

Table S1. Atmospheric pCO₂, concentrations of globally-averaged dissolved inorganic carbon (DIC), O₂, NO₃⁻, dissolved Fe (dFe), and surface (0–50 m) NO₃⁻, dFe, and PO₄⁻. Values represent means and standard deviations of 20 simulations for each configuration.

Configuration	pCO ₂ (ppm)	DIC	O ₂	NO ₃ ⁻ (mmol m ⁻³)	surface NO ₃ ⁻	surface PO ₄ ⁻	dFe (nmol m ⁻³)	surface dFe
Pictl_PIallbgc	284.4±0.1	2308±8	179±9	31.1±1.0	5.7±0.5	0.62±0.07	596±14	398±14
Pictl_LGMFedep	261.7±4.4	2310±9	160±10	30.2±1.5	4.7±0.8	0.53±0.07	670±12	574±10
Pictl_LGMFesed	337.1±8.9	2301±7	234±4	21.6±0.6	4.8±0.4	0.97±0.06	387±9	110±11
Pictl_LGMPO ₄	285.3±1.0	2307±8	179±9	32.5±1.0	6.3±0.6	0.80±0.08	599±14	391±15
Pictl_LGMbdeni	283.7±0.6	2308±9	177±8	33.1±1.1	6.7±0.7	0.61±0.07	607±14	402±15
Pictl_LGMallbgc	283.6±4.7	2308±9	179±9	34.7±1.2	8.7±1.3	0.88±0.09	574±10	330±14
LGMatmctl_PIallbgc	250.2±3.2	2323±9	174±10	31.9±1.5	5.6±0.6	0.48±0.05	546±14	367±15
LGMatmctl_LGMFedep	221.2±5.4	2327±9	150±9	28.3±3.4	3.9±0.8	0.4±0.05	636±13	581±11
LGMatmctl_LGMFesed	313.9±7.2	2315±8	241±5	22.8±0.7	4.7±0.3	0.82±0.06	354±9	110±10
LGMatmctl_LGMPO ₄	250.5±3.3	2323±9	172±10	33.7±1.4	6.3±0.6	0.64±0.07	550±14	354±14
LGMatmctl_LGMbdeni	249.1±3.6	2323±9	172±10	32.9±1.8	6.2±0.7	0.48±0.05	555±14	371±16
LGMatmctl_LGMallbgc	240.9±4.8	2324±9	169±9	32.9±2.0	6.1±1.1	0.67±0.08	549±8	369±13
LGMatmws_PIallbgc	264.3±2.3	2322±9	174±10	31.3±1.3	6.0±0.6	0.56±0.06	556±14	349±15
LGMatmws_LGMFedep	234.5±5.2	2326±9	149±9	27.5±3.8	4.2±0.9	0.45±0.06	646±13	559±12
LGMatmws_LGMFesed	327.6±7.9	2314±8	239±5	21.8±0.6	4.7±0.3	0.91±0.06	359±9	101±10
LGMatmws_LGMPO ₄	265.0±2.4	2322±9	173±9	33.0±1.2	6.6±0.6	0.73±0.08	559±14	340±14
LGMatmws_LGMbdeni	263.1±2.8	2322±9	171±9	32.4±1.6	6.6±0.7	0.55±0.06	566±14	353±16
LGMatmws_LGMallbgc	257.5±4.1	2323±9	171±9	32.6±1.8	6.8±1.1	0.78±0.09	551±9	344±13
LGMatmpi_PIallbgc	265.3±1.6	2322±9	174±9	31.3±1.1	6.1±0.6	0.57±0.06	554±14	344±13
LGMatmpi_LGMFedep	241.7±4.4	2325±9	154±10	31.5±2.1	5.0±0.9	0.47±0.06	637±12	535±11
LGMatmpi_LGMFesed	325.7±8.2	2314±8	236±5	22.2±0.6	5.1±0.3	0.91±0.06	360±9	102±10
LGMatmpi_LGMPO ₄	265.6±1.3	2322±9	173±9	33.0±1.0	6.7±0.6	0.74±0.08	557±14	335±13
LGMatmpi_LGMbdeni	264.3±1.7	2322±9	172±9	32.7±1.3	6.8±0.7	0.57±0.06	563±14	345±14
LGMatmpi_LGMallbgc	258.5±4.0	2323±9	170±9	33.6±1.5	7.6±1.1	0.80±0.09	552±9	336±13

Table S2. Net primary production (NPP), particulate organic matter (POC) export at 130 m, nitrogen fixation, water-column and benthic denitrification (WC and benthic N-loss), and particulate organic matter nitrogen:carbon (pN:C), phosphorous:carbon (pP:C), and nitrogen:phosphorous (pN:P) ratios. Values represent means and standard deviations of the 20 simulations in each configuration. For pN:C, pP:C, and pN:P, values are medians and standard deviations for the surface ocean (0–50 m), with ice-covered areas excluded.

Configuration	NPP (Pg C yr ⁻¹)	POC export (Pg C yr ⁻¹)	N ₂ fixation (Tg N yr ⁻¹)	WC N-loss (Tg N yr ⁻¹)	Benthic N-loss (Tg N yr ⁻¹)	pC:N (mol mol ⁻¹)	pC:P (mol mol ⁻¹)	pN:P (mol mol ⁻¹)
PIctl_PIallbgc	63.9±8.3	9.2±0.6	186±44	40±33	144±14	8.0±0.5	134±8	16.5±0.7
PIctl_LGMFedep	67.0±9.0	10±0.6	253±61	100±49	151±14	9.1±0.6	146±8	17.1±0.6
PIctl_LGMFesed	36.3±5.4	5.6±0.4	86±6	0±0	85±6	6.8±0.5	87±10	12.1±0.7
PIctl_LGMPO ₄	65.2±8.2	9.3±0.6	192±48	43±36	148±16	7.7±0.5	121±8	15.5±0.7
PIctl_LGMbdeni	66.5±8.5	9.4±0.6	150±42	57±37	91±12	7.7±0.6	135±9	17.0±0.6
PIctl_LGMallbgc	57.0±6.5	8.7±0.5	109±25	21±16	87±12	6.6±0.3	110±7	16.0±0.7
LGMatmctl_PIallbgc	52.3±7.5	8.7±0.6	175±41	28±30	145±15	8.7±0.6	151±9	17.5±0.6
LGMatmctl_LGMFedep	54.4±8	9.5±0.6	246±61	90±50	154±13	10.1±0.6	172±12	18.3±0.6
LGMatmctl_LGMFesed	29.4±4.8	5.3±0.4	83±6	0±0	84±7	7.1±0.6	89±11	11.7±0.7
LGMatmctl_LGMPO ₄	54.2±7.4	8.8±0.6	186±45	33±34	151±16	8.2±0.6	135±8	16.3±0.6
LGMatmctl_LGMbdeni	53.7±7.5	8.8±0.6	148±40	42±34	104±13	8.5±0.7	153±10	17.9±0.6
LGMatmctl_LGMallbgc	46.5±5.7	8.3±0.5	129±30	26±20	104±13	7.4±0.7	120±6	16.0±0.6
LGMatmws_PIallbgc	53.5±7.4	8.8±0.6	177±42	29±30	146±15	8.2±0.6	139±9	16.8±0.6
LGMatmws_LGMFedep	56.6±8.0	9.7±0.6	263±69	106±58	155±14	9.7±0.6	158±10	17.5±0.5
LGMatmws_LGMFesed	29.1±4.7	5.2±0.4	81±6	0±0	82±6	7.0±0.6	85±11	11.2±0.7
LGMatmws_LGMPO ₄	55±7.2	8.9±0.6	185±44	33±33	151±16	7.8±0.6	125±8	15.6±0.6
LGMatmws_LGMbdeni	55.1±7.4	8.9±0.6	149±41	45±35	102±13	8.0±0.7	140±10	17.2±0.5
LGMatmws_LGMallbgc	47±5.6	8.3±0.5	126±29	26±20	100±13	7.0±0.5	113±7	15.4±0.7
LGMatmpi_PIallbgc	51.6±7.0	8.6±0.6	162±33	16±21	144±15	7.9±0.5	134±8	16.5±0.6
LGMatmpi_LGMFedep	54.5±7.6	9.5±0.6	199±49	41±35	152±14	9.0±0.6	152±8	17.6±0.6
LGMatmpi_LGMFesed	29.1±4.6	5.2±0.4	81±5	0±0	82±6	6.7±0.5	82±10	11.5±0.7
LGMatmpi_LGMPO ₄	53.1±6.9	8.7±0.6	171±36	19±23	150±16	7.5±0.5	121±7	15.5±0.6
LGMatmpi_LGMbdeni	53.4±7.2	8.7±0.6	130±31	28±24	100±13	7.6±0.6	135±9	17.0±0.5
LGMatmpi_LGMallbgc	46.8±5.6	8.3±0.5	115±23	16±13	99±13	6.8±0.4	112±6	15.7±0.7

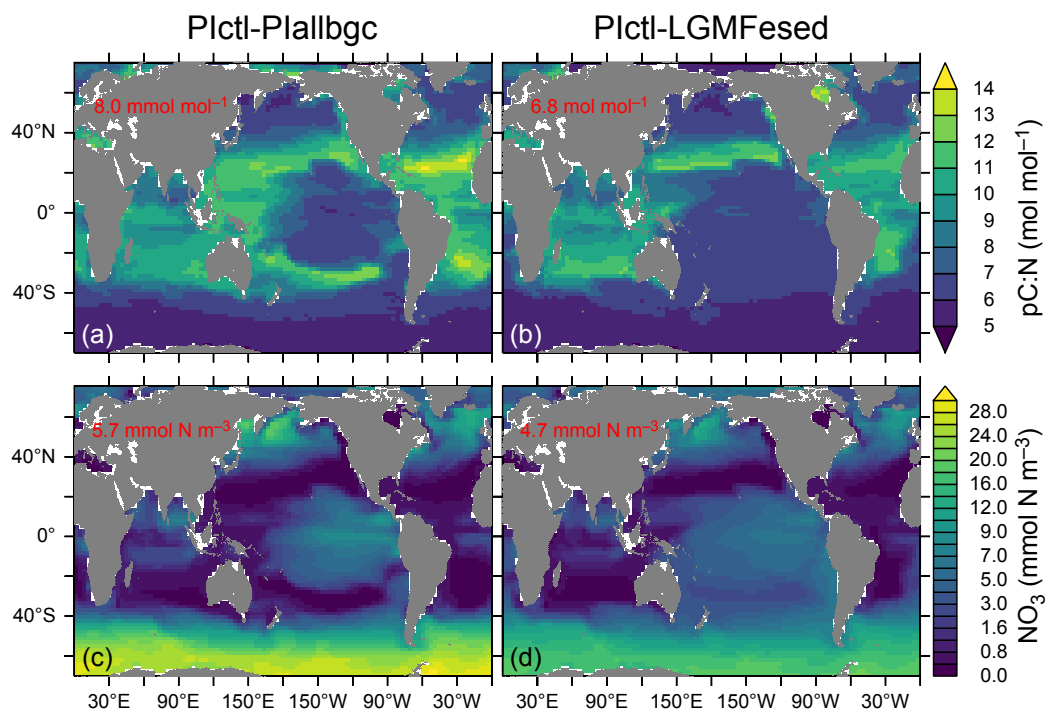


Figure S1. Surface pC:N (a, b) and NO_3^- (c, d) in Pictl-Pfallbgc (a, c) and Pictl-LGMFesed (b, d) simulations. The panels show averages of 20 simulations for each configuration. Global medians of pC:N and means of NO_3^- are shown in red.

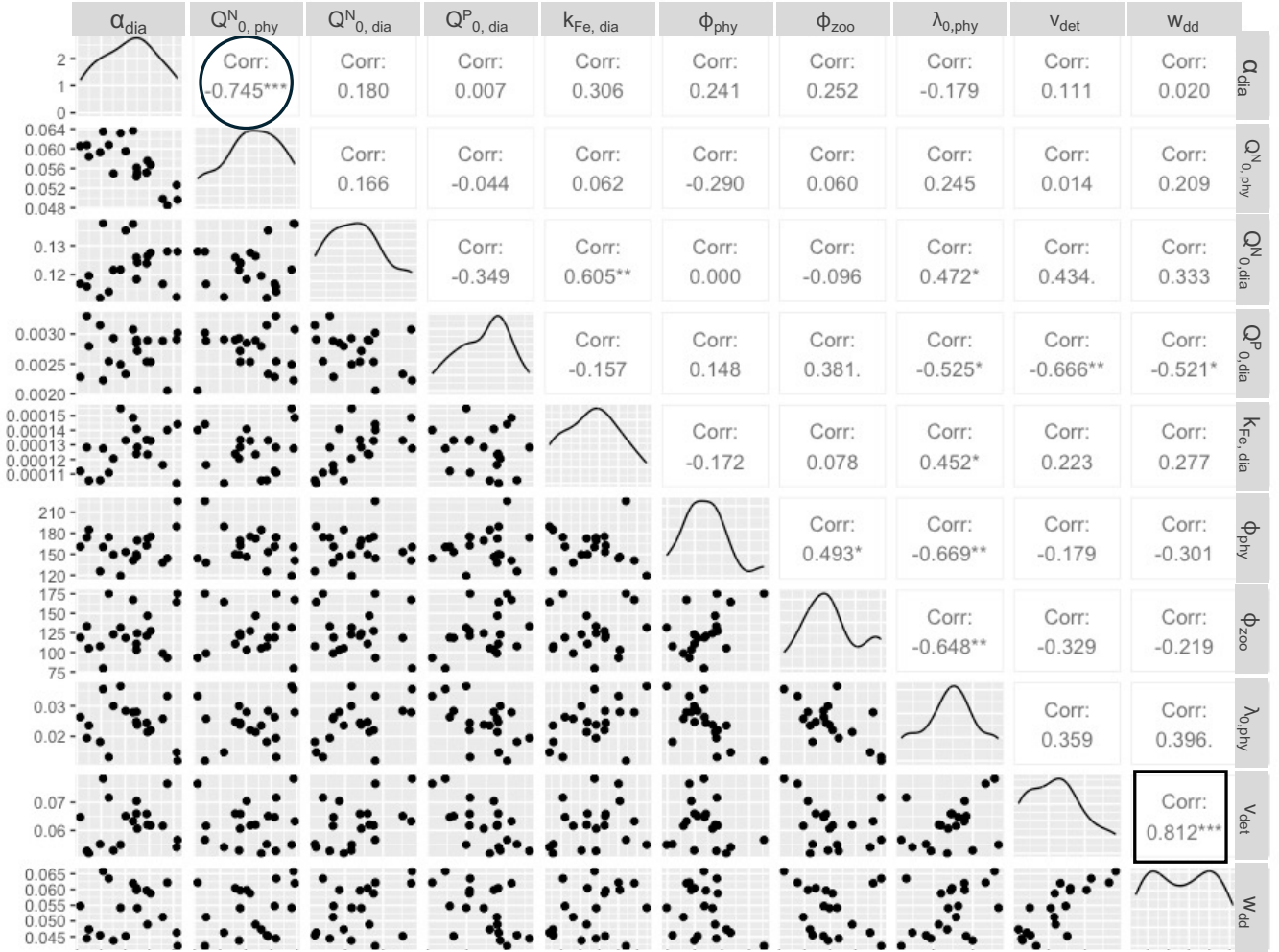


Figure S2. Relationships between the parameters applied in the model experiments. Numbers in the top right panels indicate the correlation coefficient between the parameters, and the asterisks show the statistical significance, where *: $p < 0.05$, **: $p < 0.01$, and ***: $p < 0.001$. Bottom left and the diagonal panels are scatter and density plots for each of the parameter pairs, respectively. The square and circle indicate the most positively and negatively correlated parameter pairs, respectively. Parameters are excluded if none of their pairwise correlation coefficients exceed an absolute value of 0.6.