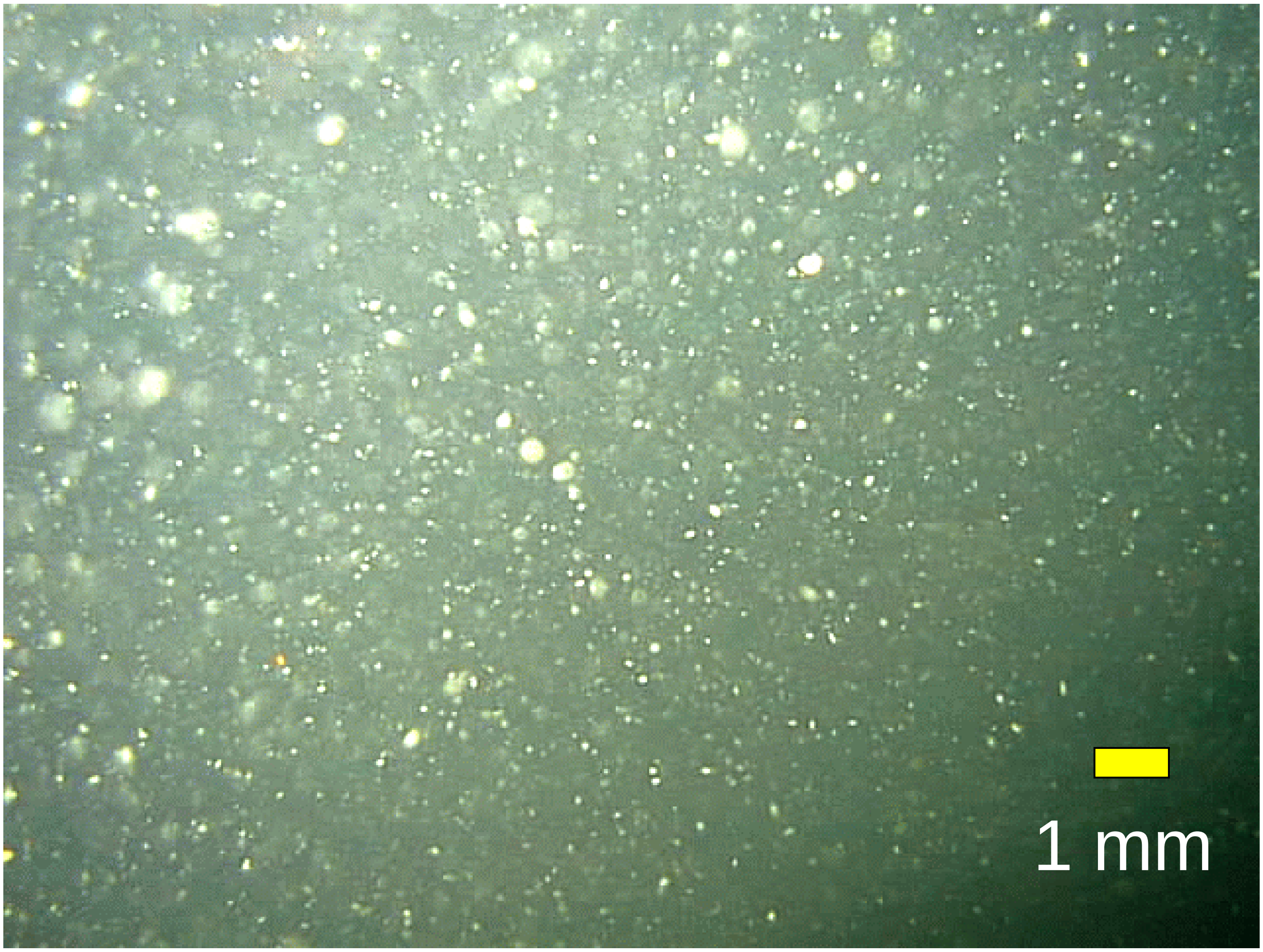
Particle aggregation and deposition

- Organic particles are sticky due to TEP

- Many (most?) particles are aggregated, especially as blooms senesce and TEP increases

- Aggregates are hard to quantify - photos are biased toward larger flocs; smaller flocs less known. The traditional Coulter Counter particle sizing method breaks up flocs.

- Aggregates are made of particles of varying density (TEP, silt, etc.), so their volume or mass is usually < D^3. This power is called the fractal index.



Flocs through the flocatron window

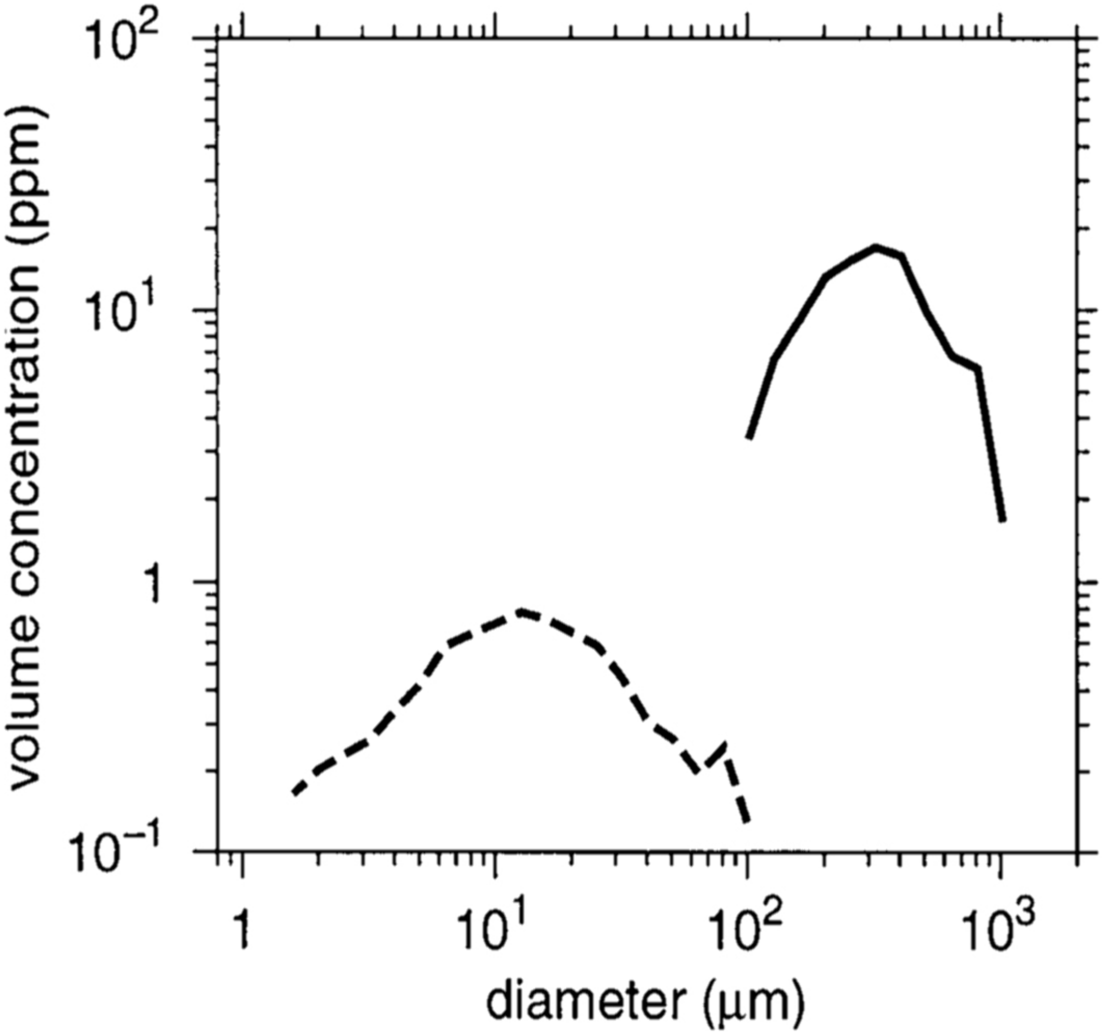


Figure 4.1 Total suspended size-spectra from the BBL in St. John Harbour, New Brunswick, show that in situ floc sizes estimated photographically (solid line) are 1-2 orders of magnitude larger than sizes estimated with a Coulter Counter (dashed line). (Data are from Milligan, 1996).

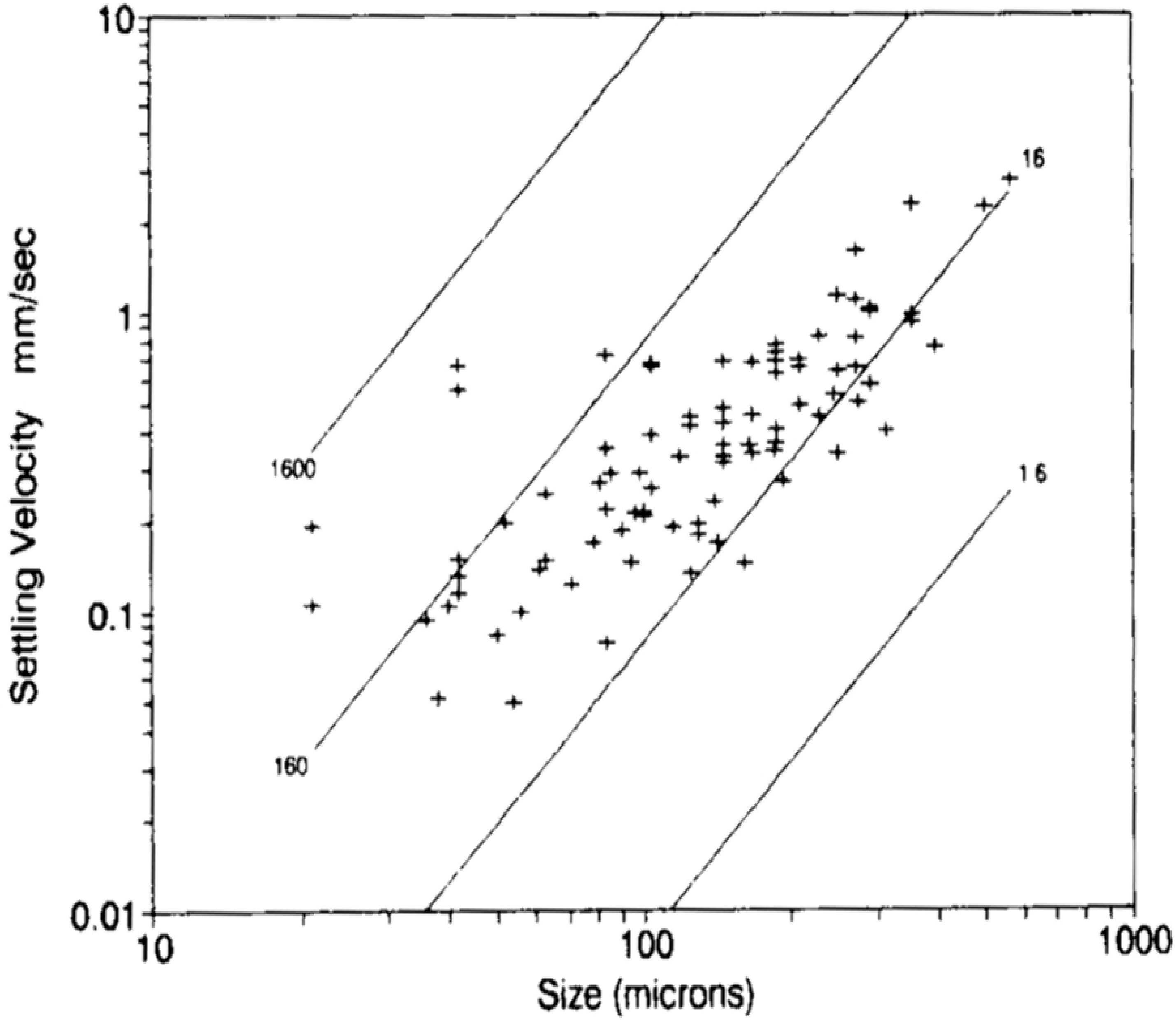


Fig. 6. Variations in settling velocity with floc size. Diagonal lines represent calculated effective density (kg m^{-3}).

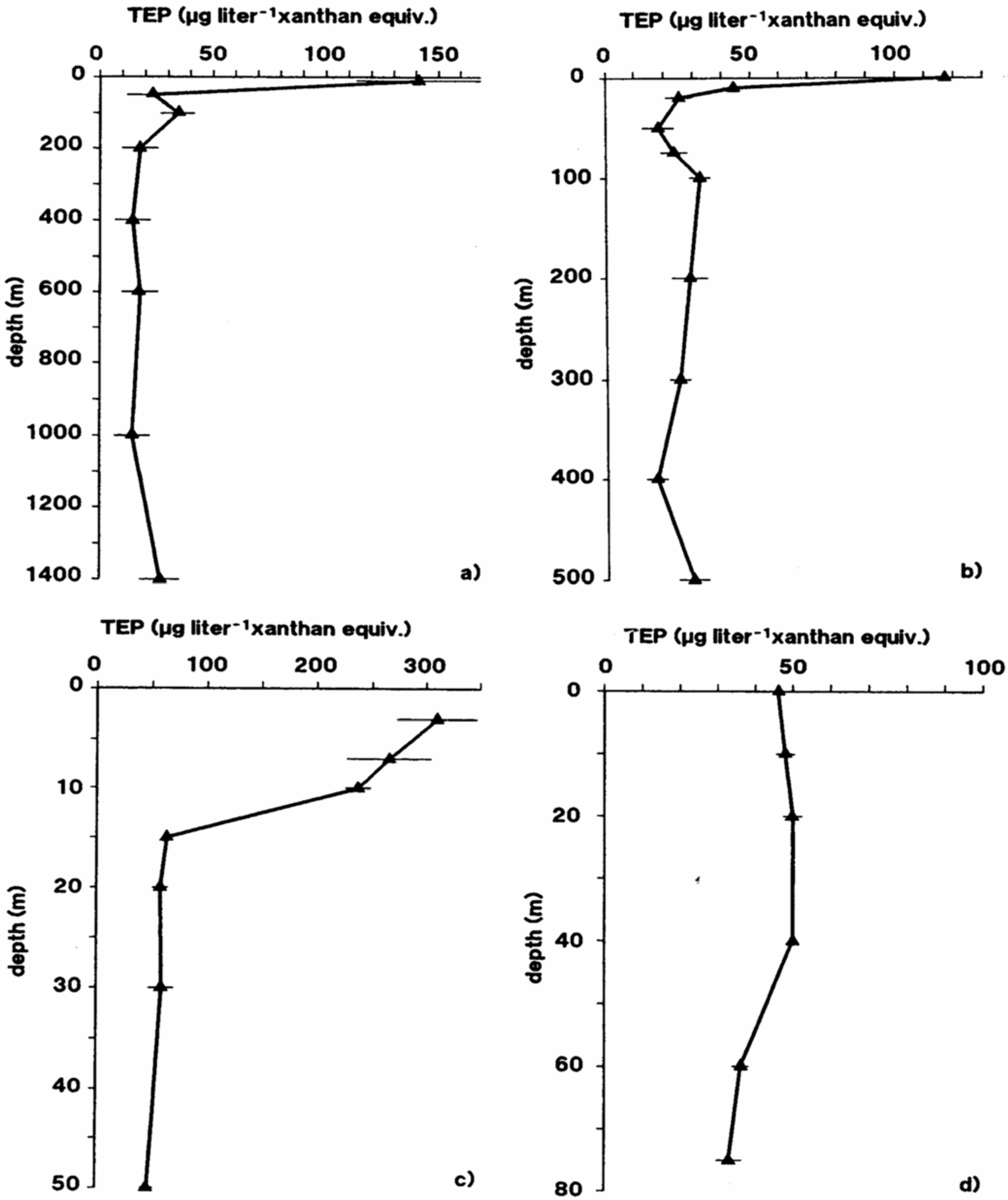
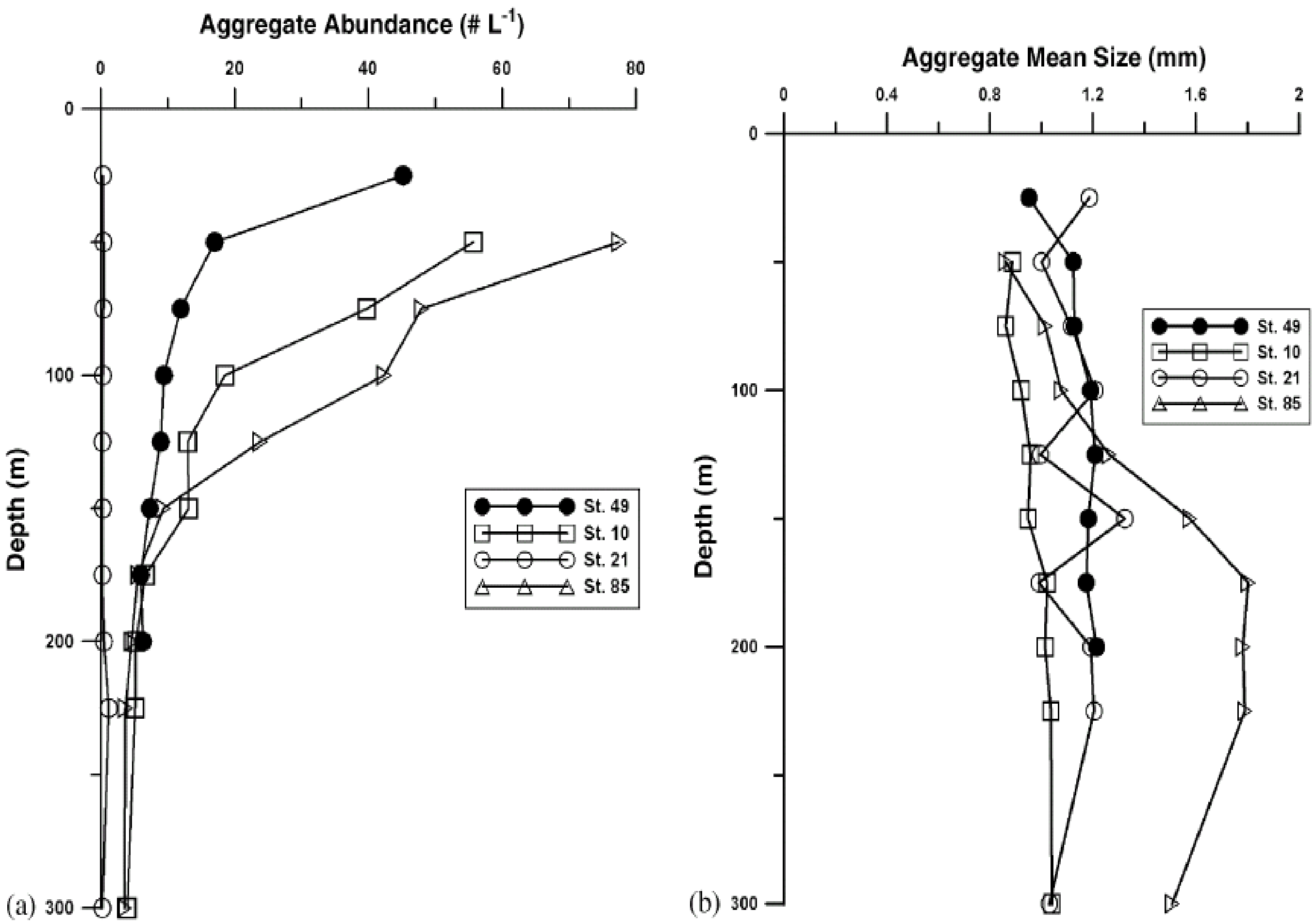


Fig. 6. Vertical distribution of TEP during summer in the Santa Barbara Channel, June 1993 (a, b), during upwelling in Monterey Bay, July 1993 (c), and during winter in the Santa Barbara Channel, March 1994 (d).


Aggregate Abundance (# L-1)
0
20
40
60
80
0
100
200
300
Depth (m)
St. 49
St. 10
St. 21
St. 85
(a)
Aggregate Mean Size (mm)
0
0.4
0.8
1.2
1.6
2
0
100
200
300
Depth (m)
St. 49
St. 10
St. 21
St. 85
(b)