A1. CARIACO model equations

The ecosystem model equations are similar to those used in Acevedo-Trejos et al. (2016). Most significant changes are that multiple phytoplankton and zooplankton functional types have been added, and that the grazing formulation was expanded to include preferential feeding on certain functional types.

Nitrogen N (and Silicate Si for Diatoms) is assimilated by the phytoplankton types P_i, which are grazed by several zooplankton types Z_j. Mortality of and excretion from plankton, and sloppy feeding by zooplankton contribute to a Detritus D. The phytoplankton types include Nanoflagellates P_{Nano}, Diatoms P_{Dia}, Coccolithophorse, P_{Cocco} and Dinoflagellates P_{Dino}. There are two Zooplankton types split by size class, names Mikrozooplankton Z_{mikro} and Mesozooplankton Z_{meso}.

$$
\begin{aligned}
\frac{\partial N}{\partial t} &= K \cdot (N_0 - N) + D \cdot \delta_D^N - \sum_{i=1}^{i_{max}} [Gains_i \cdot P_i] \\
\frac{\partial Si}{\partial t} &= K \cdot (Si_0 - Si) - Gains_{Dia} \cdot P_{Dia} \\
\frac{\partial P_{Dia}}{\partial t} &= Gains_{Dia} \cdot P_{Dia} - \sum_{j=1}^{j_{max}} [I_j^{tot} \frac{p_{Diaj} P_{Dia}}{R_j} Z_j] \\
\frac{\partial P_{Nano}}{\partial t} &= 1 \\
\frac{\partial Z_{mikro}}{\partial t} &= 1 \\
\frac{\partial D}{\partial t} &= 1
\end{aligned}
$$

where:

- **u** $= (u, v, w)$, velocity in physical model,
- $\kappa =$Mixing coefficients used in physical model,
- $\mu_j =$Growth rate of phytoplankton j (see below),
- $M_{ij} =$Matrix of Redfield ratio of element i to P for phytoplankton j
- $\zeta_{jk} =$ Grazing efficiency of zooplankton k on phytoplankton j (represents sloppy feeding),
- $g_{jk} =$Grazing of zooplankton k on phytoplankton j (see below),
- $m_j^P =$Mortality/Excretion rate for phytoplankton j,
- $m_k^Z =$Mortality/Excretion rate for zooplankton k,
- $w_j^P =$Sinking rate for phytoplankton j,
- $w_{POi} =$Sinking rate for POM i,
- $r_{DOM_i} =$Remineralization rate of DOM for element i,
- $r_{POM_i} =$Remineralization rate of POM for element i,
- $S_{N_i} =$Additional source or sink for nutrient i (see below),
- $S_{DOM_i} =$ Source of DOM i, for element i (see below),

$S_{POM_i} =$ Source of POM i, for element i (see below),

A1.1. Phytoplankton growth:

$$\mu_j = \mu_{max_j}\gamma_j^T\gamma_j^I\gamma_j^N$$

where

$\mu_{max_j} =$ maximum growth rate of phytoplankton j,
$\gamma_j^T =$Modification of growth rate by temperature for phytoplankton j,
$\gamma_j^I =$Modification of growth rate by light for phytoplankton j,
$\gamma_j^N =$Modification of growth rate by nutrients for phytoplankton j.

Temperature modification (Fig. **??**a):

$$\gamma_j^T = \frac{1}{\tau_1}(A^T e^{-B(T-T_o)^c} - \tau_2)$$

where coefficients τ_1 and τ_2 normalize the maximum value, and A, B, T_o and C regulate the form of the temperature modification function. T is the local model ocean temperature.

Light modification (Fig. **??**b):

$$\gamma_j^I = \frac{1}{F_o}(1 - e^{k_{par}I})e^{-k_{inhib}I}$$

where F_o is a factor controlling the maximum value, k_{par} is the PAR saturation coefficient and k_{inhib} is the PAR inhibition factor. I is the local PAR, that has been attenuated through the water column (including the effects of self-shading).

Nutrient limitation is determined by the most limiting nutrient:

$$\gamma_j^N = \min(N_i^{lim})$$

where typically $N_i^{lim} = \frac{N_i}{N_i + \kappa_{N_{ij}}}$ (Fig. **??**c) and $\kappa_{N_{ij}}$ is the half saturation constant of nutrient i for phytoplankton j.

When we include the nitrogen as a potential limiting nutrient (EXP2) we modify N_i^{lim} to take into account the uptake inhibition caused by ammonium:

$$N_N^{lim} = \frac{NO_2}{NO_2 + \kappa_{IN}}e^{-\psi NH_4} + \frac{NH_4}{NH_4 + \kappa_{NH4}} \qquad \text{(nsource=1)}$$

$$N_N^{lim} = \frac{NH_4}{NH_4 + \kappa_{NH4}} \qquad \text{(nsource=2)}$$

$$N_N^{lim} = \frac{NO_3 + NO_2}{NO_3 + NO_2 + \kappa_{IN}}e^{-\psi NH_4} + \frac{NH_4}{NH_4 + \kappa_{NH4}} \qquad \text{(nsource=3)}$$

where ψ reflects the inhibition and κ_{IN} and κ_{NH4} are the half saturation constant of $IN = NO_3 + NO_2$ and NH_4 respectively.

A1.2. Zooplankton grazing:

$$g_{jk} = g_{max_{jk}} \frac{\eta_{jk} P_j}{A_k} \frac{A_k}{A_k + \kappa_k^P}$$

where

$g_{max_{jk}} =$ Maximum grazing rate of zooplankton k on phytoplankton j,
$\eta_{jk} =$ Palatibility of plankton j to zooplankton k,
$A_k =$ Palatibility (for zooplankton k) weighted total phytoplankton concentration,
$= \sum_j [\eta_{jk} P_j]$
$\kappa_k^P =$Half-saturation constant for grazing of zooplankton k,

A1.3. Inorganic nutrient Source/Sink terms:

S_{N_i} depends on the specific nutrient, and includes the remineralization of organic matter, external sources and other non-biological transformations:

$$\begin{aligned}
S_{PO4} &= r_{DOP} DOP + r_{POP} POP \\
S_{Si} &= r_{POSi} POSi \\
S_{FeT} &= r_{DOFe} DOFe + r_{POFe} POFe - c_{scav} Fe' + \alpha F_{atmos} \\
S_{NO3} &= \zeta_{NO3} NO_2 \\
S_{NO2} &= \zeta_{NO2} NH4 - \zeta_{NO3} NO_2 \\
S_{NH4} &= r_{DON} DON + r_{PON} PON - \zeta_{NO2} NH_4
\end{aligned}$$

where:

$r_{DOM_i} =$Remineralization rate of DOM for element i, here P, Fe, N,
$r_{POM_i} =$Remineralization rate of POM for element i, here P, Si, Fe, N,
$c_{scav} =$scavenging rate for free iron,
$Fe' =$free iron, modelled as in Parekh et al (2004),
$alpha =$solubility of iron dust in ocean water,
$F_{atmos} =$atmospheric deposition of iron dust on surface of model ocean,
$\zeta_{NO3} = \zeta_{NO3}^0 (1 - I/I_0)_+ =$oxidation rate of NO_2 to NO_3,
$\zeta_{NO2} = \zeta_{NO2}^0 (1 - I/I_0)_+ =$oxidation rate of NH_4 to NO_2 (is photoinhibited),
$I_0 =$critical light level below which oxidation occurs,

The remineralization timescale r_{DOi} and r_{POi} parameterizes the break down of organic matter to an inorganic form through the microbial loop.

A1.3.1 Fe chemistry:

$$\begin{aligned}
Fe' &= FeT - FeL \\
FeL &= L_{tot} - \frac{L_{stab}(L_{tot} - FeT) - 1 + \sqrt{(1 - L_{stab}(L_{tot} - FeT))^2 + 4 L_{stab} L_{tot}}}{2 L_{stab}}
\end{aligned}$$

(Fe' may be constrained to be less than Fe'_{max} while preserving FeT).

A1.4 DOM and POM Source terms:
S_{DOM_i} and S_{POM_i} are the sources of dissolved and particulate organic detritus arising from mortality, excretion and sloppy feeding of the plantkon. We simply define that a fixed fraction λ_m of the the mortality/excretion term and the non-consumed grazed phytoplankton (λ_g) go into the dissolved pool and the remainder into the particulate pool.

$$
\begin{aligned}
S_{DOM_i} &= \sum_j [\lambda_{mp_{ij}} m^p_j P_j M_{ij}] + \sum_k [\lambda_{mz_{ik}} m^z_k Z_{ik}] + \sum_k \sum_j [\lambda_{g_{ijk}} (1-\zeta_{jk}) g_{ij} M_{ij} Z_k] \\
S_{POM_i} &= \sum_j [(1-\lambda_{m_{ij}}) m^p_j P_j M_{ij}] + \sum_k [(1-\lambda_{mz_{ik}}) m^z_k Z_{ik}] + \sum_k \sum_j [(1-\lambda_{g_{ijk}})(1-\zeta_{jk}) g_{ij} M_{ij} Z_k]
\end{aligned}
$$

A1.4 Geider light limitation model:
The phytoplankton growth rate is given by the carbon-specific photosynthesis rate (rate of carbon synthesized per carbon present),

$$\mu_j = P^C_j$$

The carbon-specific photosynthesis rate

$$P^C_j = P^C_{m,j} \begin{cases} 1 - e^{-\alpha_j^{\mathrm{Chl}} I \theta_j / P^C_{m,j}} & \text{if } I > 0.1 \\ 0 & \text{otherwise} \end{cases}$$

depends on the carbon-specific, light-saturated photosynthesis rate

$$P^C_{m,j} = P^C_{\mathrm{MAX}j} \gamma^N_j \gamma^T_j$$

and the Chl a to carbon ratio

$$\theta_j = \left[\frac{\theta_j^{\max}}{1 + \theta_j^{\max} \alpha_j^{\mathrm{Chl}} I / (2 P^C_{m,j})} \right]_{\theta_j^{\min}}^{\theta_j^{\max}}$$

The chlorophyll concentration is

$$Chl_j = P_j R^{PC}_j \theta_j$$

The light limitation factor can be diagnosed

$$\gamma^I_j = P^C_j / P^C_{m,j}$$

$$\alpha_j^{\mathrm{Chl}} = m Q_j^{\mathrm{yield}} A^{\mathrm{phy}}_{\mathrm{Chl,ave}}$$

Parameters:

$P^C_{\mathrm{MAX}j}$ = Maximum C-spec. photosynthesis rate at reference temperature of phytoplankton j
$\theta^{\max}_j$ = Maximum Chl a to C ratio if phytoplankton j
R^{PC}_j = Carbon to phosphorus (!) ratio of phytoplankton j
α^{Chl}_j = Chl a-specific initial slope of the photosynthesis-light curve
mQ^{yield}_j = slope of the photosynthesis-light curve per absorption
$A^{\mathrm{phy}}_{\mathrm{Chl,ave}}$ = absorption (m^{-1}) per mg Chl a

A2 Diagnostics:

Total phytoplankton biomass:

$$P_{\mathrm{tot}} = \sum_j P_j$$

name	definition		units
`PhyTot`	P_{tot}		$\mu\mathrm{M\,P}$
`PhyGrp1`	Total biomass of small phytoplankton with $\mathtt{nsrc} = 1$		$\mu\mathrm{M\,P}$
`PhyGrp2`	Total biomass of small phytoplankton with $\mathtt{nsrc} = 2$		$\mu\mathrm{M\,P}$
`PhyGrp3`	Total biomass of small phytoplankton with $\mathtt{nsrc} = 3$		$\mu\mathrm{M\,P}$
`PhyGrp4`	Total biomass of large non-diatoms		$\mu\mathrm{M\,P}$
`PhyGrp5`	Total biomass of diatoms		$\mu\mathrm{M\,P}$
`PP`	Primary production		$\mu\mathrm{M\,P\,s^{-1}}$
`Nfix`	Nitrogen fixation		$\mu\mathrm{M\,N\,s^{-1}}$
`PAR`	Photosynthetically active radiation		$\mu\mathrm{Ein\,m^{-2}\,s^{-1}}$
`Rstar01`	R^*_{PO4} of Phytoplankton species #1, ...		$\mu\mathrm{M\,P}$
`Diver1`	Number of species with $P_j > 10^{-8}\,\mu\mathrm{M\,P}$	where $P_{\mathrm{tot}} > 10^{-12}$	
`Diver2`	Number of species with $P_j > 0.1\%\,P_{\mathrm{tot}}$	where $P_{\mathrm{tot}} > 10^{-12}$	
`Diver3`	Number of species that constitute 99.9% of P_{tot}	where $P_{\mathrm{tot}} > 10^{-12}$	
`Diver4`	Number of species with $P_j > 10^{-5} \cdot \max_j P_j$	where $P_{\mathrm{tot}} > 10^{-12}$	