Supporting Information for:

Grazing strategies determine the size composition of phytoplankton in eutrophic lakes

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Supporting Information S1 - Environmental forcing to the model and model applications

The three environmental forcing applied to the model are lake water surface temperature (LWST), photosynthetically active radiance (PAR), and mixed layer depth (MLD) (Fig. S1). The former two forcing functions are based on the projection data of temperate lakes in 40°N adopted from Layden et al. (2015). The three yearly mixing regimes (i.e. constant, medium and high frequencies) applied to the model was obtained theoretically from a sinusoidal function as following:

Mixing regimes	**Sinusoidal functions**
Constant (no mixing throughout the year)	-
Medium frequency (4 mixings per year)	$\left(\frac{(Z_m - Z_t)}{2} + Z_t\right) + \frac{(Z_m - Z_t)}{2} \cdot \cos\left(\frac{DoY}{14.525}\right)$
High frequency (12 mixings per year)	$\left(\frac{(Z_m - Z_t)}{2} + Z_t\right) + \frac{(Z_m - Z_t)}{2} \cdot \cos\left(\frac{DoY}{4.825}\right)$

where

Z_m = mixing depth (m), 80m in the study

Z_t = thermocline depth (m), 2.5m in the study

DoY = day of year

The data for LWST and PAR are digitalized with WebPlotDigitizer 4.2 (Rohatgi 2021) and are archived in the Github repository (https://github.com/systemsecologygroup/Sizeb_NPZD). The model is coded in Python (version 3.7.x). The simulations are performed using the *odeint* function in the *scipy* package (Virtanen et al. 2020).

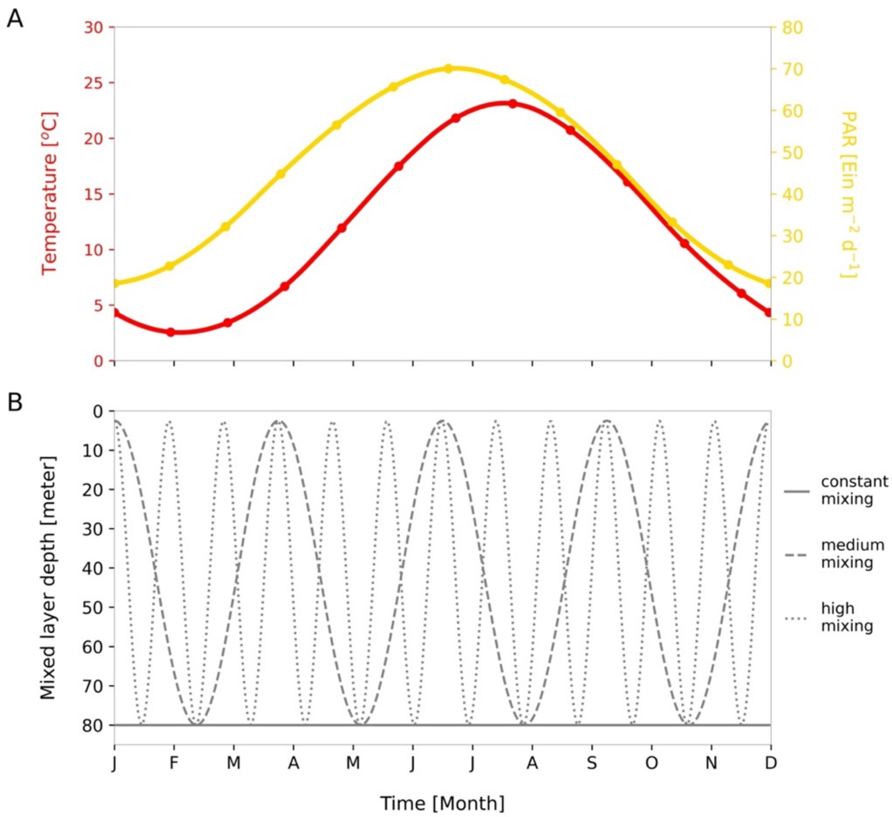


Figure S1. Temporal patterns of abiotic environmental forcing variables used in the model. (A) The red and yellow curves represent interpolated functions of annual variation in, respectively, temperature and photosynthetically active radiance (PAR, converted from net shortwave solar irradiance, W m^{-2}). The dots symbolized the projection data adopted from Layden et al. (2015). (B) The functions represent three mixing frequencies: constant, medium, and high mixing frequencies – solid, dashed, and dotted line respectively, designed to test their effects on plankton dynamics. The integrated mixed layer depth ranges between 2.5 and 80 meters.

Supporting Information S2 – Sensitivity analyses

Phytoplankton size structure is highly responsive to zooplankton grazer community structure (Fuchs and Franks 2010; Prowe et al. 2012; Chenillat et al. 2021), to investigate the robustness of our results, we conduct a series of sensitivity analyses by varying the zooplankton community structure and the allometric scaling for growth and for grazing. All sensitivity analyses are simulated for different scenarios of grazing strategies i.e., “SS”; “SG”; “GS”; and “GG” (Fig. 3), and these analyses are simulated only for more perturbed environmental conditions i.e., non-oligotrophic condition with a presence of mixing — the combination of eutrophic or hypertrophic condition and medium or high mixing — in which the system is not predominately controlled by bottom-up processes and hence the effects of different grazing strategies are more pronounced.

2.1 An increasing number of grazers and extended grazer size range

We vary the number of grazers in the system for different scenarios of grazing strategy (Fig. 3A) by dividing proportionally the specialist and generalist grazers according to the scenario. For example, a 4-grazer “SG” case involves two specialist and two generalist grazers respectively; a 6-grazer “SG” case involves three specialist and three generalist grazers respectively; *vice versa* (Supplementary Fig. S2). Essentially, the assumption where the group of small phytoplankton are under heavier grazing pressure than their larger counterparts is held for all scenarios. We additionally extended the size range of zooplankton, capturing the grazing effect from nanozooplankton to microzooplankton (i.e., 5-2000 μm), such that their grazing covers the entire phytoplankton size spectrum in the model from 1 to 100 μm (Supplementary Fig. S2). The total number of phytoplankton size classes, i, is fixed to 150.

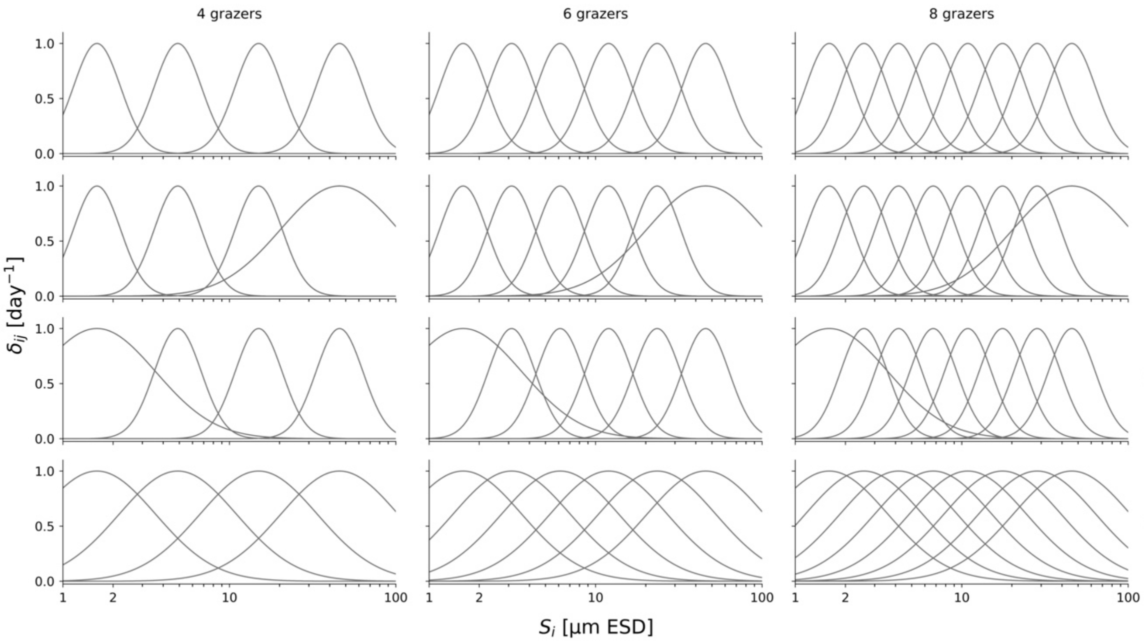


Figure S2. The configurations of sensitivity analyses for different zooplankton community structures. We vary the number of grazers to four, six and eight (column-wise) for different grazing strategies. The zooplankton community under all trophic structures are subject to a population-dependent predatory pressure (not shown in the illustration). The maximum zooplankton size is extended to 2000 µm where the grazing pressure covers the whole phytoplankton size spectrum.

2.2 Different allometric scaling exponents

Allometric relationships that describe planktonic growth and grazing are substantial for understanding selective pressure of phytoplankton community size structure (Taniguchi et al., 2014). The exponent of these allometries have been in debate for decades, especially for phytoplankton maximum growth rate and zooplankton maximum ingestion rates (e.g. Tang, 1995; Hansen et al., 1997; Saiz & Calbet, 2007; Chen & Liu, 2010; DeLong et al., 2010; Edwards et al., 2012; Kempes et al., 2012; Marañón et al., 2013; Ward et al., 2017; Zaoli et al., 2019; Hillebrand et al., 2022). Poulin & Franks (2010) also commented that any modelled trophic structure often depends on a specific set of allometric scaling relationships. To confirm the consistency of our results, we simulated the phytoplankton community size structure under different allometric relationships for the maximum growth rate, μ_{max_i} (Eq. 3), and the maximum ingestion rate, I_{max_j} (Eq. 10), by altering their allometric exponents, $\alpha_{\mu_{max}}$ and $\alpha_{I_{max}}$ respectively, for ±50% (Supplementary Fig. S3). The tested values for $\alpha_{\mu_{max}}$ are -0.54 and -0.18 and for $\alpha_{I_{max}}$ are -0.6

and -0.2. Here, a smaller $\alpha_{\mu_{max}}$ and $\alpha_{I_{max}}$ generally lead to a decrease in μ_{max_i} and I_{max_j} to the community but the decrease is less for smaller than large size classes (Supplementary Fig. S3). This leads to a lower $\alpha_{\mu_{max}}$ favours small cells over large in terms of the less reduction in growth ability whereas a lower $\alpha_{I_{max}}$ disfavours small over large in terms of the less reduction in grazing pressure.

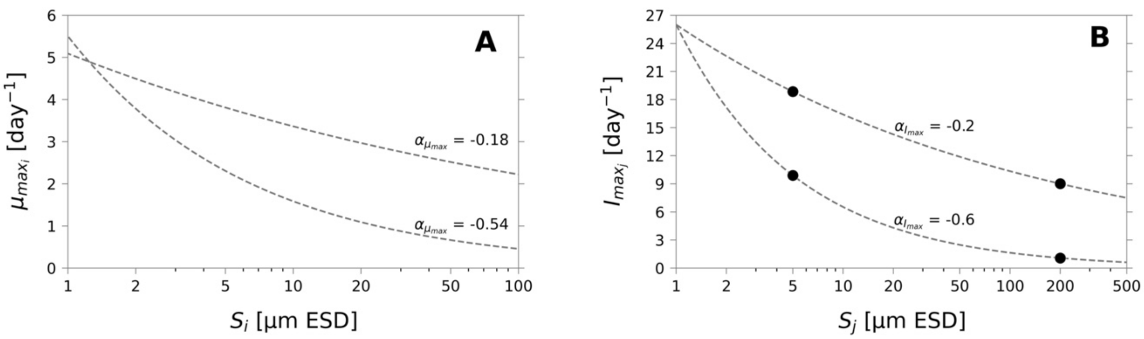


Figure S3. Sensitivity analyses for allometric scaling of (A) maximum growth rate, μ_{max_i}, and (B) maximum ingestion rates, I_{max_j}, via varying the parameters, $\alpha_{\mu_{max}}$ and $\alpha_{I_{max}}$, ±50% of their default values respectively. S_i and S_{Z_j} are the size of phytoplankton class i and zooplankton class j respectively.

Supporting Information S3 – Results of sensitivity analyses

3.1 The results for sensitivity analyses varying zooplankton community structure

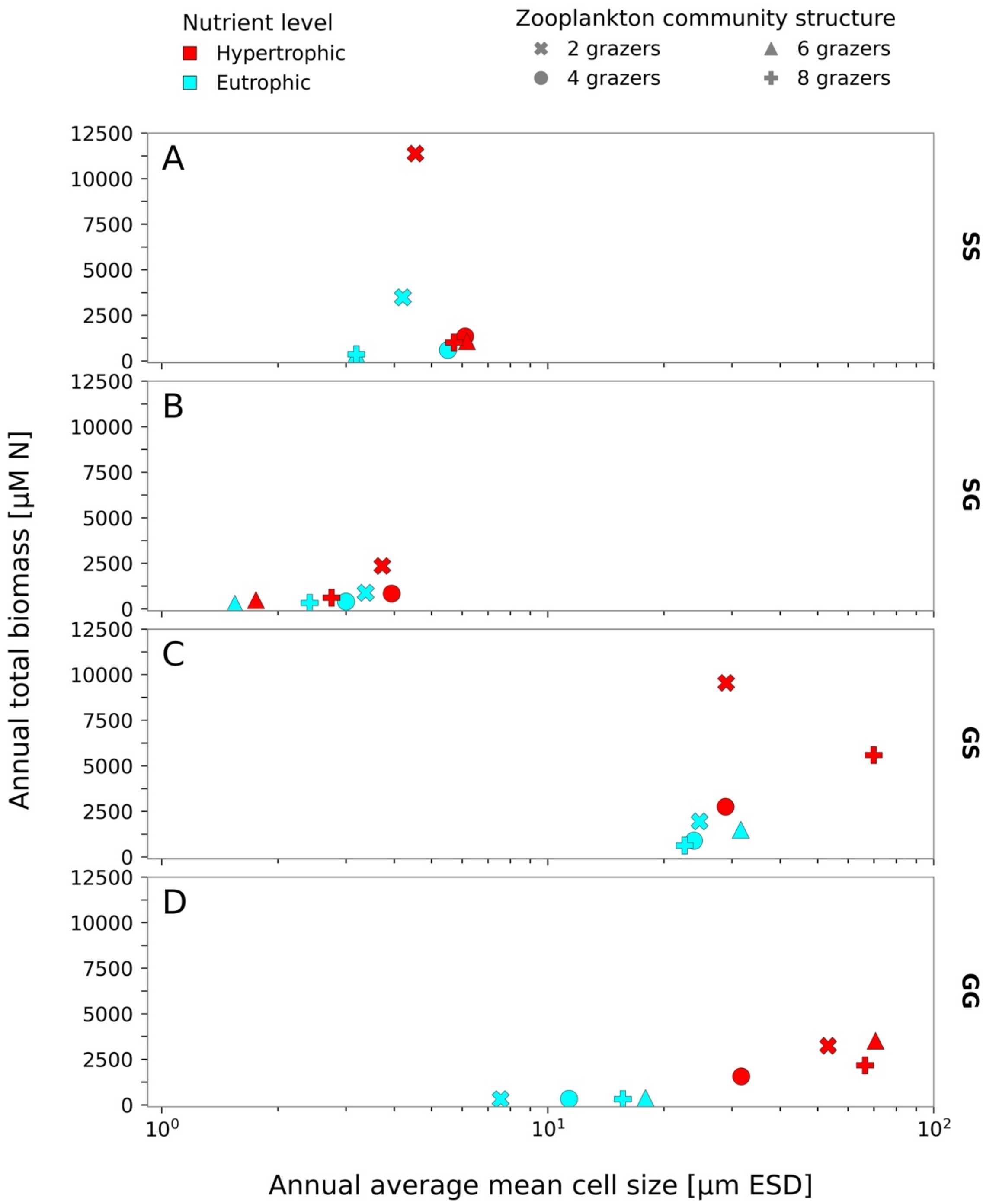
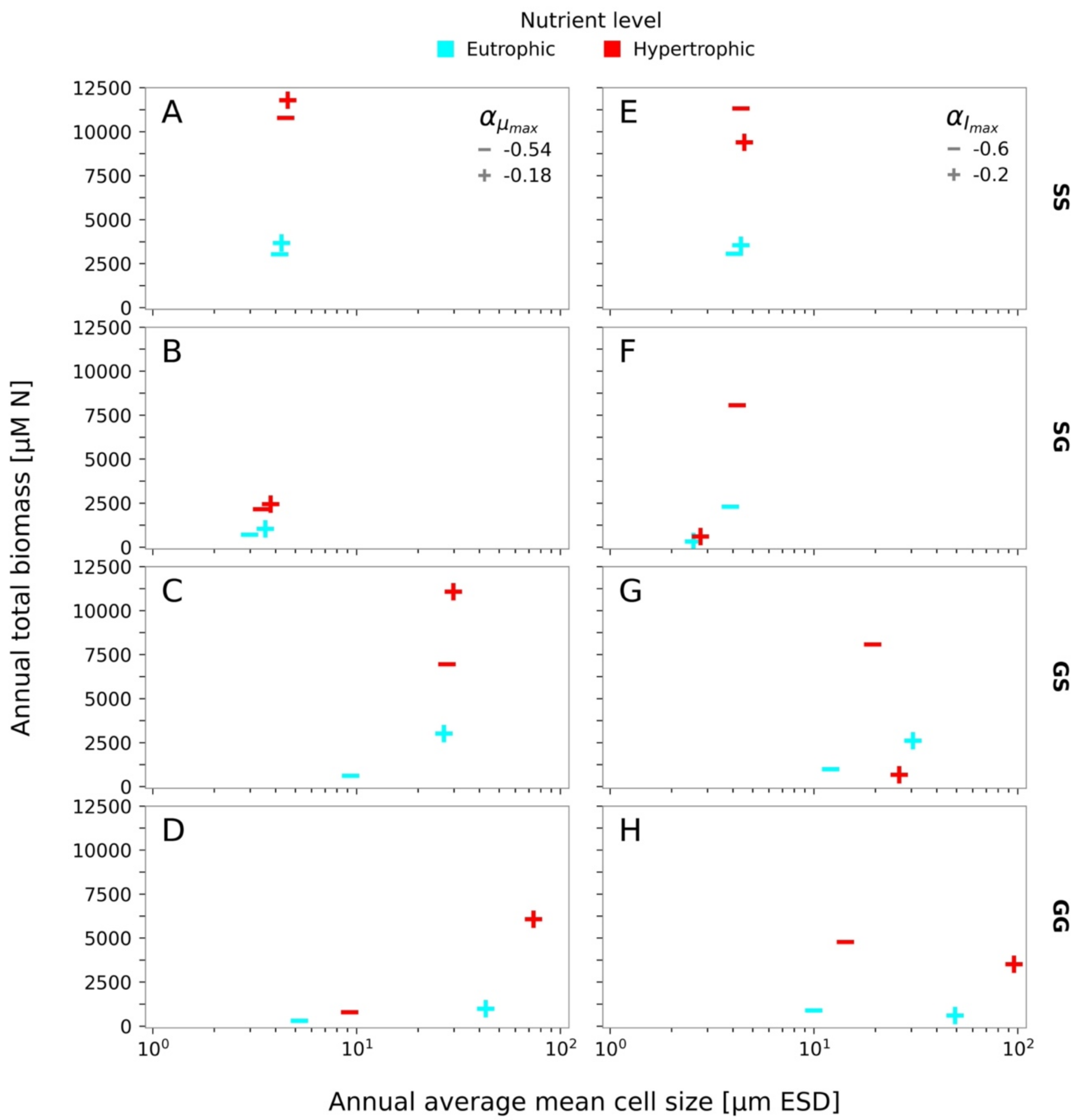


Figure S4. Annual biomass versus mean size under different grazing strategies and different nutrient conditions for different community structure of zooplankton (symbolizations). For these runs, the mixing frequency is fixed to medium.

96 *3.2 The results for sensitivity analyses varying allometric scaling*



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98 **Figure S5**. Annual biomass versus mean size for different (A-D) $\alpha_{\mu_{max}}$ and (E-H) $\alpha_{I_{max}}$ under different grazing
99 strategies and different nutrient conditions. For these runs, the mixing frequency is fixed to medium.

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Supplementary Table 1. Description of parameters used in the model along with corresponding symbols, values, units, and literature sources.

Symbol	Description	Value	Unit	Source
P_{max}	Maximum photosynthesis rate	1.1	d^{-1}	this study
α_{P_I}	Initial slope of the P-I curve	0.15	Ein m^{-2} d^{-1}	this study
K_{par}	Light attenuation coefficient	0.1	m^{-1}	Fasham et al. (1990)
ω	Cross-thermocline mixing coefficient	0.1	m d^{-1}	Fasham et al. (1990)
N_0	Scenarios of nutrient supplied from the bottom water layer	1, 15, 50	µM N	this study
ϕ_P	Natural mortality – phytoplankton	0.2	d^{-1}	this study
ϕ_Z	Natural mortality – zooplankton	0.1	d^{-1}	this study
η_Z	Higher-order mortality rate – zooplankton	0.34	d^{-1}	Oschlies & Schartau (2005)
ε	Sloppy feeding	0.69	-	Fasham et al. (1990)
γ	Assimilation efficiency	0.75	-	Oschlies & Schartau (2005)
φ	Remineralisation rate	0.6	d^{-1}	this study
K_p	Half-saturation constant – zooplankton	3	µM N	this study
θ_j	Prey size tolerance	0.2 (specialist) 0.5 (generalist)	µm ESD	Banas (2011), Hansen et al. (1994)

Symbol	Description	Value	Unit	Source
S_i	Cell sizes – phytoplankton	1-100	µm ESD	this study
S_{Z_j}	Body sizes – zooplankton	5 (Z_1) 200 (Z_2)	µm ESD	this study
$\beta_{\mu_{max}}$	Intercept of allometric relationship for μ_{max_i}	$10^{0.69}$	d^{-1}	Edwards et al. (2012)
$\alpha_{\mu_{max}}$	Exponent of allometric relationship for μ_{max_i}	-0.36	-	Edwards et al. (2012)
β_{K_N}	Intercept of allometric relationship for K_{N_i}	$10^{-0.71}$	µM N	Edwards et al. (2012)
α_{K_N}	Exponent of allometric relationship for K_{N_i}	0.52	-	Edwards et al. (2012)
$\beta_{I_{max}}$	Intercept of allometric relationship for I_{max_j}	26	d^{-1}	Hansen et al. (1997)
$\alpha_{I_{max}}$	Exponent of allometric relationship for I_{max_j}	-0.4	-	Hansen et al. (1997)
$\beta_{P_{opt}}$	Intercept of allometric relationship for P_{opt_j}	0.65	µm ESD	Hansen et al. (1997)
$\alpha_{P_{opt}}$	Exponent of allometric relationship for P_{opt_j}	0.56	-	Hansen et al. (1997)
N_0, P_0, Z_0, D_0	Initial conditions for all state variables	0.01	µM N	this study

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