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COURSE ON "MEDITERRANEAN SEA(S) CIRCULATION & ECOSYSTEM FUNCTIONING"
2 - 20 November 1998

Trieste, Italy

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"Primary Production"

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Please note: These are preliminary notes intended for internal distribution only.

ALGAE INTRODUCTION

Algae interact with ecosystem in many ways:

a) Algal dynamic and nutrients dynamic are closely linked together by the uptake process and nutrients recycling.

b) Photosynthetic oxygen production and respiration ox consumption cause diurnal variations in DO

c) In very productive water bodies seasonal ~~variation~~ of ox concentration are caused by OD of settled algae.

d) CO_2 uptake during photosynthesis and CO_2 recycling affect the pH of water

e) Algae are the dominant component in lakes and estuaries because they are the basis of the food chain

f) Suspended algae affect turbidity

g) Algae bloom results sometime in fish kills

h) Algae can cause taste and odor problems in water supply

SIMULATION APROACH

* Aggregation of all algae into single constituent (e.g. Total biomass or chlorophyll-a) is used in river models - since the major focus is a short term simulation (days-weeks) and the effects on water quality

* Aggregation of algae in few dominant functional groups (e.g. green algae, diatoms, bluegreen, dinoflagellates, etc) is used in lake and reservoir model since the major focus is on long term simulation (months, years)

For a realistic modelling aproach is often important to distinguish the species-specific differences

Multi-group models typically use the same equation with different coefficient values.

ALGAE MODELS

The general form of the model is

$$\frac{dA}{dt} = (\mu - r - ex - s - m)A - G$$

A phytoplankton biomass or concentration, dry weight biomass, chlorophyll-a or equivalent mass of nutrients C, N, P

μ gross grow rate
r respiration rate
ex excretion rate
s settling rate
m non predatory mortality rate

G loss rate due to grazing

Algae (phytopl.) can also be expressed in term of cell number.

$$\frac{dA}{dt} = (\mu - s - m)A - G$$

A cell number
μ cell division rate

TABLE 6-1. GENERAL COMPARISON OF ALGAL MODELS

Model (Author)	Number of Groups: Phyto-plankton	Number of Groups: Attached Algae	Number of Groups: Zoo-plankton	Processes Computed Separately in Model: Growth	Respir-ation	Settling	Nonpredatory Mortality	Predatory Mortality	Algal Units: Dry Wt. Biomass	Chl _a_	Carbon	Other Nutrient	Cell Numbers	Reference
AQUA-IV	1		1	X	X	X	X	X			X			Baca & Arnett (1976)
CE-QUAL-R1	2		1	X	X	X		X	X					WES (EWQOS) (1982)
CLEAN	2	1	3	X	X	X	X	X	X					Bloomfield _et al._ (1973)
CLEANER	3	1	3	X	X	X	X	X	X					Scavia & Park (1976)
MS.CLEANER	4	1	5	X	X	X	X	X	X					Park _et al._ (1980)
DEM	1			X	X	X				X				Feigner & Harris (1970)
DOSAG3	1			X	X	X				X				Duke & Masch (1973)
EAM	4	1	3	X	X	X		X	X					Tetra Tech (1979, 1980)
ESTECO	2		1	X	X	X		X	X					Brandes & Masch (1977)
EXPLORE-1	1		1	X	X			X			X			Baca _et al._ (1973)
HSPF	1	1	1	X	X	X	X	X	X					Johanson _et al._ (1980)
LAKECO	2		1	X	X	X		X	X					Chen & Orlob (1975)
MIT Network	1		1	X	X		X	X				N		Harleman _et al._ (1977)
QUAL-II	1			X	X	X				X				Roesner _et al._ (1981)
RECEIV-II	1			X	X		X			X				Raytheon (1974)
SSAM IV	1	1		X			X		X					Grenney & Kraszewski (1
WASP	2		2	X	X	X	X	X		X	X			Di Toro _et al._ (1981)
WQRRS	2	2	1	X	X	X		X	X					Smith (1978)
Bierman	5		2	X	X	X	X	X	X					Bierman _et al._ (1980)
Canale	4		9	X	X	X		X			X			Canale _et al._ (1975, 1
Jorgensen	1		1	X	X	X	X	X	X					Jorgensen (1976)
Lehman	5			X	X	X	X						X	Lehman _et al._ (1975)
Nyholm	1			X		X	X		X					Nyholm (1978)
Scavia	5		6	X	X	X	X	X			X			Scavia _et al._ (1976)

ALGAL GROWTH

Algal gross growth rate is normally modelled

$$\mu = \mu_{MAX}(T_{REF})\, f(T)\, f(L, P, N, C, Si)$$

μ gross algal growth rate

$\mu_{MAX}(T_{REF})$ maximum growth rate at a reference temperature under optimal conditions of light saturation and nutrients excess.

$f(T)$ temperat. function for growth (T in °C)

$f(L, P, N, C, Si)$ growth limiting function for light L and available inorganic nutrients

Some nutrient does not play a limiting role and can be forgotten in the formulation.

COMBINATION OF LIMITING FACTORS

4 major approaches are used

1) Multiplicative

$$f(L, P, N, C, Si) = f(L)\, f(N)\, f(P)\, f(C)\, f(Si)$$

The computed value is excessively low when a nutrient is severely limiting.

2) Minimum

$$f(L \ldots Si) = \min[f(L), \ldots f(Si)]$$

Liebig law of minimum

3 Harmonic mean

$$f(L \ldots Si) = \frac{n}{\frac{1}{f(L)} + \ldots + \frac{1}{f(Si)}}$$

Too complicate similar effect of minimum law

4 Aritmetic mean

$$f(L \ldots Si) = \frac{f(L) + \ldots + f(Si)}{n}$$

it does not restrict growth enough

TEMPERATURE EFFECT

the term

$$\mu_{MAX}(T_{REF})\, f(T)$$

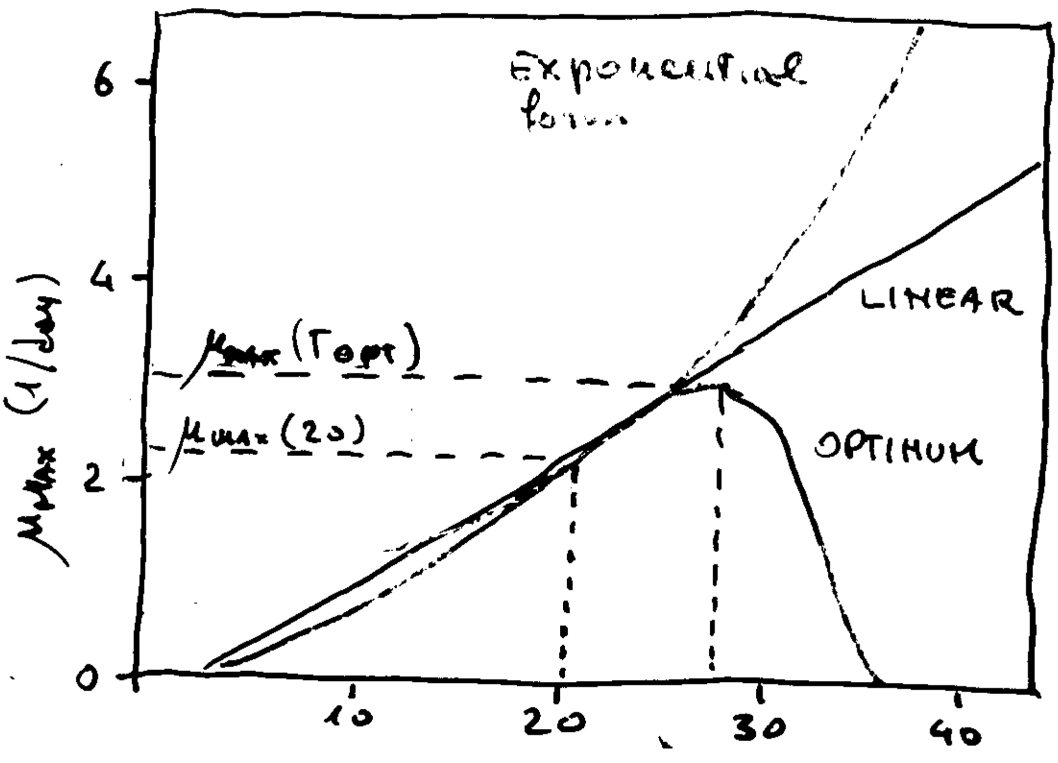
account for temp. effects

$$\mu_{MAX}(T_{REF})$$

is specified and constant for a given type of µ

$f(T)$ is the adjustment function

it takes 3 major forms



LINEAR MODEL FOR T effect

$$f(T) = \frac{T - T_{MIN}}{T_{REF} - T_{MIN}}$$

T_{MIN} if $T < T_{MIN}$ growth is zero

T_{REF} temp. of max growth rate

$\frac{1}{T_{REF} - T_{MIN}}$ slope of growth vs temperature

Exponential Model Temp effect

the usual Arrhenius or van't Hoff equation is selected as exponential growth model

$$f(T) = \theta^{(T-20)}$$

with $\mu_{max}(T_{REF}) = \mu_{max}(20\,°C)$

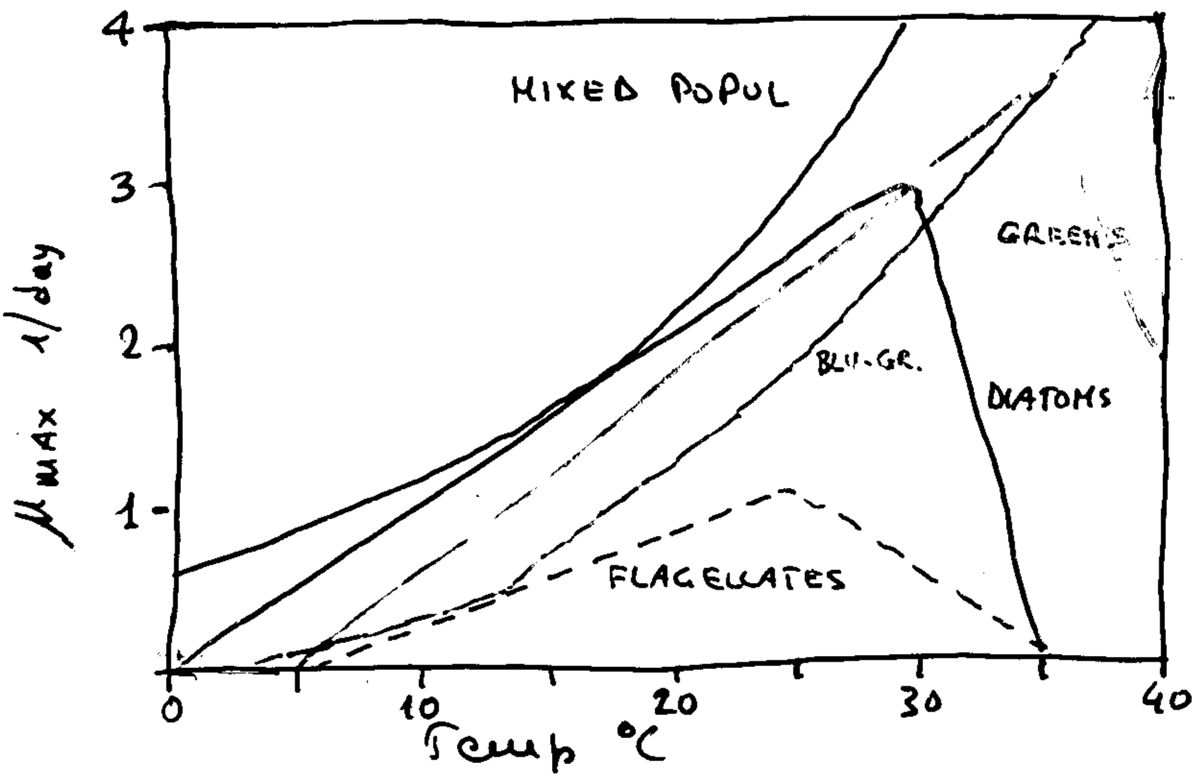
A skewed normal distribution can simulate the optimum curve for phytoplankton growth

$$f(T) = e^{\left[-2.3\left(\frac{T - T_{OPT}}{T_x - T_{OPT}}\right)^2\right]}$$

T_{OPT} optimum temperature

$$T_x \begin{cases} = T_{MIN} & \text{if } T \leq T_{OPT} \\ = T_{MAX} & \text{if } T > T_{OPT} \end{cases}$$

T_{MIN}, T_{MAX} limits of growth



Other formulas have been developped to simulate the adaptation of algae to the increasing temp.

LIGHT LIMITATION MODEL

the light limitation models consist of 2 relationship describing

- * The attenuation of light with depth and the effect of algae on light attenuation

- * The effect of resulting light level on algal growth and photosynthesis

The attenuation of light is defined by Lambert Beer law

$$I(d) = I_0 e^{-\gamma d}$$

$I(d)$ light intensity at depth d below the surface

d depth

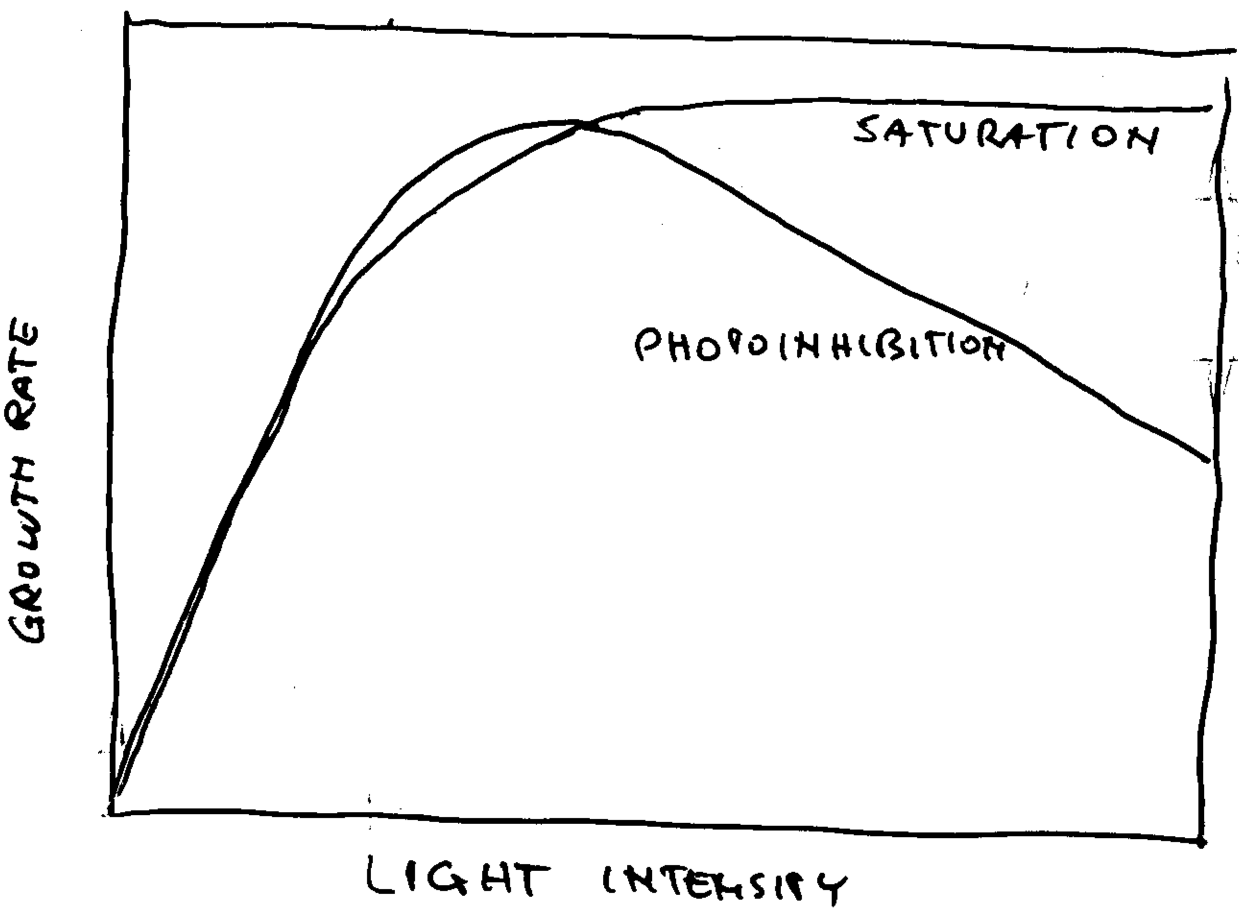
I_0 light intensity at the surface
- function of location, time (year, day), meteorologic conditions, ...
- only visible range (50% of total solar radiation

γ light extinction coefficient 1/length usually constant or accounting in its formulation for variability of turbidity

LIGHT LIMITATION

The general formula of light limitation factor f(L) for algal growth is modeled in 2 main ways

- a saturation relationship
- a photoinhibition relationship



the typical relation of Michaelis-Menten is used for light limitation

$$f(L) = \frac{I}{K_L + I}$$

its integration over time gives

$$f(L) = \frac{f_p}{\gamma d} \ln\left(\frac{K_L + I_0}{K_L + I_0 e^{\gamma d}}\right)$$

f_p photoperiod (fraction of a day)

d depth

I_0 total light at surface during the day

when averaged over the depth

$$f(L) = \frac{f_p}{\gamma(d_2 - d_1)} \ln\left(\frac{K_L + I_0 e^{-\gamma d_1}}{K_L + I e^{-\gamma d_2}}\right)$$

the optimum curve or Steele formulation is commonly used

$$f(L) = \frac{I}{I_s} e^{\left(1 - \frac{I}{I_s}\right)}$$

I_s optimum light intensity
if necessary it can be adapted accounting for the algae adaptation to light intensity

Its integration over time gives

$$f(L) = \frac{2.718 f_p}{\gamma d} \left(e^{-\frac{I_0}{I_s} e^{-\gamma d}} - e^{-\frac{I_0}{I_s}} \right)$$

if averaged over depth

$$f(L) = \frac{2.718 f_p}{\gamma (d_2 - d_1)} \left(e^{-\frac{I}{I_0} e^{-\gamma d_2}} - e^{-\frac{I}{I_0} e^{-\gamma d_1}} \right)$$

NUTRIENTS LIMITATION

2 major approaches have been used

1 Monod or Michaelis Menten Kinetics
growth rate are determined by
external concentration of available nut.
Under constant nutrient composition
of the algae.
Fixed stoichiometry model

(2) Two steps process
1st step = nutrient uptake
2nd step = cell growth or division

Cell growth depends on internal conc.
rather than the external one

The uptake depends on both extern.
and internal concentration

NUT. LIM. in fixed stoichiom.

the majority of the model uses the following ~~model~~

$$\mu = \mu_{max}\left(\frac{S}{K_s+S}\right)$$

S conc of limiting nutrient in water

K_S half saturation constant for limiting nutrient

Tipically the model uses 1 eq. per each of the nutrient

Nitrogen can be accounted as

$NH_3 + NO_3$ or separately

NUT LIM in variable stoichiom. 18

The $q = \frac{\text{internal mass of nutrient in cells}}{\text{dry weight biomass of cells}}$.

is defined as internal nutrient conc.

Several formulation for a variable stoichiom. are provided

1 $$f(q) = \frac{q}{K_1 + q}$$ Michaelis - Menten q

2 $$f(q) = \frac{(q - q_{min})}{K_2 + (q - q_{min})}$$ Mich-Ment $q - q_{min}$

3 $$f(q) = \left(1 - \frac{q_{min}}{q}\right)$$ as 2 $K_2 = q_{min}$

4 $$f(q) = \frac{q - q_{min}}{q_{max} - q_{min}}$$ linear used for N

5 $$f(q) = \frac{K_3 + (q_{max} - q_{min})}{q_{max} - q_{min}} \frac{q - q_{min}}{K_3 + (q - q_{min})}$$

as 2 if the first term is constant.

NUT UPTAKE in variable stoichiom.

Some models refer to a variable nutrients uptake rate accounted as

$$v = v_{max}(T_{ref})\, f(T)\, f(L)\, f(q, s)$$

q internal conc.
s external conc.

$f(q, s)$ are expressed as

$$f(q, s) = (q_{max} - q)\left(\frac{s}{K_1 + s}\right)$$

$$f(q, s) = \frac{q_{max} - q}{q_{max} - q_{min}}\left(\frac{s}{K_2 + s}\right)$$

other forms are also used

this is introducing a very detailed mechanism and needs many parameters

RESPIRATION - EXCRETION - MORTALITY

This processes refer to the general equation

$$\frac{dA}{dt} = (\mu - r - ex - s - m) A - G$$

and are usually accounted with the same formulation

$$x = x(T_{ref}) \, f_x(T)$$

x is the process r, ex, or m

other more complicate expressions are also available.

SETTLING

Phytoplankton settling rate depends on density, size, shape, and ph. state, viscosity and density of water, turbulence and velocity of flow.

the Stokes law is used

$$V_S = \frac{2}{9} \frac{g R^2 (\rho_p - \rho_w)}{\nu F_s}$$

V_S settling velocity
g acceleration of gravity
R equivalent radius (based on a sphere of equivalent volume)
ρ_p density of cell
ρ_w water
ν Kinematic viscosity
F_s shape factor (≥ 1)

and the settling rates is accounted as

$$S = \frac{V_S}{d}$$

d = depth

GRAZING.

Algal grazing can be modeled in several way depending on

* whether predator population is simulated in the model

* whether alternate food items are available for the predator

If the predator population is not simulated the loss rate due to grazing G is taken or

$$G = \text{constant}$$

or

$$G = e_z A$$

where

$$e_z = e_z(T_{ref})\, f_g(T)$$

More than 1 zooplankton group can be simulated and differences in assimilation and ingestion and in feeding behaviour could be accounted.