Supplemental Material- The functions and parameter settings for the NPZD model

Phytoplankton

According to field observations, the predominant algae community in the Beibu Gulf is diatoms (Jiang et al., 2012; Lai and Qiu, 2005); thus, we adopt diatoms to represent phytoplankton in the model calculation. The growth, excretion, respiration, grazing, mortality and sinking activity control the phytoplankton biomass (mg·m^{-3}) changes:

$$\frac{\partial PHY}{\partial t} = \mu_P \mathrm{P} - v_{eP}P - v_{rP}P - \frac{P}{P+POM}\mu_Z Z - m_P P^2 - w_P\frac{\partial P}{\partial z} \tag{1}$$

The illumination, temperature, solar illumination, and nutrient concentrations affect the phytoplankton growth:

$$\mu_P = \mu_{Pmax} \cdot f(T) \cdot f(I) \cdot f(Q_N, Q_P) \tag{1-1}$$

$$f(T) = \left(\frac{T}{T_{opt}}\right)^{3.5} \cdot exp\left[1 - \left(\frac{T}{T_{opt}}\right)^{3.5}\right] \tag{1-2}$$

$$f(I) = \frac{I}{I_{opt}} \cdot \exp(1 - \frac{I}{I_{opt}}) \tag{1-3}$$

$$I_0(t) = \begin{cases} I_{max}\sin^3(\frac{t}{DL}\pi) & ,(0 \le t < DL) \\ 0, (DL \le t < 24) \end{cases} \tag{1-4}$$

$$I = par \cdot I_0 \cdot e^{-k_w z - \int_{-z}^{0}(k_{chl1}\mathrm{ch}l + k_{chl2}\mathrm{ch}l^{2/3})dz} \tag{1-5}$$

$$f\left(Q_{N,}Q_P\right) = \min\left(\frac{Q_N}{Q_N + P \cdot \alpha_{[N:C]_P}}, \frac{Q_P}{Q_P + P \cdot \alpha_{[P:C]_P}}\right) \tag{1-6}$$

Here, $f(T)$, $f(I)$, and $f\left(Q_{N,}Q_P\right)$ are restriction functions of the temperature, illumination and cellular nutrients of nitrogen and phosphorus.

The spectral range that the phytoplankton can utilize is from 350 to 700 μm, which is 43% of the total solar radiation (Baker and Frouin, 1987).

The cellular Chl-*a* controls the excretion rate of phytoplankton:

$$v_{eP} = k_{eP} \cdot e^{-0.00201\alpha_{[chla:C]\cdot P}} \cdot \mu_P \tag{1-7}$$

The phytoplankton respiration rate is controlled by the temperature:

$$v_{rP} = v_{rP0} \cdot e^{\beta_{rP}T} \tag{1-8}$$

The grazing rate is controlled by the phytoplankton concentration, temperature and grazing threshold:

$$\mu_Z = \mu_{Z0} e^{\beta_Z}\left[1 - e^{\lambda(\eta - P - POM)}\right] \tag{1-9}$$

The phytoplankton mortality rate is controlled by the phytoplankton concentration, and temperature:

$$m_P = m_{P0} \cdot e^{\beta_{mP}T} \tag{1-10}$$

Zooplankton

The growth, grazing, excretion, respiration, grazing, mortality and sinking activity control the zooplankton (mgC·m^{-3}) changes:

$$\begin{aligned}\frac{\partial ZOO}{\partial t} = \frac{P}{P+POM}\mu_Z Z + \frac{POM}{P+POM}\mu_Z Z - (1-\varepsilon)\mu_Z Z - v_{rZ} Z \\ - m_Z Z^2 + w_Z\end{aligned} \tag{2}$$

The concentration of zooplankton, temperature and grazing threshold affect the zooplankton grazing rate:

$$\mu_Z = \mu_{Z0} e^{\beta_Z}\left[1 - e^{\lambda(\eta - P - POM)}\right] \tag{2-1}$$

The temperature and energy consumption of grazing activity affect the zooplankton respiration rate:

$$v_{rZ=}v_{rZ0} + \zeta\mu_Z \tag{2-2}$$

The zooplankton mortality is controlled by the temperature:

$$m_Z = m_{Z0} \cdot e^{\beta_{mZ}T} \tag{2-3}$$

The zooplankton sinking activities can be calculated as:

$$Wz = \begin{cases} -w_{upZ} \cdot \sin\left[\dfrac{\pi}{1-DL} \cdot (t - DL)\right] \cdot \dfrac{\partial Z}{\partial z}, (DL \leq t < 24) \\ w_{downZ} \cdot \sin\left(\dfrac{\pi}{DL} \cdot t\right) \cdot \dfrac{\partial Z}{\partial z}, (0 \leq t < DL) \end{cases} \tag{2-4}$$

Dissolved inorganic nitrogen (DIN)

DIN consists of NH_4, NO_2 and NO_3.

NH_4 (mg·m^{-3}) changes are controlled by the phytoplankton uptake of NH_4, cellular nitrogen released by zooplankton respiration, cellular nitrogen released by the grazing process of zooplankton, cellular nitrogen released by dead phytoplankton, nitrogen released by phytoplankton respiration, nitrogen generated by the oxidative decomposition of particulate organic matter (POM), nitrogen generated by the oxidative decomposition of dissolved organic matter (DOM), NH_4 nitrification and

NH_4 released by sediment dissolution:

$$\frac{\partial NH_4}{\partial t} = -B_{NH_4} + \alpha_{[N:C]_Z} v_{rZ} Z + \alpha_{[N:C]_P} \frac{P}{P+POM} \mu_Z Z \frac{Q_N}{P} + \alpha_{[N:C]_P} m_P P^2 \frac{Q_N}{P} + \alpha_{[N:C]_P} v_{rP} P + \alpha_{[N:C]_{POM}} v_{POM} POM + \alpha_{[N:C]_{DOM}} v_{DOM} DOM - v_{NH_4} NH_4 + \frac{v_{sNH_4}}{h} \tag{3-1}$$

The NH_4 nitration rate and sediment dissolution rate are:

$$v_{NH_4} = v_{NH_4 0} \cdot e^{\beta_{NH_4} T} \cdot \frac{DO}{DO_{NH_4} + DO} \tag{3-1-1}$$

$$v_{sNH_4} = v_{sNH_4 0} \cdot e^{\beta_{sNH_4} T - \gamma_{sNH_4} DO} \tag{3-1-2}$$

The change of NO_2 (mg·m^{-3}) is controlled by the NH_4 nitration and NO_2 nitration:

$$\frac{\partial NO_2}{\partial t} = v_{NH_4} NH_4 - v_{NO_2} NO_2 \tag{3-2}$$

The NO_2 nitration rate is:

$$v_{NO_2} = v_{NO_2 0} \cdot e^{\beta_{NO_2} T} \cdot \frac{DO}{DO_{NO_2} + DO} \tag{3-2-1}$$

The changes of NO_3 (mg·m^{-3}) are controlled by the NO_2 nitration and phytoplankton NO_3 uptake:

$$\frac{\partial NO_3}{\partial t} = v_{NO_2} NO_2 - B_{NO_3} \tag{3-3}$$

Dissolved inorganic phosphorus (DIP)

In our model, P contains only PO_4, so the term "DIP" is used to represent PO_4 in our model. DIP (mg·m^{-3}) changes are controlled by the phytoplankton uptake, cellular phosphorus released by zooplankton respiration, cellular phosphorus released by the grazing process of zooplankton, cellular phosphorus released by dead phytoplankton, phosphorus released by phytoplankton respiration, phosphorus generated by the oxidative decomposition of particulate organic matter (POM), phosphorus generated by the oxidative decomposition of dissolved organic matter (DOM) and DIP released by sediment dissolution:

$$\begin{aligned}\frac{\partial DIP}{\partial t} = {} & -B_{DIP} + \alpha_{[P:C]_Z} v_{rZ} Z + \alpha_{[P:C]_P} \frac{P}{P + POM} \mu_Z Z \frac{Q_P}{P} \\ & + \alpha_{[P:C]_P} m_P P^2 \frac{Q_P}{P} + \alpha_{[P:C]_P} v_{rP} P \\ & + \alpha_{[P:C]_{POM}} v_{POM} POM + \alpha_{[P:C]_{DOM}} v_{DOM} DOM \\ & + \frac{v_{sDIP}}{h}\end{aligned} \tag{4}$$

Cellular nitrogen

Cellular nitrogen is affected by the phytoplankton uptake of NH_4 and NO_3, DIN consumed by cells, cellular nitrogen released by the grazing process of zooplankton, cellular nitrogen released by dead phytoplankton and cellular nitrogen from the sinking activity of phytoplankton:

$$\begin{aligned}\frac{\partial Q_N}{\partial t} = {} & B_{NH_4} + B_{NO_3} - \alpha_{[N:C]_P} \mu_P P - \frac{P}{P + POM} \mu_Z \cdot \frac{Q_N}{P} \\ & - m_P P^2 \cdot \frac{Q_N}{P} - w_P \cdot \frac{\partial Q_N}{\partial z}\end{aligned} \tag{5}$$

Cellular phosphorus

The cellular phosphorus is affected by the phytoplankton uptake of DIP, DIP consumed by cells, cellular phosphorus released by the grazing process of zooplankton, cellular phosphorus released by dead phytoplankton and cellular phosphorus from the sinking activity of phytoplankton:

$$\begin{aligned}\frac{\partial Q_P}{\partial t} = {} & B_{DIP} - \alpha_{[P:C]_P} \mu_P P - \frac{P}{P + POM} \mu_Z \cdot \frac{Q_P}{P} - m_P P^2 \cdot \frac{Q_P}{P} \\ & - w_P \cdot \frac{\partial Q_P}{\partial z}\end{aligned} \tag{6}$$

Particulate organic matter (POM)

POM ($mg \cdot m^{-3}$) changes are controlled by the POM released by dead phytoplankton and zooplankton, POM excreted by zooplankton, POM released by the grazing process of zooplankton, oxidative decomposition of POM, POM dissolution process to produce dissolved organic matter (DOM), and sinking process of POM:

$$\begin{aligned}\frac{\partial POM}{\partial t} = {} & m_P P^2 + m_z Z^2 + (1 - \varepsilon_Z) \mu_z Z - \frac{P}{P + POM} \mu_Z Z \\ & - v_{POM} POM - k_{diss} v_{POM} POM \\ & - w_{POM} \frac{\partial POM}{\partial z}\end{aligned} \tag{7}$$

The POM oxidative decomposition rate is calculated by the function:

$$v_{POM} = v_{POM0} \cdot e^{\beta_{POM}T} \cdot \frac{DO}{DO_{POM} + DO} \tag{7-1}$$

Dissolved organic matter (DOM)

DOM (mg·m^{-3}) changes are controlled by the extracellular excretion of phytoplankton, POM dissolution process to produce DOM, oxidative decomposition of DOM and sediment dissolution of DOM:

$$\frac{\partial DOM}{\partial t} = v_{eP}P + k_{diss}v_{POM}POM + v_{DOM}DOM + \frac{v_{sDOM}}{h} \tag{8}$$

The DOM oxidative decomposition rate and sediment dissolution rate are calculated by the functions:

$$v_{DOM} = v_{DOM0} \cdot e^{\beta_{DOM}T} \cdot \frac{DO}{DO_{DOM} + DO} \tag{8-1}$$

$$v_{sDOM} = v_{sDOM0} \cdot e^{\beta_{sDOM}T - \gamma_{sDOM}DO} \tag{8-2}$$

Dissolved oxygen (DO)

The DO (mg·m^{-3}) changes are controlled by the oxygen produced by photosynthesis, oxygen consumed by phytoplankton and zooplankton respiration, oxygen consumed by the oxidative decomposition of POM and DOM, oxygen consumed by the nitrification of NH_4 and NO_2, oxygen consumed by sediment dissolution and oxygen generated by the exchange of DO across the sea surface and air:

$$\begin{aligned}\frac{\partial DO}{\partial t} = {} & \alpha_{[DO:C]_P}\mu_P P - \alpha_{[DO:C]_P}v_{rP}P - \alpha_{[DO:C]_Z}v_{rZ}Z \\ & - \alpha_{[DO:C]_{POM}}v_{POC}POM \\ & - \alpha_{[DO:C]_{DOM}}v_{DOM}DOM \\ & - \alpha_{[DO:C]_{NH_4}}v_{NH_4}NH_4 - \alpha_{[DO:C]_{NO_2}}v_{NO_2}NO_2 \\ & - \frac{v_{sDO}}{h} + K_{sa}(DO_s - DO)\end{aligned} \tag{9}$$

The sediment oxygen consumption rate is calculated by the function:

$$v_{sDO} = v_{sDO0} \cdot e^{\beta_{sDO}T} \tag{9-1}$$

The saturation of DO is calculated by the equation:

$$DO_s = exp\left\{-173.9894 + 255.5907 \cdot \frac{100}{T} + 146.4813 \cdot Ln\left(\frac{100}{T}\right) + (-22.2040) \cdot \frac{100}{T} + S \cdot \left[-0.0374 + 0.0165 \cdot \frac{100}{T} + (-0.0021) \cdot \left(\frac{100}{T}\right)^2\right]\right\} \cdot 0.0032 \tag{9-2}$$

Table S1. The value and meaning of ecological parameters

Parameter	Meaning	Value
μ_{Pmax}/day^{-1}	Maximum growth rate of phytoplankton	2.5
T_{opt}/°C	Optimum growth temperature of phytoplankton	27
I_{opt}/(W·m^{-2})	Optimum growth illumination of phytoplankton	72.638
I_{max}/(W·m^{-2})	Maximum shortwave illumination in summer	1000
	Maximum shortwave illumination in winter	650
	Maximum shortwave illumination in spring and autumn	850
DL/h	Daylight length in summer	14
	Daylight length in winter	10
	Daylight length in spring and autumn	12
par/%	Available shortwave radiation ratio of phytoplankton photosynthetic	43
k_w/m^{-1}	Illumination extinction coefficient in water	0.05
k_{chl1}/m^{-1}	Illumination extinction coefficient 1 generated by Chl-*a*	0.0088
k_{chl2}/m^{-1}	Illumination extinction coefficient 2 generated by Chl-*a*	0.054
k_{eP}	Phytoplankton extracellular excretion coefficient	0.01
$\alpha_{[chla:C]}$	Chl-*a*:C ratio in phytoplankton	0.020
v_{rP0}/day^{-1}	Phytoplankton respiration rate at 0 °C	0.02
β_{rP}/°C^{-1}	Temperature coefficient of phytoplankton respiration	0.052

μ_{Z0}/day^{-1}	Zooplankton grazing rate at 0 °C	0.14
β_{Z}/day^{-1}	Temperature coefficient of zooplankton grazing	0.0372
λ	Ivlev coefficient	0.01
η/(mgC·L^{-1})	Zooplankton grazing threshold	0
m_{P0}/day^{-1}	Phytoplankton mortality rate at 0 °C	0.0004
β_{mP}/°C^{-1}	Temperature coefficient of phytoplankton mortality	0
w_{P}/(m·day^{-1})	Phytoplankton sinking rate	0.173
ε/%	Zooplankton assimilation efficiency	70
v_{rZ0}/day^{-1}	Zooplankton respiration rate at 0 °C	0.06
ζ	Energy consumption coefficient of zooplankton grazing	0.3
m_{Z0}/day^{-1}	Zooplankton mortality rate at 0 °C	0.006
β_{mZ}/°C^{-1}	Temperature coefficient of zooplankton mortality	0.0
w_{up}/(m·day^{-1})	Floating speed of zooplankton at night	0.2
w_{down}/(m·day^{-1})	Sinking speed of zooplankton in daytime	0.2
$\alpha_{[N:C]P}$	N:C ratio in phytoplankton	0.144
μ_{maxN}/(mg·m^{-3}·s^{-1})	Maximum uptake rate of cellular nitrogen	1.0
k_{NH_4}/(mg·L^{-1})	Half-saturation constant of NH_4 uptake	50.0
k_{NO_3}/(mg·L^{-1})	Half-saturation constant of NO_2 uptake	50.0
ψ	Inhibition coefficient of NH_4 on NO_2 uptake	1.462
Q_{Nmax}	Upper limit of cellular nitrogen quota	8
$\alpha_{[P:C]P}$	P:C ratio in phytoplankton	0.024
μ_{maxP}/(mg·m^{-3}·s^{-1})	Maximum uptake rate of cellular phosphorus	1.0

k_{DIP}/(mg·L^{-1})	Half-saturation constant of DIP uptake	10.0
Q_{Pmax}	Upper limit of cellular phosphorus quota	8
v_{POM0}/day^{-1}	POM oxidative decomposition rate of POM at 0 °C	0.005
β_{POM}/°C^{-1}	Temperature coefficient of POM oxidative decomposition	0.0693
DO_{POM}/(mg·L^{-1})	DO half-saturation constant for POM oxidative decomposition	1.0
k_{diss}/%	POM dissolving ratio	3
w_{POC}/(mg·day^{-1})	POM sinking rate	0.5
v_{DOM0}/day^{-1}	DOM oxidative decomposition rate of POM at 0 °C	0.0001
β_{DOM}/°C^{-1}	Temperature coefficient of DOM oxidative decomposition	0.0693
DO_{DOM}/(mg·L^{-1})	DO half-saturation constant for DOM oxidative decomposition DOM	1.0
v_{sDOM0}/ (mg·m^{-2}·day^{-1})	Sediment dissolving DOM rate at 0 °C	0.0001
β_{sDOM}/°C^{-1}	Temperature coefficient of sediment dissolving DOM	0.0693
γ_{sDOM}	Oxygen inhibition coefficient of sediment dissolving DOM	0
$\alpha_{[N:C]Z}$	N:C ratio in zooplankton	0.144
$\alpha_{[N:C]POM}$	N:C ratio in POM	0.144
$\alpha_{[N:C]DOM}$	N:C ratio in DOM	0.144
$v_{NH_4 0}$/day^{-1}	NH_4 nitrification rate at 0 °C	0.006
β_{NH_4}/°C^{-1}	Temperature coefficient of NH_4 nitrification	0.0693
DO_{NH_4}/(mg·L^{-1})	DO half-saturation constant for NH_4 nitrification	0.5

v_{sNH_40}/(mg·m^{-2}·day^{-1})	Sediment dissolving NH_4 rate at 0 °C	0.85
β_{sNH_4}/°C^{-1}	Temperature coefficient of sediment dissolving NH_4	0.0392
γ_{sNH_4}	Oxygen inhibition coefficient of sediment dissolving NH_4	0
v_{NO_20}/day^{-1}	NO_2 nitrification rate at 0 °C	0.015
β_{NO_2}/°C^{-1}	Temperature coefficient of NO_2 nitrification	0.0693
DO_{NO_2}/(mg·L^{-1})	DO half-saturation constant for NO_2 nitrification	0.5
$\alpha_{[P:C]_Z}$	P:C ratio in zooplankton	0.024
$\alpha_{[P:C]_{POM}}$	P:C ratio in POM	0.024
$\alpha_{[P:C]_{DOM}}$	P:C ratio in DOM	0.024
v_{sDIP0}/(mg·m^{-2}·day^{-1})	Sediment dissolving DIP at 0 °C	0.015
β_{sDIP}/°C^{-1}	Temperature coefficient of sediment dissolving DIP	0.1353
γ_{sDIP}	Oxygen inhibition coefficient of sediment dissolving DIP	0
$\alpha_{[DO:C]_P}$	Oxygen generation or consumption rate of phytoplankton	0.00347
$\alpha_{[DO:C]_Z}$	Oxygen consumption rate of zooplankton	0.00282
$\alpha_{[DO:C]_{POM}}$	Oxygen consumption rate of POM decomposition	0.00331
$\alpha_{[DO:C]_{DOM}}$	Oxygen consumption rate of DOM mineralization	0.00282
$\alpha_{[DO:C]_{NH_4}}$	Oxygen consumption rate of NH_4 nitrification	0.048
$\alpha_{[DO:C]_{NO_2}}$	Oxygen consumption rate of NO_2 nitrification	0.016

v_{sDO0}/(mg·m^{-2}·day^{-1})	Oxygen consumption rate of sediment dissolving at 0 °C	40
β_{sDO0}/°C^{-1}	Temperature coefficient of oxygen consumption in sediment dissolving	0.0693
K_{sa}/s^{-1}	Sea surface reoxygenation rate	2.7

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