Supplement of Geosci. Model Dev., 16, 6701–6739, 2023
https://doi.org/10.5194/gmd-16-6701-2023-supplement

Geoscientific Model Development
Open Access

Supplement of

Implementation and assessment of a model including mixotrophs and the carbonate cycle (Eco3M_MIX-CarbOx v1.0) in a highly dynamic Mediterranean coastal environment (Bay of Marseille, France) – Part 1: Evolution of ecosystem composition under limited light and nutrient conditions

Lucille Barré et al.

Correspondence to: Lucille Barré (lucille.barre@mio.osupytheas.fr) and Christel Pinazo (christel.pinazo@mio.osupytheas.fr)

Supplementary materials

S1. Supplementary analysis

S1.1 Configurations without mixotrophs

In addition to the Eco3M_MIX-CarbOx configuration with mixotrophs, we implemented two configurations of Eco3M_MIX-CarbOx without mixotrophs : a first one in which mixotrophs and their associated processes are simply deleted (configuration D in the following) and a second one in which mixotrophs are replaced by organisms with strict diets (configuration R in the following).

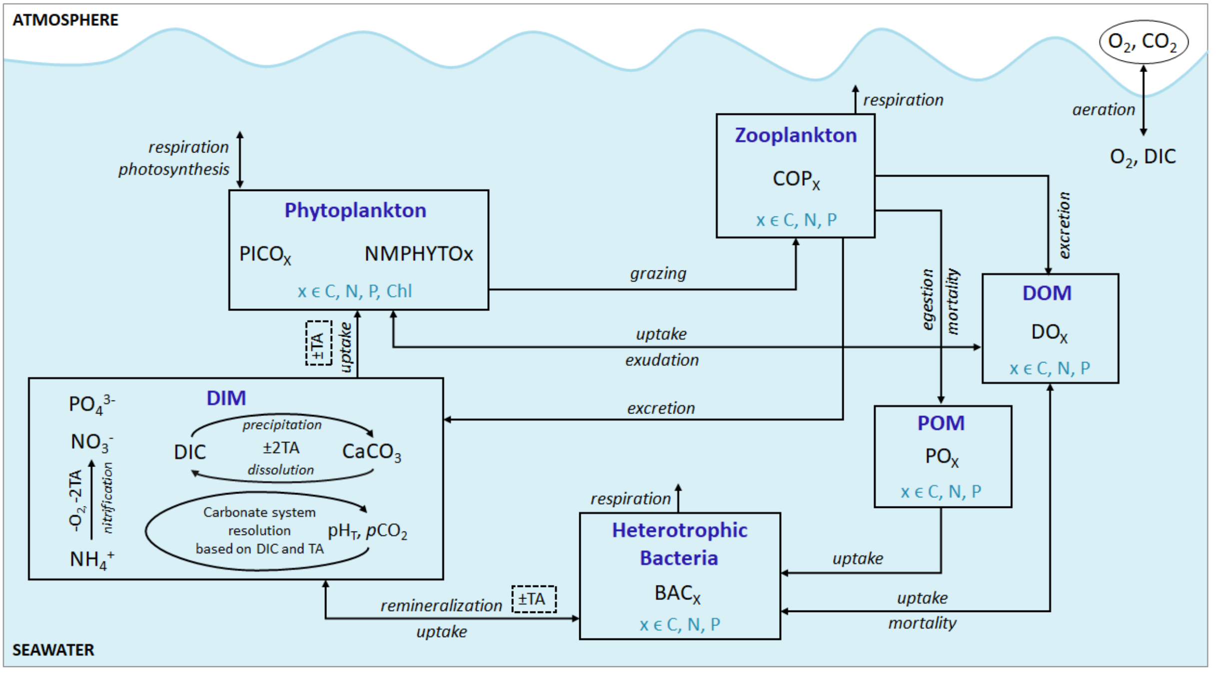

Figure S1: Schematic representation of the D configuration of Eco3M_MIX-CarbOx in which mixotrophs and their processes were deleted. Each box represents a model compartment (DIM: dissolved inorganic matter, DOM: labile dissolved organic matter, POM: detrital particulate organic matter). State variables are indicated in black (COP: copepods, NMPHYTO: nano+micro-phytoplankton, PICO: picophytoplankton, BAC : heterotrophic bacteria, O_2: dissolved oxygen, CO_2: dissolved carbon dioxide, DIC: dissolved inorganic carbon, TA: total alkalinity, pCO_2: partial pressure of CO_2, $CaCO_3$: calcium carbonate). Elements for which a state variable is expressed with a variable stoichiometry are shown in blue (C: carbon, N: nitrogen, P: phosphorus and, Chl: chlorophyll). Arrows represent processes between two state variables.

In the configuration D, mixotrophs and their processes are simply deleted (not replaced). Therefore, the model configuration includes only four types of organisms: copepods (COP), nano+micro-phytoplankton (NMPHYTO), picophytoplankton (PICO) and heterotrophic bacteria (BAC) (Fig.S1). Balance equations are detailed in Table S1. In the configuration with mixotrophs, picophytoplankton and heterotrophic bacteria were grazed by NCM and CM. In the D configuration, as NCM and CM are deleted, these organisms have no predators left. To balance PICO and BAC biomass, we add a loss term to the balance equations which represents the predation by largest organisms which are not considered in this configuration (implicit representation of predators). To formulate this term, we assumed that its value must be similar to the grazing that CM and NCM used to perform on PICO and BAC in the configuration with mixotrophs. By making this hypothesis, we ensure that PICO and BAC biomasses are well top-down regulated and that their compartment are balanced without digressing too far from the initial configuration, with mixotrophs. We then formulate predation as a sum of NCM and CM grazing and adapt it to the configuration by using constant for concentrations of predators (2.2 and 0.4 mmolC m^{-3}, mean biomasses obtained for mixotrophs in the configuration with mixotrophs). The predation flux is applied on PICO and BAC biomass and exits the model (this matter is not recycled). Other process formulations remain unchanged.

In the R configuration, NCM are replaced by strict heterotrophs which belong to the micro size class (microzooplankton, MICROZ). CM are replaced by strict autotrophs which belong to the nano size class (nanophytoplankton, NANOP). Since nanophytoplankton is represented by the NANOP variable, the MICROP variable replaced the NMPHYTO one and is used to represent organisms between 20 and 200µm (Fig. S2 and S3). The equations of MICROZ and NANOP are similar to the equations of NCM and CM except that we deleted the photosynthesis term associated with NCM and the grazing terms associated with CM. The MICROZ is represented in C, N and P and the NANOP in C, N, P and Chl according to the following state equations:

$$\frac{\partial \mathrm{MICROZ_C}}{\partial \mathrm{t}} = \sum_{i=1}^{3}\left(\mathrm{Gra}_{\mathrm{MICROZ_C}}^{\mathrm{PHYC_i}}\right) + \mathrm{Gra}_{\mathrm{MICROZ_C}}^{\mathrm{BAC_C}} - \mathrm{Resp}_{\mathrm{MICROZ_C}}^{\mathrm{DIC}} - \mathrm{Exu}_{\mathrm{MICROZ_C}}^{\mathrm{DOC}} - \mathrm{Gra}_{\mathrm{MICROZ_C}}^{\mathrm{COP_C}}$$

$$\frac{\partial \mathrm{MICROZ_N}}{\partial \mathrm{t}} = \sum_{i=1}^{3}\left(\mathrm{Gra}_{\mathrm{MICROZ_N}}^{\mathrm{PHYN_i}}\right) + \mathrm{Gra}_{\mathrm{MICROZ_N}}^{\mathrm{BAC_N}} - \mathrm{Exu}_{\mathrm{MICROZ_N}}^{\mathrm{DON}} - \mathrm{Excr}_{\mathrm{MICROZ_N}}^{\mathrm{NH_4}} - \mathrm{Gra}_{\mathrm{MICROZ_N}}^{\mathrm{COP_N}}$$

$$\frac{\partial \mathrm{MICROZ_P}}{\partial \mathrm{t}} = \sum_{i=1}^{3}\left(\mathrm{Gra}_{\mathrm{MICROZ_P}}^{\mathrm{PHYP_i}}\right) + \mathrm{Gra}_{\mathrm{MICROZ_P}}^{\mathrm{BAC_P}} - \mathrm{Exu}_{\mathrm{MICROZ_P}}^{\mathrm{DOP}} - \mathrm{Excr}_{\mathrm{MICROZ_P}}^{\mathrm{PO_4}} - \mathrm{Gra}_{\mathrm{MICROZ_P}}^{\mathrm{COP_P}}$$

PHY ϵ [MICROP, NANOP, PICOP]
(Eq. S1)

$$\frac{\partial \mathrm{NANOP_C}}{\partial \mathrm{t}} = \mathrm{Photo}_{\mathrm{NANOP_C}}^{\mathrm{DIC}} - \mathrm{Resp}_{\mathrm{NANOP_C}}^{\mathrm{DIC}} - \mathrm{Exu}_{\mathrm{NANOP_C}}^{\mathrm{DOC}} - \sum_{i=1}^{2}\left(\mathrm{Gra}_{\mathrm{NANOP_C}}^{\mathrm{ZOOC_i}}\right)$$

$$\frac{\partial \mathrm{NANOP_N}}{\partial \mathrm{t}} = \mathrm{Upt}_{\mathrm{NANOP_N}}^{\mathrm{NO_3}} + \mathrm{Upt}_{\mathrm{NANOP_N}}^{\mathrm{NH_4}} + \mathrm{Upt}_{\mathrm{NANOP_N}}^{\mathrm{DON}} - \mathrm{Exu}_{\mathrm{NANOP_N}}^{\mathrm{DON}} - \sum_{i=1}^{2}\left(\mathrm{Gra}_{\mathrm{NANOP_N}}^{\mathrm{ZOON_i}}\right)$$

$$\frac{\partial \mathrm{NANOP_P}}{\partial \mathrm{t}} = \mathrm{Upt}_{\mathrm{NANOP_P}}^{\mathrm{PO_4}} + \mathrm{Upt}_{\mathrm{NANOP_P}}^{\mathrm{DOP}} - \mathrm{Exu}_{\mathrm{NANOP_P}}^{\mathrm{DOP}} - \sum_{i=1}^{2}\left(\mathrm{Gra}_{\mathrm{NANOP_P}}^{\mathrm{ZOOP_i}}\right)$$

$$\frac{\partial \mathrm{NANOP_{Chl}}}{\partial t} = \mathrm{Syn_{NANOP_{Chl}}} - \sum_{i=1}^{2}\left(\mathrm{Gra_{NANOP_{Chl}}^{ZOO_C}}\right)$$

ZOO ϵ [COP, MICROZ]
(Eq. S2)

MICROZ process formulations are the same as the NCM ones. For NANOP, process formulations are the same as the CM one except for DOC exudation formulation (Eq. S3) in which we removed the exuded part of C coming from grazing.

$$\mathrm{Exu_{NANOP_C}^{DOC}} = \left(1 - \mathrm{frac_{resp}}\right) * \left(\mathrm{Photo_{NANOP_C}^{DIC}} * \left(1 - \mathrm{f_Q^G}\right)\right)$$

(Eq.S3)

Where $\mathrm{Exu_{NANOP_C}^{DOC}}$ is in mmolC m^{-3} s^{-1}, $\mathrm{frac_{resp}}$ is the carbon fraction allocated to respiration, $\mathrm{Photo_{NANOP_C}^{DIC}}$ is the photosynthesis flux in mmolC m^{-3} s^{-1} and $\mathrm{f_Q^G}$ is a nutrient limitation function which express the nutritional state of the cell.

For other organisms, balance equations and process formulations remain unchanged except that photosynthesis terms previously associated with NCM, and grazing terms previously associated with CM are no longer considered. Balance equations for this configuration are detailed in Table S2.

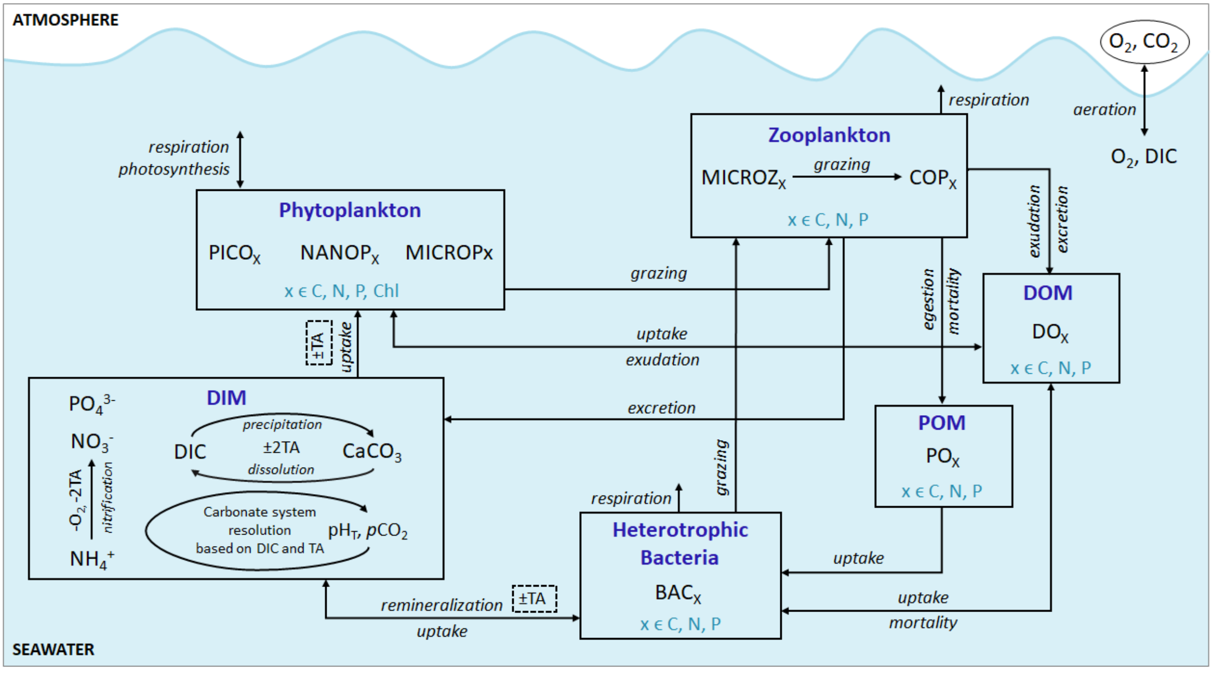

Figure S2: Schematic representation of the R configuration of Eco3M_MIX-CarbOx in which mixotrophs were replaced by strict heterotrophs (microzooplankton: MICROZ) and strict autotrophs (nanophytoplankton: NANOP). Each box represents a model compartment (DIM: dissolved inorganic matter, DOM: labile dissolved organic matter, POM: detrital particulate organic matter). State variables are indicated in black (COP: copepods, MICROP: microphytoplankton, PICO: picophytoplankton, BAC: heterotrophic bacteria, O_2: dissolved oxygen, CO_2: dissolved carbon dioxide, DIC: dissolved inorganic carbon, TA: total alkalinity, pCO_2: partial pressure of CO_2, $CaCO_3$: calcium carbonate). Elements for which a state variable is expressed with a variable stoichiometry are shown in blue (C: carbon, N: nitrogen, P: phosphorus and, Chl: chlorophyll). Arrows represent processes between two state variables.

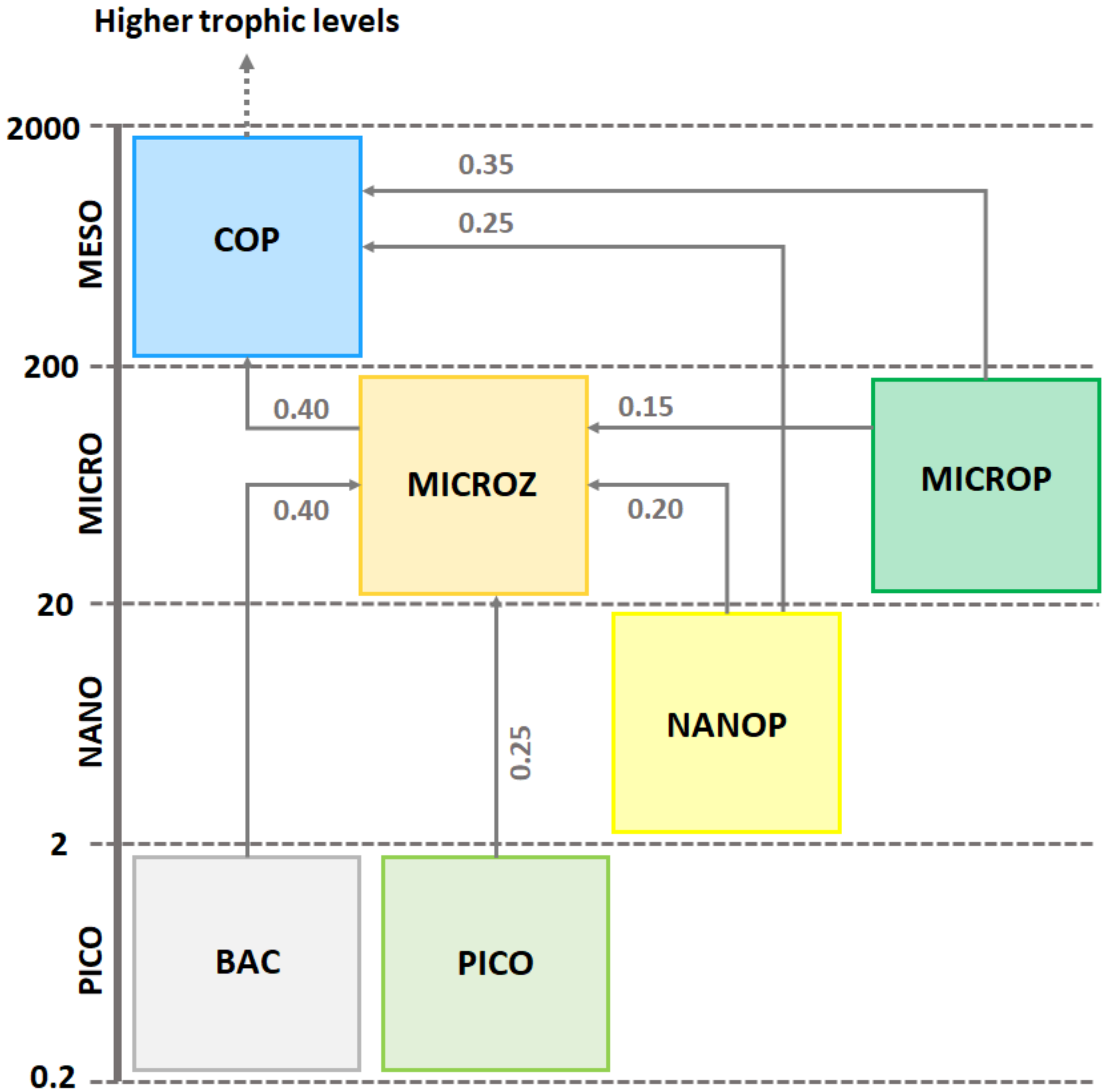

Figure S3: Repartition of modelled organisms (COP: copepods, MICROZ: microzooplankton, MICROP: microphytoplankton, NANOP: nanophytoplankton, PICO: picophytoplankton and BACT: heterotrophic bacteria) in size classes and trophic interactions between them for the R configuration of Eco3M_MIX-CarbOx. Preference values are indicated in grey for copepods (Verity, 1996) and MICROZ (Verity, 1991; Price & Turner, 1992 ; Chrsitaki, 1999).

Table S1: Balance equations for D configuration.

Variables	Balance equations
COP_X $X \in [C, N, P]$	$\frac{\partial COP_C}{\partial t} = Gra_{COP_C}^{NMPHYTO_C} - Resp_{COP_C}^{DIC} - Excr_{COP_C}^{DOC} - E_{COP_C}^{POC} - Predation_{COP_C}^{POC}$ $\frac{\partial COP_N}{\partial t} = Gra_{COP_N}^{NMPHYTO_N} - Excr_{COP_N}^{NH_4} - E_{COP_N}^{PON} - Predation_{COP_N}^{PON}$

	$\frac{\partial COP_P}{\partial t} = Gra_{COP_P}^{NMPHYTO_P} - Excr_{COP_P}^{PO_4} - E_{COP_P}^{POP} - Predation_{COP_P}^{POP}$
NMPHYTO$_X$ X ϵ [C, N, P, Chl]	$\frac{\partial NMPHYTO_C}{\partial t} = Photo_{NMPHYTO_C}^{DIC} - Resp_{NMPHYTO_C}^{DIC} - Exu_{NMPHYTO_C}^{DOC} - Gra_{NMPHYTO_C}^{COP_C}$ $\frac{\partial NMPHYTO_N}{\partial t} = Upt_{NMPHYTO_N}^{NO_3} + Upt_{NMPHYTO_N}^{NH_4} - Exu_{NMPHYTO_N}^{DON} - Gra_{NMPHYTO_N}^{COP_N}$ $\frac{\partial NMPHYTO_P}{\partial t} = Upt_{NMPHYTO_P}^{PO_4} - Exu_{NMPHYTO_P}^{DOP} - Gra_{NMPHYTO_P}^{COP_P}$ $\frac{\partial NMPHYTO_{Chl}}{\partial t} = Syn_{NMPHYTO_{Chl}} - Gra_{NMPHYTO_{Chl}}^{COP_C}$
PICO$_X$ X ϵ [C, N, P, Chl]	$\frac{\partial PICO_C}{\partial t} = Photo_{PICO_C}^{DIC} - Resp_{PICO_C}^{DIC} - Exu_{PICO_C}^{DOC} - Pred_{PICO_C}$ $\frac{\partial PICO_N}{\partial t} = Upt_{PICO_N}^{NO_3} + Upt_{PICO_N}^{NH_4} + Upt_{PICO_N}^{DON} - Exu_{PICO_N}^{DON} - Pred_{PICO_N}$ $\frac{\partial PICO_P}{\partial t} = Upt_{PICO_P}^{PO_4} + Upt_{PICO_P}^{DOP} - Exu_{PICO_P}^{DOP} - Pred_{PICO_P}$ $\frac{\partial PICO_{Chl}}{\partial t} = Syn_{PICO_{Chl}} - Pred_{PICO_{Chl}}$
BAC$_X$ X ϵ [C, N, P]	$\frac{\partial BAC_C}{\partial t} = BP_{BAC_C}^{DOC} + BP_{BAC_C}^{POC} - BR_{BAC_C}^{DIC} - Mort_{BAC_C}^{DOC} - Pred_{BAC_C}$ $\frac{\partial BAC_N}{\partial t} = Upt_{BAC_N}^{NH_4} + Upt_{BAC_N}^{DON} + Upt_{BAC_N}^{PON} - Remin_{BAC_N}^{NH_4} - Mort_{BAC_N}^{DON} - Pred_{BAC_N}$ $\frac{\partial BAC_P}{\partial t} = Upt_{BAC_P}^{PO_4} + Upt_{BAC_P}^{DOP} + Upt_{BAC_P}^{POP} - Remin_{BAC_P}^{PO_4} - Mort_{BAC_P}^{DOP} - Pred_{BAC_P}$
DOX X ϵ [C, N, P]	$\frac{\partial DOC}{\partial t} = \sum_{i=1}^{2}\left(Exu_{DOC}^{PHY_{C_i}}\right) + Excr_{DOC}^{COP_C} + Mort_{DOC}^{BAC_C} - BP_{DOC}^{BAC_C}$ $\frac{\partial DON}{\partial t} = \sum_{i=1}^{2}\left(Exu_{DON}^{PHY_{N_i}}\right) + Mort_{DON}^{BAC_N} - Upt_{DON}^{PICO_N} - Upt_{DON}^{BAC_N}$ $\frac{\partial DOP}{\partial t} = \sum_{i=1}^{2}\left(Exu_{DOP}^{PHY_{P_i}}\right) + Mort_{DOP}^{BAC_P} - Upt_{DOP}^{PICO_P} - Upt_{DOP}^{BAC_P}$ PHY ϵ [NMPHYTO, PICO]
POX X ϵ [C, N, P]	$\frac{\partial POC}{\partial t} = E_{POC}^{COP_C} + Predation_{POX}^{COP_X} - BP_{POC}^{BAC_C}$ $\frac{\partial PON}{\partial t} = E_{PON}^{COP_N} + Predation_{PON}^{COP_N} - Upt_{PON}^{BAC_N}$ $\frac{\partial POP}{\partial t} = E_{POP}^{COP_P} + Predation_{POP}^{COP_P} - Upt_{POP}^{BAC_P}$

NO_3^-	$$\frac{\partial NO_3}{\partial t} = \mathrm{Nitrif}_{NO_3}^{NH_4} - \sum_{i=1}^{2} \mathrm{Upt}_{NO_3}^{\mathrm{Phy}_{N_i}}$$ PHY ϵ [NMPHYTO, PICO]
NH_4^+	$$\frac{\partial NH_4}{\partial t} = \mathrm{Excr}_{NH_4}^{\mathrm{COP}_N} + \mathrm{Remin}_{NH_4}^{\mathrm{BAC}_N} - \sum_{i=1}^{2} \left(\mathrm{Upt}_{NH_4}^{\mathrm{Phy}_{N_i}}\right) - \mathrm{Upt}_{NH_4}^{\mathrm{BAC}_N} - \mathrm{Nitrif}_{NH_4}^{NO_3}$$ PHY ϵ [NMPHYTO, PICO]
PO_4^{3-}	$$\frac{\partial PO_4}{\partial t} = \mathrm{Excr}_{PO_4}^{\mathrm{COP}_{P_i}} + \mathrm{Remin}_{PO_4}^{\mathrm{BAC}_P} - \sum_{i=1}^{2} \left(\mathrm{Upt}_{PO_4}^{\mathrm{PHY}_{P_i}}\right) - \mathrm{Upt}_{PO_4}^{\mathrm{BAC}_P}$$ PHY ϵ [NMPHYTO, PICO]
O_2	$$\frac{\partial O_2}{\partial t} = \left(\frac{O}{C}\right)_{PP} * \sum_{i=1}^{2} \left(\mathrm{Photo}_{O_2}^{\mathrm{PHY}_i}\right) + \mathrm{Aera}_{O_2} - \sum_{i=1}^{2} \left(\mathrm{Resp}_{O_2}^{\mathrm{Phy}_i}\right) - \mathrm{Resp}_{O_2}^{\mathrm{COP}} - \mathrm{BR}_{O_2}^{\mathrm{BAC}} - \left(\frac{O}{C}\right)_{NITRIF} . \mathrm{Nitrif}_{O_2}$$ PHY ϵ [NMPHYTO, PICO]
DIC	$$\frac{\partial DIC}{\partial t} = \sum_{i=1}^{2} \left(\mathrm{Resp}_{DIC}^{\mathrm{PHY}_{C_i}}\right) + \mathrm{Resp}_{DIC}^{\mathrm{COP}_C} + \mathrm{BR}_{DIC}^{\mathrm{BAC}_C} + \mathrm{Aera}_{DIC} + \mathrm{Diss}_{DIC}^{CaCO_3} - \sum_{i=1}^{2} \left(\mathrm{Photo}_{DIC}^{\mathrm{PHY}_{C_i}}\right) - \mathrm{Prec}_{DIC}^{CaCO_3}$$ PHY ϵ [NMPHYTO, PICO]
AT	$$\frac{\partial AT}{\partial t} = 2 * \mathrm{Diss}_{AT}^{CaCO_3} + \sum_{i=1}^{2} \left(\mathrm{Upt}_{NO_3}^{\mathrm{Phy}_{N_i}}\right) + \sum_{i=1}^{2} \left(\mathrm{Upt}_{PO_4}^{\mathrm{Phy}_{P_i}}\right) + \mathrm{Remin}_{NH_4}^{\mathrm{BAC}_N} - \sum_{i=1}^{2} \left(\mathrm{Upt}_{NH_4}^{\mathrm{Phy}_{N_i}}\right) - \mathrm{Remin}_{PO_4}^{\mathrm{BAC}_P} - 2 * \mathrm{Prec}_{AT}^{CaCO_3} - 2 * \mathrm{Nitrif}_{TA}$$ PHY ϵ [NMPHYTO, PICO]
$CaCO_3$	$$\frac{\partial CaCO_3}{\partial t} = \mathrm{Prec}_{DIC}^{CaCO_3} - \mathrm{Diss}_{DIC}^{CaCO_3}$$

Table S2: Balance equations for R configuration.

Variables	Balance equations
COP_X $X \in [C, N, P]$	$\frac{\partial COP_C}{\partial t} = Gra_{COP_C}^{MICROZ_C} + \sum_{i=1}^{2}\left(Gra_{COP_C}^{PHYC_i}\right) - Resp_{COP_C}^{DIC} - Excr_{COP_C}^{DOC} - E_{COP_C}^{POC} - Predation_{COP_C}^{POC}$ $\frac{\partial COP_N}{\partial t} = Gra_{COP_N}^{MICROZ_N} + \sum_{i=1}^{2}\left(Gra_{COP_N}^{PHYN_i}\right) - Excr_{COP_N}^{NH_4} - E_{COP_N}^{PON} - Predation_{COP_N}^{PON}$ $\frac{\partial COP_P}{\partial t} = Gra_{COP_P}^{MICROZ_P} + \sum_{i=1}^{2}\left(Gra_{COP_P}^{PHYP_i}\right) - Excr_{COP_P}^{PO_4} - E_{COP_P}^{POP} - Predation_{COP_P}^{POP}$ PHY ϵ [MICROP, NANOP]
$MICROZ_X$ $X \in [C, N, P]$	$\frac{\partial MICROZ_C}{\partial t} = \sum_{i=1}^{3}\left(Gra_{MICROZ_C}^{PHYC_i}\right) + Gra_{MICROZ_C}^{BAC_C} - Resp_{MICROZ_C}^{DIC} - Exu_{MICROZ_C}^{DOC} - Gra_{MICROZ_C}^{COP_C}$ $\frac{\partial MICROZ_N}{\partial t} = \sum_{i=1}^{3}\left(Gra_{MICROZ_N}^{PHYN_i}\right) + Gra_{MICROZ_N}^{BAC_N} - Exu_{MICROZ_N}^{DON} - Excr_{MICROZ_N}^{NH_4} - Gra_{MICROZ_N}^{COP_N}$ $\frac{\partial MICROZ_P}{\partial t} = \sum_{i=1}^{3}\left(Gra_{MICROZ_P}^{PHYP_i}\right) + Gra_{MICROZ_P}^{BAC_P} - Exu_{MICROZ_P}^{DOP} - Excr_{MICROZ_P}^{PO_4} - Gra_{MICROZ_P}^{COP_P}$ PHY ϵ [MICROP, NANOP, PICO]
$MICROP_X$ $X \in [C, N, P, Chl]$	$\frac{\partial MICROP_C}{\partial t} = Photo_{MICROP_C}^{DIC} - Resp_{MICROP_C}^{DIC} - Exu_{MICROP_C}^{DOC} - \sum_{i=1}^{2}\left(Gra_{MICROP_C}^{ZOOC_i}\right)$ $\frac{\partial MICROP_N}{\partial t} = Upt_{MICROP_N}^{NO_3} + Upt_{MICROP_N}^{NH_4} - Exu_{MICROP_N}^{DON} - \sum_{i=1}^{2}\left(Gra_{MICROP_N}^{ZOON_i}\right)$ $\frac{\partial MICROP_P}{\partial t} = Upt_{MICROP_P}^{PO_4} - Exu_{MICROP_P}^{DOP} - \sum_{i=1}^{2}\left(Gra_{MICROP_P}^{ZOOP_i}\right)$ $\frac{\partial MICROP_{Chl}}{\partial t} = Syn_{MICROP_{Chl}} - \sum_{i=1}^{2}\left(Gra_{MICROP_{Chl}}^{ZOOC_i}\right)$ ZOO ϵ [COP, MICROZ]
$NANOP_X$ $X \in [C, N, P, Chl]$	$\frac{\partial NANOP_C}{\partial t} = Photo_{NANOP_C}^{DIC} - Resp_{NANOP_C}^{DIC} - Exu_{NANOP_C}^{DOC} - \sum_{i=1}^{2}\left(Gra_{NANOP_C}^{ZOOC_i}\right)$

	$\frac{\partial NANOP_N}{\partial t} = Upt^{NO_3}_{NANOP_N} + Upt^{NH_4}_{NANOP_N} + Upt^{DON}_{NANOP_N} - Exu^{DON}_{NANOP_N} - \sum_{i=1}^{2}\left(Gra^{ZOON_i}_{NANOP_N}\right)$ $\frac{\partial NANOP_P}{\partial t} = Upt^{PO_4}_{NANOP_P} + Upt^{DOP}_{NANOP_P} - Exu^{DOP}_{NANOP_P} - \sum_{i=1}^{2}\left(Gra^{ZOOP_i}_{NANOP_P}\right)$ $\frac{\partial NANOP_{Chl}}{\partial t} = Syn_{NANOP_{Chl}} - \sum_{i=1}^{2}\left(Gra^{ZOO_C}_{NANOP_{Chl}}\right)$ ZOO ϵ [COP, MICROZ]
$PICO_X$ X ϵ [C, N, P, Chl]	$\frac{\partial PICO_C}{\partial t} = Photo^{DIC}_{PICO_C} - Resp^{DIC}_{PICO_C} - Exu^{DOC}_{PICO_C} - Gra^{MICROZ_C}_{PICO_C}$ $\frac{\partial PICO_N}{\partial t} = Upt^{NO_3}_{PICO_N} + Upt^{NH_4}_{PICO_N} + Upt^{DON}_{PICO_N} - Exu^{DON}_{PICO_N} - Gra^{MICROZ_N}_{PICO_N}$ $\frac{\partial PICO_P}{\partial t} = Upt^{PO_4}_{PICO_P} + Upt^{DOP}_{PICO_P} - Exu^{DOP}_{PICO_P} - Gra^{MICROZ_P}_{PICO_P}$ $\frac{\partial PICO_{Chl}}{\partial t} = Syn_{PICO_{Chl}} - Gra^{MICROZ_C}_{PICO_{Chl}}$
BAC_X X ϵ [C, N, P]	$\frac{\partial BAC_C}{\partial t} = BP^{DOC}_{BAC_C} + BP^{POC}_{BAC_C} - BR^{DIC}_{BAC_C} - Mort^{DOC}_{BAC_C} - Gra^{MICROZ_C}_{BAC_C}$ $\frac{\partial BAC_N}{\partial t} = Upt^{NH_4}_{BAC_N} + Upt^{DON}_{BAC_N} + Upt^{PON}_{BAC_N} - Remin^{NH_4}_{BAC_N} - Mort^{DON}_{BAC_N} - Gra^{MICROZ_N}_{BAC_N}$ $\frac{\partial BAC_P}{\partial t} = Upt^{PO_4}_{BAC_P} + Upt^{DOP}_{BAC_P} + Upt^{POP}_{BAC_P} - Remin^{PO_4}_{BAC_P} - Mort^{DOP}_{BAC_P} - Gra^{MICROZ_P}_{BAC_P}$
DOX X ϵ [C, N, P]	$\frac{\partial DOC}{\partial t} = \sum_{i=1}^{3}\left(Exu^{PHY_{C_i}}_{DOC}\right) + Exu^{MICROZ_C}_{DOC} + Excr^{COP_C}_{DOC} + Mort^{BAC_C}_{DOC} - BP^{BAC_C}_{DOC}$ $\frac{\partial DON}{\partial t} = \sum_{i=1}^{3}\left(Exu^{PHY_{N_i}}_{DON}\right) + Exu^{MICROZ_N}_{DON} + Mort^{BAC_N}_{DON} - Upt^{NANOP_N}_{DON} - Upt^{PICO_N}_{DON}$ $- Upt^{BAC_N}_{DON}$ $\frac{\partial DOP}{\partial t} = \sum_{i=1}^{3}\left(Exu^{PHY_{P_i}}_{DOP}\right) + Exu^{MICROZ_P}_{DOP} + Mort^{BAC_P}_{DOP} - Upt^{NANOP_P}_{DOP} - Upt^{PICO_P}_{DOP} - Upt^{BAC_P}_{DOP}$ PHY ϵ [MICROP, NANOP, PICO]
POX X ϵ [C, N, P]	$\frac{\partial POC}{\partial t} = E^{COP_C}_{POC} + Predation^{COP_X}_{POX} - BP^{BAC_C}_{POC}$ $\frac{\partial PON}{\partial t} = E^{COP_N}_{PON} + Predation^{COP_N}_{PON} - Upt^{BAC_N}_{PON}$ $\frac{\partial POP}{\partial t} = E^{COP_P}_{POP} + Predation^{COP_P}_{POP} - Upt^{BAC_P}_{POP}$

NO_3^-	$$\frac{\partial NO_3}{\partial t} = \mathrm{Nitrif}_{NO_3}^{NH_4} - \sum_{i=1}^{3} \mathrm{Upt}_{NO_3}^{\mathrm{Phy}_{N_i}}$$ PHY ϵ [MICROP, NANOP, PICO]
NH_4^+	$$\frac{\partial NH_4}{\partial t} = \sum_{i=1}^{2}\left(\mathrm{Excr}_{NH_4}^{\mathrm{ZOO}_{N_i}}\right) + \mathrm{Remin}_{NH_4}^{\mathrm{BAC}_N} - \sum_{i=1}^{3}\left(\mathrm{Upt}_{NH_4}^{\mathrm{Phy}_{N_i}}\right) - \mathrm{Upt}_{NH_4}^{\mathrm{BAC}_N} - \mathrm{Nitrif}_{NH_4}^{NO_3}$$ PHY ϵ [MICROP, NANOP, PICO] ZOO ϵ [COP, MICROZ]
PO_4^{3-}	$$\frac{\partial PO_4}{\partial t} = \sum_{i=1}^{2}\left(\mathrm{Excr}_{PO_4}^{\mathrm{ZOO}_{P_i}}\right) + \mathrm{Remin}_{PO_4}^{\mathrm{BAC}_P} - \sum_{i=1}^{2}\left(\mathrm{Upt}_{PO_4}^{\mathrm{PHY}_{P_i}}\right) - \mathrm{Upt}_{PO_4}^{\mathrm{CM}_P} - \mathrm{Upt}_{PO_4}^{\mathrm{BAC}_P}$$ PHY ϵ [MICROP, NANOP, PICO] ZOO ϵ [COP, MICROZ]
O_2	$$\frac{\partial O_2}{\partial t} = \left(\frac{O}{C}\right)_{PP} * \sum_{i=1}^{3}\left(\mathrm{Photo}_{O_2}^{\mathrm{PHY}_i}\right) + \mathrm{Aera}_{O_2} - \sum_{i=1}^{3}\left(\mathrm{Resp}_{O_2}^{\mathrm{Phy}_i}\right) - \sum_{i=1}^{2}\left(\mathrm{Resp}_{O_2}^{\mathrm{ZOO}_i}\right) - \mathrm{BR}_{O_2}^{\mathrm{BAC}} - \left(\frac{O}{C}\right)_{\mathrm{NITRIF}} . \mathrm{Nitrif}_{O_2}$$ PHY ϵ [MICROP, NANOP, PICO] ZOO ϵ [COP, MICROZ]
DIC	$$\frac{\partial DIC}{\partial t} = \sum_{i=1}^{3}\left(\mathrm{Resp}_{DIC}^{\mathrm{PHY}_{C_i}}\right) + \sum_{i=1}^{2}\left(\mathrm{Resp}_{DIC}^{\mathrm{ZOO}_{C_i}}\right) + \mathrm{BR}_{DIC}^{\mathrm{BAC}_C} + \mathrm{Aera}_{DIC} + \mathrm{Diss}_{DIC}^{CaCO_3} - \sum_{i=1}^{3}\left(\mathrm{Photo}_{DIC}^{\mathrm{PHY}_{C_i}}\right) - \mathrm{Prec}_{DIC}^{CaCO_3}$$ PHY ϵ [MICROP, NANOP, PICO] ZOO ϵ [COP, MICROZ]
AT	$$\frac{\partial AT}{\partial t} = 2 * \mathrm{Diss}_{AT}^{CaCO_3} + \sum_{i=1}^{3}\left(\mathrm{Upt}_{NO_3}^{\mathrm{Phy}_{N_i}}\right) + \sum_{i=1}^{3}\left(\mathrm{Upt}_{PO_4}^{\mathrm{Phy}_{P_i}}\right) + \mathrm{Remin}_{NH_4}^{\mathrm{BAC}_N} - \sum_{i=1}^{3}\left(\mathrm{Upt}_{NH_4}^{\mathrm{Phy}_{N_i}}\right) - \mathrm{Remin}_{PO_4}^{\mathrm{BAC}_P} - 2 * \mathrm{Prec}_{AT}^{CaCO_3} - 2 * \mathrm{Nitrif}_{TA}$$ PHY ϵ [MICROP, NANOP, PICO]
$CaCO_3$	$$\frac{\partial CaCO_3}{\partial t} = \mathrm{Prec}_{DIC}^{CaCO_3} - \mathrm{Diss}_{DIC}^{CaCO_3}$$

S2 Supplementary results

S2.1 Configurations without mixotrophs

We present the ecosystem composition in C biomass (Fig. S4), dynamics of modelled organisms in C biomass for the three years of simulation (2017 repeated three times, Fig. S5), total chlorophyll (Fig. S6) for configurations D, R and with mixotrophs in typical conditions (Table 5).

We also provided the percentage of each prey in total copepod grazing (Table S3), predation on copepods which is an indicator of the quantity of C transferred to the higher trophic levels, and total photosynthesis and respiration fluxes (Table S4) for each configuration in typical conditions (Table 5).

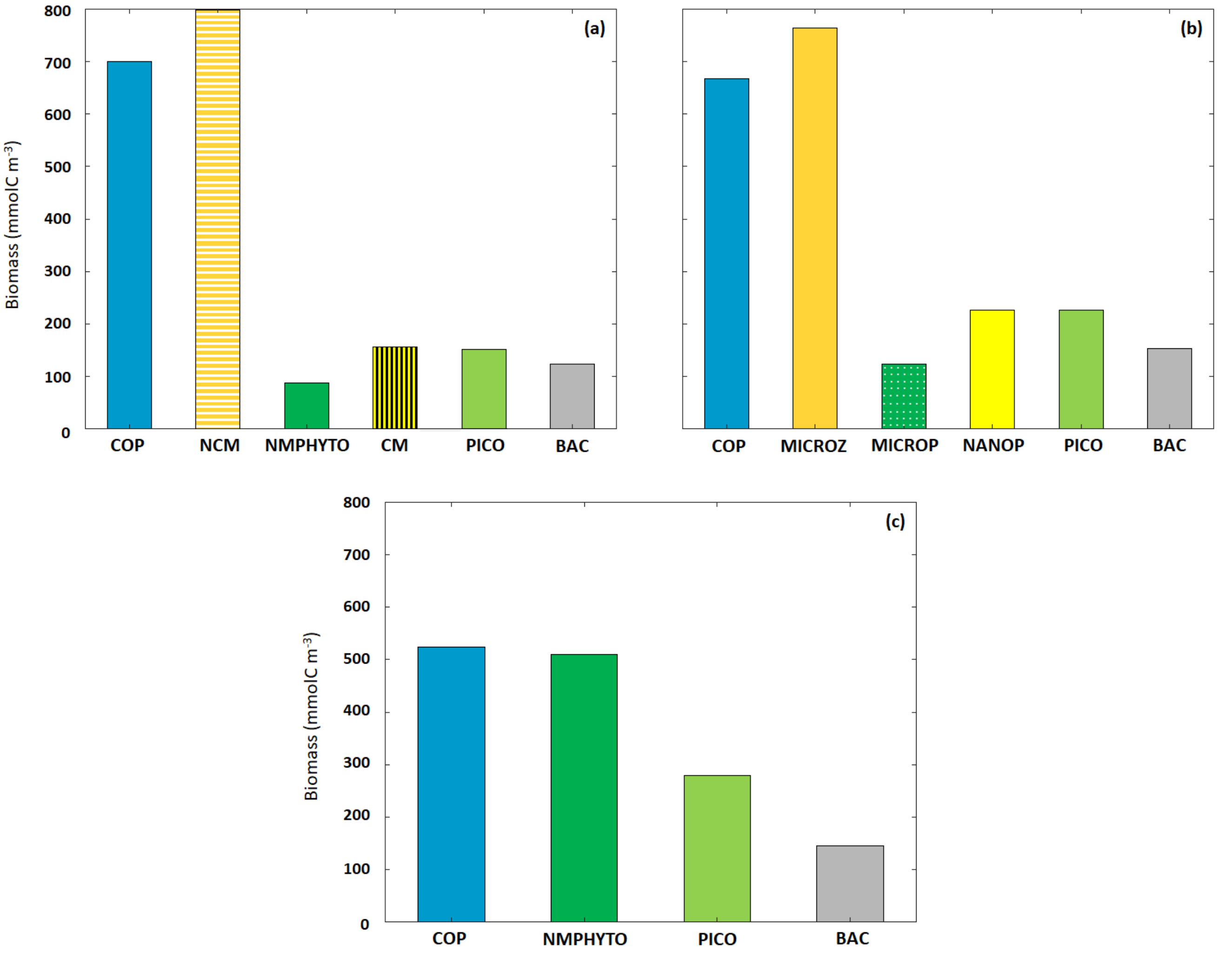

Figure S4: Yearly total carbon biomass in typical conditions for (a) the configuration with mixotrophs, (b) the configuration R (in which mixotrophs are replaced) and (c) the configuration D (in which mixotrophs are deleted).

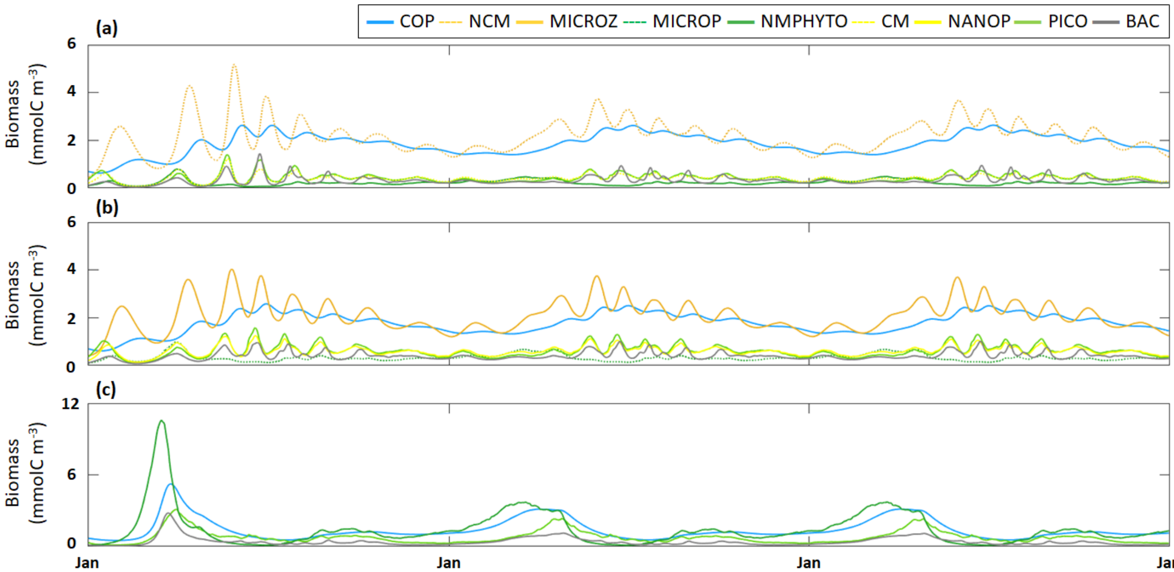

Figure S5: Repeating cycles of model simulations for (a) the configuration with mixotrophs, (b) the R configuration and (c) the D configuration. Lines represents daily averaged carbon biomass of copepods (COP), NCM, MICROZ (microzooplankton), MICROP (microphytoplankton), NMPHYTO (nano+micro-phytoplankton), CM, NANOP (nanophytoplankton), PICO (picophytoplankton) and BAC (heterotrophic bacteria) for the three years of simulation (repetition of 2017 three times).

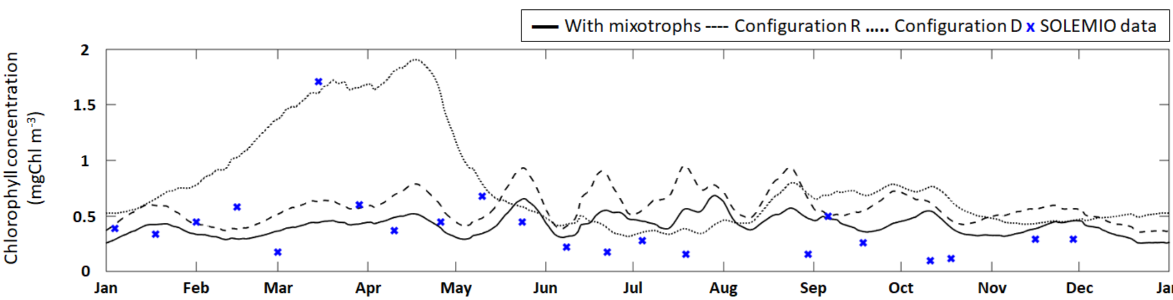

Figure S6: Total chlorophyll concentration (for the configuration with mixotrophs: sum of daily average chlorophyll concentrations of PICO, NMPHYTO, CM and NCM; for the R configuration: sum of daily average chlorophyll concentrations of PICO, NANOP and MICROP ; for the D configuration: sum of daily average chlorophyll concentrations of PICO and NMPHYTO) for the three configurations of Eco3M_MIX-CarbOx. The markers represent in situ SOLEMIO data.

Table S3: Percentage of copepod total grazing represented by each prey in typical conditions for the configurations with mixotrophs, R and D.

Configuration	NCM or MICROZ	NMPHYTO or MICROP	CM or NANOP
With mixotrophs	96.4%	1.2%	2.4%
R configuration	92.2%	2.6%	5.2%
D configuration		100%	

Table S4: Yearly mean predation on copepods ($PRED_{COP}$), total photosynthesis ($PHOTO_{TOT}$), and total respiration ($RESP_{TOT}$) fluxes in typical and nutrient limited conditions for the configurations with and without mixotrophs.

Configuration	$RESP_{TOT}$ (mg m^{-2} d^{-1})	$PHOTO_{TOT}$ (mg m^{-2} d^{-1})	$PRED_{COP}$ (mg m^{-2} d^{-1})
With mixotrophs	6.6	6.8	1.5
R	8.2	8.3	1.3
D	6.2	9.2	1.1