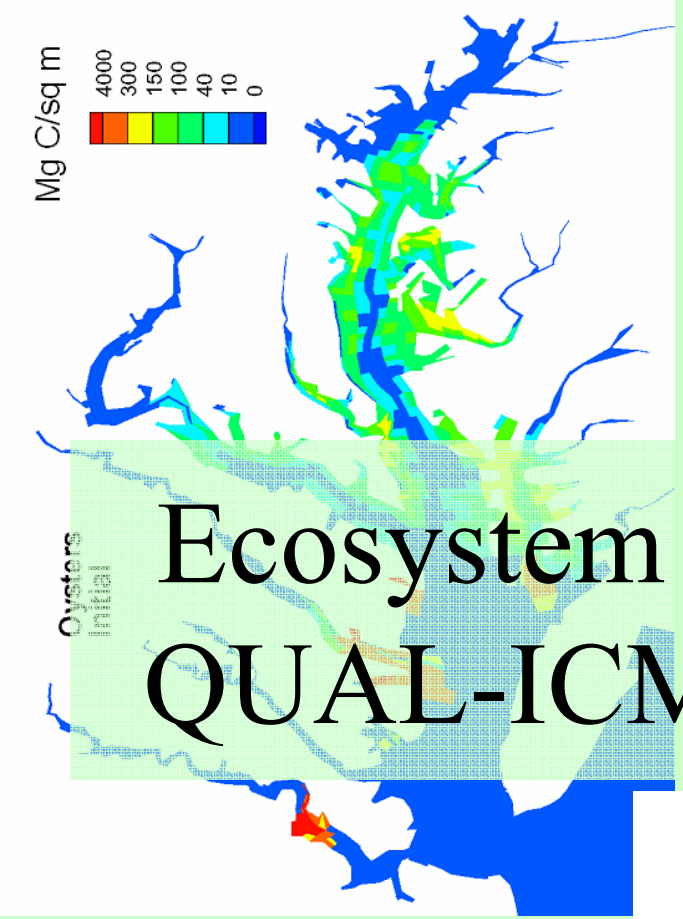
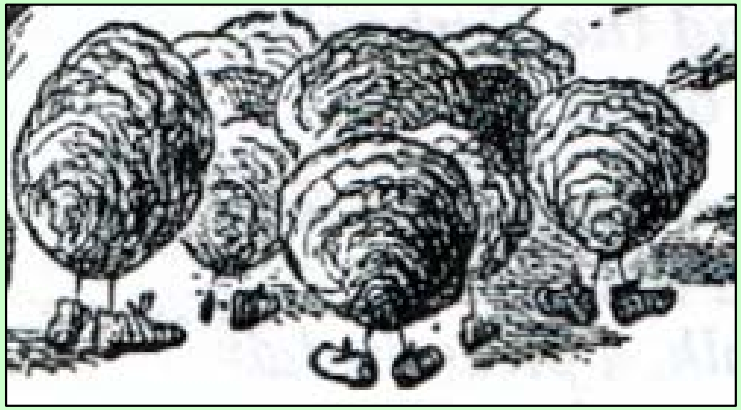
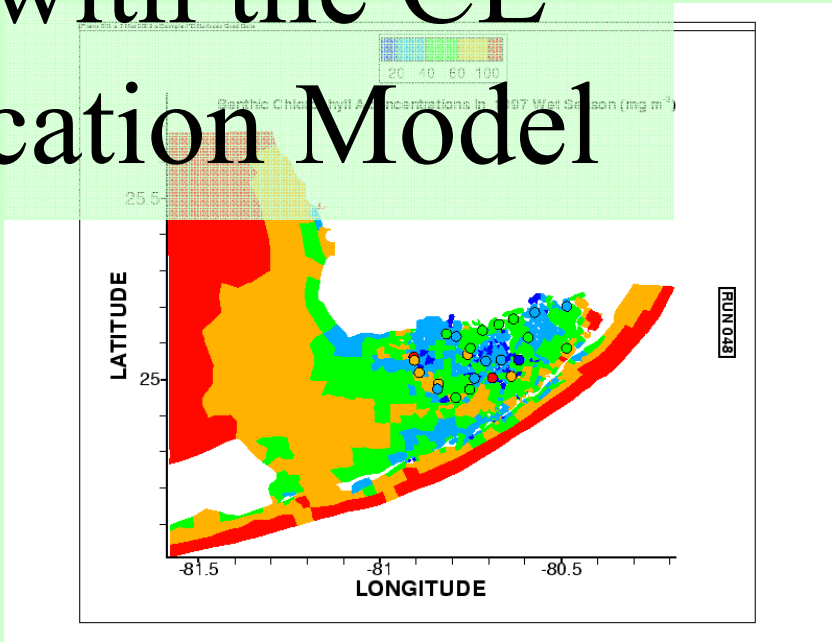
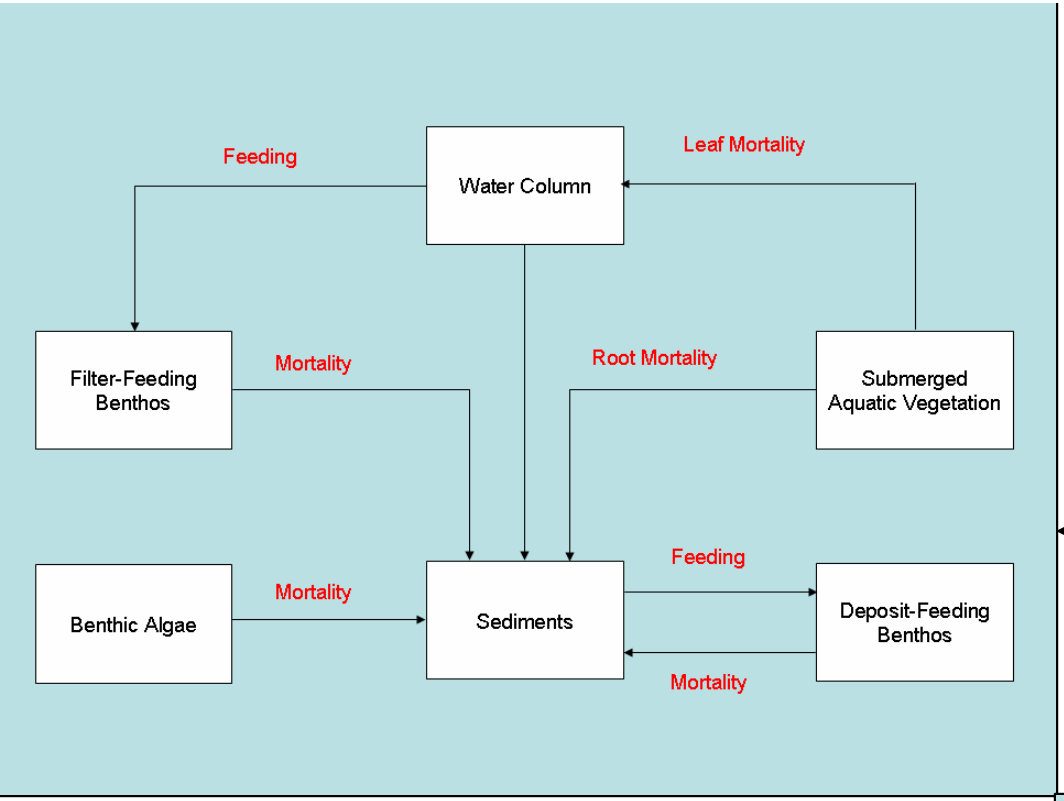


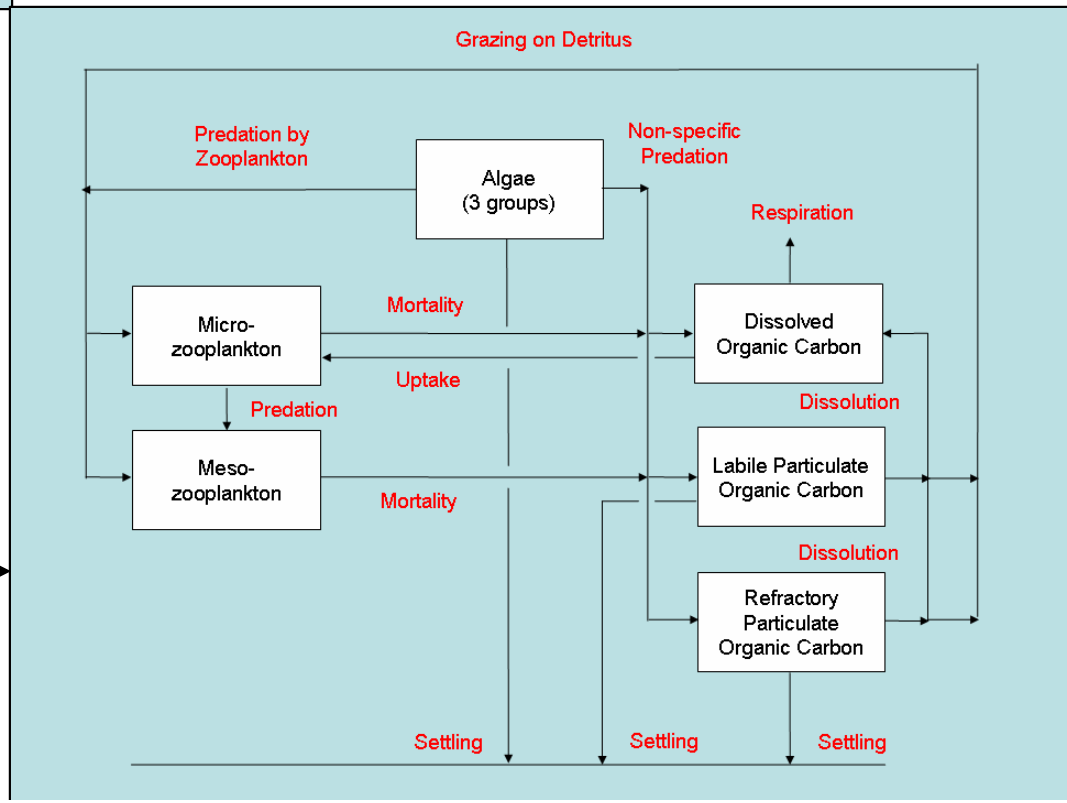
# Ecosystem Modeling with the CE-QUAL-ICM Eutrophication Model






# Major components of the ICM carbon cycle

# The water-column carbon cycle



# The Basic ICM Equation

$$\frac{\delta V_j C_j}{\delta t} = \sum_{k=1}^{n} Q_k C_k + \sum_{k=1}^{n} A_k D_k \frac{\delta C}{\delta x_k} + \sum S_j$$

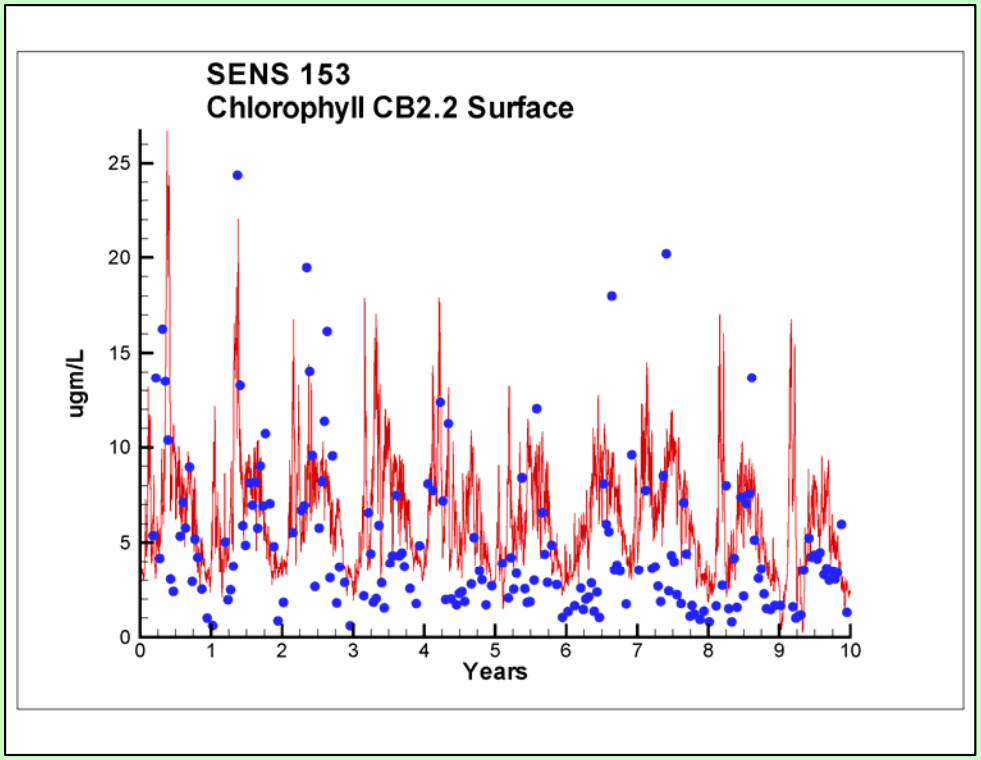
Vj = volume of $j^{th}$ control volume ($m^3$)
Cj = concentration in $j^{th}$ control volume (gm $m^{-3}$)
Qk = volumetric flow across flow face k of $j^{th}$ control volume ($m^3$ $sec^{-1}$)
Ck = concentration in flow across flow face k (gm $m^{-3}$)
Ak = area of flow face k ($m^2$)
Dk = diffusion coefficient at flow face k ($m^2$ $sec^{-1}$)
n = number of flow faces attached to $j^{th}$ control volume
Sj = external loads and kinetic sources and sinks in $i^{th}$ control volume (gm $sec^{-1}$)
t, x = temporal and spatial coordinates

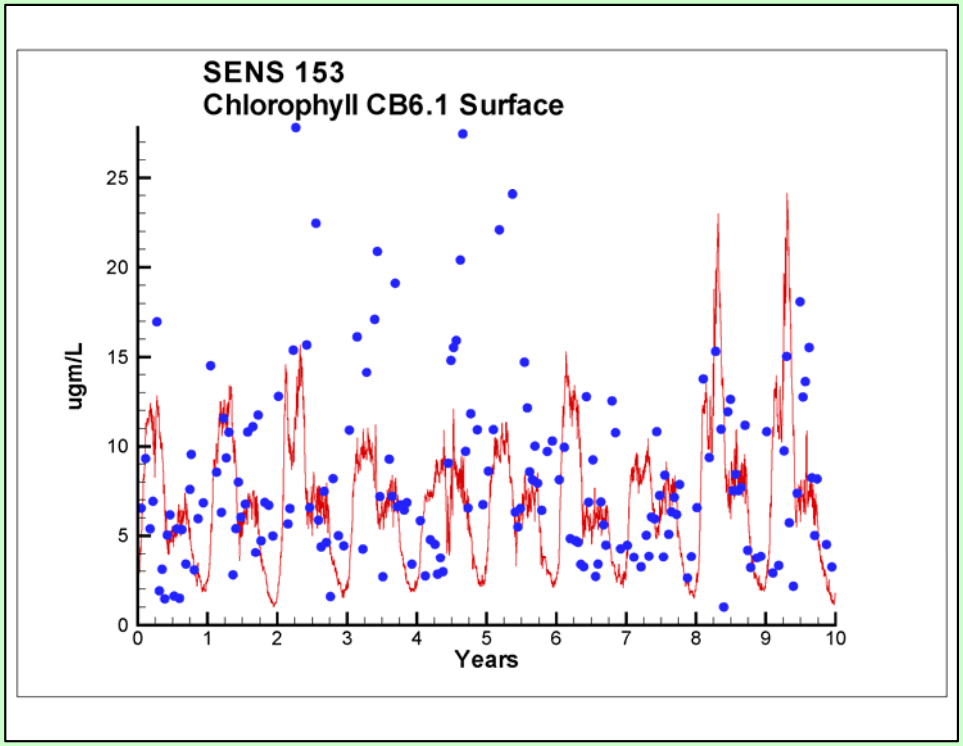
# Phytoplankton Kinetics

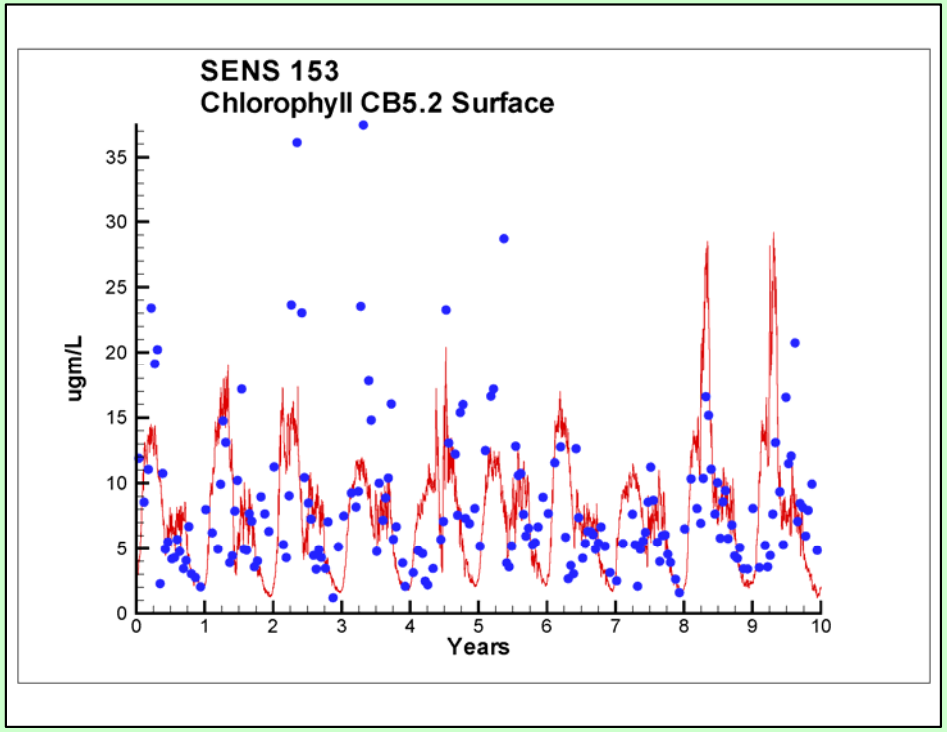
$$\frac{\delta}{\delta t} B = \left( G - BM - Wa \bullet \frac{\delta}{\delta z} \right) B - PR$$

B = algal biomass, expressed as carbon (g C $m^{-3}$)
G = growth ($d^{-1}$)
BM = basal metabolism ($d^{-1}$)
Wa = algal settling velocity (m $d^{-1}$)
PR = predation (g C $m^{-3}$ $d^{-1}$)
z = vertical coordinate

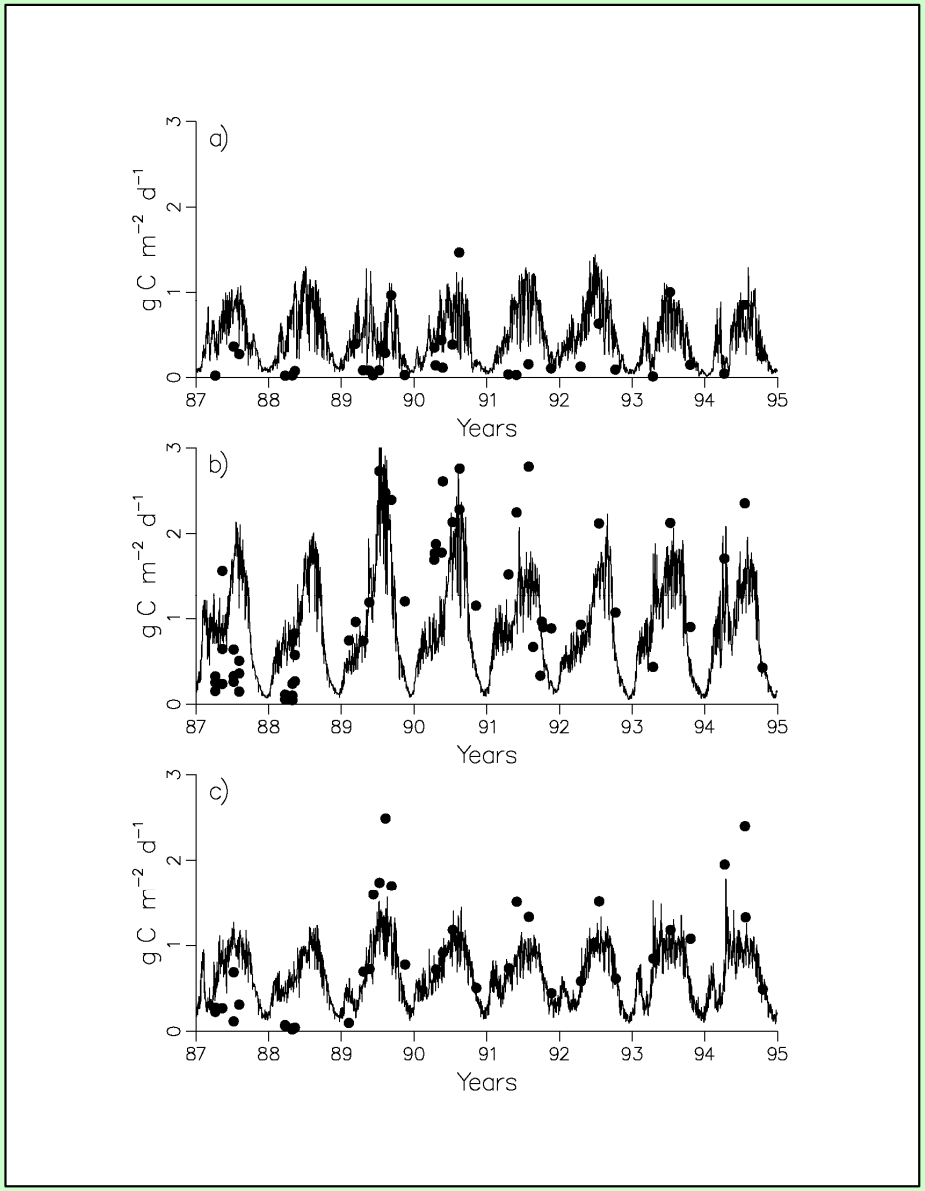
# Computed and Observed Chlorophyll in Chesapeake Bay



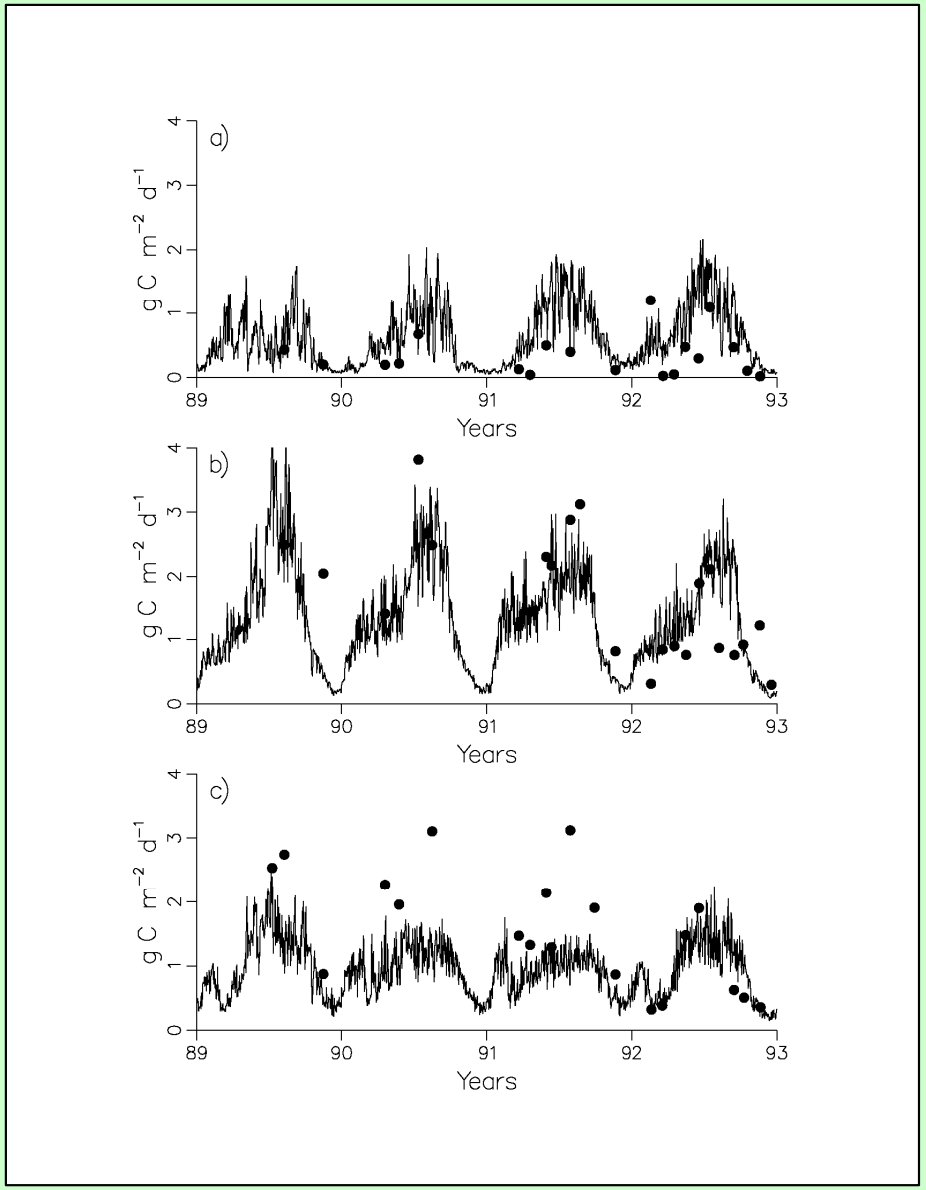



## Net Phytoplankton Primary Production in Upper, Middle, and Lower Bay



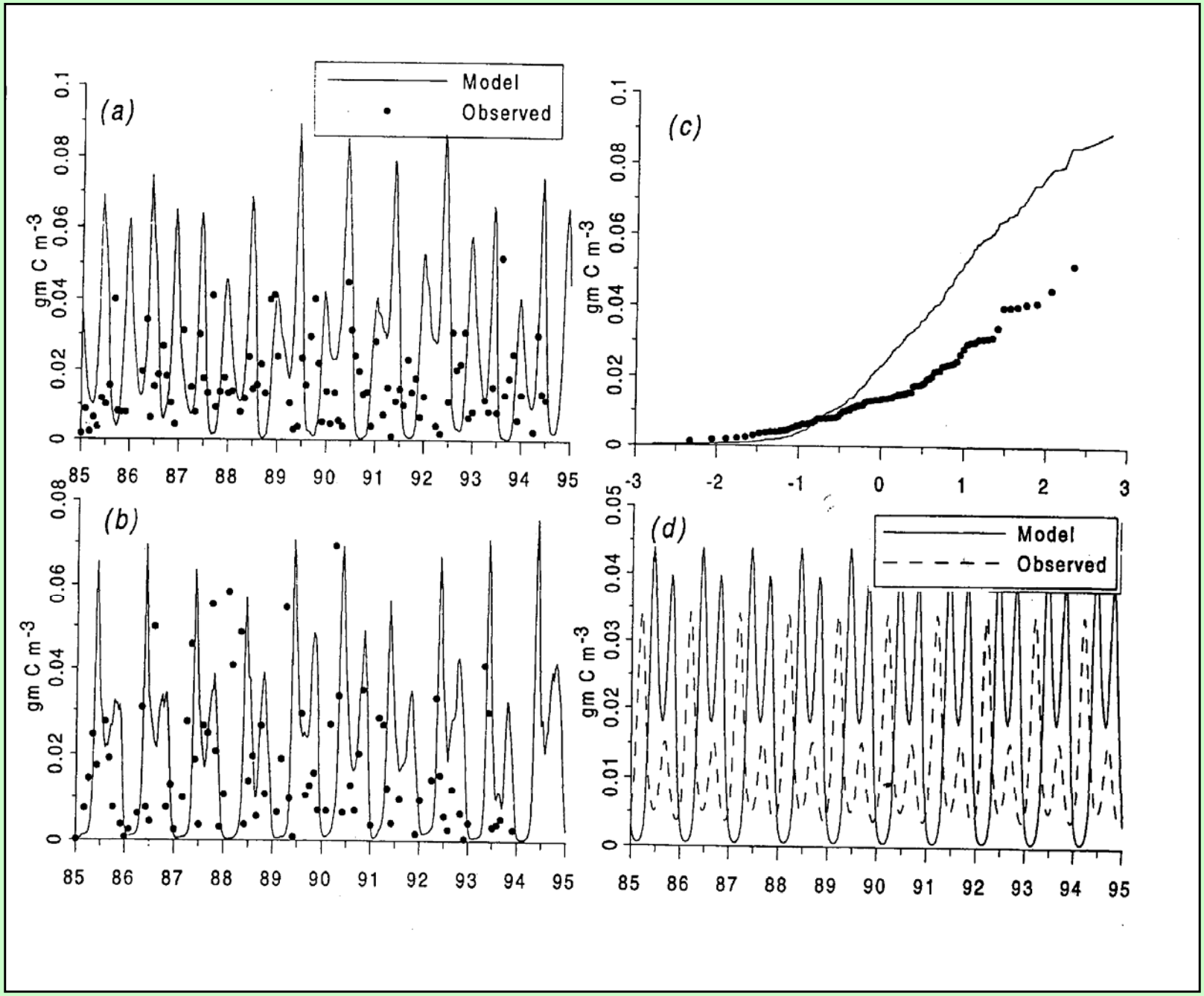

## Gross Phytoplankton Primary Production in Upper, Middle, and Lower Bay



# Zooplankton Kinetics

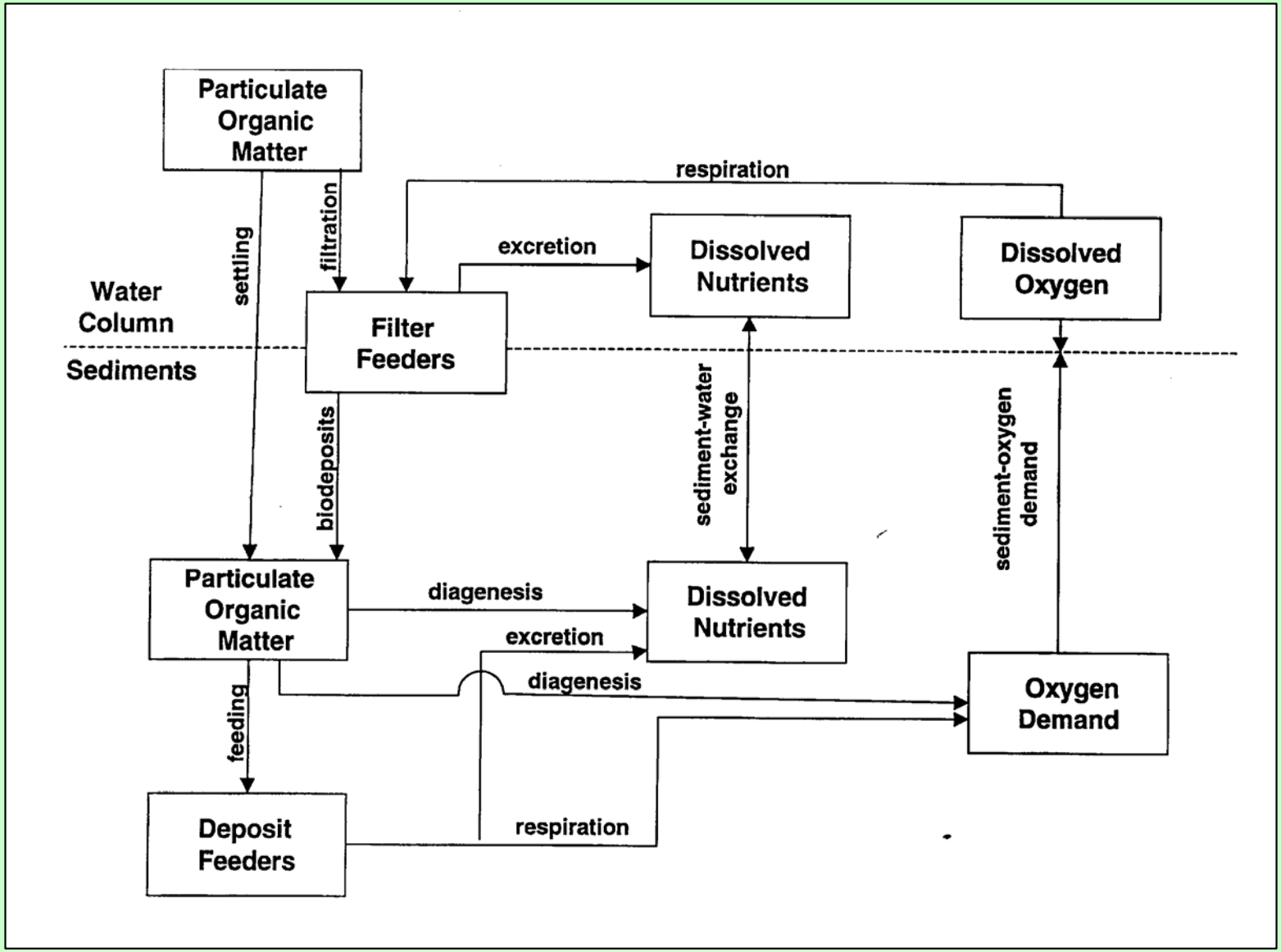
$$\frac{\delta Z}{\delta t} = [Gz - BMz - Mz] \cdot Z - PRz$$

Z = zooplankton biomass (g C $m^{-3}$)
Gz = growth rate of zooplankton group z ($d^{-1}$)
BMz = basal metabolic rate of zooplankton group z ($d^{-1}$)
Mz = mortality ($d^{-1}$)
PRz = predation on zooplankton group z (g C $m^{-3}$ $d^{-1}$)




a) Mesozoo; b) Microzoo; c) Microzoo; d) Mesozoo harmonics

# Benthic Deposit Feeders



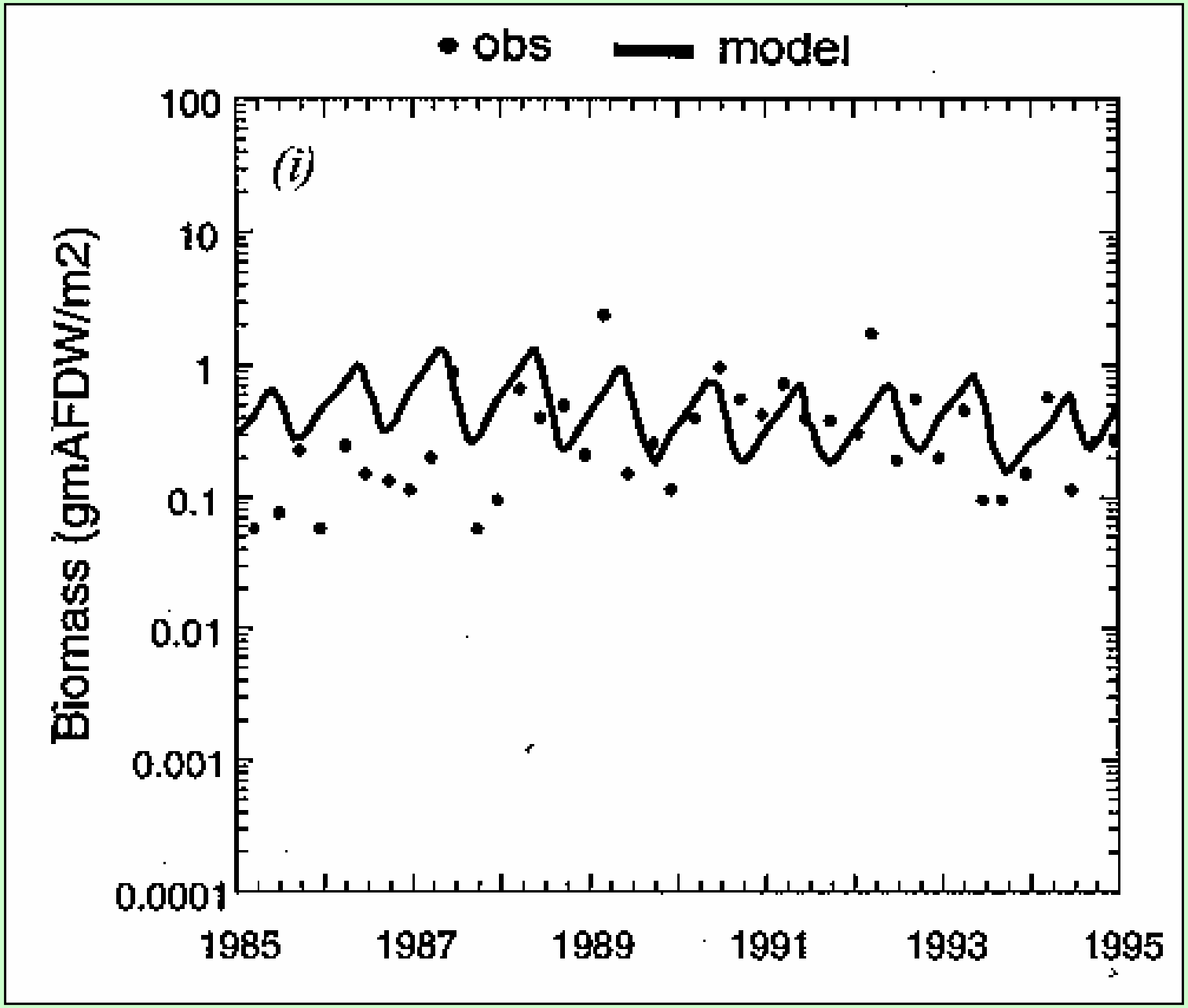

Benthos Model Schematic

# Benthic Deposit Feeders

$$\frac{dDF}{dt} = \alpha \cdot \frac{I}{m} \cdot \frac{POC \cdot Khdf}{POC + Khdf} \cdot DF - r \cdot DF - \beta \cdot DF^2 - hmr \cdot DF$$

DF = deposit feeder biomass (mg C $m^{-2}$)
$\alpha$ = assimilation efficiency ($0 < \alpha < 1$)
m = sediment solids concentration (mg $m^{-3}$)
I = ingestion rate (mg sediment $mg^{-1}$ deposit feeder carbon $d^{-1}$)
POC = sediment particulate organic carbon (mg $m^{-3}$)
Khdf = half-saturation concentration for carbon uptake (mg $m^{-3}$)
r = specific respiration rate ($d^{-1}$)
$\beta$ = predation rate ($m^2$ $mg^{-1}$ deposit feeder C $d^{-1}$)
hmr = mortality rate due to hypoxia ($d^{-1}$)
t = time (d)

# Deposit Feeders in Central James Estuary

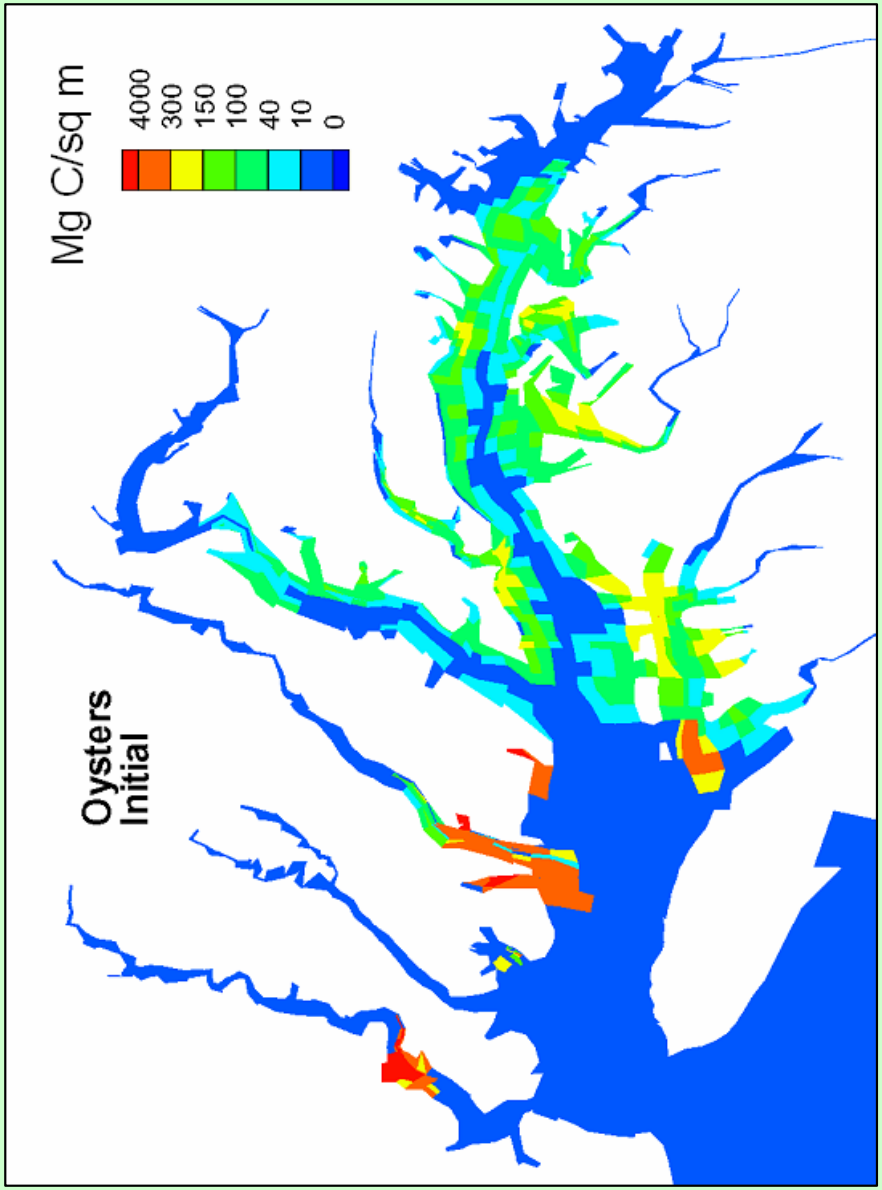


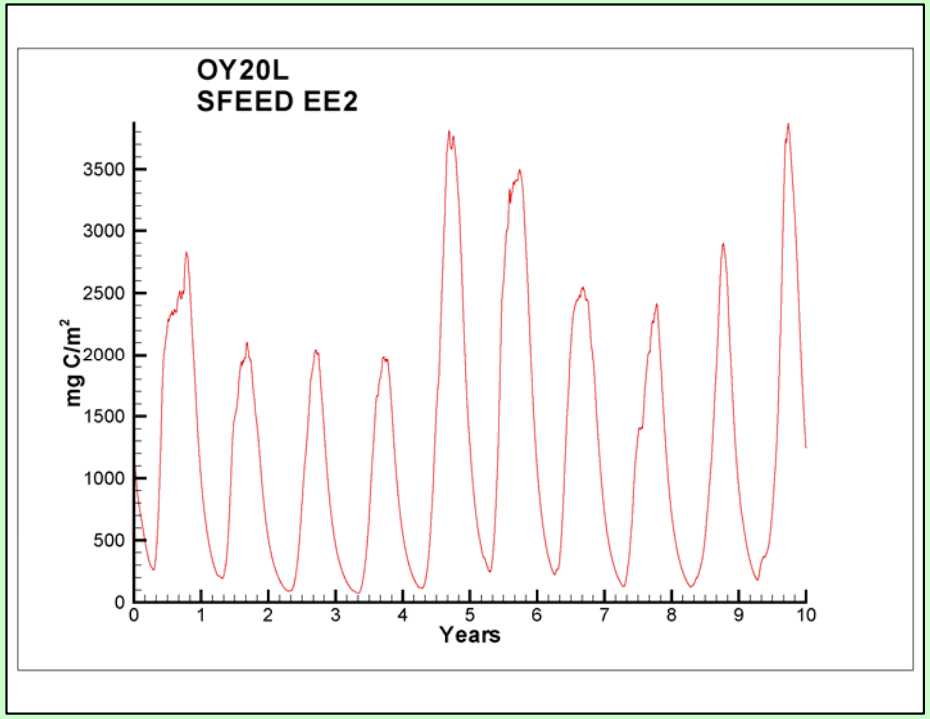
# Benthic Filter Feeders

$$\frac{dFF}{dt} = \alpha \cdot Fr \cdot POC \cdot FF - r \cdot FF - \beta \cdot FF^2 - hmr \cdot FF$$

FF = filter feeder biomass (mg C $m^{-2}$)
$\alpha$ = assimilation efficiency ($0 < \alpha < 1$)
Fr = filtration rate ($m^3$ $mg^{-1}$ filter feeder carbon $d^{-1}$)
POC = particulate organic carbon in overlying water (mg $m^{-3}$)
r = specific respiration rate ($d^{-1}$)
$\beta$ = predation rate ($m^2$ $mg^{-1}$ filter feeder C $d^{-1}$)
hmr = mortality rate due to hypoxia ($d^{-1}$)
t = time (d)

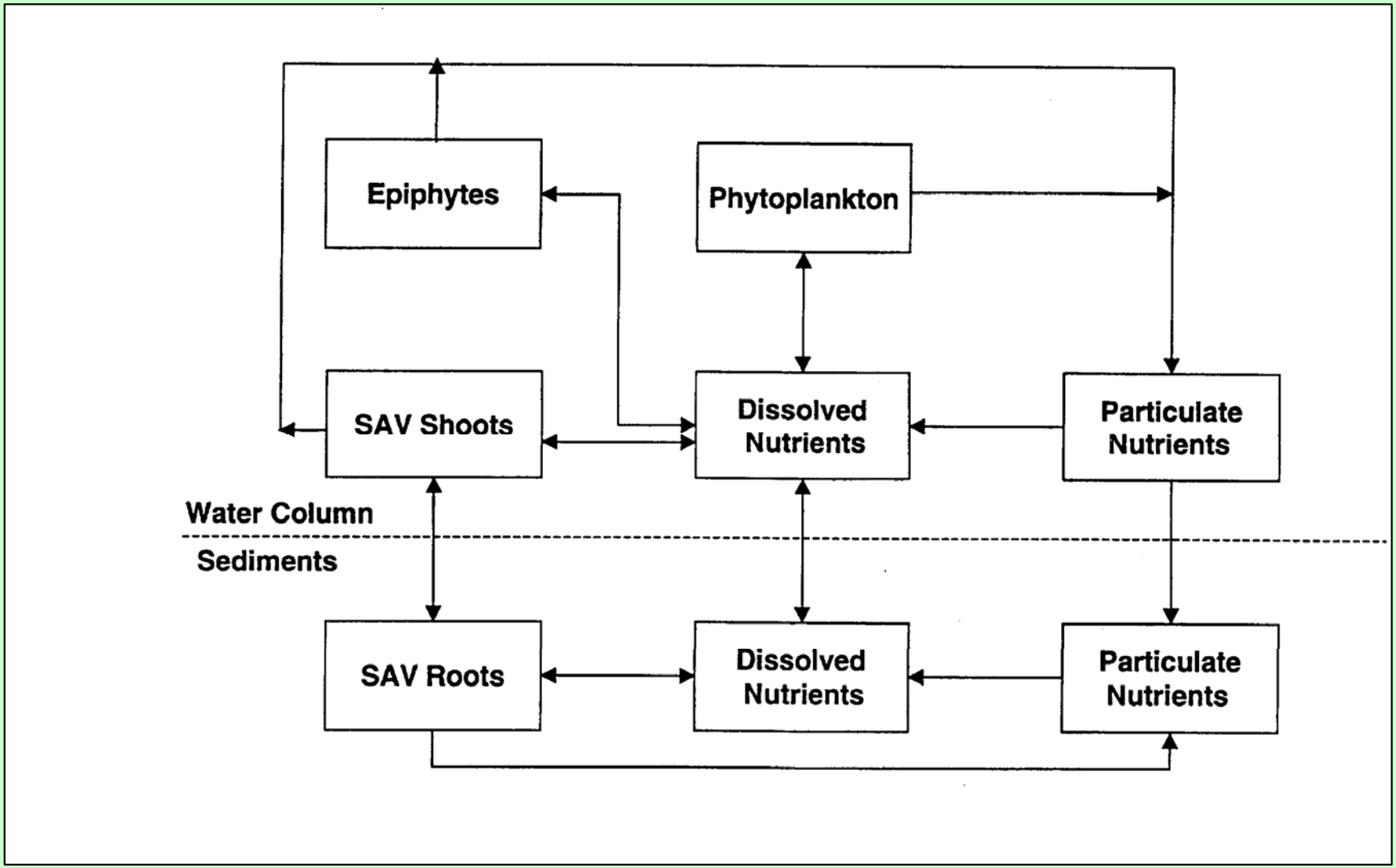
# Native Oyster Restoration




**Calculated oyster density in the lower Choptank River, 1985-1994**

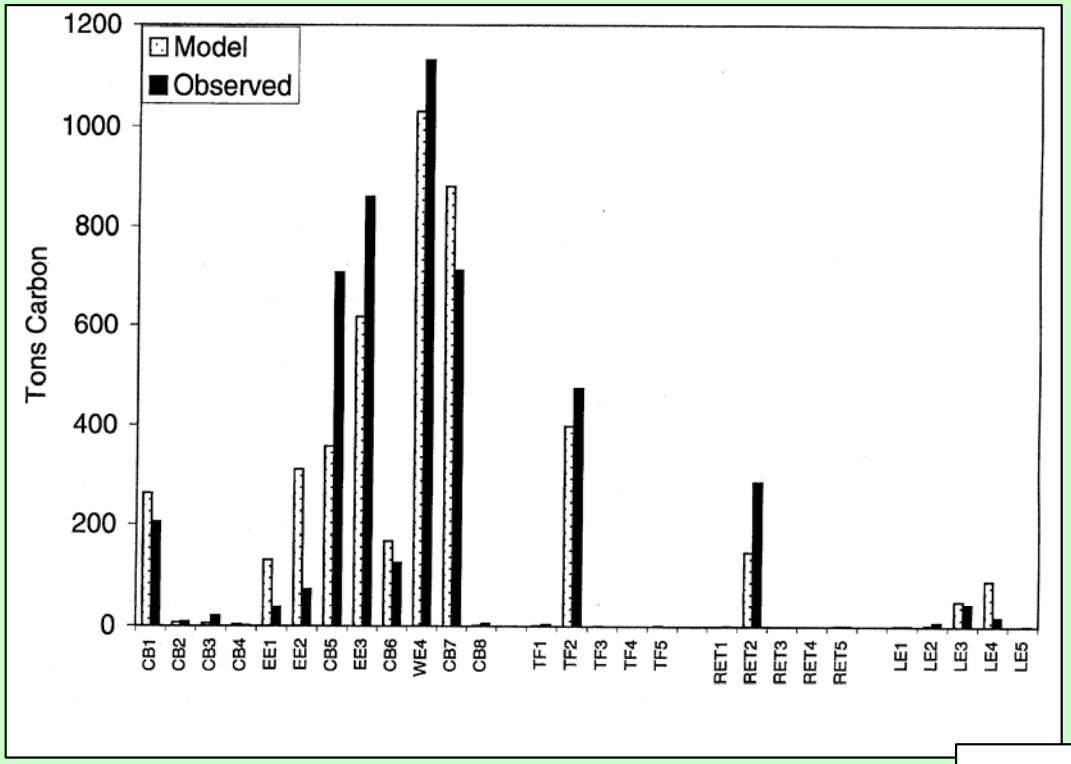
# Submerged Aquatic Vegetation



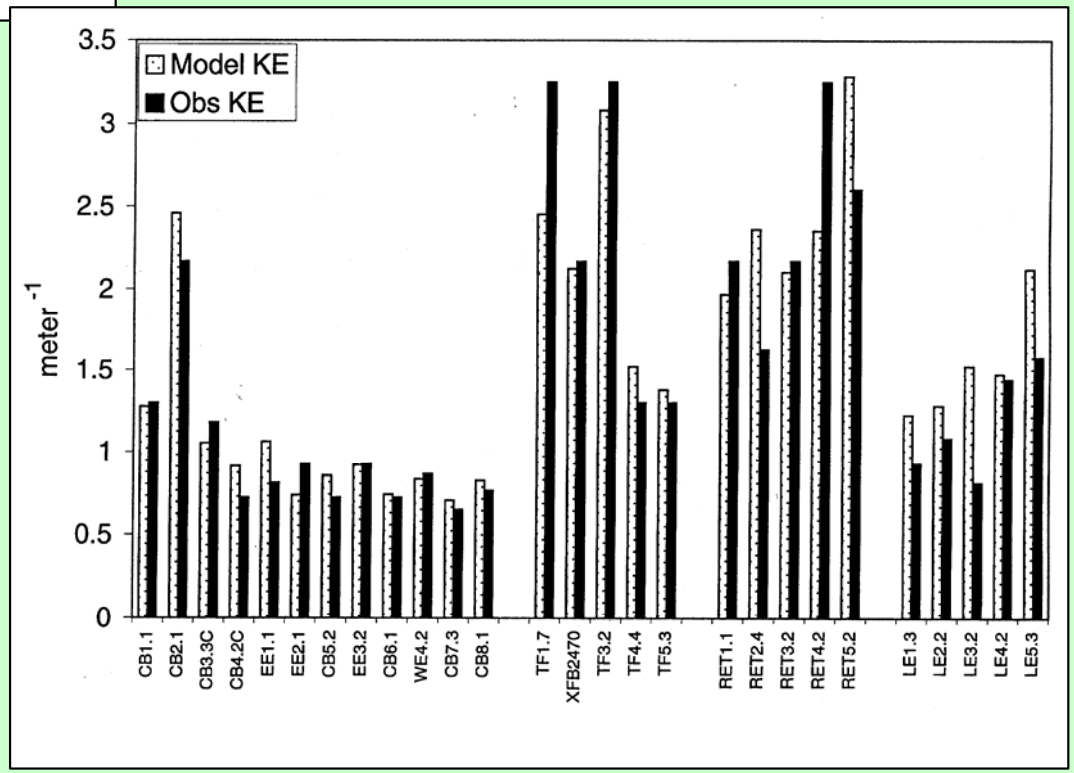
# Submerged Aquatic Vegetation

$$\frac{d\,SH}{dt} = (P \cdot (1 - Fpsr) - Rsh - SL) \cdot SH + Trs \cdot RT$$

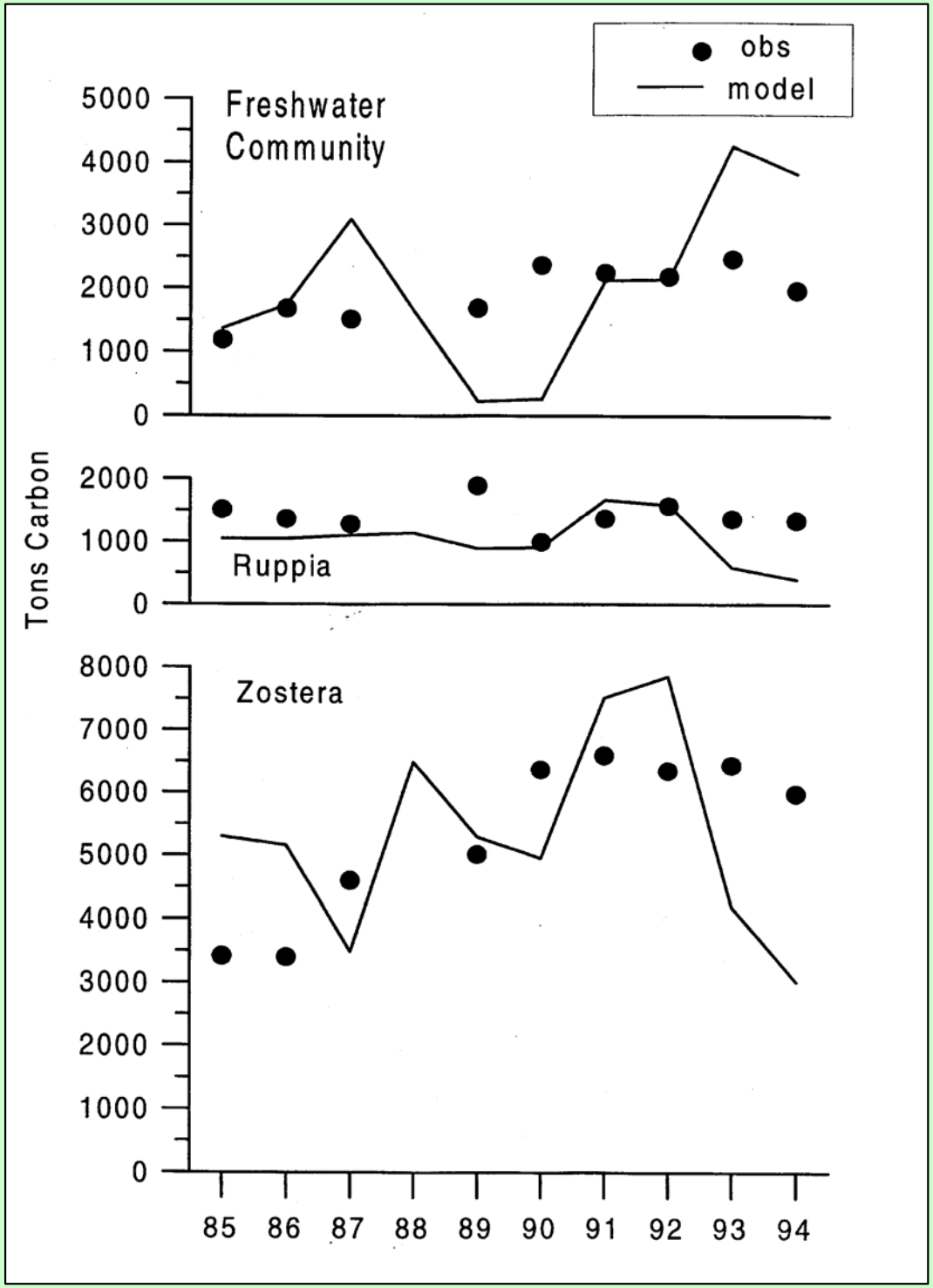
SH = shoot biomass (g C $m^{-2}$)
P = production ($d^{-1}$)
Fpsr = fraction of production routed from shoot to root
Rsh = shoot respiration ($d^{-1}$)
SL = sloughing ($d^{-1}$)
Trs = rate at which carbon is transported from root to shoot ($d^{-1}$)
RT = root biomass (g C $m^{-2}$)




**Observed and computed mean abundance, April-October 1985-1994**

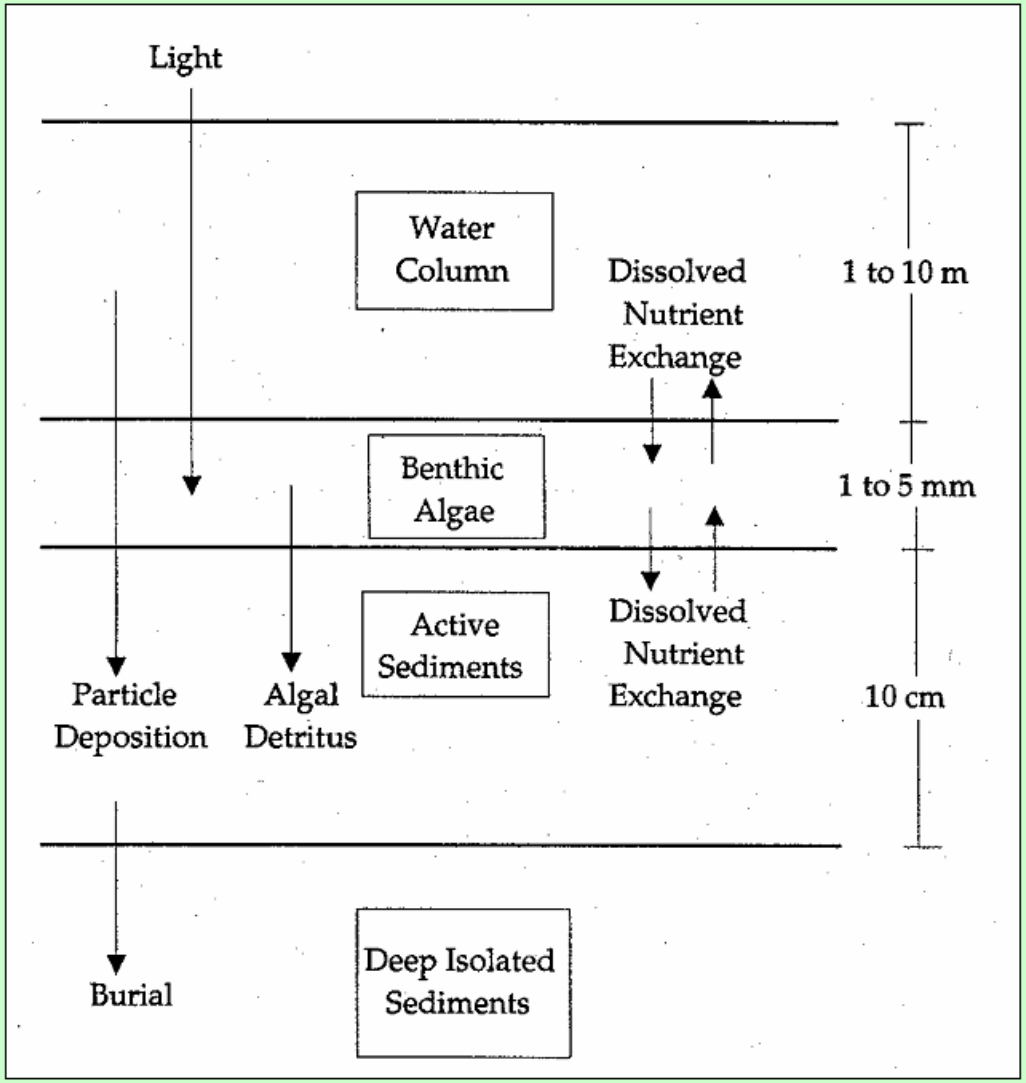



**Observed and computed median light attenuation at 27 stations in the bay system, April-October 1985-1994**




**Observed and computed maximum abundance, by community type, 1985-1994.**

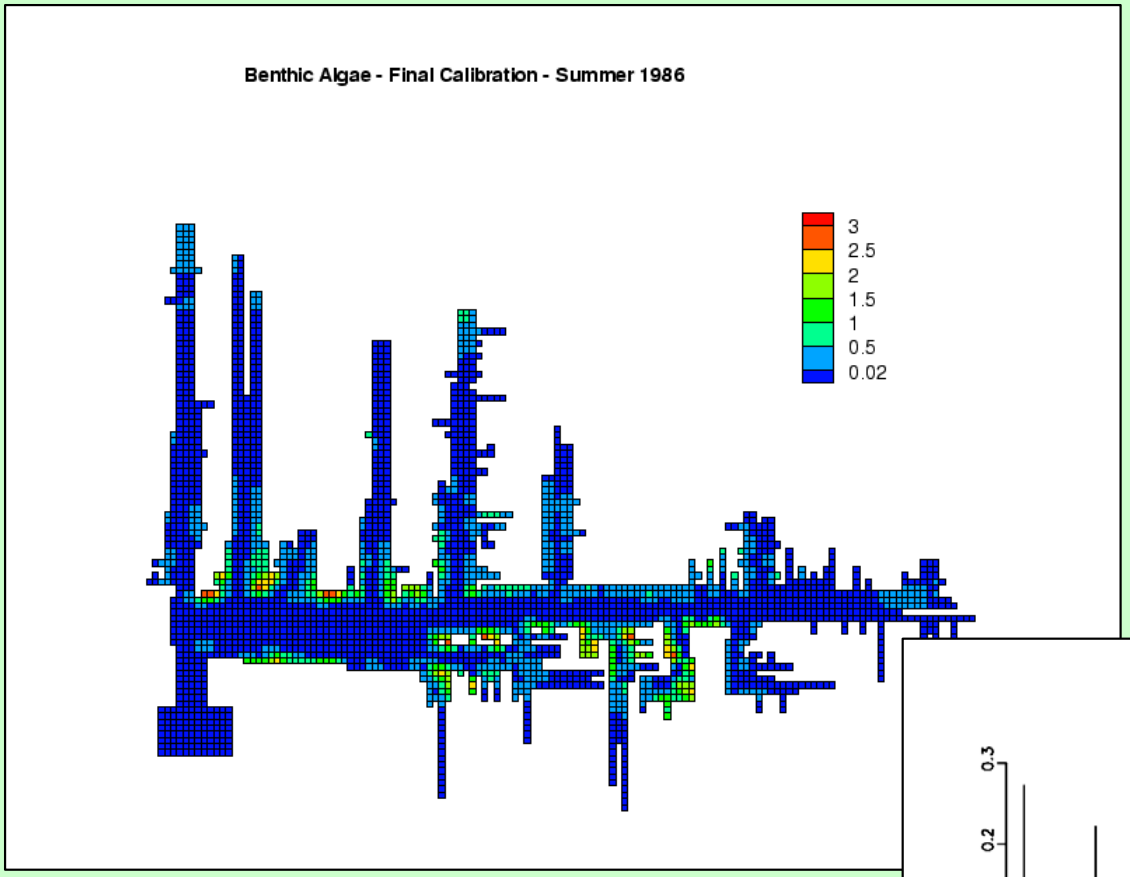
# Benthic Micro-Algae



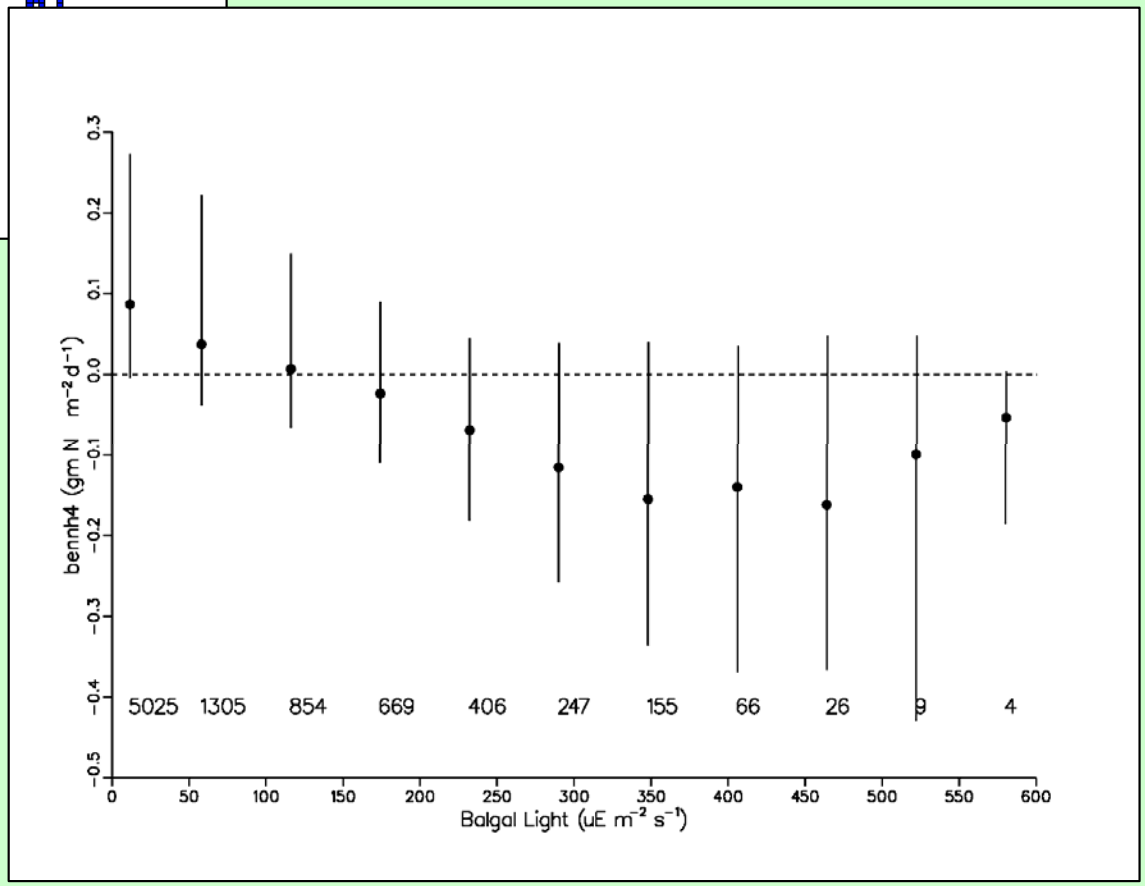
# Benthic Micro-Algae

$$\frac{\delta B}{\delta t} = (G - BM) \cdot B - PR$$

B = algal biomass, as carbon (g C $m^{-2}$)
G = growth ($d^{-1}$)
BM = basal metabolism ($d^{-1}$)
PR = predation (g C $m^{-2}$ $d^{-1}$)




**Computed summer-average benthic algal biomass in Chesapeake Bay, 1986.**




**Computed (mean and range) sediment-water ammonium flux as a function of irradiance at the sediment-water interface. Benthic algal biomass 1 to 3 g C m$^{-2}$. Positive fluxes are from sediments to the water column.**

# Strengths

- Mass-balance based approach
- Interactions between organisms and environment
- Oriented towards primary producers

# Weaknesses

- Population processes are missing
- Features of individual organisms are missing
- Interactions between groups are weak