Supplementary material for Box-modeling of the impacts of atmospheric nitrogen deposition and benthic remineralization on the nitrogen cycle of the eastern tropical South Pacific

Appendix A: Effect of facultative N_2 fixation

It is known from laboratory experiments that diazotrophic phytoplankton can also utilize DIN for growth [e.g., Holl and Montoya, 2005]. In contrast to our NF model where NF always fix N_2 from the atmosphere, Schmittner et al. [2008] introduced a formulation to allow also NO_3^- uptake by diazotrophs. In Schmittner et al. (2008)'s model, nitrogen fixers preferentially use nitrate when available and cover only the residual N demand by N_2 fixation, denoted as facultative N_2-fixation. Thus, we explore the effect of facultative N_2-fixation on our model results with extra fixed-N input by nitrogen deposition.

Compared to results from the configurations in which NF always fix N_2, both Phy and NF in the U-box are more robust to the extra nitrogen input via nitrogen deposition, for instance, Phy increases by 1.5 % (facultative N_2-fixation) vs. 2.9 % (obligate N_2 fixation), and NF decreases by 3.9 % (facultative N_2-fixation) vs. 10 % (obligate N_2 fixation). Again, the biogeochemical concentrations at steady state are relatively insensitive to nitrogen deposition (not shown).

The negative feedback between nitrogen deposition and facultative N_2-fixation is stronger, since nitrogen fixation is reduced by about 21 % (facultative N_2-fixation) compared to 12 % (obligate N_2 fixation) (Fig. S1). The increased lateral fluxes of NO_3^- only account for about 21 % of the extra nitrogen input by nitrogen deposition (facultative N_2-fixation) compared to 50 % (obligate N_2 fixation) (Fig. S1). Thus, facultative N_2-fixation modulates the response of nitrogen fixation to nutrient additions to the surface boxes and controls the magnitude of our model domain being a NO_3^- source.

Appendix B: Sensitivity to atmospheric deposition and benthic remineralization

Figure. S2 shows the steady-state sensitivity of biogeochemical tracer concentrations to nitrogen deposition. Figures. S3 and S4 are time-course sensitivity of biogeochemical tracer concentrations to benthic denitrification and phosphorus regeneration.

Appendix C: Sensitivity to aphotic N_2 fixation

The sensitivity experiment results for including aphotic nitrogen fixation estimated by Bonnet et al. [2013] are shown in Figs. S5 and S6.

Appendix D: Sensitivity to variations in the Martin Curve exponent

Figs. S7 and S8 indicate, respectively, the model fluxes and nitrogen fixer concentrations at steady-state after incorporating different Martin Curve exponent b values.

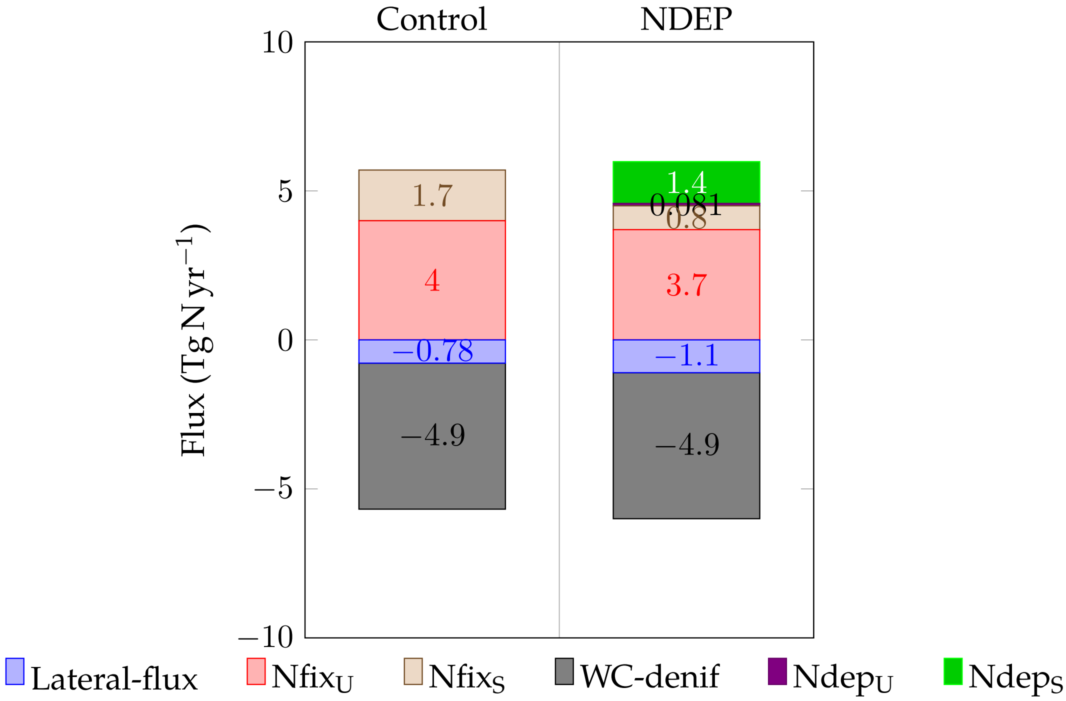

Figure S1: Nitrogen fluxes after including atmospheric nitrogen deposition in the model with facultative N_2-fixation. Lateral-flux is the nitrogen efflux or influx through the southern boundary; Nfix$_U$ and Nfix$_S$ represent the nitrogen fixation rate by NF, respectively, in the U and S boxes; WC-denif is water-column denitrification; Ndep$_U$ and Ndep$_S$ are the nitrogen inputs into surface U and S boxes via nitrogen deposition.

References

S. Bonnet, J. Dekaezemacker, K. A. Turk-Kubo, T. Moutin, R. M. Hamersley, O. Grosso, J. P. Zehr, and D. G. Capone. Aphotic N_2 fixation in the eastern tropical south pacific ocean. *PLoS one*, 8 (e81265):1–14, December 2013. doi: 10.1371/journal.pone.0081265.

C. M. Holl and J. P. Montoya. Interactions between nitrate uptake and nitrogen fixation in continuous cultures of the marine diazotroph trichodesmium (cyanobacteria). *J. Phycol.*, 41:1178–1183, 2005. doi: 10.1111/j.1529-8817.2005.00146.x.

A. Schmittner, A. Oschlies, H. D. Matthews, and E. D. Galbraith. Future changes in climate, ocean circulation, ecosystems, and biogeochemical cycling simulated for a business-as-usual CO_2 emission scenario until year 4000 AD. *Global Biogeochem. Cycles*, 21(GB1013), 2008. doi: 10.1029/2007GB002953.

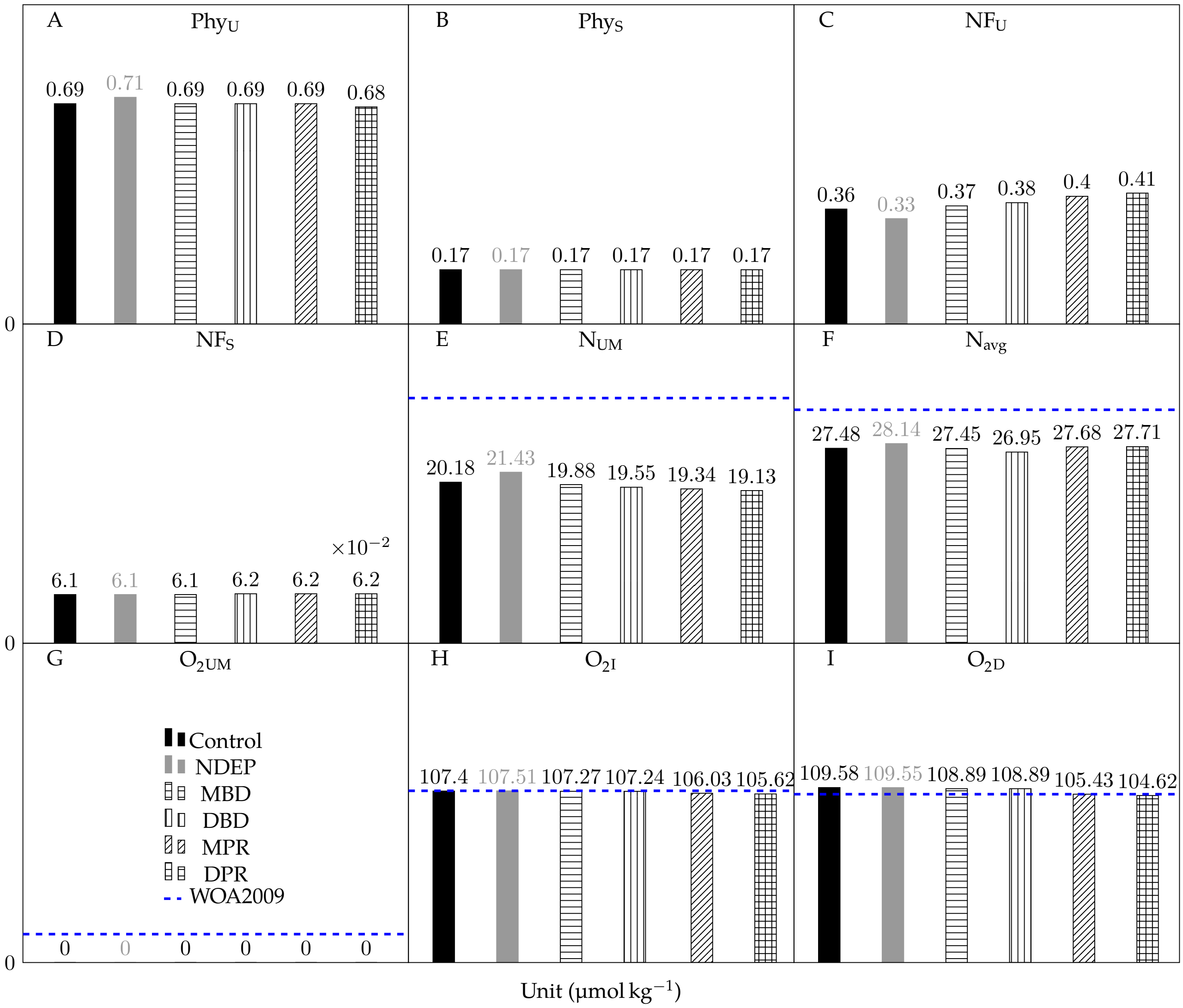

Figure S2: Steady-state sensitivity of biogeochemical tracer concentrations to nitrogen deposition. Each panel uses linear scale on the y-axis starting at zero. Blue dashed lines represent the average of the WOA2009 data of the corresponding boxes (no data exist for PhyU, PhyS, NFU and NFS).

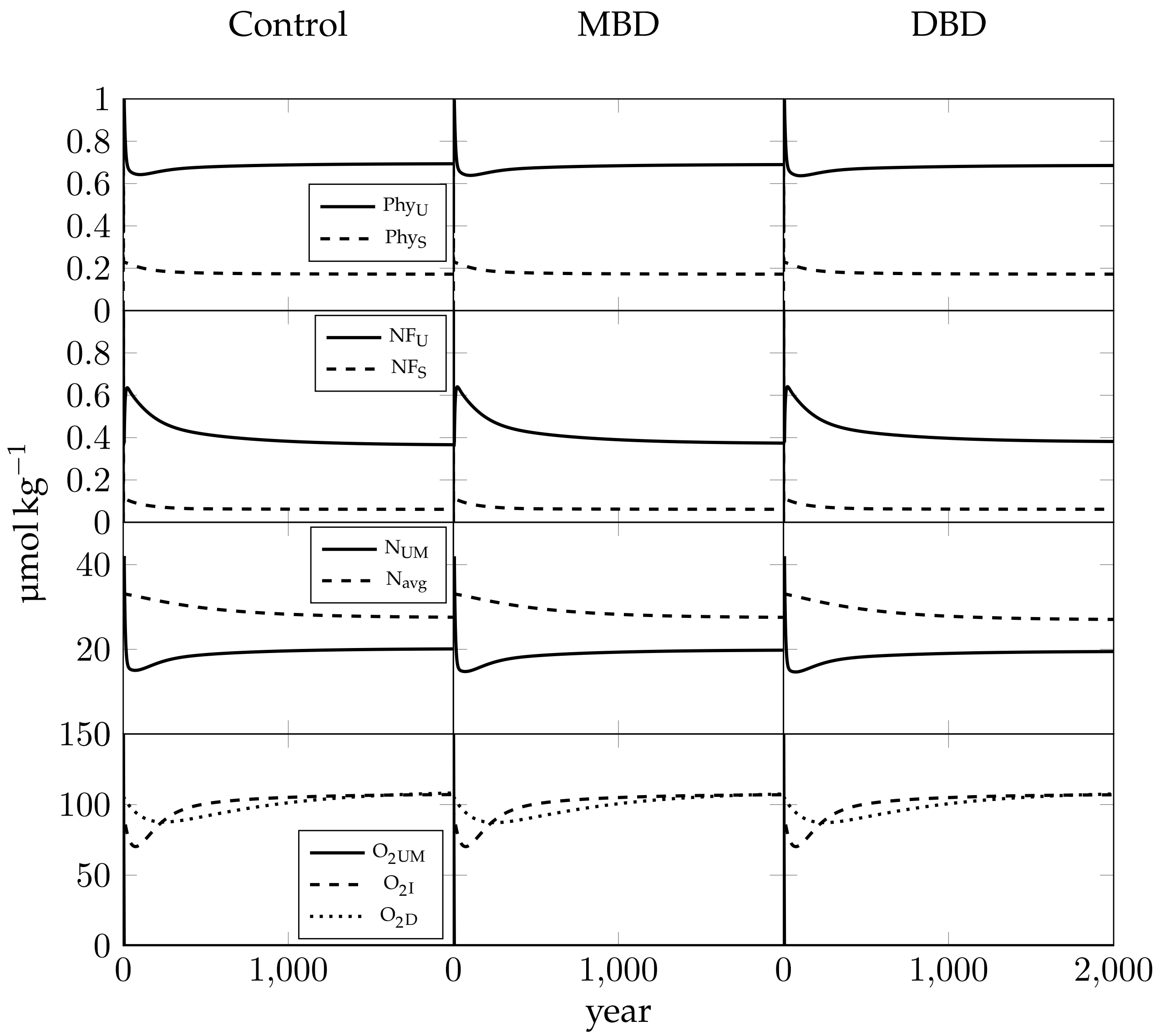

Figure S3: Time-course sensitivity of biogeochemical tracer concentrations to benthic denitrification.

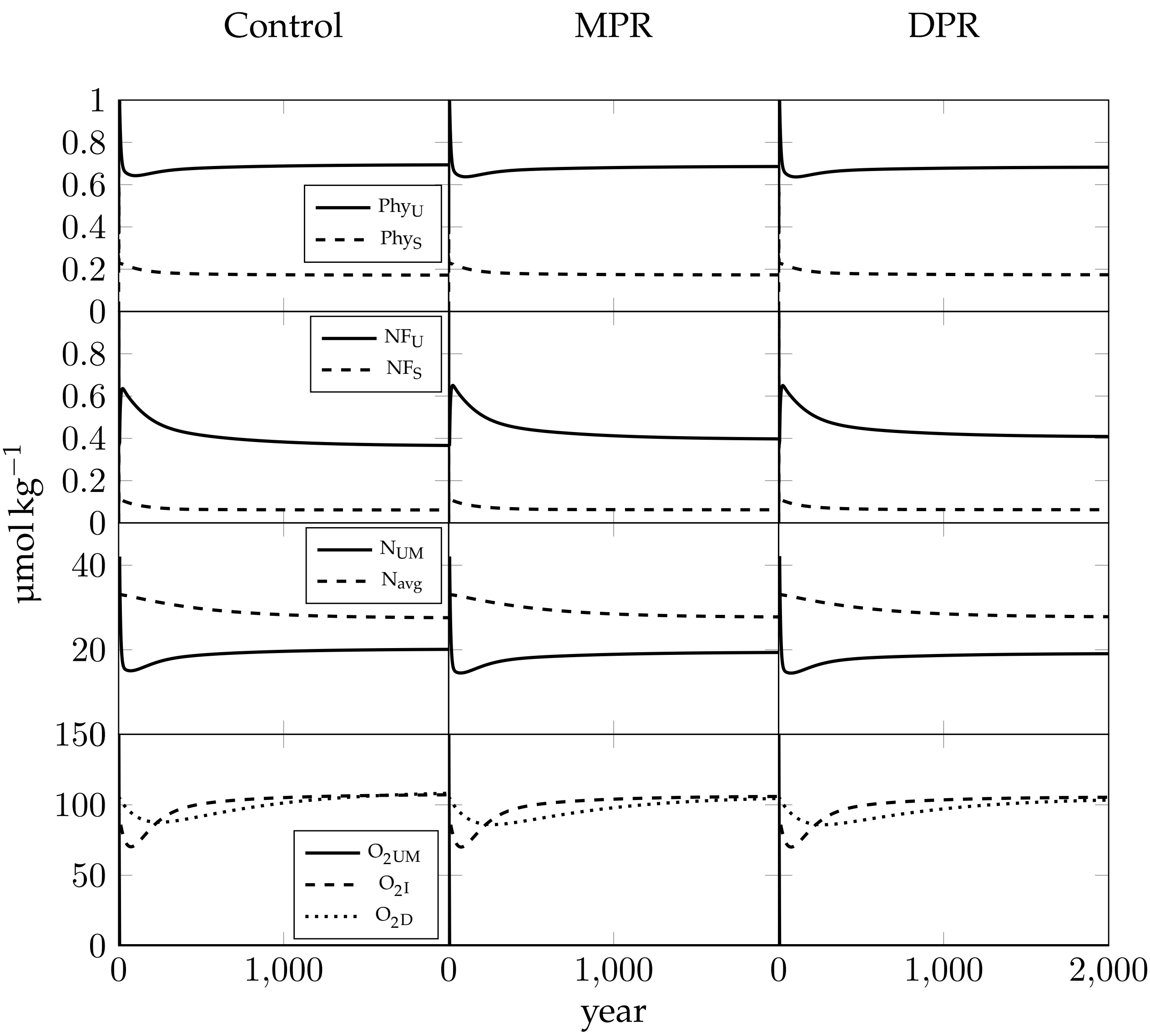

Figure S4: Time-course sensitivity of biogeochemical tracer concentrations to benthic phosphorus regeneration.

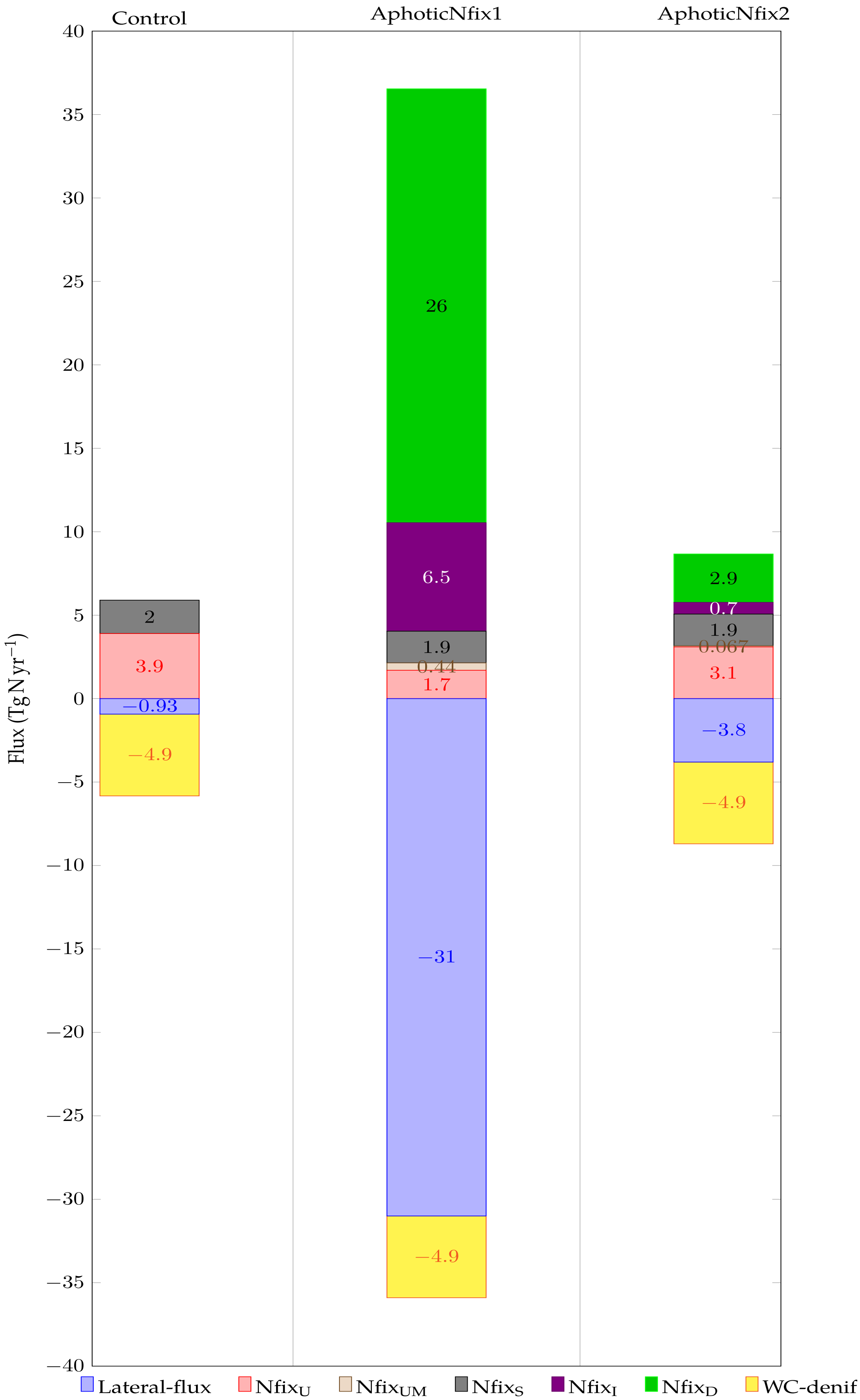

Figure S5: Nitrogen fluxes after including aphotic nitrogen fixation in the control configuration. Lateral-flux is the nitrogen efflux or influx through the southern boundary; Nfix$_U$, Nfix$_{UM}$, Nfix$_S$, Nfix$_I$ and Nfix$_D$ represent the nitrogen fixation rates by NF for the corresponding boxes; WC-denif is water-column denitrification. AphoticNfix1 and AphoticNfix2 are configurations with aphotic nitrogen fixation estimated, respectively, from the 2010 and 2011 cruises.

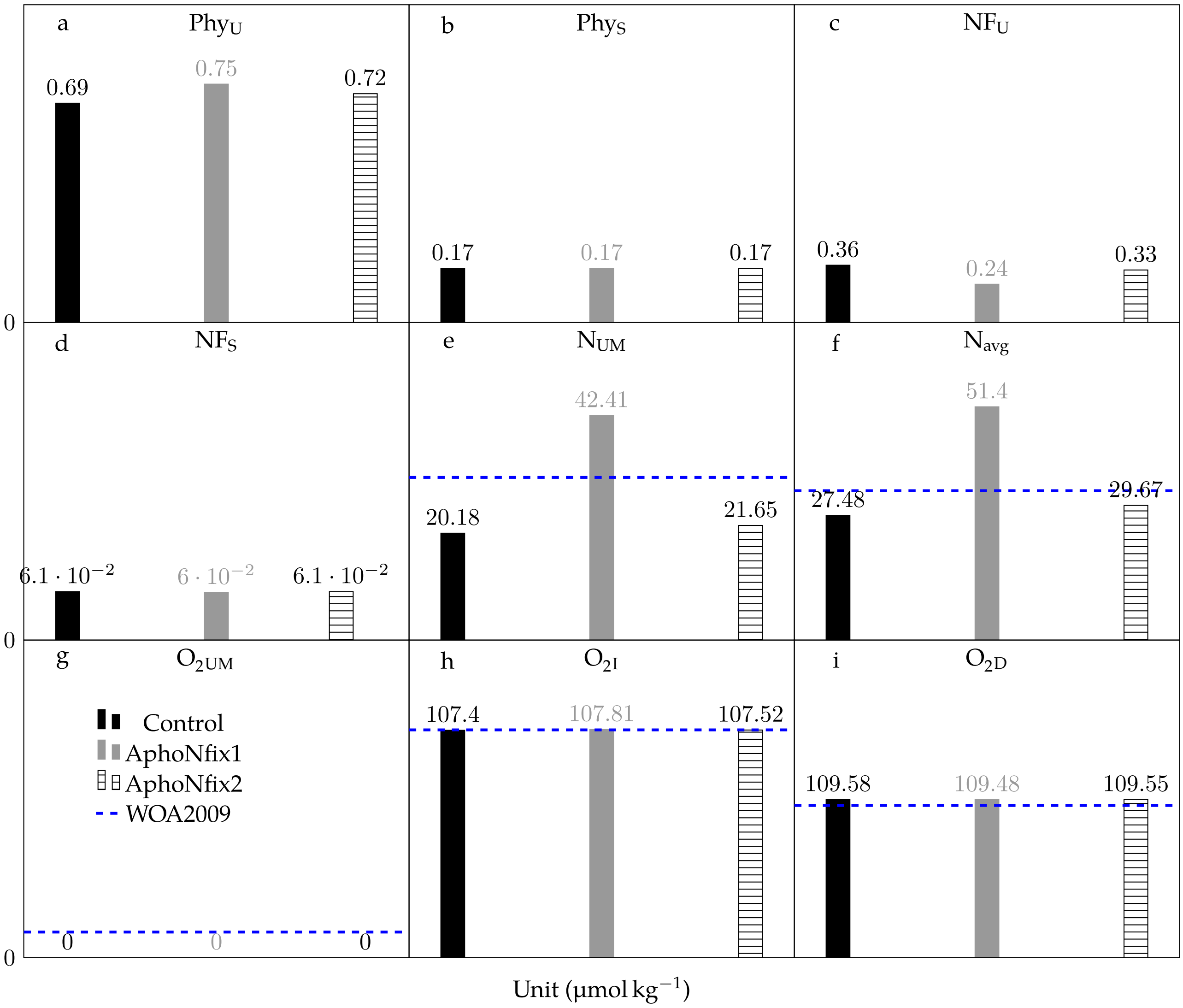

Figure S6: Simulated steady-state phytoplankton, nutrient, and oxygen concentrations for the control configuration modified by including aphotic N_2 fixation. Each panel uses a linear scale on the y axis starting at zero. Dashed blue lines represent the averages of the WOA2009 nitrate and oxygen data for the corresponding boxes (no data exist for PhyU, PhyS, NFU and NFS).

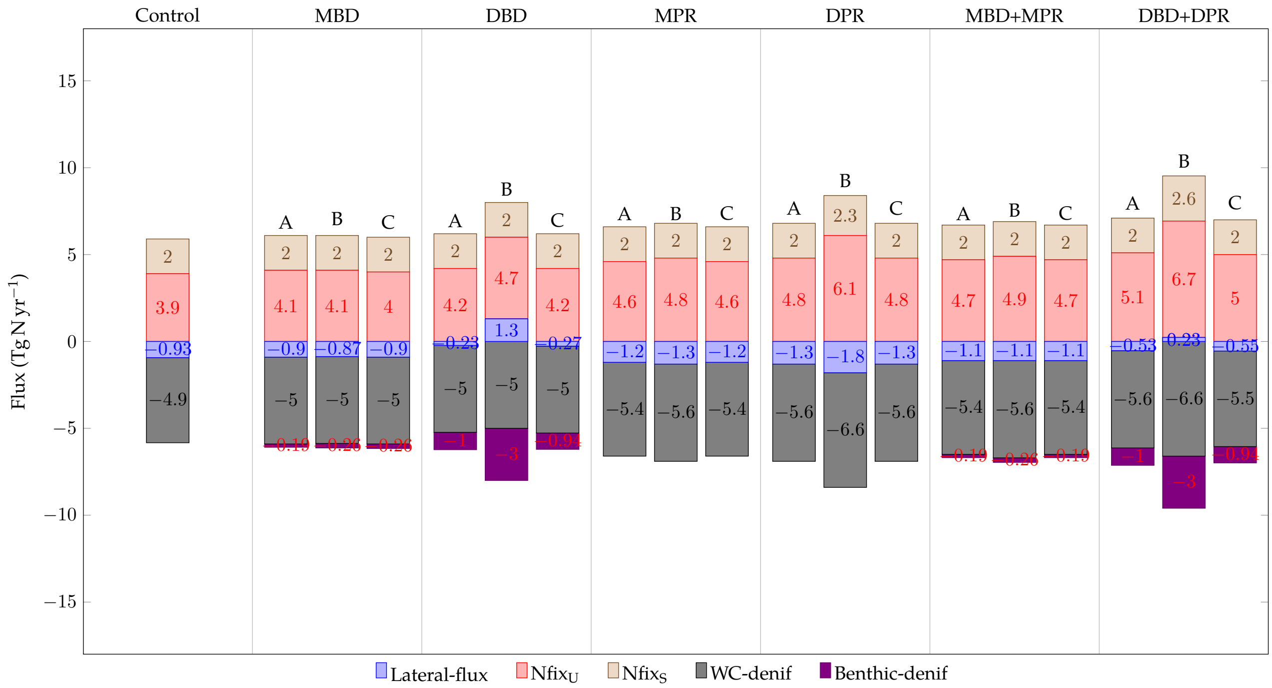

Figure S7: Nitrogen fluxes after including benthic denitrification and/or phosphorus regeneration fluxes estimated by different Martin Curve exponents b. Bar labels: A, Martin Curve exponent $b = 0.82$; B, sensitivity experiments with $b = 0.4$; C, sensitivity experiments with $b = 0.83$ for the UM- and $b = 0.85$ for the D-box. Lateral-flux is the nitrogen efflux or influx through the southern boundary; N-fix represents the nitrogen fixation rate by NF; WC-denif is water-column denitrification; Benthic-denif represents the fixed-N loss via benthic denitrification in the model domain.

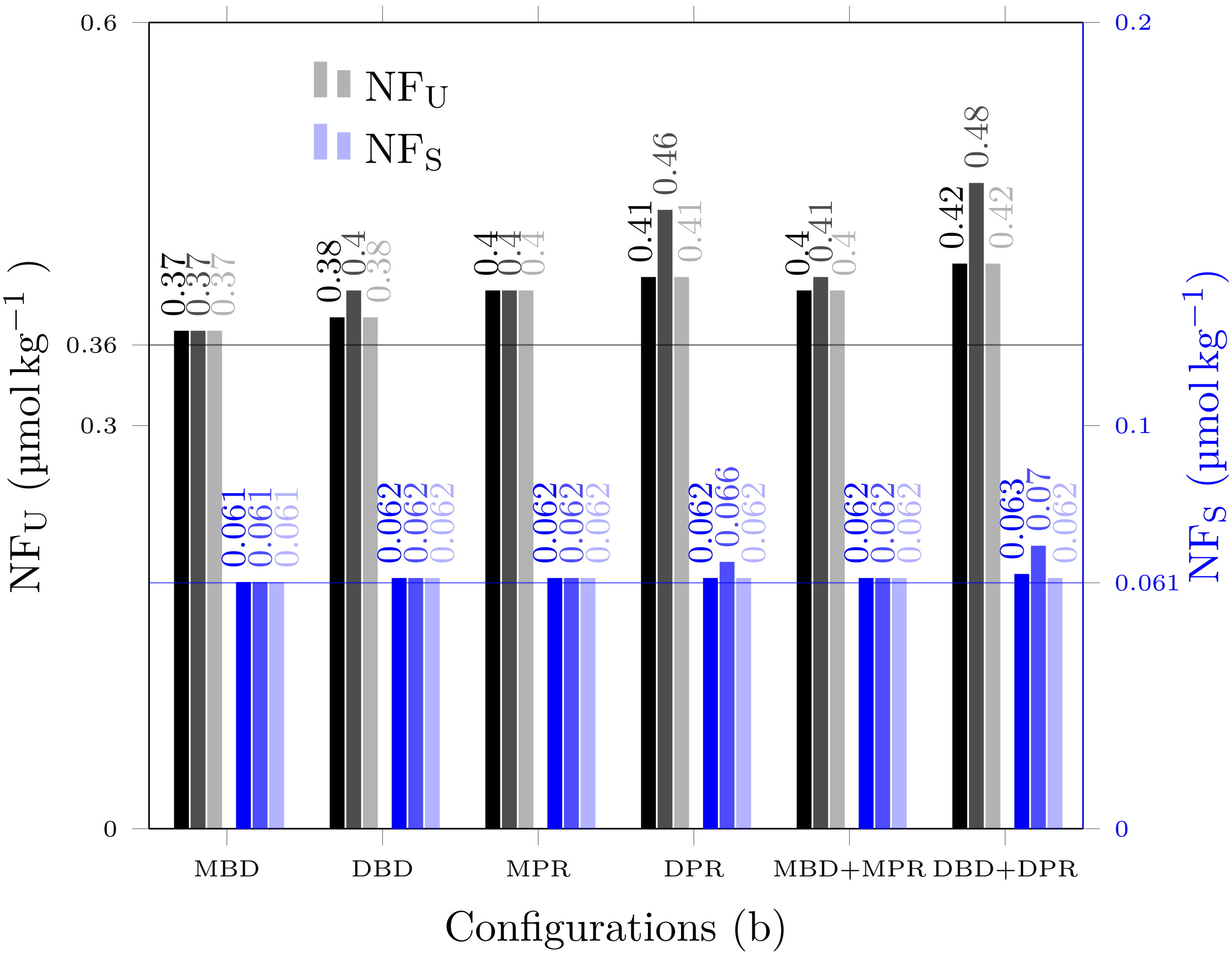

Figure S8: Sensitivity of simulated steady-state concentrations of nitrogen fixers (NFU and NFS) in the U and S boxes respectively after applying Martin Curve exponents $b = 0.82$ (black and dark blue), $b = 0.4$ (dark grey and blue) and variable $b = 0.83$ (UM-box) and 0.85 (D-box) (light grey and light blue). Horizontal grey and light blue lines represent the NFU and NFS concentrations in the control configuration.