

**Figure S1.** Model misfit, plotted for each pair of parameter combinations of MOPS<sup>oD</sup>. Color indicates misfit (see the color bars on the right). A circle indicates the parameter of one individual of the last generation. For better visibility the parameter range to its boundaries (see Table 1).



Figure S2. Parameter distribution of model simulations obtained during the optimisation of MOPS<sup>oD</sup>, whose misfit do not exceed a threshold limit of  $\Delta J = 1.1 J^*$  (10%, red bars) or  $\Delta J = 1.01 J^*$  (1%, open bars) of the minimum misfit  $J^*$ . For the projection parameters of all model simulations in the optimisation trajectory were grouped into 50 classes.



Figure S3. Zonal mean oxygen for three different basins of two sensitivity experiments with RetroMOPS and observations. Upper panels: RetroMOPS with low DOP recycling ( $\lambda_{sDOP} = 0, \lambda_{DOP} = 0.18$ ). Lower panels: RetroMOPS with high DOP recycling ( $\lambda_{sDOP} = 0.36, \lambda_{DOP} = 0.72$ ). Mid panels: observations. Contour lines show simulated zonal average DOP (dashed: 0.1 mmol P m<sup>-3</sup>).



Figure S4. Zonal mean N<sup>\*</sup> (NO<sub>3</sub>-PO<sub>4</sub> × 16 for three different basins of two sensitivity experiments with RetroMOPS and observations. Upper panels: RetroMOPS with low DOP recycling ( $\lambda_{sDOP} = 0$ ,  $\lambda_{DOP} = 0.18$ ). Lower panels: RetroMOPS with high DOP recycling ( $\lambda_{sDOP} = 0.36$ ,  $\lambda_{DOP} = 0.72$ ). Mid panels: observations. Contour lines show simulated zonal average annual fixed nitrogen loss through denitrification (thin: 1  $\mu$ mol N m<sup>-3</sup>y<sup>-1</sup>, dashed: 10  $\mu$ mol N m<sup>-3</sup>y<sup>-1</sup> thick: 100  $\mu$ mol N m<sup>-3</sup>y<sup>-1</sup>).



**Figure S5.** Model misfit, plotted for each pair of parameter combinations of RetroMOPS<sup>o</sup>. Color indicates misfit (see the color bars on the right). A circle indicates the parameter of one individual of the last generation. For better visibility the parameter range to its boundaries (see Table 1).