Ecological model for GEOCLIM: the ECOWEB module

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1 Generality

The model includes three trophic levels: primary producers, predators, and super predators. The ecological model uses the P input in each oceanic reservoir to calculate the uptake of P and C by the primary producers (entrance gate of those elements in the trophic chains). ECOWEB then sends this uptake back to the GEOCLIM model which stores it into the POC reservoir. Within ECOWEB, the exchange fluxes are in molC/yr, and the stocks in molC. Each species is thus represented by a carbon mass.

The number of species of the three trophic levels is fixed prior to any simulation.

2 Mass balance for the primary producers

At each time step, the mass of species i is calculated by solving the following mass balance equation:

$$\frac{dy_i}{dt} = \alpha_i - \omega_i \tag{1}$$

where y_i is the biomass of species i (mol C). α_i is the birth rate of species i, and ω_i is the sum of the death rate and grazing rate when applicable.

2.1 Reproduction rate

α_i (mol/yr) is dependent on the temperature of the reservoir T, on pH, and on the input of dissolved PO_4^{2-} inside the oceanic reservoir.

$$\alpha_i = br_i \cdot a_1^i \cdot \exp\left[\frac{-\left(T - b_1^i\right)^2}{2\left(c_1^i\right)^2}\right] \cdot a_2^i \cdot \exp\left[\frac{-\left(pH - b_2^i\right)^2}{2\left(c_2^i\right)^2}\right] \cdot I_i \cdot F_{in}^P \tag{2}$$

The two exponential factors are gaussian functions. b_1^i and b_2^i are respectively the optimum living temperature and pH for the species i. c_1^i and c_2^i define the temperature and pH tolerance of species i. b_1^i is set to the averaged long term temperature, with a random noise between 0 and ±5 degrees C around the optimum living temperature. The temperature tolerance for each species is randomly set a value between 0 and ±4 degrees C around each respective optimum temperature b_1^i. Optimal living pH b_2^i and tolerance c_2^i are similarly randomly set. The interval goes from -0.1 to +0.1 for the noise added to the averaged long term pH of the surficial reservoir. Tolerance runs from ±0.3 pH unit.

Finally, I_i represents the potential competition for resources amongst the primary producers. For each species i, the existence of a competitive relationship is randomly fixed (yes/no). If the answer is no, $I_{i,j}$ is set to 1. Conversely, If the answer is yes, $I_{i,j}$ is calculated as follows for species i:

$$I_{i,j} = \frac{\left(\frac{y_i}{y_j}\right)}{1 + \left(\frac{y_i}{y_j}\right)} \tag{3}$$

For species j with respect to species i, it is calculated as:

$$I_{j,i} = 1 - I_{i,j} \tag{4}$$

where y_i and y_j are respectively the biomasses of species i and j. If the ratio between these two biomasses tends towards 0, then the efficiency of species j in gathering resources leads to the extinction of i. If the biomass ratio turns at the advantage of species i, and the reproduction of j) tends towards 0. The factor I_i is calculated as the average of all the I_i, j, for j covering the whole range of species in competition with i. This formalism implies that if a species is in competition with one or several others, its reproduction rate is somewhat reduced (I_i is little than 1) compared to non-competing species.

2.2 Death rate

The death rate of each primary producer is equal to the sum of the natural death rate D_i and the predation rate $G_{i,k}$ of species by the predator k (both fuxes in moleC/year). The death rate is set proportional to the total mass of the primary producer himself:

$$D_i = k_{death} \cdot y_i \tag{5}$$

Several predators can feed on the same primary producer species i. The is fixed by drawing lots. Then the total loss of biomass of species i due to predation is:

$$G_i = \sum_k G_(i,k) = \sum_k k_{pred}^{k,i} \cdot \frac{\frac{y_i}{y_k}}{10 + \frac{y_i}{y_k}} \cdot y_k \tag{6}$$

where the sum extends over all the predators (k) feeding on species i. $k_{pred}^{k,i}$ is a fix constant, but can also be randomly fixed. The relative predator biomass within the whole ecosystem depends on this (those) constant(s). The predation rate is also set proportional to the predator biomass (the more they are, the more they eat. But the proportionality is modulated by a Michaelis-Menten function of the prey/predator ratio. Overall, the second term of equation 1 can be written:

$$\omega_i = D_i + G_i \tag{7}$$

3 Mass balance for the predators

The reproduction rate of predators is set to their grazing rate, following the principle that they are tight to the disponibility of ressources. The number of grazed species for each predator is fixed randomly. Some of them are thus specialist (feeding on few species), and other generalist (feeding on many species). Predators are allowed to feed on other predators. This is once again randomly fixed. The death rate of predator is calculated in the same way as the death rate of primary producers.

4 Mass balance for the super predators

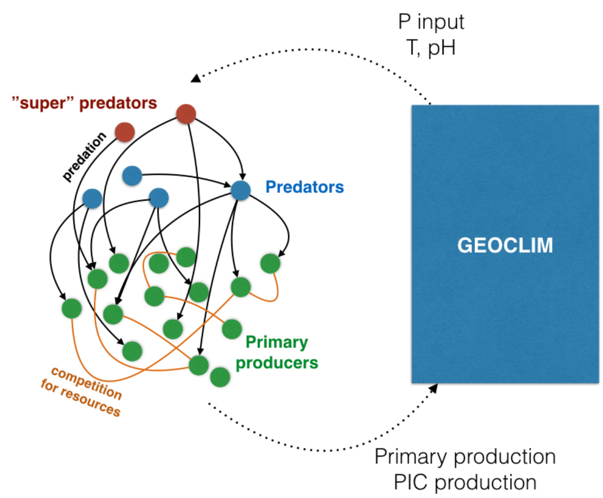
Predators of the trophic level 3 behave as predator of the trophic level 2, with the notable exception that they cannot feed on each other. The D_i terms is thus the only term appearing in the calculation of ω_i.

5 Pelagic carbonate producers

A random number of primary producers are assumed to be carbonate shell producers. No more than 20% of the primary producer species can be carbonate producers (this is an adjustable parameter). For each surficial oceanic reservoir, the ECOWEB module calculates the ratio between the biomass of primary producers building carbonate shells, and the total biomass of primary producers. This ratio is sent to GEOCLIM which translate it into a carbonate flux as a function of the saturation state of the seawater with respect to calcite. Note that if the surface water becomes undersaturated, the carbonate primary producers undergo extinction (α_i is set to zero).

6 Extinction

If, for any given reason, the biomass of a species falls below 1% of its original steady-state value, the species undergoes extinction. α_i is set to zero, translating the fact that the critical threshold below which reproduction is not more possible has been reached. The threshold of 1% is an adjustable parameter. α_i is maintained to zero even if favorable conditions are restores over the course of the simulation.



Schematic view of the ECOWEB module