SP.1 Governing equations of the biogeochemical model

The biogeochemical model in this study was based on nitrogen (Fig. S1). Phosphate-related variables were calculated based on a Redfield ratio of 16:1. The governing equations of the biogeochemical model are as follows

$$\frac{\partial DIN}{\partial t} + adv(DIN) - diff(DIN)$$
$$= -Phytosynthsis + Respiration + Excretion + Mineralization$$

$$\frac{\partial PHY}{\partial t} + adv(PHY) - diff(PHY) + S_{PHY}\frac{\partial PHY}{\partial Z}$$
$$= Phytosynthsis - Respiration - Mortality\ of\ PHY - Grazing$$

$$\frac{\partial ZOO}{\partial t} + adv(ZOO) - diff(ZOO)$$
$$= Grazing - Mortality\ of\ ZOO - Egestion - Excretion$$

$$\frac{\partial PON}{\partial t} + adv(PON) - diff(PON) + S_{PON}\frac{\partial PON}{\partial Z}$$
$$= Motality\ of\ PHY + Mortality\ of\ ZOO + Egestion - Mineraliztion$$

$$\frac{\partial DIP}{\partial t} + adv(DIP) - diff(DIP)$$
$$= (-Phytosynthsis + Excretion + Mineralization + Respiration)/16$$

$$adv(\quad) = u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}$$

$$diff(\quad) = \frac{\partial}{\partial x}\left(K_h\frac{\partial}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h\frac{\partial}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v\frac{\partial}{\partial z}\right)$$

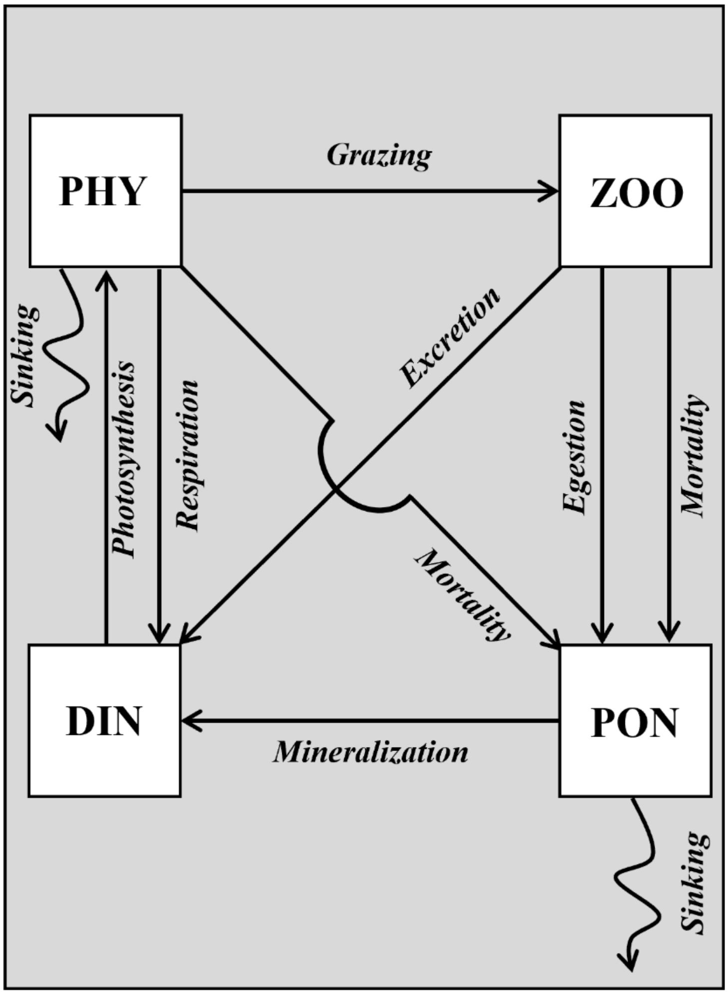

Figure S1. Sketch of the biogeochemical model.

SP.2 Parameterized formulas of the biogeochemical model

The parameterized formulas for each biogeochemical process are as follows, and the parameter values are shown in Table S2.

$$Photosynthesis = V_{max} \cdot min\left\{\frac{DIN}{DIN + K_{DIN}}, \frac{DIP}{DIP + K_{DIP}}\right\} \cdot \frac{I}{I_{opt}} exp^{\left(1-\frac{I}{I_{opt}}\right)} \cdot exp^{k_1 \cdot T} \cdot PHY$$

$$I(z) = I_o exp^{-\int_o^z \kappa(z)dz}$$

$$\kappa(z) = \kappa_1 + \kappa_2 PHY(z)$$

Where I_0 is the photosynthetically active solar radiation at the surface, which is 40% of the shortwave radiation at the surface. T is the water temperature.

$$Respiration = P_{resp} \cdot exp^{k_2 \cdot T} \cdot PHY$$

$$Mortality\ of\ PHY = P_{mor} \cdot exp^{k_3 \cdot T} \cdot PHY^2$$

$$Grazing = R_{max} \cdot \left[1 - exp^{\lambda(P_{lim} - PHY)}\right] \cdot exp^{k_4 \cdot T} \cdot ZOO$$

$$Mortality\ of\ ZOO = Z_{mor} \cdot exp^{\kappa_5 \cdot T} \cdot ZOO^2$$

$$Egestion = (1 - \alpha) \cdot R_{max} \cdot \left[1 - exp^{\lambda(P_{lim} - PHY)}\right] \cdot exp^{k_4 \cdot T} \cdot ZOO$$

$$Excretion = (\alpha - \beta) \cdot R_{max} \cdot \left[1 - exp^{\lambda(P_{lim} - PHY)}\right] \cdot exp^{k_4 \cdot T} \cdot ZOO$$

$$Decomposition = D_{deco} \cdot exp^{\kappa_6 \cdot T} \cdot PON$$

Table S1. Parameters for the biogeochemical model in this study

Symbol	Parameter	Value	Unit
V_{max}	Phytoplankton maximum photosynthesis rate at 0°C	0.8	day^{-1}
K_{DIN}	Phytoplankton half saturation for DIN	3	$mmol\ N\ m^{-3}$
K_{DIP}	Phytoplankton half saturation for DIP	0.12	$mmol\ P\ m^{-3}$
I_{opt}	Phytoplankton optimum light intensity	104.7	$W\ m^{-2}$
k_1	Phytoplankton temperature coefficient for photosynthesis	0.0693	$°C^{-1}$
κ_1	Light extinction coefficient of seawater	0.04	m^{-1}
κ_2	Self-shading coefficient of phytoplankton	0.04	$(mmol\ N\ m^{-3})^{-1}$
P_{resp}	Phytoplankton respiration rate at 0°C	0.03	day^{-1}
k_2	Phytoplankton temperature coefficient for respiration	0.0519	$°C^{-1}$
P_{mor}	Phytoplankton mortality rate at 0°C	0.05	day^{-1}
k_3	Phytoplankton temperature coefficient for mortality	0.0693	$°C^{-1}$
R_{max}	Zooplankton maximum grazing rate at 0°C	0.2	day^{-1}
λ	Zooplankton Ivlev constant	1.4	$(mmol\ N\ m^{-3})^{-1}$
P_{lim}	Zooplankton threshold value for grazing phytoplankton	0.043	$mmol\ N\ m^{-3}$
k_4	Zooplankton temperature coefficient for grazing	0.0693	$°C^{-1}$
Z_{mor}	Zooplankton mortality rate at 0°C	0.0585	$mmol\ N\ m^{-3}$
k_5	Zooplankton temperature coefficient for mortality	0.0693	$°C^{-1}$
α	Assimilation efficiency of zooplankton	0.7	No dim
β	Growth efficiency of zooplankton	0.3	No dim
D_{deco}	Decomposition rate at 0°C	0.05	$mmol\ N\ m^{-3}$
k_6	Detritus temperature coefficient for decomposition	0.0693	$°C^{-1}$
S_{PHY}	Sinking velocity of phytoplankton	1	$m\ day^{-1}$
S_{PON}	Sinking velocity of particulate organic nitrogen	0.1	$m\ day^{-1}$

SP.3 Annual mean discharge and DIN loading of each river

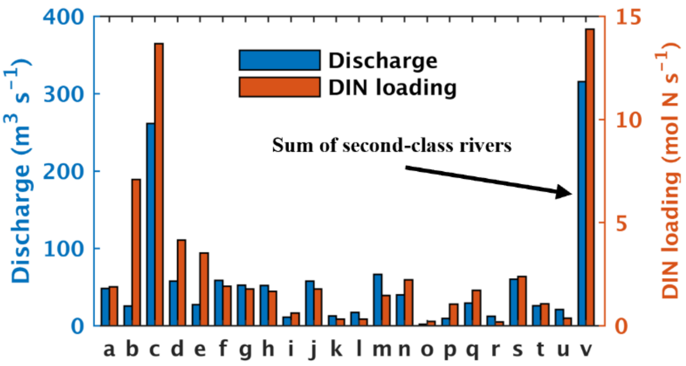

Figure S2. Annual mean river discharge (m^3s^{-1}) and DIN loading $(mol\ s^{-1})$. The letter a to u represents the first-class rivers, and the letter v represents the sum of second-class rivers.

Table S2. 21 first-class rivers in this model. The label is in Fig. 1b and Fig. 2a.

Label	River name
a	Kino River
b	Yamato River
c	Yodo River
d	Kako River
e	Ibo River
f	Yoshii River
g	Asahi River
h	Takahashi River
i	Ashida River
j	Oota River
k	Oze River
l	Saba River
m	Naka River
n	Yoshino River
o	Doki River
p	Shigenobu River
q	Hiji River
r	Bansho River
s	Oono River
t	Oita River
u	Yamakuni River

SP.4 DIN concentration at the open boundaries

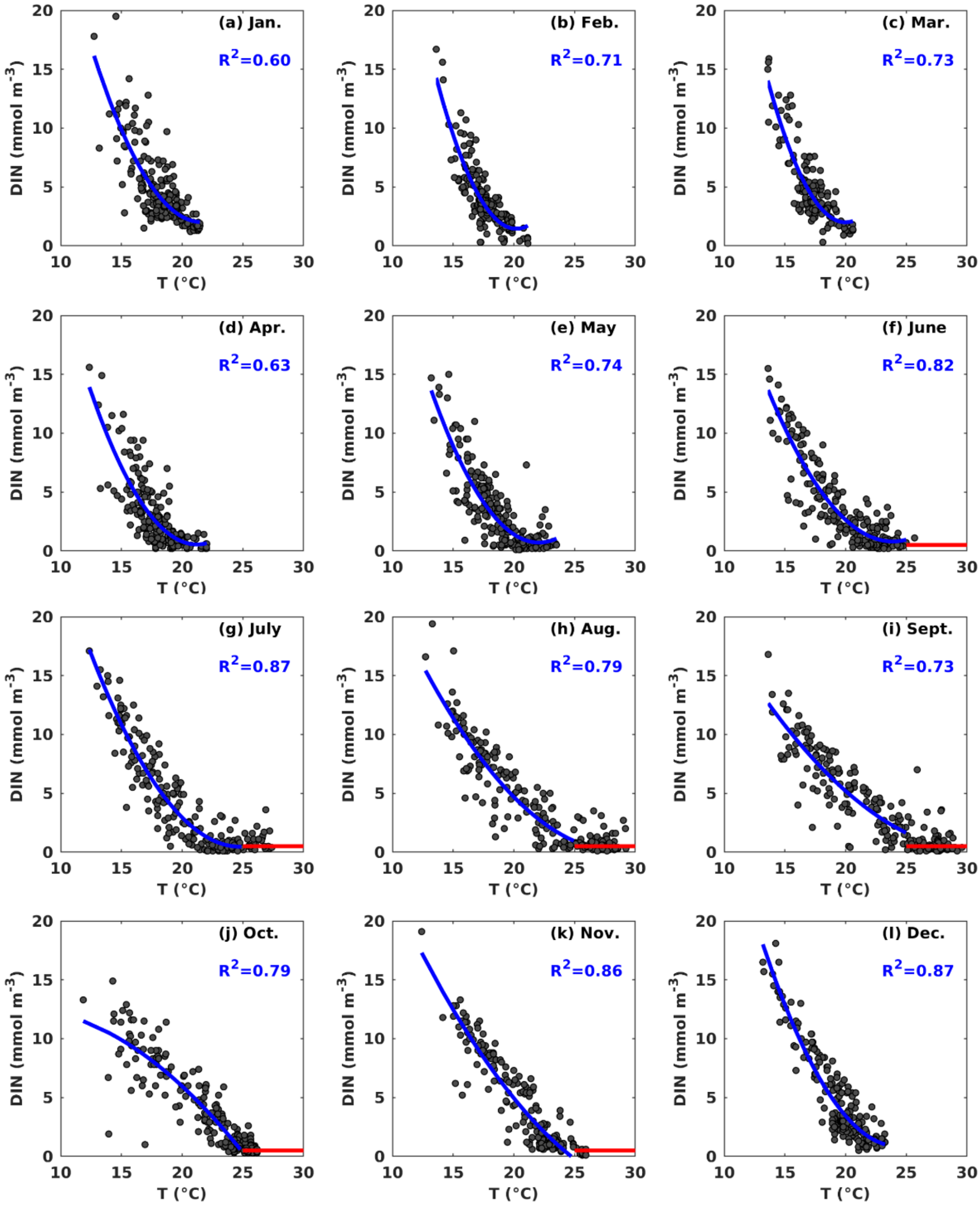

Figure S3. Relationship between water temperature (℃) and DIN concentration ($mmol\ m^{-3}$) at Bungo Channel from 1991 to 2005. Blue line in each figure represents regression line for T lower than 25 ℃ DIN concentration is equal to 0.5 $mmol\ m^{-3}$ for T larger than 25 ℃ from **(f)** June to **(k)** Nov. represented by the red line.

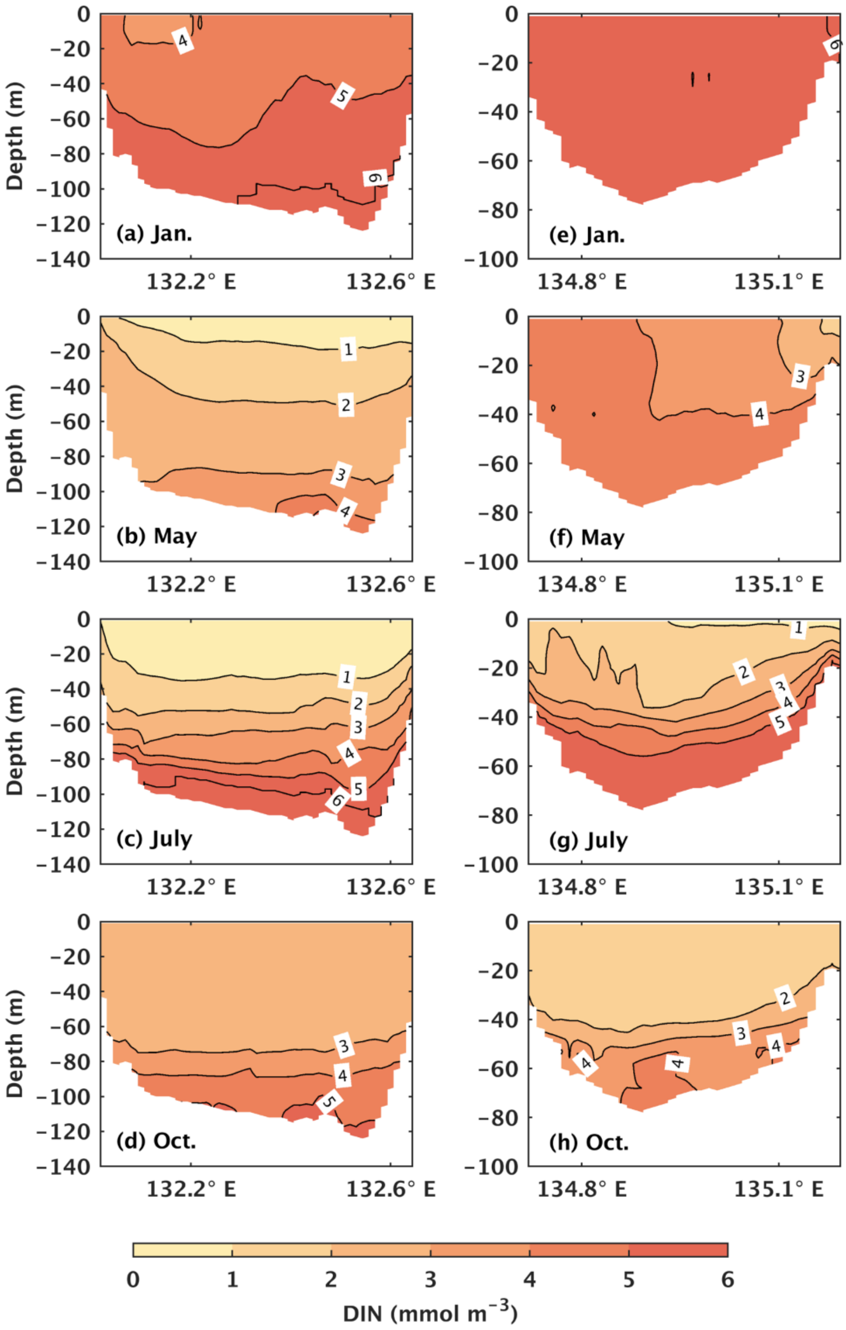

Figure S4. Vertical profiles of DIN concentration ($mmol\ m^{-3}$) at the open boundary between the Bungo Channel and the open ocean (**a to d**), and the open boundary between the Kii Channel and the open ocean (**e to h**).

SP.5 TN concentration at the surface of sediment

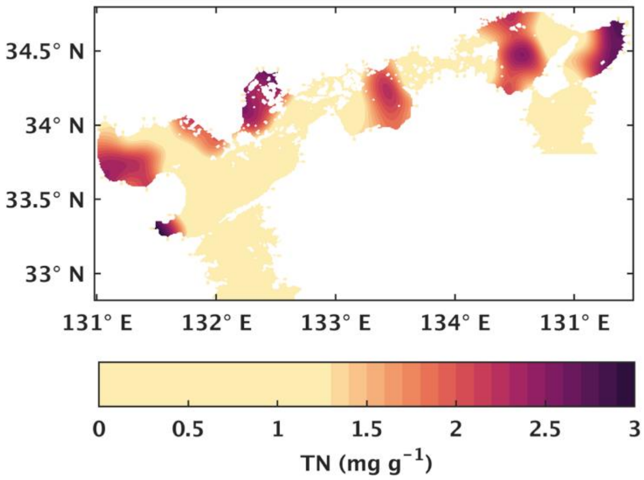

Figure S5. Annual mean TN concentration ($mg\ g^{-1}$) at the surface of the sediment.

SP.6 Governing equations of tracking technique

The governing equations of tracking open ocean are as follows

$$
\begin{aligned}
\frac{\partial DIN_{ocean}}{\partial t} + adv(DIN_{ocean}) - diff(DIN_{ocean}) \\
&= -Phytosynthsis \cdot \frac{DIN_{ocean}}{DIN} \\
&+ Respiration \cdot \frac{PHY_{ocean}}{PHY} \\
&+ Excretion \cdot \frac{ZOO_{ocean}}{ZOO} \\
&+ Mineralization \cdot \frac{PON_{ocean}}{PON}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial PHY_{ocean}}{\partial t} + adv(PHY_{ocean}) - diff(PHY_{ocean}) + S_{PHY}\frac{\partial PHY_{ocean}}{\partial z} \\
&= Phytosynthsis \cdot \frac{DIN_{ocean}}{DIN} \\
&- Respiration \cdot \frac{PHY_{ocean}}{PHY} \\
&- Mortality\ of\ PHY \cdot \frac{PHY_{ocean}}{PHY} \\
&- Grazing \cdot \frac{PHY_{ocean}}{PHY}
\end{aligned}
$$

$$\frac{\partial ZOO_{ocean}}{\partial t} + adv(ZOO_{ocean}) - diff(ZOO_{ocean})$$

$$= Grazing \cdot \frac{PHY_{ocean}}{PHY}$$

$$- Mortality\ of\ ZOO \cdot \frac{ZOO_{ocean}}{ZOO}$$

$$- Egestion \cdot \frac{ZOO_{ocean}}{ZOO}$$

$$- Excretion \cdot \frac{ZOO_{ocean}}{ZOO}$$

$$\frac{\partial PON_{ocean}}{\partial t} + adv(PON_{ocean}) - diff(PON_{ocean}) + S_{PON} \frac{\partial PON_{ocean}}{\partial z}$$

$$= Motality\ of\ PHY \cdot \frac{PHY_{ocean}}{PHY}$$

$$+ Mortality\ of\ ZOO \cdot \frac{ZOO_{ocean}}{ZOO}$$

$$+ Egestion \cdot \frac{ZOO_{ocean}}{ZOO}$$

$$- Mineraliztion \cdot \frac{PON_{ocean}}{PON}$$

$$adv(\quad) = u \frac{\partial}{\partial x} + v \frac{\partial}{\partial y} + w \frac{\partial}{\partial z}$$

$$diff(\quad) = \frac{\partial}{\partial x}\left(K_h \frac{\partial}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h \frac{\partial}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v \frac{\partial}{\partial z}\right)$$

The governing equations of tracking rivers are as follows

$$\frac{\partial DIN_{river}}{\partial t} + adv(DIN_{river}) - diff(DIN_{river})$$

$$= -Phytosynthsis \cdot \frac{DIN_{river}}{DIN}$$

$$+ Respiration \cdot \frac{PHY_{river}}{PHY}$$

$$+ Excretion \cdot \frac{ZOO_{river}}{ZOO}$$

$$+ Mineralization \cdot \frac{PON_{river}}{PON}$$

$$\begin{aligned}
&\frac{\partial PHY_{river}}{\partial t} + adv(PHY_{river}) - diff(PHY_{river}) + S_{PHY}\frac{\partial PHY_{river}}{\partial z} \\
&\qquad = Phytosynthsis \cdot \frac{DIN_{river}}{DIN} \\
&\qquad - Respiration \cdot \frac{PHY_{river}}{PHY} \\
&\qquad - Mortality\ of\ PHY \cdot \frac{PHY_{river}}{PHY} \\
&\qquad - Grazing \cdot \frac{PHY_{river}}{PHY}
\end{aligned}$$

$$\begin{aligned}
&\frac{\partial ZOO_{river}}{\partial t} + adv(ZOO_{river}) - diff(ZOO_{river}) \\
&\qquad = Grazing \cdot \frac{PHY_{river}}{PHY} \\
&\qquad - Mortality\ of\ ZOO \cdot \frac{ZOO_{river}}{ZOO} \\
&\qquad - Egestion \cdot \frac{ZOO_{river}}{ZOO} \\
&\qquad - Excretion \cdot \frac{ZOO_{river}}{ZOO}
\end{aligned}$$

$$\begin{aligned}
&\frac{\partial PON_{river}}{\partial t} + adv(PON_{river}) - diff(PON_{river}) + S_{PON}\frac{\partial PON_{river}}{\partial z} \\
&\qquad = Motality\ of\ PHY \cdot \frac{PHY_{river}}{PHY} \\
&\qquad + Mortality\ of\ ZOO \cdot \frac{ZOO_{river}}{ZOO} \\
&\qquad + Egestion \cdot \frac{ZOO_{river}}{ZOO} \\
&\qquad - Mineraliztion \cdot \frac{PON_{river}}{PON}
\end{aligned}$$

$$adv(\quad) = u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}$$

$$diff(\quad) = \frac{\partial}{\partial x}\left(K_h\frac{\partial}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h\frac{\partial}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v\frac{\partial}{\partial z}\right)$$

The governing equations of tracking sediment are as follows

$$\begin{aligned}
&\frac{\partial DIN_{sediment}}{\partial t} + adv(DIN_{sediment}) - diff(DIN_{sediment}) \\
&\qquad = -Phytosynthsis \cdot \frac{DIN_{sediment}}{DIN} \\
&\qquad + Respiration \cdot \frac{PHY_{sediment}}{PHY} \\
&\qquad + Excretion \cdot \frac{ZOO_{sediment}}{ZOO} \\
&\qquad + Mineralization \cdot \frac{PON_{sediment}}{PON}
\end{aligned}$$

$$\begin{aligned}
&\frac{\partial PHY_{sediment}}{\partial t} + adv(PHY_{sediment}) - diff(PHY_{sediment}) + S_{PHY} \frac{\partial PHY_{sediment}}{\partial z} \\
&\qquad = Phytosynthsis \cdot \frac{DIN_{sediment}}{DIN} \\
&\qquad - Respiration \cdot \frac{PHY_{sediment}}{PHY} \\
&\qquad - Mortality\ of\ PHY \cdot \frac{PHY_{sediment}}{PHY} \\
&\qquad - Grazing \cdot \frac{PHY_{sediment}}{PHY}
\end{aligned}$$

$$\begin{aligned}
&\frac{\partial ZOO_{sediment}}{\partial t} + adv(ZOO_{sediment}) - diff(ZOO_{sediment}) \\
&\qquad = Grazing \cdot \frac{PHY_{sediment}}{PHY} \\
&\qquad - Mortality\ of\ ZOO \cdot \frac{ZOO_{sediment}}{ZOO} \\
&\qquad - Egestion \cdot \frac{ZOO_{sediment}}{PHY} \\
&\qquad - Excretion \cdot \frac{ZOO_{sediment}}{PHY}
\end{aligned}$$

$$\begin{aligned}
&\frac{\partial PON_{sediment}}{\partial t} + adv(PON_{sediment}) - diff(PON_{sediment}) + S_{PON} \frac{\partial PON_{sediment}}{\partial z} \\
&\qquad = Motality\ of\ PHY \cdot \frac{PHY_{sediment}}{PHY} \\
&\qquad + Mortality\ of\ ZOO \cdot \frac{ZOO_{sediment}}{ZOO} \\
&\qquad + Egestion \cdot \frac{ZOO_{sediment}}{ZOO} \\
&\qquad - Mineraliztion \cdot \frac{PON_{sediment}}{PON}
\end{aligned}$$

$$adv(\quad) = u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}$$

$$diff(\quad) = \frac{\partial}{\partial x}\left(K_h \frac{\partial}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h \frac{\partial}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v \frac{\partial}{\partial z}\right)$$

SP.7 Oceanic DIN flux at the open boundaries

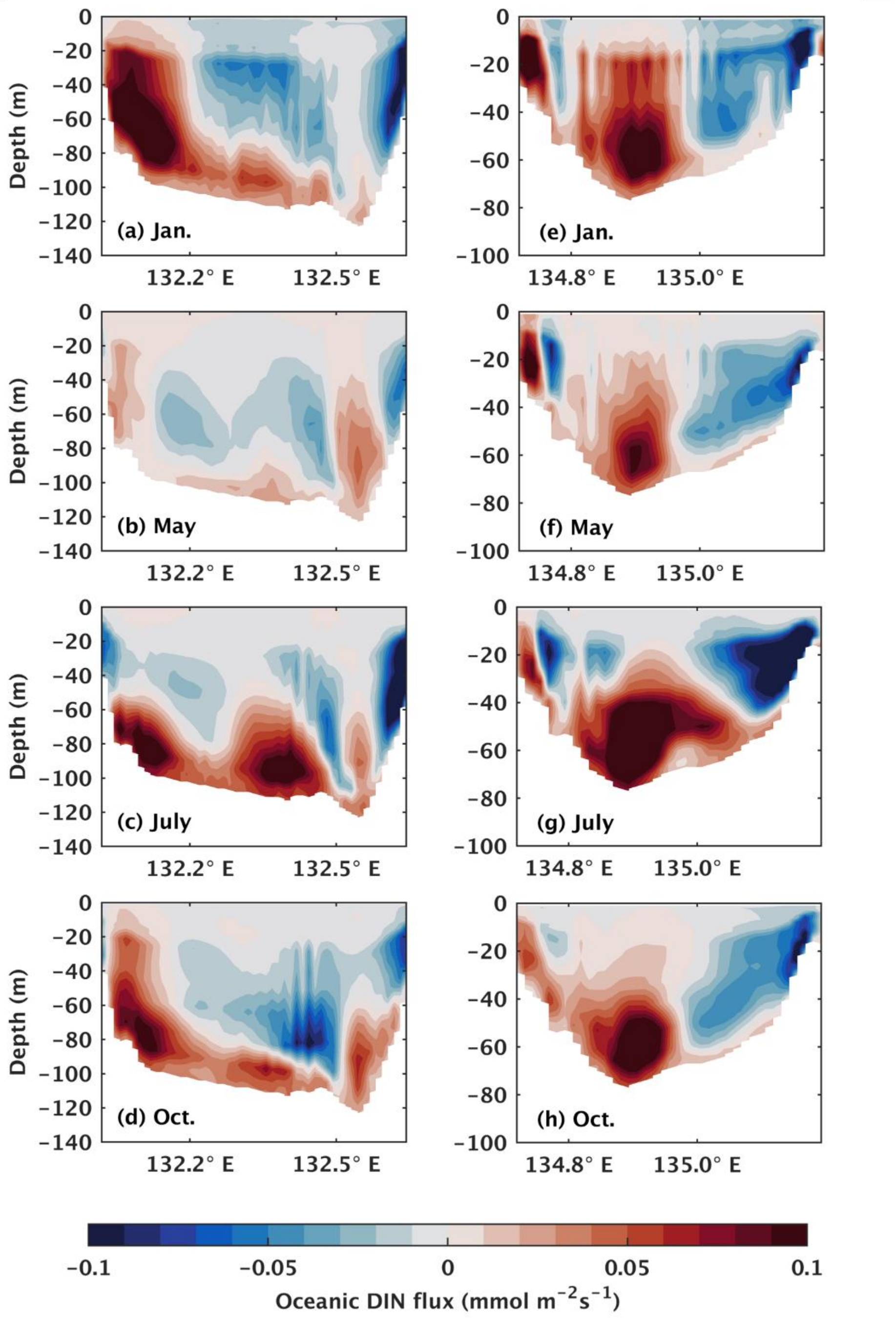

Figure S6. Monthly mean of oceanic DIN flux ($mmol\ m^{-2}s^{-1}$) at the open boundary between the Bungo Channel and the open ocean **(a-d)** and at the open boundary between the Kii Channel and the open ocean **(e-h)**. The red colors represent the oceanic DIN transported from the open ocean into the Seto Inland Sea, and the blue colors represent the oceanic DIN transported from the Seto Inland Sea into the open ocean.