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# Oceanic nutrient rise and the late Miocene inception of Pacific oxygen-deficient zones

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The modern Pacific Ocean hosts the largest oxygen-deficient zones (ODZs), where oxygen concentrations are so low that nitrate is used to respire organic matter. However, the history of these ODZs is not well understood, hampering a mechanistic prediction of how these ODZs might evolve in the future under global warming. In a 12-million-year (Ma) record from the eastern Pacific, we observed a gradual increase in foraminifera-bound nitrogen isotopes ($^{15}N/^{14}N$) since the late Miocene (8-9 Ma ago), with low $^{15}N/^{14}N$ prior to 9 Ma indicating the absence of ODZs. Coinciding with the $^{15}N/^{14}N$ change is an increase in the ocean's nutrient content reconstructed from the P and Fe concentrations of hydrothermal sediments at the same site. A simple box model calculation incorporating the $^{15}N/^{14}N$ and nutrient content records yields a strong linear correlation ($r^2$>0.98) between the ocean's nutrient content and water-column denitrification rates since 8 Ma, indicating the nutrient rise was probably necessary for the inception of modern ODZs. The early part of the nutrient rise also coincides with the global benthic carbon isotope ($^{13}C/^{12}C$) decline and C4 expansion on land, consistent with the previous suggestion that there was an increase in the delivery of nutrients to the ocean in the late Miocene. A rise in the ocean's nutrient content would have caused an increase in the ocean's "biological carbon pump" and a sequestration of $CO_2$ from the atmosphere into the deep ocean, contributing to the global cooling and other observed environmental and evolutionary changes (e.g., C4 photosynthesis) since the late Miocene.