Supplementary Material

Variable organic matter stoichiometry enhances the biological drawdown of CO₂ in the Northwest European shelf seas

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1 Supplementary Figures and Tables

1.1 Supplementary Figure



Supplementary Figure S1: Differences between simulated and observed seasonal phosphate (PO₄) concentrations over 2000-2010. The total of 161,152 data points from the International Council for the Exploration of the Sea (ICES) are compared to respective model output, co-located by a horizontal and vertical nearest neighbor search, for all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). The data includes both bottle and pump data from the ocean hydrochemistry data collection.



Supplementary Figure S2: Differences between simulated and observed seasonal nitrate (NO₃) concentrations over 2000-2010. The total of 135,469 data points from the International Council for the Exploration of the Sea (ICES) are compared to respective model output, colocated by a horizontal and vertical nearest neighbor search, for all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). The data includes both bottle and pump data from the ocean hydrochemistry data collection.

RS-Obs.:



Supplementary Figure S3: Differences between simulated and observed seasonal in-situ temperature (T) over 2000-2010. The total of 2,153,726 data points from the International Council for the Exploration of the Sea (ICES) are compared to respective model output, colocated by a horizontal and vertical nearest neighbor search for the Redfield Stoichiometry (RS) configuration. As the physical simulation is consistent between all four simulations, it is not shown for each of the configurations. The data includes the surface, bottle, and pump data from the ocean hydrochemistry data collection.



Supplementary Figure S4: Differences between simulated and observed seasonal salinity (S) over 2000-2010. The total of 1,913,297 data points from the International Council for the Exploration of the Sea (ICES) are compared to respective model output, co-located by a horizontal and vertical nearest neighbor search for the Redfield Stoichiometry (RS) configuration. As the physical simulation is consistent between all four simulations, it is not shown for each of the configurations. The data includes the bottle and pump data from the ocean hydrochemistry data collection.



Supplementary Figure S5: Taylor diagrams for phosphate (PO_4) and nitrate (NO_3), both limiting nutrients for primary production, showing correlation, root mean squared difference (RMSD), and normalized standard deviation of the model output with respect to observations. For each of the variables, the respective observations from Figures S1 and S2 are combined for all seasons and compared to the co-located model output using a horizontal and vertical nearest neighbor search. The model performance is differentiated by configuration, as indicated by color, and subregion, as indicated by shape.



Supplementary Figure S6: Taylor diagrams for the physical variables in-situ temperature (T) and salinity (S), showing correlation, root mean squared difference (RMSD), and normalized standard deviation of the model output with respect to observations. For each of the variables, the respective observations from Figures S3 and S4 are combined for all seasons and compared to the co-located model output. As all four physical model configurations are consistent, we here only show the results for the Redfield Stoichiometry (RS) configuration.



Supplementary Figure S7: Differences between simulated and observed seasonal dissolved inorganic carbon (DIC) concentrations over 2000-2010. The total of 5,685 data points from the Global Ocean Data Analysis Project (GLODAP) are compared to respective model output, co-located by a horizontal and vertical nearest neighbor search, for all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR).



Supplementary Figure S8: Differences between simulated and observed seasonal total alkalinity (TA) over 2000-2010. The total of 5,110 data points from the Global Ocean Data Analysis Project (GLODAP) are compared to respective model output, co-located by a horizontal and vertical nearest neighbor search, for all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR).



Supplementary Figure S9: Differences between simulated and observed seasonal surface partial pressure of CO_2 (p CO_2) over 2000-2010. The total of 772,202 data points in the Northwest European shelf seas from the Surface Ocean CO_2 Atlas (SOCAT) are compared to respective model output, co-located by a horizontal nearest neighbor search, for all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). Observations were converted from fCO₂ to pCO₂ using PyCO2SYS (Humphreys et al., 2022, 2024). Model CO₂ concentrations in parts per million were converted to pCO₂ using Eq. 15-16, based on the conversion suggested by PyCO2SYS (Humphreys et al., 2022, 2024) and an improved temperature-dependent saturation vapor pressure equation (Huang, 2018).

Annual Vertically-Integrated Subarea Carbon Fixation



Supplementary Figure S10: Time Series of annual vertically-integrated carbon fixation for the entire Northwest European shelf seas (NWES), the North Sea (NS), the Norwegian Trench (NT), and the Northern, Central and Southern North Sea (NNS, CNS, SNS). These include all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR).

Annual Vertically-Integrated Subarea Pelagic Carbon Remineralization



Supplementary Figure S11: Time Series of annual vertically-integrated pelagic carbon remineralization for the entire Northwest European shelf seas (NWES), the North Sea (NS), the Norwegian Trench (NT), and the Northern, Central and Southern North Sea (NNS, CNS, SNS). These include all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR).

Annual Subarea-Integrated Benthic Carbon Remineralization



Supplementary Figure S12: Time Series of annual subarea-integrated benthic carbon remineralization for the entire Northwest European shelf seas (NWES), the North Sea (NS), the Norwegian Trench (NT), and the Northern, Central and Southern North Sea (NNS, CNS, SNS). These include all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR).

Annual Vertically-Integrated Subarea Net Community Production



Supplementary Figure S13: Time Series of annual vertically-integrated net community production for the entire Northwest European shelf seas (NWES), the North Sea (NS), the Norwegian Trench (NT), and the Northern, Central and Southern North Sea (NNS, CNS, SNS). These include all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR).

Annual Subarea-Integrated Net Air-Sea CO₂-Flux



Supplementary Figure S14: Time Series of subarea-integrated annual net air-sea CO₂-flux for the entire Northwest European shelf seas (NWES), the North Sea (NS), the Norwegian Trench (NT), and the Northern, Central and Southern North Sea (NNS, CNS, SNS). These include all four configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR).



Supplementary Figure S15: Simulated spatial distribution of seasonal means of vertically-integrated carbon fixation for the Redfield Stoichiometry (RS) configuration and differences for the Extracellular Release (ER), Preferential Remineralization (PR), and the combined (ER&PR) configurations. In the ER and ER&PR configurations, the carbon fixation includes the extracellular release of DOC.



Supplementary Figure S16: Simulated spatial distribution of seasonal means of vertically-integrated carbon respiration for the Redfield Stoichiometry (RS) configuration and differences for the Extracellular Release (ER), Preferential Remineralization (PR), and the combined (ER&PR) configurations. Carbon respiration here includes both pelagic and benthic heterotrophic remineralization.

Supplementary Figure S17: Simulated spatial distribution of seasonal means of vertically-integrated net community production (NCP) for the Redfield Stoichiometry (RS) configuration and differences for the Extracellular Release (ER), Preferential Remineralization (PR), and the combined (ER&PR) configurations. Net community production is here defined as carbon fixation minus respiration, where carbon respiration includes both pelagic and benthic heterotrophic remineralization.

Supplementary Figure S18: Simulated spatial distribution of the respective seasonal means of the air-sea CO₂-exchange for all four configurations: the Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined (ER&PR) configuration.

Supplementary Figure S19: Vertical distribution of observed and simulated, seasonally and subarea-averaged NO₃ and PO₄ concentrations for all four model configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). Both model output and observational data are averages over the simulated period 2000-2010 for the respective season. For the combined Northern (NNS) and Central North Sea (CNS) sub-regions 11,636 and 11,065 data points were selected for PO₄ and NO₃ respectively from the bottle and pump data in the ocean hydrochemistry data collection of the International Council for the Exploration of the Sea (ICES). The vertical profiles were generated by firstly calculating the mean concentrations and standard deviation within every meter of depth, and secondly, generating a fifth-order polynomial fit for the vertical profiles of means and standard deviations using *numpy.polyfit* for each season. The coefficients are listed below in Table S16.

1.2 Supplementary Tables

Supplementary Table S1: Summary of the ECOSMO II parameter set used for this study. Values in square brackets indicate different configurations for the respective experiments. This means, the first value is for the Redfield-based model, the second for the model with preferential remineralization only, the third with both preferential remineralization and extracellular release and the fourth with extracellular release only. For the variable stoichiometry ECOSMO II model description, see below in Supplementary Material section 2.

Definition	Abbr.	Value	Unit
Maximum growth rate for P_2 (diatoms)	σ_{P_2}	1.30	$[d^{-1}]$
Maximum growth rate for P_1 (flagellates)	σ_{P_1}	1.10	$[d^{-1}]$
Photosynthesis efficiency	α	0.01	$[m^2 W^{-1}]$
Phytoplankton self-shading	$\kappa_{ m phyto}$	0.03	$[m^2 (mmolC)^{-1}]$
Particulate organic matter (POM) self- shading	$\kappa_{ m POM}$	0.20	$[m^2 (mmolC)^{-1}]$
Dissolved organic matter (DOM) self- shading	κ _{DOM}	0.29	$[m^2 (mmolC)^{-1}]$
Water background light extinction coefficient	κ_W	0.03	$[m^{-1}]$
External suspended particulate matter (SPM) light extinction coefficient	$\kappa_{ m SPM}$	0.0	$[mg \ l^{-1} \ m^{-1}]$
Photosynthetically active radiation (PAR) fraction of incident light	par_fraction	0.6	-
Ammonium (NH ₄) half saturation const.	$r_{ m NH_4}$	0.20	$[mmolN \ m^{-3}]$
Nitrate (NO ₃) half saturation const.	$r_{\rm NO_3}$	0.5	$[mmolN \ m^{-3}]$
Ammonium (NH ₄) inhibition parameter	Ψ	3.0	$[m^3 (mmolN)^{-1}]$
Diatom mortality rate	m_{P_2}	0.04	$[d^{-1}]$
Flagellate mortality rate	m_{P_1}	0.08	$[d^{-1}]$
Grazing rate of meso-zooplankton on phytoplankton	$\sigma_{Z_2,P}$	0.8	$[d^{-1}]$
Grazing rate of micro-zooplankton on phytoplankton	$\sigma_{Z_1,P}$	1.0	$[d^{-1}]$
Grazing rate of meso-zooplankton on micro-zooplankton	σ_{Z_2,Z_1}	0.5	$[d^{-1}]$
Zooplankton half saturation constant	r_{Z}	0.5	$[mmolC m^{-3}]$
Meso-zooplankton mortality rate	m_{Z_2}	0.1	$[d^{-1}]$
Micro-zooplankton mortality rate	m_{Z_1}	0.2	$[d^{-1}]$
Meso-zooplankton excretion rate	μ_{Z_2}	0.06	$[d^{-1}]$
Micro-zooplankton excretion rate	μ_{Z_1}	0.08	$[d^{-1}]$
Meso-zooplankton assimilation efficiency on plankton	$\gamma_{Z_2,P}$	0.75	-
Micro-zooplankton assimilation efficiency on plankton	$\gamma_{Z_1,P}$	0.75	-
Zooplankton assimilation efficiency on POM	<i>Y</i> _{Z,POM}	0.75	-
POC remineralization rate	ε _{POC}	0.003	$[d^{-1}]$

POM sinking rate	WPOM	5.0	$[m d^{-1}]$
Phosphate (PO ₄) half saturation const.	r_{PO_4}	0.05	$[mmolP \ m^{-3}]$
Silicate (SiO ₂) half saturation const.	r _{si}	0.5	$[mmolSi m^{-3}]$
Silicate (SiO ₂) remineralization rate	$\varepsilon_{ m Si}$	0.015	$[d^{-1}]$
Maximum growth rate of cyanobacteria	σ_{P_3}	1.0	$[d^{-1}]$
Cyanobacteria temperature control	T_{ctrl,P_3}	1.0	[°C ⁻¹]
Cyanobacteria reference temperature	T_{ref,P_3}	0.0	[°C]
Cyanobacteria maximum grazing rate	eta_{P_3}	0.3	$[d^{-1}]$
Cyanobacteria mortality rate	m_{P_3}	0.08	$[d^{-1}]$
Critical bottom shear stress for resuspension	$ au_{crit}$	0.007	$[N \ m^{-2}]$
Resuspension rate for $\tau > \tau_{crit}$	$\lambda_{ m res}$	25.0	$[d^{-1}]$
Sedimentation rate for $\tau \leq \tau_{crit}$	$\lambda_{ m dep}$	3.5	$[m d^{-1}]$
Burial rate	$\delta_{ m bur}$	0.00001	$[d^{-1}]$
Sediment base remineralization rate	$\varepsilon_{ m Sed}$	0.001	$[d^{-1}]$
Temperature control of denitrification	$T_{ m ref,denit}$	0.15	[°C ⁻¹]
Sed. PIP release parameter p1	RelSEDp1	0.15	-
Sed. PIP release parameter p2	RelSEDp2	0.10	-
Sed. remineralization rate Si	E _{Sed3}	0.0002	$[d^{-1}]$
Biogenic opal $(SiO_2 \cdot 2H_2O)$ sinking rate	W _{Opal}	5.0	$[m d^{-1}]$
Cyanobacteria sinking rate	W_{P_3}	-1.0	$[m \ d^{-1}]$
Diatom sinking rate	W _{P2}	0.0	$[m d^{-1}]$
Grazing preference of micro-zooplankton on flagellates	$a_{Z_{1},P_{1}}$	0.7	-
Grazing preference of micro-zooplankton on diatoms	a_{Z_1,P_2}	0.25	-
Grazing preference of micro-zooplankton on particulate organic matter	$a_{Z_1,\text{POM}}$	0.1	-
Grazing preference of micro-zooplankton on cyanobacteria	a_{Z_1,P_3}	0.3	-
Grazing preference of meso-zooplankton on flagellates	a_{Z_2,P_1}	0.1	-
Grazing preference of meso-zooplankton on diatoms	a_{Z_2,P_2}	0.85	-
Grazing preference of meso-zooplankton on micro-zooplankton	a_{Z_2,Z_1}	0.15	-
Grazing preference of meso-zooplankton on particulate organic matter	$a_{Z_2,\mathrm{POM}}$	0.1	_
Grazing preference of meso-zooplankton on cyanobacteria	a_{Z_2,P_3}	0.3	-
Fraction of dissolved organic matter from new detrital matter	a _{DOM}	0.4	-

Fraction of particulate organic matter from new detrital matter	$a_{\rm POM} = (1 - a_{\rm DOM})$	0.6	-
Surface deposition of nitrate (here provided from monthly observations instead)	Surf _{NO3}	0.08	$[mmolN \ m^{-2} \ d^{-1}]$
Surface deposition of ammonium (here provided from monthly observations instead)	Surf _{NH4}	0.05	$[mmolN\ m^{-2}\ d^{-1}]$
Surface deposition of phosphate	Surf _{PO4}	0.0	$[mmolP \ m^{-2} \ d^{-1}]$
Surface deposition of silicate	Surf _{SiO2}	0.0	$[mmolSi m^{-2} d^{-1}]$
Minimum daily radiation for cyanobacteria growth	I_{P_3}	120.	$[W \ m^{-2}]$
Minimum daily photosynthetically active radiation for nitrogen fixation	PAR _{P3}	120.	$[W \ m^{-2}]$
Remineralization ratio of DOC to POC	$\epsilon_{ ext{DOC:POC}}$	0.5	-
Remineralization ratio of POC to PON	$\epsilon_{\mathrm{POC:PON}}$	[1, 0.625, 0.7692, 1]	-
Remineralization ratio of POC to POP	€ _{POC:POP}	[1, 0.5, 0.6666, 1]	-
Remineralization ratio of DOC to DON	$\epsilon_{ m DOC:DON}$	[1, 0.625, 0.7692, 1]	-
Remineralization ratio of DOC to DOP	$\epsilon_{ ext{DOC:DOP}}$	[1, 0.5, 0.6666, 1]	-
Rate of flocculation from DOM to POM	F _{DOM2POM}	[0, 0, 0.02, 0.02]	_
Extracellular release scaling factor	B _{ER}	[0, 0, 0.2, 0.4]	-

Supplementary Table S2: Model percentage biases for all four configurations RS, ER, PR and ER&PR with respect to observations for dissolved inorganic carbon (DIC), total alkalinity (TA), and surface partial pressure of CO_2 (pCO₂) across different subareas of the Northwest European shelf seas. Both DIC and TA observations are from the Global Ocean Data Analysis Project (GLODAP), whereas pCO₂ measurements are from the Surface Ocean CO₂ Atlas (SOCAT).

	Model percentage	bias [%] compared to co-loca	ated observational data from	n GLODAP, SOCAT and IC	CES
Variable	Sub-Region	RS	ER	PR	ER&PR
	NNS	0.661	0.596	0.630	0.610
	CNS	1.105	0.947	1.025	0.967
DIC	SNS	1.254	1.149	1.100	1.101
	NT	0.870	0.975	0.871	0.916
	SK	1.115	1.319	1.140	1.195
	NNS	0.544	0.542	0.542	0.541
	CNS	0.884	0.891	0.856	0.869
TA	SNS	0.872	0.882	0.850	0.866
	NT	0.666	0.664	0.660	0.660
	SK	0.917	0.909	0.914	0.912
	NNS	4.492	4.337	4.313	4.100
	CNS	7.993	6.341	6.978	6.297
	SNS	15.119	13.441	14.002	13.379
nCO	NT	18.701	16.709	17.723	16.700
pCO_2	SK	24.801	29.812	24.277	27.552
	EC	11.591	10.076	11.118	10.520
	SWC	7.158	9.202	7.167	7.608
	AS	16.642	13.367	14.731	13.718

Supplementary Table S3: Literature compilation of observational data on concentrations of bulk dissolved organic carbon (DOC), nitrogen (DON), and phosphorus (DOP), including both the (semi-) labile and refractory fractions of dissolved organic matter (DOM). Individual numbers without parentheses represent averages over regions or a series of measurements, whereas values in parentheses show ranges between individual measurements or sub-regions. Ranges of concentrations with a double-asterisk represent estimates from figures in the respective references.

	Bulk DOM Concentrations		ns		
Location	Sub-Region or Focus	DOC [µM]	DON [µM]	DOP [µM]	Source
	Surface Ocean Biogeochemical Regions	65.8 (52.4-73.5)	4.5 (3.7-5.3)	0.17 (0.11-0.27)	(Liang et al., 2023)
	Full Water Column	(46.2-65.3)	(2.1-4.5)	(0.04-0.19)	(Letscher and Moore, 2015; Letscher et al., 2015)
Global Ocean	Coastal Ocean	(50-60)	(4.5-45)	(0.08-0.50)	(Lønborg and Álvarez-Salgado, 2012)
	Shelf, Slope and Open Ocean (surface only 0-100m)	(30-160)**	(1-11)**	(0.00-0.45)**	(Hopkinson and Vallino, 2005)
	Georges Bank (Surface Ocean)	65-92	5	0.17	(Hopkinson et al., 1997)
	Georges Bank (Deep Waters)	50	3	0.02	(Hopkinson et al., 1997)
Atlantia Occan	Middle Atlantic Bight (Surface Ocean)	125 (81-201)	10.2 (7.1-14.3)	0.30 (0.14-0.42)	(Hopkinson et al., 2002)
Atlantic Ocean	Middle Atlantic Bight (Deep Slope Waters)	46.7	2.76	0.03	(Hopkinson et al., 2002)
	Northeast Atlantic (Surface Waters)	(61-83)	(4.2-6.1)	(0.07-0.14)	(Aminot and Kérouel, 2004)
	Northeast Atlantic (Deep Waters)	(41-55)	(2.6-4.0)	(0.01-0.08)	(Aminot and Kérouel, 2004)
Pagifia Oggan	Eastern North Pacific	(35-72)	(1.5-4.5)	(0.013-0.229)	(Loh and Bauer, 2000)
Facilie Ocean	North Pacific Subtropical Gyre	(63-105)	(3.7-6.2)	(0.10-0.27)	(Church et al., 2002)
Southern Ocean	-	(39-53)	(2.5-5.2)	(0.061-0.225)	(Loh and Bauer, 2000)
	Southern Adriatic Basin (Surface)	(49-79)	(2.3-7.2)	(0.02-0.08)	(Santinelli et al., 2012)
	Southern Adriatic Basin (Intermediate Waters)	(45-54)	(1.8-5.3)	(0.02-0.06)	(Santinelli et al., 2012)
	Southern Adriatic Basin (Deep Waters)	(47-60)	(2.9-6.2)	(0.02-0.08)	(Santinelli et al., 2012)
Mediterranean Sea	Northwestern Mediterranean	(44-95)	(2.8-6.2)	-	(Doval et al., 1999)
	Northwestern Mediterranean	(40-120)**	(0-6)**	(0.0-0.4)**	(Lucea et al., 2003)
	Northwestern Mediterranean (Surface Waters)	(67-69)	(4.0-4.2)	(0.08-0.08)	(Aminot and Kérouel, 2004)
	Northwestern Mediterranean (Deep Waters)	(46-48)	(2.7-3.0)	(0.03-0.04)	(Aminot and Kérouel, 2004)

	Northwestern Mediterranean	(80-100)	(4.5-5.5)	(0.06-0.10)	(Raimbault et al., 1999)
	Western Basin	(37.6-69.4)	(2.5-5.5)	(0-0.09)	(Pujo-Pay et al., 2011)
	Eastern Basin	(37.5-72.4)	(2.1-6.3)	(0-0.10)	(Pujo-Pay et al., 2011)
East China Sea	-	(60-120)	(6-9.6)	(0.05-0.25)	(Hung et al., 2003)
South China Sea	Northern Parts	(43-132)	-	-	(Hung et al., 2007)
	Norwegian Coastal Waters	-	(8-11.5)**	-	(Frigstad et al., 2013)
	Celtic Sea	(65-70)	(3.9-6)	(0.19-0.35)	(Davis et al., 2019)
	North Sea	46.9-107.5 (32.7-224.8)	5.2-9.0 (2.8-13.7)	-	(Chaichana et al., 2017, 2019)
Northwest	Northern North Sea (Surface)	60.7-73.8 (32.7-104.2)	5.3-6.6 (3.0-8.7)	-	(Chaichana et al., 2017, 2019)
European Shelf	Northern North Sea (Bottom)	46.9-73.8 (36.8-120.1)	5.2-5.9 (1.0-11.7)	-	(Chaichana et al., 2017, 2019)
	Southern North Sea	65.5-97.5 (36.3-224.8)	5.3-9.0 (2.8-13.7)	-	(Chaichana et al., 2017, 2019)
	Central North Sea	(68-318)	(2-11)**	-	(Suratman et al., 2009)
	North Sea	108.7 (61.7-185.0)	6.6 (3.5-16.4)	0.26 (0.13-0.46)	(Painter et al., 2018)
	Bothnian Sea	466	-	-	(Rowe et al., 2018)
	Bothnian Bay	416	-	-	(Rowe et al., 2018)
	Gulf of Finland	(290-724)	(8.6-38.5)	(0.06-0.80)	(Hoikkala et al., 2012, 2015)
	Gulf of Bothnia	(241-520)	(7.8-14.8)	(0.12-0.18)	(Hoikkala et al., 2015)
Baltic Sea	Gulf of Riga	(400-1230)	(10-38)	(0.5-0.9)	(Hoikkala et al., 2015)
	Baltic Proper	(259-708)	(10.2-203)	-	(Hoikkala et al., 2015; Rowe et al., 2018)
	Estuaries	(318.41-736.74)	(14.14-45.22)	(0.14-0.38)	(Voss et al., 2021)
	Southwestern Baltic Sea (Heiligendamm)	290	17.2	-	(Osterholz et al., 2021)
	Gotland Basin	-	-	(0.20-0.29)	(Nausch et al., 2008)

Supplementary Table S4: Literature compilation of observational data on concentrations of biodegradable or (semi-)labile dissolved organic carbon (LDOC), nitrogen (LDON), and phosphorus (LDOP). Individual numbers or ranges (e.g., between sub-regions or different years) without parentheses represent averages over regions or a series of measurements whereas values in parentheses show ranges between individual measurements. The given percentage indicates the fraction of labile dissolved organic carbon, nitrogen, and phosphorus in relation to the bulk pool.

		Biodegradable	or (Semi-)Labile DO		
Location	Sub-Region or Focus	LDOC $[\mu M]$	LDON $[\mu M]$	LDOP $[\mu M]$	Source
	Surface Ocean Biogeochemical Regions	25.0 (10.5-29.1)	2.8 (1.9-3.5)	0.14 (0.06-0.22)	(Liang et al., 2023)
Global Ocean	Shelf, Slope and Open Ocean	(15-80)	-	-	(Hopkinson and Vallino, 2005)
	Coastal Ocean	(1-199) (2-51%)	(0.6-15.2) (10-65%)	(0.04-0.33) (30-96%)	(Lønborg and Álvarez-Salgado, 2012)
Atlantic Ocean	Northeast Atlantic	(16.0-16.3) (26-27%)	(1.5-1.6) (34-36%)	(0.04-0.10) (60-78%)	(Aminot and Kérouel, 2004)
Mediterranean Sea	Northwestern Mediterranean	23.3 34%	1.2 30%	0.04 60%	(Aminot and Kérouel, 2004)
Baltic Sea	Open Sea Only	(0-82) (0-17%)	(0-6.5) (0-41%)	(0.01-0.34) (8-65%)	(Hoikkala et al., 2012, 2015)

Supplementary Table S5: Literature compilation of observational data on concentrations of refractory or recalcitrant dissolved organic carbon (RDOC), nitrogen (RDON), and phosphorus (RDOP). Individual numbers or ranges (e.g., between sub-regions or different years) without parentheses represent averages over regions or a series of measurements whereas values in parentheses show ranges between individual measurements.

		Refractory or F	Recalcitrant DOM	Concentrations	
Location	Sub-Region or Focus	RDOC $[\mu M]$	RDON [µM]	RDOP $[\mu M]$	Source
Global Ocean	Surface Ocean	46 (45-49)	2.7 (2.5-2.8)	-	(Liang et al., 2023)
	Deep Ocean	42	3.0	0.05	(Liang et al., 2023)
	Surface Ocean	42	-	-	(Hopkinson and Vallino, 2005)
	Deep Ocean	34	-	-	(Hopkinson and Vallino, 2005)
	Deep Ocean	(33.8-48.1)	-	-	(Hansell and Carlson, 1998)
Atlantic and Mediterranean	NE Atlantic and NW Mediterranean	44.9 (43.8-45.9)	2.85 (2.73-3.00)	0.029 (0.023-0.034)	(Aminot and Kérouel, 2004)

Supplementary Table S6: Literature compilation of observational data on concentrations of particulate organic carbon (POC), nitrogen (PON), and phosphorus (POP). Individual numbers or ranges (e.g., between sub-regions or different years) without parentheses represent averages over regions or a series of measurements whereas values in parentheses show ranges between individual measurements. Ranges of concentrations with a double-asterisk represent estimates from figures in the respective references. Strong outliers in the measurement referenced as "Patch" were excluded from (Nausch et al., 2008).

		POM	A Absolute Concentration		
Location	Sub-Region or Focus	POC [μ <i>M</i>]	PON [μ <i>M</i>]	POP [<i>nM</i>]	Source
Global Ocean	Surface Ocean Biogeochemical Regions	6.4 (2.3-17.2)	0.83 (0.32-2.2)	40 (10-170)	(Martiny et al., 2014; Tanioka et al., 2022; Liang et al., 2023)
Pacific Ocean	Eastern North Pacific	(0.09-5.76)	(0.012-0.917)	(0.45-37.32)	(Loh and Bauer, 2000)
Southern Ocean	South of the Tasman Sea	(0.05-3.48)	(0.004-0.490)	(0.25-13.48)	(Loh and Bauer, 2000)
	NW Mediterranean	(0.9-14.9)	(0.1-1.7)	-	(Doval et al., 1999)
Mediterranean	NW Mediterranean	(4-15)**	(0.2-0.7)**	(0-55)**	(Lucea et al., 2003)
Sea	Western Basin	(0.74-8.70)	(0.01-0.87)	(1-45)	(Pujo-Pay et al., 2011)
	Eastern Basin	(0.70-5.41)	(0.01-0.66)	(1-30)	(Pujo-Pay et al., 2011)
South China Sea	Northern Parts	(1.1-13)	-	-	(Hung et al., 2007)
	Hebrides Shelf	(4.73-6.74)	(0.37-0.76)	(1-10)	(Painter et al., 2017)
	Norwegian Coastal Waters	(6-14)**	(0.8-2.5)**	(6-14)**	(Frigstad et al., 2013)
	Celtic Sea	(2-15)**	(0.2-3)**	(1-13)**	(Davis et al., 2019)
Northwest	North Sea	7.3-16.0 (1.1-43.8)	1.5-2.2 (0.3-5.9)	-	(Chaichana et al., 2017, 2019)
European Shelf	Northern North Sea (Surface)	10.5 (2.7-21.8)	2.0 (0.6-2.9)	-	(Chaichana et al., 2017, 2019)
	Northern North Sea (Bottom)	7.3 (1.1-16.2)	1.5 (0.3-2.7)	-	(Chaichana et al., 2017, 2019)
	Southern North Sea	16.0 (5.8-43.8)	2.2 (0.6-5.9)	-	(Chaichana et al., 2017, 2019)
	Central North Sea	(1.9-38.4)	(0.2-5.8)**	-	(Suratman et al., 2009)
	Estuaries	(29.8-388)	-	-	(Voss et al., 2021)
Baltic Sec	Gotland and Gdansk Deep	(8.3-79.9)	(0.7-11.4)	-	(Winogradow et al., 2019)
Baue Sea	SW Baltic Sea (Heiligendamm)	33	4.8	-	(Osterholz et al., 2021)
	Gotland Basin	(27.98-93.92)	(3.88-13.42)	(140-390)	(Nausch et al., 2008)

Supplementary Table S7: Literature compilation of observational data on elemental ratios of carbon, nitrogen, and phosphorus in bulk dissolved organic matter (DOM). Individual numbers or ranges (e.g., between sub-regions or different years) without parentheses represent averages over regions or a series of measurements whereas values in parentheses show ranges between individual measurements. A single asterisk indicates implicit estimates of individual C:N, C:P or N:P ratios from provided ranges of C:N:P ratios where they were not provided explicitly. Ranges of values with a double-asterisk represent estimates from figures in the respective references.

Location	Sub region or focus	Bulk DOM stoichiometry			Source
Location	Sub-region of focus	DOC:DON	DOC:DOP	DON:DOP	Source
	Global surface ocean (biogeochemical regions)	14.6 (13.0-16.1)	387 (251-638)	26 (17-44)	(Liang et al., 2023)
	Full water column	17*	810	48	(Letscher and Moore, 2015; Letscher et al., 2015)
Global ocean	Coastal ocean	9*	1164	123	(Lønborg and Álvarez-Salgado, 2012)
	Shelf, slope, and open ocean	14*	778	54	(Hopkinson and Vallino, 2005)
	Shelf, slope, and open ocean (surface only 0-100m)	14	374	27	(Hopkinson and Vallino, 2005)
	Georges Bank (Surface Ocean)	(11-15)	(400-800)	(24-55)	(Hopkinson et al., 1997)
	Geroges Bank (Deep Waters)	(14-20)	(700-2500)	(40-140)	(Hopkinson et al., 1997)
Atlantia Qaaan	Middle Atlantic Bight (Surface Ocean)	12 (9-14)*	431 (290-1101)	36 (25.8-86.7)	(Hopkinson et al., 2002)
Atlantic Ocean	Middle Atlantic Bight (Deep Slope Waters)	13 (12-14)*	2700 (986-4404)	215 (70-360)	(Hopkinson et al., 2002)
	NE Atlantic (Surface Waters)	(13.1-14.3)	(440-850)	(31-62)	(Aminot and Kérouel, 2004)
	NE Atlantic (Deep Waters)	(12.6-16.4)	(640-3100)	(45-200)	(Aminot and Kérouel, 2004)
	Eastern North Pacific	(13-30)	(277-537)	(13-34)	(Loh and Bauer, 2000)
Facilie Ocean	North Pacific Subtropical Gyre	(14.8-16.4)	(390-483)	(24.0-31.4)	(Church et al., 2002)
Southern Ocean	South of the Tasman Sea	(9-18)	(229-682)	(12-49)	(Loh and Bauer, 2000)
	Southern Adriatic Basin (Surface)	(14-16)	(1189-1411)	(86-88)	(Santinelli et al., 2012)
	Southern Adriatic Basin (Intermediate Waters)	(13-14)	(1107-1279)	(83-97)	(Santinelli et al., 2012)
	Southern Adriatic Basin (Deep Waters)	(11-15)	(993-1693)	(85-108)	(Santinelli et al., 2012)
Mediterranean Sea	NW Mediterranean	15.5	-	-	(Doval et al., 1999)
	NW Mediterranean	(30-60)*	(1510-1984)	(25-66)	(Lucea et al., 2003)
	NW Mediterranean (Surface Waters)	(16.7-16.9)	(920-970)	(55-57)	(Aminot and Kérouel, 2004)
	NW Mediterranean (Deep Waters)	(15.1-17.2)	(1100-1800)	(64-106)	(Aminot and Kérouel, 2004)

	Western Basin	12.1	1941	162.7	(Pujo-Pay et al., 2011)
	Eastern Basin	13.0	2055	160.8	(Pujo-Pay et al., 2011)
East China Sea	-	(8.9-15.3)	(200-853)	(19-83.6)	(Hung et al., 2003)
South China Sea	Northern Parts	(11-13)*	(322-510)	(29-39)	(Hung et al., 2007)
Sea of Japan (East Sea)	-	17*	374	22	(Kim and Kim, 2013)
	Norwegian Coastal Waters	-	-	(59.8-73.6)	(Frigstad et al., 2013)
	Celtic Sea	(12-17)*	(281-416)	(17-33)	(Davis et al., 2014)
Northwest	Celtic Sea	(11.0-17.4)	(147-377)	(11.7-31.7)	(Davis et al., 2019)
European Shelf	North Sea	(5.9-36.5)	-	-	(Chaichana et al., 2017, 2019)
	Central North Sea	(9.5-67.4)	-	-	(Suratman et al., 2009)
	North Sea	(10-25)**	(200-900)**	(15-75)**	(Painter et al., 2018)
	Baltic Proper	31.6	527.0	16.6	(Rowe et al., 2018)
	Bothnian Sea	21.3	402.6	18.9	(Rowe et al., 2018)
	Bothnian Bay	23.1	780.7	33.8	(Rowe et al., 2018)
	Gulf of Finland	(10-54)	-	(25-419)	(Hoikkala et al., 2012, 2015)
D-14:- 9	Gulf of Bothnia	(25-28)	-	100	(Hoikkala et al., 2015)
Baine Sea	Gulf of Riga	-	-	(20-60)	(Hoikkala et al., 2015)
	Baltic Proper	(17-26)	-	(20-30)	(Hoikkala et al., 2015)
	Estuaries	(16-23)*	(1199-3714)	(52-221)	(Voss et al., 2021)
	Rivers	31*	2790	91	(Stepanauskas et al., 2002)
	Southwestern Baltic Sea (Heiligendamm)	(12.5-20)**	-	-	(Osterholz et al., 2021)

Supplementary Table S8: Literature compilation of observational data on elemental ratios of carbon, nitrogen, and phosphorus in biodegradable or (semi-)labile dissolved organic matter (LDOM). Individual numbers or ranges (e.g., between sub-regions or different years) without parentheses represent averages over regions or a series of measurements whereas values in parentheses show ranges between individual measurements. A single asterisk indicates implicit estimates from provided ranges of C:N:P ratios where they were not provided explicitly.

Location Sub-region or focus		Biodegradable or (semi-)labile DOM stoichiometry			Source
		LDOC:LDON	LDOC:LDOP	LDON:LDOP	
	Global surface ocean (biogeochemical regions)	8.9 (5.4-12.0)	179 (83-414)	20 (15-49)	(Liang et al., 2023)
Global ocean	Coastal ocean	(8-9)*	(197-216)	(24-25)	(Lønborg and Álvarez-Salgado, 2012)
	Shelf, slope, and open ocean	10.7 (8.7-14.1)	199 (154-245)	20 (15.6-25)	(Hopkinson and Vallino, 2005)
Atlantic	NE Atlantic	(10.1-10.7)	(159-380)	(14.8-38)	(Aminot and Kérouel, 2004)
	Middle Atlantic Bight	(10.0-14.1)	(193-203)	(15.6-20.2)	(Hopkinson and Vallino, 2005)
	Georges Bank	9.8	245	25	(Hopkinson and Vallino, 2005)
Pacific Ocean	Hawaiian Ocean	8.7	154	17.8	(Hopkinson and Vallino, 2005)
Mediterranean Sea	NW Mediterranean	19.2	530	28	(Aminot and Kérouel, 2004)
Baltic Sea	Gulf of Finland	(0.8-11.7)	-	-	(Hoikkala et al., 2012, 2015)

Supplementary Table S9: Literature compilation of observational data on elemental ratios of carbon, nitrogen, and phosphorus in refractory or recalcitrant dissolved organic matter (RDOM). Individual numbers or ranges (e.g., between sub-regions or different years) without parentheses represent averages over regions or a series of measurements whereas values in parentheses show ranges between individual measurements. A single asterisk indicates implicit estimates from provided ranges of C:N:P ratios where they were not provided explicitly.

Location	Refractory	or recalcitrant DOM stoi	Source	
Looudon	RDOC:RDON	RDOC:RDOP	RDON:RDOP	Source
Global ocean	17.0 (16.5-18.1)	1,373 (900-2,300)	82 (50-140)	(Liang et al., 2023)
Coastal ocean	18*	2,835	159	(Lønborg and Álvarez-Salgado, 2012)
Shelf, slope, and open ocean	17*	3,511	202	(Hopkinson and Vallino, 2005)
NE Atlantic and NW Mediterranean	15.7	1,570	10	(Aminot and Kérouel, 2004)

Supplementary Table S10: Literature compilation of observational data on elemental ratios of carbon, nitrogen, and phosphorus in particulate organic matter (POM). Individual numbers represent averages over regions or a series of measurements whereas values in parentheses show ranges between sub-regions or measurements. A single asterisk indicates implicit estimates from provided ranges of C:N:P ratios where they were not provided as individual ratios explicitly. Ranges of values with a double-asterisk represent estimates from figures in the respective references.

Location	Sub-region or focus		POM stoichiometry	Source	
2000000		POC:PON	POC:POP	PON:POP	
	Surface ocean	7.7 (6.1-9.2)	160 (73-295)	21 (10-37)	(Martiny et al., 2014; Tanioka et al., 2022; Liang et al., 2023)
	-	6.6	163	22	(Martiny et al., 2014)
Global Ocean	Surface layer (50m)	-	146	-	(Tanioka et al., 2021)
	Twilight zone (100-1000m)	-	294 (83-500)	-	(Tanioka et al., 2021)
	Bermuda Atlantic	6 (1-19)	210 (45-532)	36 (7-140)	(Singh et al., 2015)
Pacific Ocean	Eastern North Pacific	(6-10)	(117-630)	(12-74)	(Loh and Bauer, 2000)
Southern Ocean	-	(4-14)	(59-336)	(6-46)	(Loh and Bauer, 2000)
	NW Mediterranean	8.6	-	-	(Doval et al., 1999)
Maditamanaan Saa	NW Mediterranean	(14-19)*	(220-426)	(15-22)	(Lucea et al., 2003)
Mediterranean Sea	Western Basin	13.3	256	19.8	(Pujo-Pay et al., 2011)
	Eastern Basin	14.0	235	18.8	(Pujo-Pay et al., 2011)
South China Sea	Northern Parts	(8-12)*	(148-502)	(18-42)	(Hung et al., 2007)
	Hebrides Shelf	(8.26-13.67)	(142.4-259.97)	(16.4-26.32)	(Painter et al., 2017)
	Norwegian Coastal Waters	(7.1-7.4)	(110.8-125.2)	(14.6-17.6)	(Frigstad et al., 2013)
Northwest European	Celtic Sea	(5-6)*	(63-223)	(10-38)	(Davis et al., 2014)
Shelf	Celtic Sea	(4.3-11.6)	(144-283)	(24-47)	(Davis et al., 2019)
	North Sea	(0.7-16.8)	-	-	(Chaichana et al., 2017, 2019)
	Central North Sea	(2.5-34.9)	-	-	(Suratman et al., 2009)
	Estuaries	6*	253	39	(Voss et al., 2021)
Baltic Sea	Gotland and Gdansk Deep	(5.8-10.8)	_	_	(Winogradow et al., 2019)
	SW Baltic Sea (Heiligendamm)	(2.5-11)**	_	-	(Osterholz et al., 2021)

Supplementary Table S11: Annual vertically- and subarea-integrated carbon fixation averaged over the simulation period 2000-2010 for all four model configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). For each configuration, the mean is provided both area-integrated and per area. The variable stoichiometry configurations also include the per area difference with respect to the RS configuration.

	Annual vertically- and subarea-integrated carbon fixation averaged over 2000-2010										
	R	S		ER			PR			ER&PR	
Subarea	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference $[molC m^{-2}yr^{-1}]$	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]
Entire NWES	9.708	7.909	14.790	12.049	+4.141	10.593	8.630	+0.721	12.786	10.416	+2.508
Entire North Sea	4.473	7.413	6.923	11.474	+4.061	4.922	8.158	+0.745	5.994	9.935	+2.522
Northern North Sea	0.598	7.591	0.907	11.515	+3.924	0.632	8.033	+0.441	0.775	9.849	+2.257
Central North Sea	1.739	7.155	2.870	11.807	+4.652	1.919	7.896	+0.741	2.434	10.013	+2.858
Southern North Sea	1.518	7.446	2.180	10.694	+3.248	1.696	8.321	+0.874	1.962	9.621	+2.175
Norwegian Trench	0.618	7.951	0.966	12.437	+4.486	0.674	8.682	+0.731	0.823	10.600	+2.649
English Channel	0.676	8.210	0.952	11.562	+3.352	0.737	8.947	+0.737	0.850	10.323	+2.113
Skagerrak Kattegat	0.471	6.056	0.747	9.601	+3.546	0.535	6.875	+0.820	0.644	8.275	+2.220
NE Celtic Sea	0.973	9.078	1.448	13.510	+4.432	1.045	9.746	+0.668	1.252	11.684	+2.605
SW Celtic Sea	0.832	9.101	1.320	14.439	+5.338	0.886	9.694	+0.594	1.105	12.097	+2.996
Irish Sea	0.408	8.547	0.533	11.175	+2.627	0.429	8.980	+0.432	0.479	10.035	+1.487
Inner Seas (Scotland)	0.382	8.630	0.541	12.212	+3.582	0.405	9.140	+0.509	0.474	10.705	+2.075
Armorican Shelf	0.603	8.626	0.992	14.190	+5.564	0.685	9.807	+1.181	0.838	11.987	+3.361
Hebrides Shelf	0.302	8.491	0.453	12.749	+4.257	0.321	9.025	+0.534	0.391	10.990	+2.499
Malin Shelf	0.190	8.960	0.282	13.264	+4.304	0.199	9.387	+0.427	0.241	11.360	+2.400
West Irish Shelf	0.401	8.507	0.603	12.815	+4.308	0.432	9.175	+0.668	0.520	11.052	+2.545

Supplementary Table S12: Annual vertically- and subarea-integrated pelagic carbon remineralization averaged over the simulation period 2000-2010 for all four model configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). For each configuration, the mean is provided both area-integrated and per area. The variable stoichiometry configurations also include the per area difference with respect to the RS configuration.

Annual vertically- and subarea-integrated pelagic carbon remineralization averaged over 2000-2010											
	R	LS		ER			PR			ER&PR	
Subarea	Total [<i>TmolC</i> yr ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [<i>molC</i> m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [<i>molC</i> m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]
Entire NWES	9.635	7.849	14.908	12.145	+4.296	10.507	8.560	+0.710	12.834	10.455	+2.606
Entire North Sea	4.528	7.505	7.068	11.715	+4.210	4.971	8.238	+0.733	6.104	10.118	+2.612
Northern North Sea	0.571	7.257	0.901	11.443	+4.186	0.606	7.700	+0.443	0.760	9.655	+2.398
Central North Sea	1.709	7.032	2.808	11.555	+4.522	1.872	7.703	+0.671	2.379	9.787	+2.755
Southern North Sea	1.544	7.574	2.207	10.823	+3.249	1.730	8.487	+0.913	2.000	9.811	+2.237
Norwegian Trench	0.704	9.056	1.152	14.834	+5.777	0.762	9.805	+0.749	0.965	12.425	+3.368
English Channel	0.665	8.077	0.942	11.443	+3.366	0.727	8.833	+0.756	0.840	10.197	+2.121
Skagerrak Kattegat	0.416	5.341	0.731	9.394	+4.053	0.479	6.156	+0.815	0.619	7.948	+2.608
NE Celtic Sea	0.975	9.094	1.449	13.525	+4.430	1.051	9.804	+0.710	1.254	11.705	+2.611
SW Celtic Sea	0.843	9.227	1.364	14.924	+5.697	0.904	9.889	+0.662	1.142	12.495	+3.268
Irish Sea	0.433	9.062	0.569	11.916	+2.854	0.457	9.574	+0.512	0.513	10.738	+1.676
Inner Seas (Scotland)	0.375	8.460	0.545	12.313	+3.853	0.394	8.889	+0.439	0.472	10.665	+2.205
Armorican Shelf	0.556	7.950	0.935	13.377	+5.427	0.627	8.969	+1.019	0.781	11.170	+3.220
Hebrides Shelf	0.299	8.406	0.461	12.966	+4.560	0.315	8.873	+0.466	0.391	10.991	+2.584
Malin Shelf	0.179	8.400	0.279	13.113	+4.713	0.189	8.898	+0.498	0.233	10.959	+2.559
West Irish Shelf	0.364	7.734	0.564	11.981	+4.246	0.391	8.298	+0.564	0.483	10.252	+2.518

Supplementary Table S13: Annual subarea-integrated benthic carbon remineralization averaged over the simulation period 2000-2010 for all four model configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). For each configuration, the mean is provided both area-integrated and per area. The variable stoichiometry configurations also include the per area difference with respect to the RS configuration.

	Annual subarea-integrated benthic carbon remineralization averaged over 2000-2010										
	R			ER			PR			ER&PR	
Subarea	Total [<i>TmolC</i> yr ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]
Entire NWES	0.706	0.575	0.845	0.689	+0.114	0.832	0.678	+0.102	0.812	0.662	+0.086
Entire North Sea	0.369	0.611	0.448	0.743	+0.132	0.442	0.732	+0.120	0.430	0.712	+0.101
Northern North Sea	0.039	0.499	0.042	0.539	+0.040	0.043	0.551	+0.053	0.042	0.534	+0.035
Central North Sea	0.102	0.419	0.122	0.502	+0.082	0.125	0.514	+0.094	0.120	0.492	+0.072
Southern North Sea	0.068	0.332	0.101	0.493	+0.162	0.094	0.459	+0.128	0.093	0.454	+0.123
Norwegian Trench	0.160	2.061	0.183	2.360	+0.299	0.180	2.312	+0.251	0.176	2.259	+0.198
English Channel	0.002	0.027	0.003	0.032	+0.005	0.003	0.036	+0.009	0.003	0.034	+0.007
Skagerrak Kattegat	0.135	1.734	0.175	2.246	+0.512	0.155	1.989	+0.255	0.158	2.029	+0.295
NE Celtic Sea	0.011	0.105	0.013	0.119	+0.013	0.014	0.130	+0.025	0.013	0.123	+0.018
SW Celtic Sea	0.008	0.084	0.008	0.085	+0.001	0.008	0.089	+0.005	0.008	0.085	+0.001
Irish Sea	0.005	0.114	0.007	0.138	+0.023	0.007	0.147	+0.033	0.007	0.140	+0.025
Inner Seas (Scotland)	0.044	0.982	0.048	1.084	+0.102	0.051	1.157	+0.175	0.049	1.105	+0.123
Armorican Shelf	0.059	0.847	0.067	0.953	+0.106	0.070	1.007	+0.160	0.067	0.959	+0.112
Hebrides Shelf	0.018	0.508	0.019	0.538	+0.030	0.020	0.569	+0.061	0.019	0.545	+0.037
Malin Shelf	0.013	0.612	0.014	0.642	+0.030	0.014	0.681	+0.069	0.014	0.648	+0.036
West Irish Shelf	0.042	0.889	0.045	0.962	+0.073	0.047	0.997	+0.108	0.045	0.958	+0.069

Supplementary Table S14: Annual vertically- and subarea-integrated net community production (NCP) averaged over the simulation period 2000-2010 for all four model configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). For each configuration, the mean is provided both area-integrated and per area. The variable stoichiometry configurations also include the per area difference with respect to the RS configuration.

Annual vertically- and subarea-integrated net community production averaged over 2000-2010											
	R	.S		ER			PR			ER&PR	
Subarea	Total [<i>TmolC yr</i> ⁻¹]	Per Area $[molC m^{-2}yr^{-1}]$	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [<i>molC</i> m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [<i>molC</i> m ⁻² yr ⁻¹]
Entire NWES	-0.633	-0.516	-0.963	-0.785	-0.269	-0.745	-0.607	-0.092	-0.860	-0.701	-0.185
Entire North Sea	-0.425	-0.704	-0.594	-0.984	-0.280	-0.490	-0.812	-0.108	-0.540	-0.895	-0.191
Northern North Sea	-0.013	-0.164	-0.037	-0.467	-0.303	-0.017	-0.219	-0.054	-0.027	-0.340	-0.175
Central North Sea	-0.072	-0.297	-0.061	-0.249	+0.048	-0.078	-0.321	-0.024	-0.065	-0.266	+0.031
Southern North Sea	-0.094	-0.459	-0.127	-0.623	-0.163	-0.128	-0.626	-0.167	-0.131	-0.644	-0.185
Norwegian Trench	-0.246	-3.166	-0.370	-4.757	-1.591	-0.267	-3.436	-0.270	-0.317	-4.084	-0.918
English Channel	0.009	0.106	0.007	0.088	-0.018	0.006	0.078	-0.028	0.008	0.092	-0.014
Skagerrak Kattegat	-0.079	-1.019	-0.159	-2.039	-1.020	-0.099	-1.270	-0.251	-0.132	-1.702	-0.682
NE Celtic Sea	-0.013	-0.121	-0.014	-0.133	-0.012	-0.020	-0.188	-0.067	-0.015	-0.144	-0.023
SW Celtic Sea	-0.019	-0.210	-0.052	-0.570	-0.360	-0.026	-0.284	-0.074	-0.044	-0.484	-0.274
Irish Sea	-0.030	-0.629	-0.042	-0.879	-0.250	-0.035	-0.741	-0.113	-0.040	-0.843	-0.214
Inner Seas (Scotland)	-0.036	-0.812	-0.053	-1.185	-0.373	-0.041	-0.916	-0.104	-0.047	-1.065	-0.253
Armorican Shelf	-0.012	-0.171	-0.010	-0.139	+0.031	-0.012	-0.168	+0.002	-0.001	-0.142	+0.029
Hebrides Shelf	-0.015	-0.423	-0.027	-0.756	-0.332	-0.015	-0.417	+0.007	-0.019	-0.545	-0.122
Malin Shelf	-0.007	-0.312	-0.014	-0.648	-0.336	-0.008	-0.386	-0.075	-0.011	-0.495	-0.183
West Irish Shelf	-0.005	-0.116	-0.006	-0.127	-0.011	-0.006	-0.121	-0.005	-0.007	-0.158	-0.042

Supplementary Table S15: Annual subarea-integrated air-sea CO_2 -flux averaged over the simulation period 2000-2010 for all four model configurations: Redfield Stoichiometry (RS), Extracellular Release (ER), Preferential Remineralization (PR), and the combined configuration (ER&PR). For each configuration, the mean is provided both area-integrated and per area. The variable stoichiometry configurations also include the per area difference with respect to the RS configuration.

Annual subarea-integrated air-sea CO ₂ -exchange averaged over 2000-2010											
	R	S		ER			PR			ER&PR	
Subarea	Total [<i>TmolC yr</i> ⁻¹]	Per Area $[molC\ m^{-2}yr^{-1}]$	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [<i>molC</i> m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]	Total [<i>TmolC yr</i> ⁻¹]	Per Area [molC m ⁻² yr ⁻¹]	Difference [molC m ⁻² yr ⁻¹]
Entire NWES	1.105	0.900	1.444	1.176	+0.276	1.207	0.984	+0.083	1.316	1.072	+0.171
Entire North Sea	0.670	1.110	0.889	1.474	+0.364	0.736	1.221	+0.110	0.812	1.346	+0.236
Northern North Sea	0.156	1.977	0.187	2.379	+0.402	0.162	2.063	+0.085	0.174	2.211	+0.234
Central North Sea	0.331	1.361	0.445	1.833	+0.472	0.363	1.495	+0.134	0.407	1.673	+0.312
Southern North Sea	0.087	0.425	0.135	0.661	+0.236	0.106	0.522	+0.097	0.121	0.596	+0.171
Norwegian Trench	0.097	1.245	0.122	1.570	+0.325	0.104	1.341	+0.095	0.110	1.414	+0.168
English Channel	0.056	0.685	0.058	0.702	+0.017	0.057	0.691	+0.007	0.057	0.692	+0.008
Skagerrak Kattegat	-0.051	-0.651	-0.042	-0.537	+0.114	-0.048	-0.615	+0.036	-0.046	-0.588	+0.063
NE Celtic Sea	0.085	0.790	0.101	0.945	+0.155	0.088	0.817	+0.028	0.094	0.873	+0.083
SW Celtic Sea	0.105	1.145	0.135	1.480	+0.335	0.116	1.272	+0.127	0.124	1.357	+0.212
Irish Sea	0.001	0.028	-0.001	-0.017	-0.045	-0.001	-0.020	-0.048	-0.001	-0.030	-0.058
Inner Seas (Scotland)	0.023	0.522	0.025	0.562	+0.040	0.023	0.530	+0.008	0.024	0.532	+0.010
Armorican Shelf	0.044	0.624	0.073	1.039	+0.416	0.056	0.805	+0.181	0.062	0.892	+0.268
Hebrides Shelf	0.069	1.939	0.079	2.227	+0.289	0.071	1.992	+0.054	0.074	2.095	+0.156
Malin Shelf	0.037	1.757	0.044	2.063	+0.306	0.038	1.794	+0.037	0.040	1.903	+0.146
West Irish Shelf	0.066	1.408	0.082	1.752	+0.343	0.071	1.503	+0.095	0.076	1.608	+0.200

			Polynomia	l fit coefficients of function	on $f(z)$ for seasonally and	l subarea-averaged vertica	al profiles of DIC, PO4 a	nd NO ₃		
	$f(z) = C_5 \times z^5 + C_4 \times z^4 + C_3 \times z^3 + C_2 \times z^2 + C_1 \times z^1 + C_0$									
Va	riable	Subarea	Season	<i>C</i> ₅	<i>C</i> ₄	<i>C</i> ₃	<i>C</i> ₂	<i>C</i> ₁	Co	
			Winter (DJF)	-8.501×10^{-11}	-1.081×10^{-7}	-4.813×10^{-5}	-8.865×10^{-3}	-7.422×10^{-1}	2155.466	
			Spring (MAM)	-6.082×10^{-10}	-6.708×10^{-7}	-2.746×10^{-4}	-5.125×10^{-2}	-4.264	2071.123	
		NT	Summer (JJA)	-3.553×10^{-10}	-4.544×10^{-7}	-2.158×10^{-4}	-4.683×10^{-2}	-4.581	2053.557	
			Autumn (SON)	-1.250×10^{-10}	-1.764×10^{-7}	-9.315×10^{-5}	-2.294×10^{-2}	-2.685	2087.112	
	Mean		Winter (DJF)	1.307×10^{-11}	1.787×10^{-8}	8.678×10^{-6}	1.732×10^{-3}	1.283×10^{-1}	6.088	
	N C	NNS	Spring (MAM)	1.062×10^{-10}	1.390×10^{-7}	6.476×10^{-5}	1.324×10^{-2}	1.165	37.925	
		CNS	Summer (JJA)	-3.300×10^{-11}	-3.122×10^{-8}	-8.317×10^{-6}	1.009×10^{-4}	2.911×10^{-1}	29.286	
			Autumn (SON)	-1.119×10^{-11}	-1.588×10^{-8}	-8.153×10^{-6}	-1.746×10^{-3}	-1.029×10^{-1}	8.571	
DIC	SD NNS + CNS		Winter (DJF)	1.731×10^{-8}	5.925×10^{-6}	7.261×10^{-4}	3.926×10^{-2}	$8.554 imes 10^{-1}$	2174.176	
			Spring (MAM)	$5.204 imes 10^{-8}$	1.950×10^{-5}	2.563×10^{-3}	1.341×10^{-1}	1.749	2146.274	
		NT	Summer (JJA)	4.971×10^{-8}	2.015×10^{-5}	2.854×10^{-3}	1.580×10^{-1}	1.676	2119.107	
			Autumn (SON)	2.894×10^{-8}	1.159×10^{-5}	1.640×10^{-3}	9.021×10^{-2}	$4.800 imes 10^{-1}$	2119.163	
			Winter (DJF)	-4.945×10^{-9}	-1.923×10^{-6}	-2.668×10^{-4}	-1.574×10^{-2}	-3.270×10^{-1}	3.823	
		NNS	Spring (MAM)	7.860×10^{-10}	$4.200 imes 10^{-7}$	8.976×10^{-5}	9.472×10^{-3}	$5.431 imes 10^{-1}$	17.771	
		CNS	Summer (JJA)	8.581×10^{-9}	3.947×10^{-6}	6.208×10^{-3}	3.719×10^{-2}	$6.910 imes 10^{-1}$	16.854	
			Autumn (SON)	3.858×10^{-8}	1.471×10^{-5}	1.993×10^{-3}	1.126×10^{-1}	2.417	27.440	
			Winter (DJF)	1.543×10^{-11}	5.092×10^{-9}	4.692×10^{-7}	1.669×10^{-5}	8.289×10^{-4}	$6.420 imes 10^{-1}$	
		NNS	Spring (MAM)	1.295×10^{-11}	4.443×10^{-9}	2.278×10^{-7}	-3.684×10^{-5}	-3.438×10^{-3}	$3.455 imes 10^{-1}$	
	Mean	CNS	Summer (JJA)	2.356×10^{-10}	1.011×10^{-7}	1.531×10^{-5}	9.266×10^{-4}	1.236×10^{-2}	1.828×10^{-1}	
			Autumn (SON)	-3.862×10^{-11}	-1.422×10^{-8}	-9.474×10^{-7}	1.247×10^{-4}	9.711×10^{-3}	5.298×10^{-1}	
PO_4			Winter (DJF)	4.952×10^{-11}	$2.624 imes 10^{-8}$	5.055×10^{-6}	$4.170 imes 10^{-4}$	1.303×10^{-2}	$1.930 imes 10^{-1}$	
		NNS	Spring (MAM)	2.932×10^{-12}	6.676×10^{-10}	3.308×10^{-8}	1.007×10^{-5}	2.239×10^{-3}	1.656×10^{-1}	
	SD	CNS	Summer (JJA)	3.750×10^{-11}	1.584×10^{-8}	2.202×10^{-6}	9.837×10^{-5}	2.461×10^{-4}	1.187×10^{-1}	
			Autumn (SON)	-2.413×10^{-11}	-1.177×10^{-8}	-1.909×10^{-6}	-1.087×10^{-4}	-9.343×10^{-4}	1.350×10^{-1}	
			Winter (DJF)	-3.479×10^{-10}	-1.539×10^{-7}	-2.202×10^{-5}	-8.834×10^{-4}	1.298×10^{-2}	8.414	
		NNS	Spring (MAM)	1.271×10^{-9}	$6.194 imes 10^{-7}$	1.096×10^{-4}	8.300×10^{-3}	1.842×10^{-1}	4.268	
	Mean	CNS	Summer (JJA)	-6.435×10^{-10}	-3.310×10^{-7}	-5.331×10^{-5}	-3.027×10^{-3}	-1.045×10^{-1}	$5.854 imes 10^{-1}$	
			Autumn (SON)	-5.051×10^{-10}	-2.309×10^{-7}	-2.912×10^{-5}	-3.413×10^{-4}	$4.106 imes 10^{-2}$	5.507	
NO ₃			Winter (DJF)	4.146×10^{-10}	2.243×10^{-7}	4.467×10^{-5}	3.863×10^{-3}	1.315×10^{-1}	2.406	
		NNS	Spring (MAM)	9.102×10^{-10}	4.563×10^{-7}	8.320×10^{-5}	6.706×10^{-3}	2.320×10^{-1}	3.504	
	SD	+ CNS	Summer (JJA)	1.081×10^{-9}	4.807×10^{-7}	7.366×10^{-5}	4.320×10^{-3}	7.011×10^{-2}	1.109	
			Autumn (SON)	6.768×10^{-11}	9.436×10^{-8}	3.034×10^{-5}	3.737×10^{-3}	1.827×10^{-1}	3.542	

Supplementary Table S16: Polynomial fit coefficients for seasonally and subarea-averaged vertical profiles of DIC, PO₄ and NO₃ in Fig. 12 and S15. Each variable is given by a function f(z) as defined below with depth z and polynomial coefficients C_N .

2 Ecosystem model equations: variable stoichiometry ECOSMO II

The here introduced variable stoichiometry version of ECOSMO II is an extension to the model presented in Daewel and Schrum (2013). Dissolved and particulate organic matter, formerly constrained to constant Redfield stoichiometry (Redfield, 1963), are now separated into individual variables for carbon, nitrogen, and phosphorus contents in both pelagic and benthic reservoirs. While primary and secondary production remain at Redfield stoichiometry, we here introduce two pathways for variable organic matter stoichiometry: firstly, we allow for carbon fixation beyond nutrient limitation in form of an extracellular release of carbon-enriched dissolved organic matter. This implementation represents the release of carbohydrates observed in phytoplankton blooms under nutrient stress (Fajon et al., 1999; Søndergaard et al., 2000; Børsheim et al., 2005) and was adapted from the model parametrization in Neumann et al. (2022). With this, we also include the suggested particle formation from dissolved to particulate organic matter as transparent exopolymer particles (Engel, 2002; Neumann et al., 2022), and add a dependence on the nutrient state as for the DIC uptake by the extracellular release itself. Secondly, we consider the observed preferential remineralization of nitrogen and phosphorus with the sequence P>N>C (Williams et al., 1980; Clark et al., 1998; Thomas et al., 1999; Loh and Bauer, 2000; Hopkinson et al., 2002) with a constant ratio between the remineralization rates of carbon, nitrogen and phosphorus. By considering variable stoichiometry in the production and degradation of organic matter, the model can represent variations in organic matter composition and their control on the coupling of elemental fluxes. It further incorporates the additional variables dissolved inorganic carbon (DIC) and total alkalinity (TA) introduced in Kossack et al., 2024 (submitted to Front. Mar. Sci.) for the coupling to a carbonate system model (Blackford and Gilbert, 2007). This enables the analysis of the effects of variable stoichiometry on inorganic carbon contents and carbon cycling.

The model integrates a total of twenty-four prognostic equations for tracer concentrations of different functional groups. Besides DIC and TA, these include three phytoplankton (flagellates, diatoms, and cyanobacteria), two zooplankton (microand meso-zooplankton), seven detritus (pelagic DOC, DON, DOP, POC, PON, POP, and biogenic opal), five sediment (benthic POC, PON, POP, PIP, and opal), and four nutrient variables (NO_3^- , NH_4^+ , PO_4^{3-} , SiO_2) in addition to oxygen. Each tracer concentration *C* is integrated in time based on a prognostic equation of the form:

(1)
$$C_t + (v \cdot \nabla)C + w_d C_z = (A_v C_z)_z + R_c$$
,

where subscripts of time t and depth z represent derivatives d/dt and d/dz respectively. Here, v = (u, v, w) is the threedimensional velocity field, A_v the sub-scale diffusion coefficient, w_d a constant sinking velocity and R_c the local sources and sinks. The sinking velocity w_d is only non-zero for particulate organic matter, cyanobacteria, and opal. Whereas the physical model component provides physical transports by advection $(v \cdot \nabla)C$, diffusion $(A_vC_z)_z$, and sinking w_dC_z , the ECOSMO II module describes the biogeochemical processes in R_c that act as local sources and sinks. The table below summarizes these terms R_c for all twenty-four tracers. For a more detailed description of the primary production, secondary production, and nutrient limitation dynamics, the reader is referred to the original ECOSMO II model description (Daewel and Schrum, 2013).

	Local sink and source terms R_C for all tracer concentrations C_X of tracer X								
Variable	Definition	Unit							
	Primary Production								
C _{Pj} : biomass of phytoplankton group P _j	$R_{P_j} = \sigma_j \beta_{T_j} \Phi_{P_j} C_{P_j} - \sum_{l=1}^2 G_l (C_{P_j}) C_{Z_l} - m_{P_j} C_{P_j} \text{ for j in } [1, 2, 3]$	$[mg \ C \ m^{-3}]$							
C _{P1} : flagellate biomass	$\Phi_{P_1} = \min(\alpha(I), \beta_N, \beta_P)$	$[mg \ C \ m^{-3}]$							
C_{P_2} : diatom biomass	$\Phi_{P_2} = \min(\alpha(I), \beta_N, \beta_P, \beta_{Si})$	$[mg \ C \ m^{-3}]$							
C _{P3} : cyanobacteria biomass	$\Phi_{P_3} = \begin{cases} 0, & \text{if } C_{Sal} > 10.0 \text{ or } I_s(x, y) < 120 W m^{-2} \\ \min(\alpha(I), \beta_P), & \text{else if } n_z = N_z \\ \min(\alpha(I), \beta_N, \beta_P), & \text{else} \end{cases} \text{ with } C_{Sal} \text{ provided by the physical model.}$	[mg C m ⁻³]							
$\alpha(I)$: light limitation	$\alpha(l) = \tanh(a \cdot l(x, y, z, t))$	-							
I(x, y, z, t): photosyn- thetically active radiation	$I(x, y, z, t) = \frac{l_{\mathrm{s}}(x, y)}{2} \exp(-k_{\mathrm{w}}z - k_{\mathrm{phyto}} \int_{z}^{0} \sum_{j=1}^{3} C_{P_{j}} \partial z)$	$[Wm^{-2}]$							
$\beta_{\rm N}$: nitrogen limitation	$\beta_{\rm N} = \beta_{\rm NH_4} + \beta_{\rm NO_3}$	-							
$\beta_{\rm NH_4}$: ammonium limitation	$\beta_{\mathrm{NH}_4} = \frac{c_{\mathrm{NH}_4}}{r_{\mathrm{NH}_4} + c_{\mathrm{NH}_4}}$	-							
$\beta_{\rm NO_3}$: nitrate limitation	$\beta_{\rm NO_3} = \frac{c_{\rm NO_3}}{r_{\rm NO_3} + c_{\rm NO_3}} \exp(-\Psi \cdot C_{\rm NH_4})$	-							
$\beta_{\rm P}$: phosphorus limitation	$\beta_{\rm PO_4} = \frac{c_{\rm PO_4}}{r_{\rm PO_4} + c_{\rm PO_4}}$	-							
β_{Si} : silicate limitation	$\beta_{\rm Si} = \max(0, \frac{c_{\rm Sio_2} - R_{\rm Sio_2}}{r_{\rm Sio_2} + c_{\rm Sio_2}})$	-							
$\beta_{T_{1,2,3}}$: temperature dependence	$\beta_{T_1} = 1, \ \beta_{T_2} = 1, \ \beta_{T_3}(T) = \frac{1}{1 + \exp(-T)}$	-							
σ_{P_j} : maximum growth rate of phytoplankton group P_j	$\sigma_{P_1} = 1.10, \ \sigma_{P_2} = 1.30, \ \sigma_{P_3} = 1.00$	[d ⁻¹]							
m_{P_j} : mortality rate of phytoplankton group P_i	$m_{P_1} = 0.08, \ m_{P_2} = 0.05, \ m_{P_3} = 0.08$	[d ⁻¹]							
$I_s(x, y)$: short wave radiation	Prescribed fields loaded from file.	$[Wm^{-2}]$							
<i>α</i> : Photosynthesis efficiency	$\alpha = 0.01$	$[(Wm^{-2})^{-1}]$							
<i>k</i> _w : water background light extinction coefficient	k _w = 0.05	$[m^{-1}]$							
k _{phyto} : phytoplankton light extinction coefficient	$k_{\rm phyto} = 0.20$	$[m^2(mmol \ C)^{-1}]$							
Ψ : NH ₄ inhibition parameter	$\Psi = 3.00$	$[m^3(mmol N)^{-1}]$							

r _{NO3} : NO3 half saturation constant	$r_{NO_3} = 0.50$	$[mmol N m^{-3}]$
r _{NH4} : NH4 half saturation constant	$r_{NH_4} = 0.20$	$[mmol N m^{-3}]$
r _{PO4} : PO ₄ half saturation constant	$r_{PO_4} = 0.05$	$[mmol P m^{-3}]$
r_{SiO_2} : SiO ₂ half saturation constant	$r_{SiO_2} = 0.50$	$[mmol Si m^{-3}]$
Rr _{SiO2} : SiO ₂ constant	$\operatorname{Rr}_{\operatorname{SiO}_2} = 1.00$	[mmol Si m ⁻³]
	Secondary Production	
C_{Z_1} : micro- zooplankton biomass	$R_{Z_1} = \gamma_1 C_{Z_1} \sum_{j=1}^3 G_1 \left(C_{P_j} \right) + \gamma_2 G_1 (\min(C_{\text{POC}}, C_{\text{PON}}, C_{\text{POP}})) C_{Z_1} - G_2 (C_{Z_1}) C_{Z_2} - \mu_1 C_{Z_1} - m_{Z_1} C_{Z_1}$	$[mg \ C \ m^{-3}]$
C _{Z2} : meso- zooplankton biomass	$R_{Z_{2}} = \gamma_{1}C_{Z_{2}}\sum_{j=1}^{3}G_{2}\left(C_{P_{j}}\right) + \gamma_{1}G_{2}\left(C_{Z_{1}}\right)C_{Z_{2}} + \gamma_{2}G_{2}(\min(C_{\text{POC}}, C_{\text{PON}}, C_{\text{POP}}))C_{Z_{2}} - \mu_{2}C_{Z_{2}} - m_{Z_{2}}C_{Z_{2}}$	$[mg \ C \ m^{-3}]$
$G_i(C_X)$: zooplankton grazing rates	$G_i(C_X) = \sigma_{i,X} \frac{a_{i,X} C_X}{r_i + H_i}$ with $H_i = \sum_X a_{i,X} C_X$	-
r_Z : zooplankton half saturation constant	$r_{\rm Z} = 3.3$	$[mmol \ C \ m^{-3}]$
m_{Z_i} : zooplankton mortality rate of group Z_i	$m_{Z_1} = 0.2, \ m_{Z_2} = 0.1$	$[d^{-1}]$
μ_{Z_i} : zooplankton excretion rate of group Z_i	$\mu_{Z_1} = 0.08, \ \mu_{Z_2} = 0.06$	$[d^{-1}]$
γ_1 : assimilation efficiency of grazing on $P_{1,2,3}$ and Z_1	$\gamma_1 = 0.75$	-
γ_2 : assimilation efficiency of grazing on POC	$\gamma_2 = 0.30$	-
$\sigma_{Z_1,X}$: grazing parameter of Z_1 on X	$\sigma_{Z_1,P_1} = 1.00, \ \sigma_{Z_1,P_2} = 1.00, \ \sigma_{Z_1,P_3} = 0.30, \ \sigma_{Z_1,Z_1} = 0.00, \ \sigma_{Z_1,POC} = 1.00$	-
$a_{Z_1,X}$: grazing parameter of Z_1 on X	$a_{Z_1,P_1} = 0.70, \ a_{Z_1,P_2} = 0.25, \ a_{Z_1,P_3} = 0.30, \ a_{Z_1,Z_1} = 0.00, \ a_{Z_1,POC} = 0.10$	-
$\sigma_{Z_2,X}$: grazing parameter of Z_2 on X	$\sigma_{Z_2,P_1} = 0.80, \ \sigma_{Z_2,P_2} = 0.80, \ \sigma_{Z_2,P_3} = 0.30, \ \sigma_{Z_2,Z_1} = 0.50, \ \sigma_{Z_2,POC} = 0.80$	-
$a_{Z_2,X}$: grazing parameter of Z_2 on X	$a_{Z_2,P_1} = 0.10, \ a_{Z_2,P_2} = 0.85, \ a_{Z_2,P_3} = 0.30, \ a_{Z_2,Z_1} = 0.15, \ a_{Z_2,POC} = 0.10$	-
	Degradation Products	
C _{DOC} : dissolved organic carbon concentration	$R_{\rm DOC} = a_{\rm DOM} R_{\rm OM}^+ - \epsilon_{\rm DOC} C_{\rm DOC} + E_{\rm DOC} - F_{\rm DOC2POC}$	$[mg \ C \ m^{-3}]$
C _{DON} : dissolved organic nitrogen concentration	$R_{\rm DON} = a_{\rm DOM} R_{\rm OM}^+ - \epsilon_{\rm DON} C_{\rm DON} + E_{\rm DON} - F_{\rm DON2PON}$	$[mg \ C \ m^{-3}]$
C _{DOP} : dissolved organic phosphorus concentration	$R_{\rm DOP} = a_{\rm DOM} R_{\rm OM}^+ - \epsilon_{\rm DOP} C_{\rm DOP} + E_{\rm DOP} - F_{\rm DOP2POP}$	$[mg \ C \ m^{-3}]$
C _{POC} : particulate organic carbon concentration	$R_{\rm POC} = (1 - a_{\rm DOM})R_{\rm OM}^+ - R_{\rm POC}^- + \left[\frac{\lambda_{\rm res} c_{\rm Sed, \rm POC} - \lambda_{\rm dep} c_{\rm POC}}{dz}\right]_{n_z=0} + F_{\rm DOC2POC}$	$[mg\ C\ m^{-3}]$
C _{PON} : particulate organic nitrogen concentration	$R_{\text{PON}} = (1 - a_{\text{DOM}})R_{\text{OM}}^+ - R_{\text{PON}}^- + \left[\frac{\lambda_{\text{res}}c_{\text{sed},\text{PON}} - \lambda_{\text{dep}}c_{\text{PON}}}{dz}\right]_{n_z=0} + F_{\text{DON2PON}}$	$[mg \ C \ m^{-3}]$

C _{POP} : particulate organic phosphorus concentration	$R_{\rm POP} = (1 - a_{\rm DOM})R_{\rm OM}^+ - R_{\rm POP}^- + \left[\frac{\lambda_{\rm res} c_{\rm Sed, \rm POP} - \lambda_{\rm dep} c_{\rm POP}}{dz}\right]_{n_z=0} + F_{\rm DOP2POP}$	$[mg \ C \ m^{-3}]$
C_{Opal} : biogenic opal concentration	$R_{\text{Opal}} = \frac{1}{\text{REDF}_{\text{C.Si}}} \left[\sum_{i=1}^{2} G_i(P_2) C_{Z_i} + m_2 P_2 - \epsilon_{\text{Si}} C_{\text{Opal}} \right] + \left[\frac{\lambda_{\text{res}} C_{\text{Sed.SiO}_2} - \lambda_{\text{dep}} C_{\text{Opal}}}{dz} \right]_{n_z = 0}$	[mg C m ⁻³]
R_{OM}^+ : new detrital matter from assimilation losses and mortality	$R_{OM}^{+} = (1 - \gamma_1) \left(\sum_{i=1}^2 C_{Z_i} \sum_{j=1}^3 G_i \left(C_{P_j} \right) + G_2 (C_{Z_1}) \right) + (1 - \gamma_2) \sum_{i=1}^2 C_{Z_i} G_i (\min(C_{POC}, C_{PON}, C_{POP})) + \sum_{j=1}^3 m_{P_j} C_{P_j} + \sum_{i=1}^2 m_{Z_i} C_{Z_i} \right)$	$[mg \ C \ m^{-3}s^{-1}]$
R_X^- : POM losses through grazing and remineralization	$R_X^- = \sum_{i=1}^2 C_{Z_i} G_i(\min(C_{\text{POC}}, C_{\text{PON}}, C_{\text{POP}})) + \epsilon_X(T) C_X \text{ for } X \text{ in [POC, PON, POP]}$	$[mg \ C \ m^{-3}s^{-1}]$
$\epsilon_{POC}(T)$: remineralization rate of POC	$\epsilon_{\text{POC}}(T) = 0.006 \times (1 + 20 \times (\frac{T^2}{T_{\text{ref}}^2 + T^2}))$	$[d^{-1}]$
$\epsilon_{PON}(T)$: remineralization rate of PON	$\epsilon_{\text{PON}}(T) = \frac{\epsilon_{\text{POC}}(T)}{\epsilon_{\text{POC:PON}}}$ with parameter $\epsilon_{\text{POC:PON}}$ specified in configuration	$[d^{-1}]$
$\epsilon_{POP}(T)$: remineralization rate of POP	$\epsilon_{POP}(T) = \frac{\epsilon_{POC}(T)}{\epsilon_{POC:POP}}$ with parameter $\epsilon_{POC:POP}$ specified in configuration	$[d^{-1}]$
$\epsilon_{\text{DOC}}(T)$: remineralization rate of DOC	$\epsilon_{\text{DOC}}(T) = \epsilon_{\text{DOC:POC}} \epsilon_{POC}(T)$ with parameter $\epsilon_{\text{DOC:POC}}$ specified in configuration	$[d^{-1}]$
$\epsilon_{\text{DON}}(T)$: remineralization rate of DON	$\epsilon_{\text{DON}}(T) = \frac{\epsilon_{\text{DOC}}(T)}{\epsilon_{\text{DOC:DON}}}$ with parameter $\epsilon_{\text{DOC:DON}}$ specified in configuration	$[d^{-1}]$
$\epsilon_{\text{DOP}}(T)$: remineralization rate of DOP	$\epsilon_{\text{DOP}}(T) = \frac{\epsilon_{DOC}(T)}{\epsilon_{DOC:\text{DOP}}}$ with parameter $\epsilon_{\text{DOC:DOP}}$ specified in configuration	$[d^{-1}]$
ϵ_{Si} : remineralization rate of opal	$\epsilon_{ m Si} = 0.015$	$[d^{-1}]$
<i>a</i> _{DOM} : fraction of dissolved organic matter from new detrital matter	$a_{\text{DOM}} = 0.4$	-
T_{ref} : reference temperature for remineralization	$T_{\rm ref} = 13$	[°C]
w_D : sinking rate of particulate organics and opal	$w_D = 5$	$[md^{-1}]$
n_z : depth index with bottom index $n_z = 0$, surface index $n_z = N_z$	Provided by the physical model component.	-
dz: vertical step size at depth level n_z	Provided by the physical model component.	[<i>m</i>]
	Extracellular Release and Flocculation	
<i>E</i> : extracellular release base rate	$E = B_{ER} \times \Sigma_{j=1}^{3}(\sigma_{j} C_{P_{j}} \beta_{T_{j}})$ with temperature limitation $\beta_{T_{j}}$ of phytoplankton group P_{j} where applicable	$[mg \ C \ m^{-3}s^{-1}]$
E_{DON} : extracellular release of DON	$E_{\text{DON}} = \begin{cases} E \times \min(1 - \beta_{\text{P}}, \beta_{\text{N}}, \alpha(I)), \ \beta_{\text{N}} > 0.1 \\ 0, \ \beta_{\text{N}} \le 0.1 \end{cases}$	$[mg \ C \ m^{-3}s^{-1}]$
E_{DOP} : extracellular release of DOP	$E_{\text{DOP}} = \begin{cases} E \times \min(\beta_{\text{P}}, \ 1.1 - \beta_{\text{N}}, \ \alpha(l)), \ \beta_{\text{P}} > 0.1 \text{ and } \beta_{\text{N}} < 1.1 \\ 0, \ \beta_{\text{P}} \le 0.1 \text{ or } \beta_{\text{N}} \ge 1.1 \end{cases}$	$[mg \ C \ m^{-3}s^{-1}]$
E_{DOC} : extracellular release of DOC	$E_{\text{DOC}} = E_{\text{DON}} + E_{\text{DOP}} + \begin{cases} E \times \min(\max(1 - \beta_{\text{P}}, 1.1 - \beta_{\text{N}}), \alpha(I)), \ \beta_{\text{P}} < 1 \text{ and } \beta_{\text{N}} < 1.1 \\ 0, \ \beta_{\text{P}} \ge 1 \text{ or } \beta_{\text{N}} \ge 1.1 \end{cases}$	$[mg \ C \ m^{-3}s^{-1}]$
<i>F</i> : flocculation base rate	$F = F_{\text{DOM2POM}} \times B_{\text{ER}}$	[<i>s</i> ⁻¹]
<i>F</i> _{DON2PON} : flocculation from DON to PON	$F_{\text{DON2PON}} = \begin{cases} F \times C_{\text{DON}} \times \min(1 - \beta_{\text{P}}, \beta_{\text{N}}, \alpha(l)), & \beta_{\text{N}} > 0.1 \\ 0, & \beta_{\text{N}} \le 0.1 \end{cases}$	$[mg \ C \ m^{-3}s^{-1}]$

F_{DOP2POP} : flocculatio n from DOP to POP	$F_{\text{DOP2POP}} = \begin{cases} F \times C_{\text{DOP}} \times \min(\beta_{\text{P}}, \ 1.1 - \beta_{\text{N}}, \ \alpha(l)), \ \beta_{\text{P}} > 0.1 \text{ and } \beta_{\text{N}} < 1.1 \\ 0, \ \beta_{\text{P}} \le 0.1 \text{ or } \beta_{\text{N}} \ge 1.1 \end{cases}$	$[mg \ C \ m^{-3}s^{-1}]$
<i>F</i> _{DOC2POC} : flocculation from DOC to POC	$F_{\text{DOC2POC}} = F_{\text{DON2PON}} + F_{\text{DOP2POP}} + \begin{cases} F \times C_{\text{DOC}} \times \min(\max(1 - \beta_{\text{P}}, 1.1 - \beta_{\text{N}}), \alpha(l)), & \beta_{\text{P}} < 1 \text{ and } \beta_{\text{N}} < 1.1 \\ 0, & \beta_{\text{P}} \ge 0.1 \text{ or } \beta_{\text{N}} \ge 1.1 \end{cases}$	$[mg \ C \ m^{-3}s^{-1}]$
B_{ER} : extracellular release scaling factor	Specified in configuration.	-
F _{DOM2POM} : flocculation scaling factor	Specified in configuration.	$[d^{-1}]$
	Nutrients	
C _{NH4} : ammonium concentration	$\begin{split} R_{\mathrm{NH}_4} &= -\frac{\beta_{\mathrm{NH}_4}}{\beta_{\mathrm{N}}} (\Sigma_{j=1}^3 \sigma_j \beta_{\mathrm{T}_j} \Phi_{P_j} C_{P_j} + E_{\mathrm{DON}}) + \sum_{i=1}^2 \mu_i C_{Z_i} + \epsilon_{\mathrm{PON}} C_{\mathrm{PON}} + \epsilon_{\mathrm{DON}} C_{\mathrm{DON}} - \Omega_a (O_2, T) C_{\mathrm{NH}_4} + \\ \left[\frac{C_{\mathrm{Sed},\mathrm{PON}} (\theta(O_2) \epsilon_{\mathrm{Sed},\mathrm{OX}}}{dz} \right]_{n_z=0} + \left[\frac{\theta(-O_2) \epsilon_{\mathrm{Sed},\mathrm{Aox}}}{dz} \right]_{n_z=0} + \mathrm{SurfNH}_4 \\ \text{with surface deposition SurfNH}_4 \text{ provided from observational data.} \end{split}$	$[mgC \ m^{-3}]$
C _{NO3} : nitrate concentration	$\begin{split} R_{\text{NO}_3} &= -\frac{\beta_{\text{NO}_3}}{\beta_{\text{N}_1}} \left(\sum_{j=1}^3 \sigma_j \beta_{\text{T}_j} \Phi_{P_j} C_{P_j} + E_{\text{DON}} \right) + \Omega_a(O_2, T) C_{\text{NH}_4} - \theta(-O_2) \theta(\text{NO}_3) a_{\text{denit}}(\epsilon_{\text{POC}} C_{\text{POC}} + \epsilon_{\text{DOC}} C_{\text{DOC}}) - \left[\frac{-\theta(-O_2)\theta(\text{NO}_3) a_{\text{denit}}(\epsilon_{\text{POC}} C_{\text{POC}} + \epsilon_{\text{DOC}} C_{\text{DOC}}) - B_{\text{DOC}} + S_{\text{DOC}} B_{\text{DOC}} \right]_{n_2 = 0} + Surf \text{NO}_3 \\ \text{with surface deposition SurfNO}_3 \text{ provided from observational data.} \end{split}$	$[mgC \ m^{-3}]$
C _{PO4} : phosphate concentration	$R_{\text{PO}_4} = \left[-\sum_{j=1}^{3} \sigma_j \beta_{\text{T}_j} \Phi_{P_j} C_{P_j} - E_{\text{DOP}} + \epsilon_{\text{POP}} C_{\text{POP}} + \epsilon_{\text{DOP}} C_{\text{DOP}} + \sum_{i=1}^{2} \mu_i C_{Z_i} \right] + \left[\frac{\theta(\sigma_2) \epsilon_{\text{p}(1-0.15\sigma)} C_{\text{sed}-\text{PIP}}}{dz} \right]_{n_z=0} + \left[\frac{\theta(-\sigma_2) \epsilon_{\text{p}(1-0.15\sigma)} C_{\text{sed}-\text{PIP}}}{dz} \right]_{n_z=0}$	[mgC m ⁻³]
C _{SiO2} : silicate concentration	$R_{\rm SiO_2} = \left[-\Phi_2 \sigma_2 P_2 + \epsilon_{\rm Si} C_{\rm Opal} \right] + \left[\frac{\epsilon_{\rm SedSiO_2} c_{\rm SedSiO_2}}{dz} \right]_{n_z=0}$	$[mgC m^{-3}]$
C _{O2} : oxygen concentration	$R_{O_2} = \frac{1}{\text{REDF}_{CO_2}\text{REDF}_{CN}} \left(\frac{6.625\beta_{\text{NH}_4} + 8.125\beta_{\text{NO}_3}}{\beta_{\text{N}}} \sum_{j=1}^{3} \sigma_j \beta_{\text{T}_j} \Phi_{P_j} C_{P_j} - \theta(O_2) (6.625 (\epsilon_{\text{POC}} C_{\text{POC}} + \epsilon_{\text{DOC}} C_{\text{DOC}} + \sum_{i=1}^{2} \mu_i C_{Z_i}) + 2\Omega_a (O_2, T) C_{\text{NH}_4}) \right) + \frac{E_{\text{DOC}}}{\text{REDF}_{CO_2}} + \text{SurfO}_2 + \text{BottomO}_2$	$[mmolO_2 m^{-3}]$
$\Omega_a(O_2, T)$: oxygen and temperature scaling	$\Omega_{a}(O_{2}, T) = 0.1 \times \theta(O_{2}) \exp(0.11 \times T) \frac{c_{O_{2}}}{0.01 + C_{O_{2}}}$	-
$\theta(x)$: distinction for oxygen and nitrogen conditions	$\theta(x) = \begin{cases} 1, \ \forall x > 0\\ 0, \ \forall x \le 0 \end{cases}$	-
SurfO ₂ : air-sea O ₂ exchange	$\operatorname{SurfO}_{2} = \left[\frac{v_{P}}{dz(O_{2\operatorname{sat}}(T,S) - C_{O_{2}})}\right]_{n_{z} = N_{z}}$	$[mmolO_2 m^{-3} d^{-1}]$
BottomO ₂ : benthic- pelagic O ₂ exchange flux	$\operatorname{BottomO}_{2} = -\left[\frac{\theta(O_{2})(2\times 6.625\times \epsilon_{\operatorname{Sed},\operatorname{OZ}} c_{\operatorname{Sed},\operatorname{POC}} + \Omega_{a}(O_{2},T)\epsilon_{\operatorname{Sed},\operatorname{OZ}} c_{\operatorname{Sed},\operatorname{POC}})}{dz\operatorname{REDF}_{C:O_{2}}\operatorname{REDF}_{C:O_{2}}\operatorname{REDF}_{C:O_{2}}\operatorname{REDF}_{C:O_{2}}\operatorname{REDF}_{C:O_{2}}\operatorname{REDF}_{C:O_{2}}}\right]_{n_{z}=0} - \left[\frac{\theta(-O_{2})\theta(-\operatorname{NO}_{3})6.625\times \epsilon_{\operatorname{Sed},\operatorname{Anox}} c_{\operatorname{Sed},\operatorname{POC}}}{dz\operatorname{REDF}_{C:O_{2}}\operatorname{REDF}_{C:O_{2}}}\right]_{n_{z}=0}$	$[mmolO_2 m^{-3} d^{-1}]$
$O_{2sat}(T, S)$: oxygen saturation	$\begin{aligned} 0_{2\text{sat}}(T,S) &= \exp\left(-135.90205 + 1.575701 \times 10^5 \times T_{0_2} - 6.642308 \times 10^7 \times T_{0_2}^2 + 1.2438 \times 10^{10} \times T_{0_2}^3 - 8.621949 \times 10^{11} \times T_{0_2}^4 - C_{\text{Sal}}\left(1.7674 \times 10^{-2} - 10.754 \times T_{0_2} + 2140.7 \times T_{0_2}^2\right)\right) \\ &\text{with } T_{0_2}(T) &= \frac{1}{T + 273.15} \end{aligned}$	$[mmolO_2 m^{-3}]$
a_{denit} : increased nitrate loss as oxidation agent under anoxic conditions	$a_{\text{denit}} = 5$	-
Ω_{aMax} : NH ₄ maximum oxidation rate	$\Omega_{aMax} = 0.05$	$[d^{-1}]$
Ω_{nMax} : NO ₂ maximum oxidation rate	$\Omega_{nMax} = 0.10$	$[d^{-1}]$
Ω_{rMax} : NO ₃ maximum reduction rate	$\Omega_{\rm rMax} = 0.01$	$[d^{-1}]$
$\Omega_{\rm dMax}$: NO ₂ maximum reduction rate	$\Omega_{\rm dMax}=0.01$	$[d^{-1}]$

v_P : oxygen piston velocity	$v_P = 5$	$[md^{-1}]$	
REDF _{C:N} : Redfield ratio of carbon to nitrogen	$\text{REDF}_{C:N} = 6.625$	$\left[\frac{mol \ C}{mol \ N}\right]$	
REDF _{C:P} : Redfield ratio of carbon to phosphorus	$\text{REDF}_{\text{C:P}} = 106$	$\left[\frac{mol \ C}{mol \ P}\right]$	
REDF _{C:Si} : Redfield ratio of carbon to silicon	$\text{REDF}_{\text{C.Si}} = 6.625$	$\left[\frac{mol \ C}{mol \ Si}\right]$	
REDF _{C:O2} : molar mass of carbon	$\text{REDF}_{\text{C:O}_2} = 12.01$	$\left[\frac{g C}{mol C}\right]$	
Sediment Processes			
$C_{\text{Sed.POC}}$: benthic POC concentration	$R_{\text{Sed.POC}} = \lambda_{\text{dep}} C_{POC} - C_{\text{Sed.POC}} (\lambda_{\text{res}} + \theta(O_2) 2\epsilon_{\text{Sed.Ox}} + \theta(-O_2)\epsilon_{\text{Sed.Anox}} + \delta_{\text{bur}})$	$[mg \ C \ m^{-2}]$	
C _{Sed.PON} : benthic PON concentration	$R_{\text{Sed.PON}} = \lambda_{\text{dep}} C_{PON} - C_{\text{Sed.PON}} (\lambda_{\text{res}} + \theta(O_2) \epsilon_{\text{Sed.Ox}} + \theta(-O_2) \epsilon_{\text{Sed.Anox}} + \delta_{\text{bur}})$	$[mg \ C \ m^{-2}]$	
C _{Sed.POP} : benthic POP concentration	$R_{\text{Sed.POP}} = \lambda_{\text{dep}} C_{POP} - C_{\text{Sed.POP}} (\lambda_{\text{res}} + \theta(O_2) 2\epsilon_{\text{Sed.Ox}} + \theta(-O_2)\epsilon_{\text{Sed.Anox}} + \delta_{\text{bur}})$	$[mg \ C \ m^{-2}]$	
C _{Sed.PIP} : benthic inorganic iron-bound phosphate concentration	$R_{\text{Sed.PIP}} = \theta(O_2)(2\epsilon_{\text{Sed.Ox}}C_{\text{Sed.POP}} - \epsilon_{\text{PIP}}(1 - 0.15\sigma)C_{\text{Sed.PIP}}) + \theta(-O_2)(\epsilon_{\text{Sed.Anox}}C_{\text{Sed.POP}} - \epsilon_{\text{PIP}}C_{\text{Sed.PIP}})$	[mg C m ⁻²]	
$C_{\text{Sed.SiO}_2}$: benthic opal concentration	$R_{\text{Sed.SiO}_2} = \lambda_{\text{dep}} C_{Opal} - C_{\text{Sed.SiO}_2} (\lambda_{\text{res}} + \epsilon_{\text{Sed.SiO}_2} + \delta_{\text{bur}})$	$[mg \ C \ m^{-2}]$	
$\epsilon_{\text{Sed.Ox}}(T)$: organic sediment remineralization under oxic conditions	$\epsilon_{\text{Sed.Ox}}(T) = 0.001 \times \exp(0.15 \times T)$	$[d^{-1}]$	
$\epsilon_{\text{Sed.Anox}}(T)$: organic sediment remineralization under anoxic conditions	$\epsilon_{\text{SedAnox}}(T) = 2 \times \epsilon_{\text{Sed.Ox}}(T)$	$[d^{-1}]$	
$\epsilon_{\text{PIP}}(T)$: release of phosphate from benthic PIP into the water column	$\epsilon_{\text{PIP}}(T) = 2 \times \epsilon_{\text{Sed.Ox}}(T)$	$[d^{-1}]$	
σ : oxygen dependence of organic sediment phosphorous remineralization	$\sigma = \frac{\left(\frac{C_{O_2}}{375}\right)^2}{0.1^2 + \left(\frac{C_{O_2}}{375}\right)^2}$	-	
$\epsilon_{\text{Sed.SiO}_2}$: sediment opal remineralization rate	$\epsilon_{\text{Sed.SiO}_2} = 0.0002$	$[d^{-1}]$	
λ_{dep} : sedimentation rate below critical bottom shear stress	$\lambda_{\rm dep} = \begin{cases} 3.5, \ \tau < \tau_{\rm crit} \\ 0, \ \tau \ge \tau_{\rm crit} \end{cases}$	$[d^{-1}]$	
λ_{res} : resuspension rate above critical bottom shear stress	$\lambda_{\rm res} = \begin{cases} 0, \ \tau < \tau_{\rm crit} \\ 25, \ \tau \ge \tau_{\rm crit} \end{cases}$	$[d^{-1}]$	
$\tau_{\rm crit}$: critical bottom shear stress	$\tau_{\rm crit} = 0.007$	$[Nm^{-2}]$	
$\delta_{\rm bur}$: burial rate	$\delta_{\rm bur} = 10^{-5}$	$[d^{-1}]$	
Carbonate System Variables			
<i>C</i> _{DIC} : dissolved inorganic carbon concentration	$R_{\text{DIC}} = \frac{1}{\text{REDF}_{\text{C},0_2}} \left(\sum_{i=1}^2 \mu_i C_{Z_i} + \epsilon_{\text{DOC}} C_{\text{DOC}} + \epsilon_{\text{POC}} C_{\text{POC}} - \sum_{j=1}^3 \sigma_j \beta_{\text{T}_j} \Phi_{P_j} C_{P_j} - E_{\text{DOC}} \right) + \frac{1}{\text{REDF}_{\text{C},0_2}} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\frac{\theta(o_2)(2\epsilon_{\text{Sed},\text{POC}})}{dz} \right]_{n_2 = 0} + \frac{1}{(1 + 1)^2} \left[\theta(o_2)$	$[mmol \ C \ m^{-3}]$	

	$\frac{1}{\text{REDF}_{C.O_2}} \left[\frac{\theta(-O_2)(\epsilon_{\text{Sed},\text{ROO}}c_{\text{Sed},\text{POC}})}{dz} \right]_{n_z=0}$	
C _{TA} : total alkalinity	$R_{\text{TA}} = \frac{R_{\text{NH}4}^* - R_{\text{NO}3}^*}{\text{REDF}_{\text{C:O}2}\text{REDF}_{\text{C:N}}} - 0.5 \times \theta(-O_2)R_{O_2} - \frac{R_{\text{PO}4}^*}{\text{REDF}_{\text{C:O}2}\text{REDF}_{\text{C:P}}} + \text{BottomTA}$ where terms with * exclude surface and bottom exchange fluxes	$[mmol \ m^{-3}]$
BottomTA: benthic- pelagic total alkalinity exchange flux	$BottomTA = \left[\frac{\theta(O_2)(\epsilon_{Sed Ox}C_{Sed PON})}{dz \operatorname{REDF}_{CO_2}\operatorname{REDF}_{CN}}\right]_{n_z} + \left[\frac{\theta(-O_2)(\epsilon_{Sed Anox}C_{Sed PON})}{dz \operatorname{REDF}_{CO_2}\operatorname{REDF}_{CN}}\right]_{n_z} + \left[\frac{\theta(-O_2)\theta(NO_3)(a_{denit}\epsilon_{Sed Anox}C_{Sed PON})}{dz \operatorname{REDF}_{CO_2}\operatorname{REDF}_{CN}}\right]_{n_z} - 0.5 \times \theta(-O_2)BottomO_2$	$[mmol \ m^{-3}s^{-1}]$

References

- Aminot, A., and Kérouel, R. (2004). Dissolved organic carbon, nitrogen and phosphorus in the N-E Atlantic and the N-W Mediterranean with particular reference to non-refractory fractions and degradation. *Deep Sea Res. Part Oceanogr. Res. Pap.* 51, 1975–1999. doi: 10.1016/j.dsr.2004.07.016
- Blackford, J. C., and Gilbert, F. J. (2007). pH variability and CO2 induced acidification in the North Sea. J. Mar. Syst. 64, 229–241. doi: 10.1016/j.jmarsys.2006.03.016
- Børsheim, K. Y., Vadstein, O., Myklestad, S. M., Reinertsen, H., Kirkvold, S., and Olsen, Y. (2005). Photosynthetic algal production, accumulation and release of phytoplankton storage carbohydrates and bacterial production in a gradient in daily nutrient supply. J. Plankton Res. 27, 743–755. doi: 10.1093/plankt/fbi047
- Chaichana, S., Jickells, T., and Johnson, M. (2017). Distribution and C/N stoichiometry of dissolved organic matter in the North Sea in summer 2011-12. *Biogeosciences Discuss*, 1–33.
- Chaichana, S., Jickells, T., and Johnson, M. (2019). Interannual variability in the summer dissolved organic matter inventory of the North Sea: Implications for the continental shelf pump. *Biogeosciences* 16, 1073–1096. doi: 10.5194/bg-16-1073-2019
- Church, M. J., Ducklow, H. W., and Karl, D. M. (2002). Multiyear increases in dissolved organic matter inventories at Station ALOHA in the North Pacific Subtropical Gyre. *Limnol. Oceanogr.* 47, 1–10. doi: 10.4319/lo.2002.47.1.0001
- Clark, L. L., Ingall, E. D., and Benner, R. (1998). Marine phosphorus is selectively remineralized. *Nature* 393, 426–426. doi: 10.1038/30881
- Daewel, U., and Schrum, C. (2013). Simulating long-term dynamics of the coupled North Sea and Baltic Sea ecosystem with ECOSMO II: Model description and validation. *J. Mar. Syst.* 119–120, 30–49. doi: 10.1016/j.jmarsys.2013.03.008
- Davis, C. E., Blackbird, S., Wolff, G., Woodward, M., and Mahaffey, C. (2019). Seasonal organic matter dynamics in a temperate shelf sea. *Prog. Oceanogr.* 177. doi: 10.1016/j.pocean.2018.02.021
- Davis, C. E., Mahaffey, C., Wolff, G. A., and Sharples, J. (2014). A storm in a shelf sea: Variation in phosphorus distribution and organic matter stoichiometry. *Geophys. Res. Lett.* 41, 8452–8459. doi: 10.1002/2014GL061949
- Doval, M. D., Pérez, F. F., and Berdalet, E. (1999). Dissolved and particulate organic carbon and nitrogen in the Northwestern Mediterranean. *Deep Sea Res. Part Oceanogr. Res. Pap.* 46, 511–527. doi: 10.1016/S0967-0637(98)00072-7

- Engel, A. (2002). Direct relationship between CO2 uptake and transparent exopolymer particles production in natural phytoplankton. J. Plankton Res. 24, 49–53. doi: 10.1093/plankt/24.1.49
- Fajon, C., Cauwet, G., Lebaron, P., Terzic, S., Ahel, M., Malej, A., et al. (1999). The accumulation and release of polysaccharides by planktonic cells and the subsequent bacterial response during a controlled experiment. *FEMS Microbiol. Ecol.* 29, 351–363. doi: 10.1016/S0168-6496(99)00029-X
- Frigstad, H., Andersen, T., Hessen, D. O., Jeansson, E., Skogen, M., Naustvoll, L.-J., et al. (2013). Long-term trends in carbon, nutrients and stoichiometry in Norwegian coastal waters: Evidence of a regime shift. *Prog. Oceanogr.* 111, 113–124. doi: 10.1016/j.pocean.2013.01.006
- Hansell, D. A., and Carlson, C. A. (1998). Deep-ocean gradients in the concentration of dissolved organic carbon. *Nature* 395, 263–266. doi: 10.1038/26200
- Hoikkala, L., Kortelainen, P., Soinne, H., and Kuosa, H. (2015). Dissolved organic matter in the Baltic Sea. J. Mar. Syst. 142, 47–61. doi: 10.1016/j.jmarsys.2014.10.005
- Hoikkala, L., Lahtinen, T., Perttilä, M., and Lignell, R. (2012). Seasonal dynamics of dissolved organic matter on a coastal salinity gradient in the northern Baltic Sea. *Cont. Shelf Res.* 45, 1–14. doi: 10.1016/j.csr.2012.04.008
- Hopkinson, C. S., Fry, B., and Nolin, A. L. (1997). Stoichiometry of dissolved organic matter dynamics on the continental shelf of the northeastern U.S.A.
- Hopkinson, C. S., and Vallino, J. J. (2005). Efficient export of carbon to the deep ocean through dissolved organic matter. *Nature* 433, 142–145. doi: 10.1038/nature03191
- Hopkinson, C. S., Vallino, J. J., and Nolin, A. (2002). Decomposition of dissolved organic matter from the continental margin. Deep Sea Res. Part II Top. Stud. Oceanogr. 49, 4461–4478. doi: 10.1016/S0967-0645(02)00125-X
- Huang, J. (2018). A Simple Accurate Formula for Calculating Saturation Vapor Pressure of Water and Ice. J. Appl. Meteorol. Climatol. 57, 1265–1272. doi: 10.1175/JAMC-D-17-0334.1
- Humphreys, M. P., Lewis, E. R., Sharp, J. D., and Pierrot, D. (2022). PyCO2SYS v1.8: marine carbonate system calculations in Python. *Geosci. Model Dev.* 15, 15–43. doi: 10.5194/gmd-15-15-2022
- Humphreys, M. P., Schiller, A. J., Sandborn, D., Gregor, L., Pierrot, D., van Heuven, S. M. A. C., et al. (2024). PyCO2SYS: marine carbonate system calculations in Python. doi: 10.5281/zenodo.10671397
- Hung, J.-J., Chen, C.-H., Gong, G.-C., Sheu, D.-D., and Shiah, F.-K. (2003). Distributions, stoichiometric patterns and crossshelf exports of dissolved organic matter in the East China Sea. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 50, 1127–1145. doi: 10.1016/S0967-0645(03)00014-6
- Hung, J.-J., Wang, S.-M., and Chen, Y.-L. (2007). Biogeochemical controls on distributions and fluxes of dissolved and particulate organic carbon in the Northern South China Sea. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 54, 1486– 1503. doi: 10.1016/j.dsr2.2007.05.006
- Kim, T.-H., and Kim, G. (2013). Factors controlling the C:N:P stoichiometry of dissolved organic matter in the N-limited, cyanobacteria-dominated East/Japan Sea. J. Mar. Syst. 115–116, 1–9. doi: 10.1016/j.jmarsys.2013.01.002

- Letscher, R. T., and Moore, J. K. (2015). Preferential remineralization of dissolved organic phosphorus and non-Redfield DOM dynamics in the global ocean: Impacts on marine productivity, nitrogen fixation, and carbon export. *Glob. Biogeochem. Cycles* 29, 325–340. doi: 10.1002/2014GB004904
- Letscher, R. T., Moore, J. K., Teng, Y.-C., and Primeau, F. (2015). Variable C : N : P stoichiometry of dissolved organic matter cycling in the Community Earth System Model. *Biogeosciences* 12, 209–221. doi: 10.5194/bg-12-209-2015
- Liang, Z., Letscher, R. T., and Knapp, A. N. (2023). Global Patterns of Surface Ocean Dissolved Organic Matter Stoichiometry. *Glob. Biogeochem. Cycles* 37, e2023GB007788. doi: 10.1029/2023GB007788
- Loh, A. N., and Bauer, J. E. (2000). Distribution, partitioning and fluxes of dissolved and particulate organic C, N and P in the eastern North Pacific and Southern Oceans.
- Lønborg, C., and Álvarez-Salgado, X. A. (2012). Recycling versus export of bioavailable dissolved organic matter in the coastal ocean and efficiency of the continental shelf pump. *Glob. Biogeochem. Cycles* 26. doi: 10.1029/2012GB004353
- Lucea, A., Duarte, C. M., Agustí, S., and Søndergaard, M. (2003). Nutrient (N, P and Si) and carbon partitioning in the stratified NW Mediterranean. J. Sea Res. 49, 157–170. doi: 10.1016/S1385-1101(03)00005-4
- Martiny, A. C., Vrugt, J. A., and Lomas, M. W. (2014). Concentrations and ratios of particulate organic carbon, nitrogen, and phosphorus in the global ocean. *Sci. Data* 1, 140048. doi: 10.1038/sdata.2014.48
- Nausch, M., Nausch, G., Wasmund, N., and Nagel, K. (2008). Phosphorus pool variations and their relation to cyanobacteria development in the Baltic Sea: A three-year study. J. Mar. Syst. 71, 99–111. doi: 10.1016/j.jmarsys.2007.06.004
- Neumann, T., Radtke, H., Cahill, B., Schmidt, M., and Rehder, G. (2022). Non-Redfieldian carbon model for the Baltic Sea (ERGOM version 1.2) – implementation and budget estimates. *Geosci. Model Dev.* 15, 8473–8540. doi: 10.5194/gmd-15-8473-2022
- Osterholz, H., Burmeister, C., Busch, S., Dierken, M., Frazão, H. C., Hansen, R., et al. (2021). Nearshore Dissolved and Particulate Organic Matter Dynamics in the Southwestern Baltic Sea: Environmental Drivers and Time Series Analysis (2010–2020). *Front. Mar. Sci.* 8. Available at: https://www.frontiersin.org/articles/10.3389/fmars.2021.795028 (Accessed November 15, 2023).
- Painter, S. C., Hartman, S. E., Kivimäe, C., Salt, L. A., Clargo, N. M., Daniels, C. J., et al. (2017). The elemental stoichiometry (C, Si, N, P) of the Hebrides Shelf and its role in carbon export. *Prog. Oceanogr.* 159, 154–177. doi: 10.1016/j.pocean.2017.10.001
- Painter, S. C., Lapworth, D. J., Woodward, E. M. S., Kroeger, S., Evans, C. D., Mayor, D. J., et al. (2018). Terrestrial dissolved organic matter distribution in the North Sea. *Sci. Total Environ.* 630, 630–647. doi: https://doi.org/10.1016/j.scitotenv.2018.02.237
- Pujo-Pay, M., Conan, P., Oriol, L., Cornet-Barthaux, V., Falco, C., Ghiglione, J.-F., et al. (2011). Integrated survey of elemental stoichiometry (C, N, P) from the western to eastern Mediterranean Sea. *Biogeosciences* 8, 883–899. doi: 10.5194/bg-8-883-2011
- Raimbault, P., Pouvesle, W., Diaz, F., Garcia, N., and Sempéré, R. (1999). Wet-oxidation and automated colorimetry for simultaneous determination of organic carbon, nitrogen and phosphorus dissolved in seawater. *Mar. Chem.* 66, 161–169. doi: 10.1016/S0304-4203(99)00038-9

Redfield, A. C. (1963). The influence of organisms on the composition of seawater. The sea 2, 26–77.

- Rowe, O. F., Dinasquet, J., Paczkowska, J., Figueroa, D., Riemann, L., and Andersson, A. (2018). Major differences in dissolved organic matter characteristics and bacterial processing over an extensive brackish water gradient, the Baltic Sea. *Mar. Chem.* 202, 27–36. doi: 10.1016/j.marchem.2018.01.010
- Santinelli, C., Ibello, V., Lavezza, R., Civitarese, G., and Seritti, A. (2012). New insights into C, N and P stoichiometry in the Mediterranean Sea: The Adriatic Sea case. *Cont. Shelf Res.* 44, 83–93. doi: 10.1016/j.csr.2012.02.015
- Singh, A., Baer, S. E., Riebesell, U., Martiny, A. C., and Lomas, M. W. (2015). C : N : P stoichiometry at the Bermuda Atlantic Time-series Study station in the North Atlantic Ocean. *Biogeosciences* 12, 6389–6403. doi: 10.5194/bg-12-6389-2015
- Søndergaard, M., Williams, P. J. le B., Cauwet, G., Riemann, B., Robinson, C., Terzic, S., et al. (2000). Net accumulation and flux of dissolved organic carbon and dissolved organic nitrogen in marine plankton communities. *Limnol. Oceanogr.* 45, 1097–1111. doi: 10.4319/lo.2000.45.5.1097
- Stepanauskas, R., JØrgensen, N. O. G., Eigaard, O. R., Žvikas, A., Tranvik, L. J., and Leonardson, L. (2002). Summer Inputs of Riverine Nutrients to the Baltic Sea: Bioavailability and Eutrophication Relevance. *Ecol. Monogr.* 72, 579–597. doi: 10.1890/0012-9615(2002)072[0579:SIORNT]2.0.CO;2
- Suratman, S., Weston, K., Jickells, T., and Fernand, L. (2009). Spatial and seasonal changes of dissolved and particulate organic C in the North Sea. *Hydrobiologia* 628, 13–25. doi: 10.1007/s10750-009-9730-z
- Tanioka, T., Larkin, A. A., Moreno, A. R., Brock, M. L., Fagan, A. J., Garcia, C. A., et al. (2022). Global Ocean Particulate Organic Phosphorus, Carbon, Oxygen for Respiration, and Nitrogen (GO-POPCORN). Sci. Data 9, 688. doi: 10.1038/s41597-022-01809-1
- Tanioka, T., Matsumoto, K., and Lomas, M. W. (2021). Drawdown of Atmospheric pCO2 Via Variable Particle Flux Stoichiometry in the Ocean Twilight Zone. *Geophys. Res. Lett.* 48, e2021GL094924. doi: 10.1029/2021GL094924
- Thomas, H., Ittekkot, V., Osterroht, C., and Schneider, B. (1999). Preferential recycling of nutrients—the ocean's way to increase new production and to pass nutrient limitation? *Limnol. Oceanogr.* 44, 1999–2004. doi: 10.4319/lo.1999.44.8.1999
- Voss, M., Asmala, E., Bartl, I., Carstensen, J., Conley, D. J., Dippner, J. W., et al. (2021). Origin and fate of dissolved organic matter in four shallow Baltic Sea estuaries. *Biogeochemistry* 154, 385–403. doi: 10.1007/s10533-020-00703-5
- Williams, P., Carlucci, A., and Olson, R. (1980). A deep profile of some biologically important properties in the central North Pacific gyre. *Oceanol. Acta* 3, 471–476.
- Winogradow, A., Mackiewicz, A., and Pempkowiak, J. (2019). Seasonal changes in particulate organic matter (POM) concentrations and properties measured from deep areas of the Baltic Sea. *Oceanologia* 61, 505–521. doi: 10.1016/j.oceano.2019.05.004