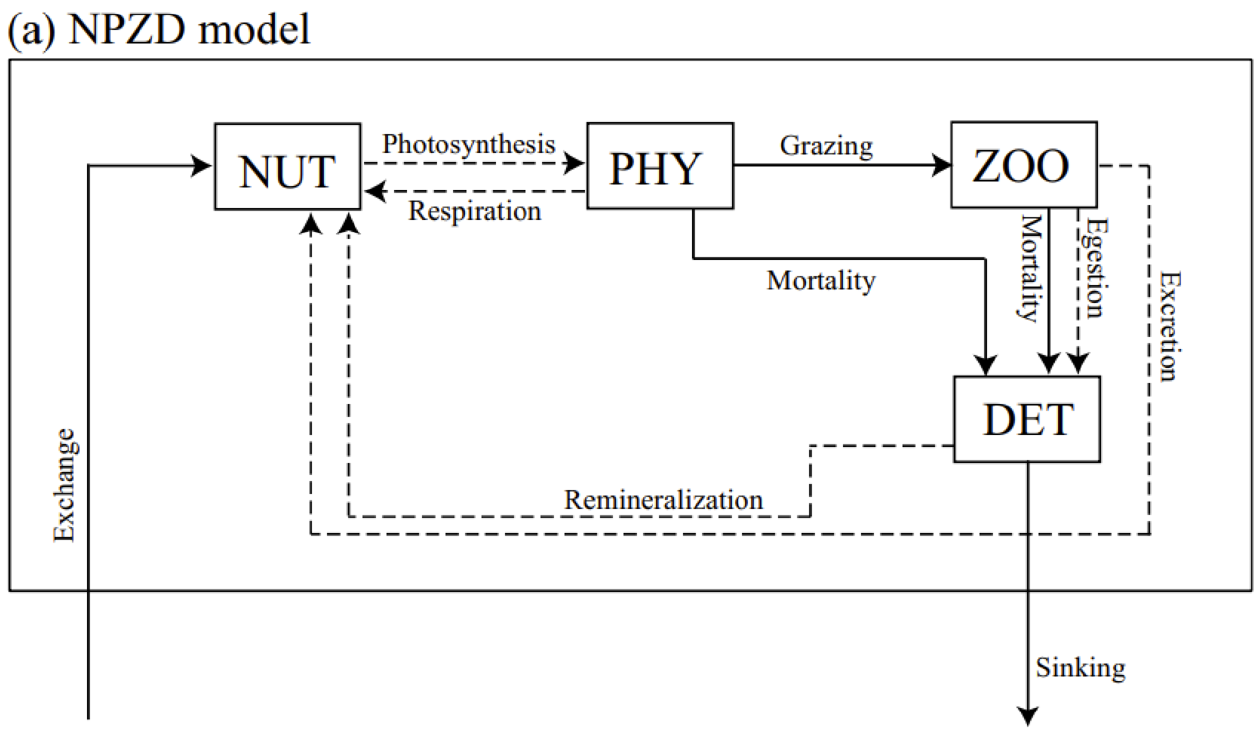
NPZD-nitrogen-isotope model, adapted from Sarmiento and Gruber (2006) and Yoshikawa et al. (2005).



NPZD-model:

$$\frac{dPHY}{dt} = Photosynthesis - Grazing - Mortality_{PHY}$$

$$\frac{dZOO}{dt} = Grazing - Excretion - Egestion - Mortality_{ZOO}$$

$$\frac{dNUT}{dt} = -Photosynthesis + Excretion + Remineralization$$
$$- entr \times ([NUT] - [NUT_{low}])$$

$$\frac{dDET}{dt} = Egestion + Mortality_{PHY} + Mortality_{ZOO} - Remineralization - Sinking$$

With each biological process is determined as follows:

$$Photosynthesis = V_{max} \times \frac{[NUT]}{[NUT] + K_{NUT}} \times \frac{\bar{I}}{\bar{I} + KI} \times [PHY]$$

$$Grazing = \frac{g}{K_p} \times [ZOO] \times [PHY]$$

$$Excretion = (\alpha - \beta) \times \frac{g}{K_p} \times [ZOO] \times [PHY]$$

$$Egestion = (1 - \alpha) \times \frac{g}{K_p} [ZOO] \times [PHY]$$

$$Sinking = \frac{W_{sink}}{MLD} \times [DET]$$

$$Mortality_{PHY} = l_P \times [PHY]$$

$$Mortality_{ZOO} = l_Z \times [ZOO]$$

$$Remineralization = l_D \times [DET]$$

NPZD-^{14}N model:

$$\frac{d^{14}PHY}{dt} = Photosynthesis \times [^{14}PHY] - Grazing \times [^{14}PHY] - Mortality_{PHY} \times [^{14}PHY]$$

$$\frac{d^{14}ZOO}{dt} = Grazing \times [^{14}PHY] - Excretion \times [^{14}ZOO] - Egestion \times [^{14}ZOO] - Mortality_{ZOO} \times [^{14}ZOO]$$

$$\frac{d^{14}NUT}{dt} = -Photosynthesis \times [^{14}PHY] + Excretion \times [^{14}ZOO] + Remineralization \times [^{14}DET] - entr \times ([NUT] \times [^{14}NUT] - [NUT_{low}] \times [^{14}NUT_{low}])$$

$$\frac{d^{14}DET}{dt} = Egestion \times [^{14}ZOO] + Mortality_{PHY} \times [^{14}PHY] + Mortality_{ZOO} \times [^{14}ZOO] - Remineralization \times [^{14}DET] - Sinking \times [^{14}DET]$$

NPZD-^{15}N model:

$$\frac{d^{15}PHY}{dt} = Photosynthesis \times [^{15}PHY] \times \alpha_{uptake} - Grazing \times [^{15}PHY] - Mortality_{PHY} \times [^{15}PHY]$$

$$\frac{d^{15}ZOO}{dt} = Grazing \times [^{15}PHY] - Excretion \times [^{15}ZOO] \times \alpha_{excretion} - Egestion \times [^{15}ZOO] \times \alpha_{egestion} - Mortality_{ZOO} \times [^{15}ZOO]$$

$$\frac{d^{15}NUT}{dt} = -Photosynthesis \times [^{15}PHY] \times \alpha_{uptake} + Excretion \times [^{15}ZOO] \times \alpha_{excretion} + Remineralization \times [^{15}DET] \times \alpha_{remineralization} - entr \times ([NUT] \times [^{15}NUT] - [NUT_{low}] \times [^{15}NUT_{low}])$$

$$\frac{d^{15}DET}{dt} = Egestion \times [^{15}ZOO] \times \alpha_{egestion} + Mortality_{PHY} \times [^{15}PHY] + Mortality_{ZOO} \times [^{15}ZOO] - Remineralization \times [^{15}DET] \times \alpha_{remineralization} - Sinking \times [^{15}DET]$$

Model parameters:

Simulation of environment parameters with time:

Seasonal MLD:

$$MLD(t) = h_0 + h_1\left(1 + \cos\left(\frac{2\pi t}{360}\right)\right)$$

$$dMLDdt = -h_1\left(\frac{2\pi}{360}\right)\sin\left(\frac{2\pi}{360}\right)$$

Entrainment:

$$Entr = \frac{dMLDdt}{MLD}(if\ dMLDdt > 0) + c$$

Seasonal light:

$$I_O(t) = f_{PAR}\left(I_0 + I_1\left(\cos\left(\frac{2\pi t}{360}\right)\right)\right)$$

Average ML light:

$$\bar{I} = I_O(t)\frac{z_I}{MLD(t)}$$

$\mathbf{V_{max}}$	Phytoplankton maximum photosynthetic rate	2	day^{-1}
$\mathbf{K_{NUT}}$	Phytoplankton half saturation constant	2	$\mu mol/m^3$
$\mathbf{l_P}$	Phytoplankton mortality rate	0.05	day^{-1}
$\mathbf{K_p}$		2.8	$\mu mol/m^3$
Ψ	Phytoplankton ammonium inhibition coefficient	1	1/ µmol
α	Zooplankton assimilation efficiency	0.7	nodim
β	Zooplankton growth efficiency	0.3	Nodim
g	Zooplankton grazing rate	1.4	day^{-1}
$\mathbf{l_Z}$	Zooplankton mortality rate	0.12	day^{-1}
$\mathbf{l_D}$	Detritus remineralization rate	0.05	day^{-1}
$\mathbf{W_{sink}}$	Detritus sinking rate	20	day^{-1}
c	Background mixing rate	0.01	day^{-1}
$\mathbf{h_0}$		50	m
$\mathbf{h_1}$		100	m
$\mathbf{I_0}$		20	W/m^2
$\mathbf{I_1}$		150	W/m^2
$\mathbf{z_I}$		20	m
$\mathbf{K_I}$		80	W/m^2
$\mathbf{f_{PAR}}$		0.4	
$\mathbf{^{15}N_{low}}$	Natural abundance of deep water ^{15}N	1.005	
$\mathbf{\epsilon_{uptake}}$	Discrimination factor of nitrate uptake	-5	‰
$\mathbf{\epsilon_{excretion}}$	Discrimination factor of zooplankton excretion	-1	‰
$\mathbf{\epsilon_{egestion}}$	Discrimination factor of zooplankton egestion	-1	‰

$\epsilon_{remineralization}$	Discrimination factor of remineralization	-1	‰

Natural abundance of ^{15}N in a sample relative to the isotopic composition of a standard reference material

$$\delta^{15}N = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000$$

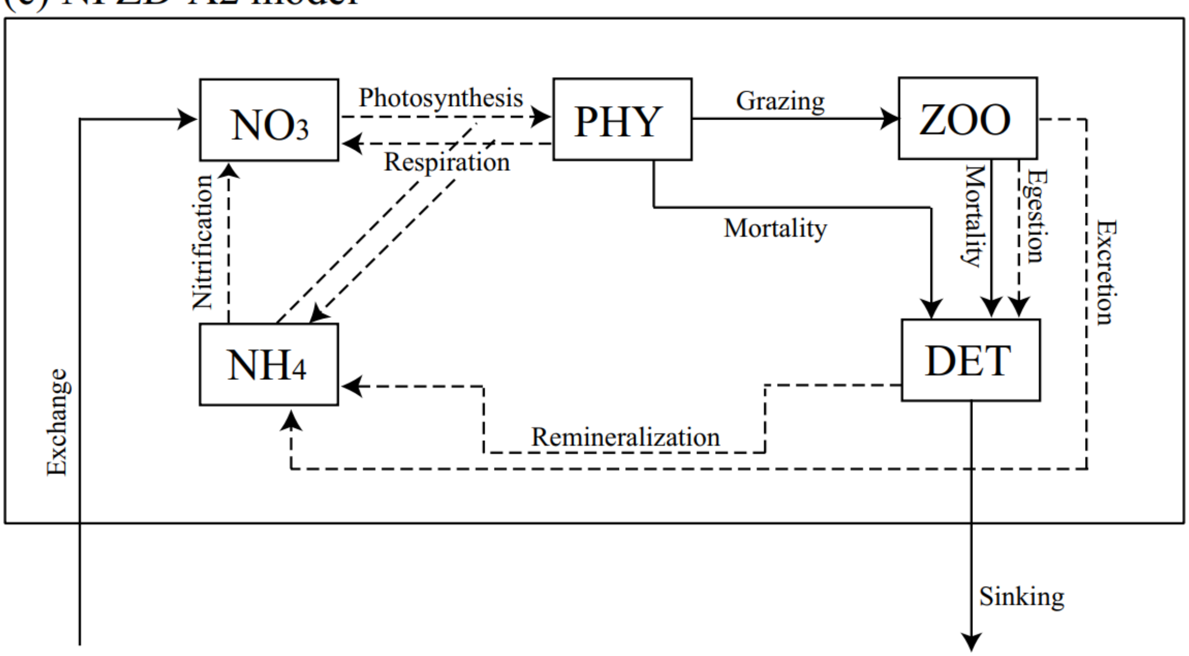
Isotope ratio, $R_{standard}$ of atmospheric nitrogen is 0.00366:

$$R = \frac{^{15}N}{^{15}N + {}^{14}N}$$

Isotopic fractionation coefficient:

$$\alpha = e^{\frac{\epsilon}{1000}}$$

(c) NPZD-A2 model



NPZD-A2-model:

$$\frac{dPHY}{dt} = Photosynthesis - Grazing - Mortality_{PHY}$$

$$\frac{dZOO}{dt} = Grazing - Excretion - Egestion - Mortality_{ZOO}$$

$$\frac{dNO_3}{dt} = -Photosynthesis \times F + Nitrification - entr \times \left([NO_3] - [NO_{3_{low}}]\right)$$

$$\frac{dNH_4}{dt} = -Photosynthesis \times (1 - F) + Excretion + Remineralization - Nitrification$$

$$\frac{dDET}{dt} = Egestion + Mortality_{PHY} + Mortality_{ZOO} - Remineralization - Sinking$$

With each biological process is determined as follows:

$$Photosynthesis = V_{max} \times \left[\frac{[NO_3]}{[NO_3] + K_{NO_3}} \times e^{-\Psi \times [NH_4]} + \frac{[NH_4]}{[NH_4] + K_{NH_4}}\right] \times \frac{\bar{I}}{\bar{I} + KI} \times [PHY]$$

$$F = \frac{\frac{[NO_3]}{[NO_3] + K_{NO_3}} \times e^{-\Psi \times [NH_4]}}{\left[\frac{[NO_3]}{[NO_3] + K_{NO_3}} \times e^{-\Psi \times [NH_4]} + \frac{[NH_4]}{[NH_4] + K_{NH_4}}\right]}$$

$$Grazing = \frac{g}{K_p} \times [ZOO] \times [PHY]$$

$$Excretion = (\alpha - \beta) \times \frac{g}{K_p} \times [ZOO] \times [PHY]$$

$$Egestion = (1 - \alpha) \times \frac{g}{K_p} \times [ZOO] \times [PHY]$$

$$Sinking = \frac{W_{sink}}{MLD} \times [DET]$$

$$Mortality_{PHY} = l_P \times [PHY]$$

$$Mortality_{ZOO} = l_Z \times [ZOO]$$

$$Remineralization = l_D \times [DET]$$

$$Nitrification = Nit \times [NH_4]$$

NPZD-^{14}N model:

$$\frac{d^{14}PHY}{dt} = Photosynthesis \times [^{14}PHY] - Grazing \times [^{14}PHY] - Mortality_{PHY} \times [^{14}PHY]$$

$$\frac{d^{14}ZOO}{dt} = Grazing \times [^{14}PHY] - Excretion \times [^{14}ZOO] - Egestion \times [^{14}ZOO] - Mortality_{ZOO} \times [^{14}ZOO]$$

$$\frac{d^{14}NO_3}{dt} = -Photosynthesis \times [^{14}PHY] \times F + Nitrification \times [NH_4] \times [^{14}NH_4] - entr \times \left([NO_3] \times [^{14}NO_3] - \left[NO_{3_{low}}\right] \times \left[^{14}NO_{3_{low}}\right]\right)$$

$$\frac{d^{14}NH_4}{dt} = -Photosynthesis \times [^{14}PHY] \times (1 - F) + Excretion \times [^{14}ZOO] + Remineralization \times [^{14}DET] - Nitrification \times [NH_4] \times [^{14}NH_4]$$

$$\frac{d^{14}DET}{dt} = Egestion \times [^{14}ZOO] + Mortality_{PHY} \times [^{14}PHY] + Mortality_{ZOO} \times [^{14}ZOO] - Remineralization \times [^{14}DET] - Sinking \times [^{14}DET]$$

NPZD-^{15}N model:

$$\frac{d\,^{15}PHY}{dt} = Photosynthesis \times [^{15}PHY] \times \alpha_{uptake} - Grazing \times [^{15}PHY] - Mortality_{PHY} \times [^{15}PHY]$$

$$\frac{d\,^{15}ZOO}{dt} = Grazing \times [^{15}PHY] - Excretion \times [^{15}ZOO] \times \alpha_{excretion} - Egestion \times [^{15}ZOO] \times \alpha_{egestion} - Mortality_{ZOO} \times [^{15}ZOO]$$

$$\frac{d\,^{15}NO_3}{dt} = -Photosynthesis \times [^{15}PHY] \times F \times \alpha_{uptake} + Nitrification \times [NH_4] \times [^{15}NH_4] \times \alpha_{nitrification} - entr \times \left([NO_3] \times [^{15}NO_3] - \left[NO_{3_{low}}\right] \times \left[^{15}NO_{3_{low}}\right]\right)$$

$$\frac{d\,^{15}NH_4}{dt} = -Photosynthesis \times [^{15}PHY] \times (1 - F) \times \alpha_{uptake} + Excretion \times [^{15}ZOO] \times \alpha_{excretion} + Remineralization \times [^{15}DET] \times \alpha_{remineralization} - Nitrification \times [NH_4] \times [^{15}NH_4] \times \alpha_{nitrification}$$

$$\frac{d\,^{15}DET}{dt} = Egestion \times [^{15}ZOO] \times \alpha_{egestion} + Mortality_{PHY} \times [^{15}PHY] + Mortality_{ZOO} \times [^{15}ZOO] - Remineralization \times [^{15}DET] \times \alpha_{remineralization} - Sinking \times [^{15}DET]$$