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Supplement of

Modelling the impacts of marine heatwaves on plankton in the Salish Sea

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Phototrophic Growth Rate Equations

Phytoplankton (diatom and nanoflagellate) growth in SalishSeaCast model may be limited by temperature, light, or nutrients (nitrate, silicon, or ammonium). The phototrophic growth rate equations (1-9), first described in Olson et al., (2020) and Suchy et al., (2025a), are modified for v202111 of the model and listed below. These equations can be used to calculate the extent to which each parameter is limiting to growth. Here, *DIAT* is diatoms, *FLAG* is nanoflagellates, C_i is the concentration of each phytoplankton group in mmol N m^{-3}, Θ is Conservative Temperature in degrees Celsius, *I* is photosynthetically active radiation (PAR) in units of $W\,m^{-2}$, $[NH_4]$ and $[NO_3]$ are the ammonium and nitrate concentrations, respectively, in mmol N m^{-3}, and [dSi] is the dissolved silicon concentration in mmol Si m^{-3} (see Olson et al., 2020 for details). Phototrophic growth parameters for diatoms and nanoflagellates for v202111 are provided in Supplemental Table S1.

$$r_i = \{\mu_i C_i, \quad i \in (DIAT, FLAG) \tag{1}$$

$$\mu_i = \mu^i_{max} f(\Theta) \hat{L}_i(I, [NH_4^+], [NO_3^-], [\mathrm{dSi}]) \tag{2}$$

where $f(\Theta)$ and $\hat{L}_i$ are defined as:

$$f(\Theta) = \exp\left[0.07(\Theta - 20°\mathrm{C})\right] \cdot \begin{cases} 1, & \Theta \le \Theta_{max} - \Theta_{range} \\ \frac{\Theta_{max} - \Theta}{\Theta_{range}}, & \Theta_{max} - \Theta_{range} < \Theta < \Theta_{max} \\ 0, & \Theta \ge \Theta_{max} \end{cases} \tag{3}$$

$$\hat{L}_i = \min\left(L_I^i, L_{Si}^i, L_N^i\right) \tag{4}$$

$$L_I^i = 1.06\exp\left(-\frac{I}{30I_{opt}^i}\right)\left[1 - \exp\left(-\frac{I}{0.33I_{opt}^i}\right)\right] \tag{5}$$

$$L_{Si}^i = \frac{[\mathrm{dSi}]}{k_{Si}^i + [\mathrm{dSi}]} \tag{6}$$

$$L_N^i = L_O^i + L_H^i \tag{7}$$

$$L_O^i = \frac{K^i[\mathrm{NO_3^-}]}{K_N^i + K^i[\mathrm{NO_3^-}] + [\mathrm{NH_4^+}]} \tag{8}$$

$$L_H^i = \frac{[\mathrm{NH_4^+}]}{K_N^i + K^i[\mathrm{NO_3^-}] + [\mathrm{NH_4^+}]} \tag{9}$$

Table S1. Parameter values for photosynthetic growth of diatoms (^{DIAT}) and nanoflagellates (^{FLAG}) in the SalishSeaCast model v202111. See Olson et al. (2020) for equations and definitions of parameters.

Parameter	Current Value	v201905 Value	Units
μ_{max}^{DIAT}	5.8e-05	5.45e-05	s^{-1}
μ_{max}^{FLAG}	1.8e-05	1.90e-05	s^{-1}
Θ_{max}^{DIAT}	26.0	26.0	°C
Θ_{max}^{FLAG}	31.0	31.0	°C
Θ_{range}^{DIAT}	14.0	14.0	°C
Θ_{range}^{FLAG}	13.0	13.0	°C
I_{opt}^{DIAT}	75.0	45.0	W m^{-2}
I_{opt}^{FLAG}	20.0	10.0	W m^{-2}
k_{Si}^{DIAT}	1.2	2.2	µM Si
k_{Si}^{FLAG}	0.0	0.0	µM Si
K^{DIAT}	1.0	1.0	
K^{FLAG}	0.3	0.2	
K_{N}^{DIAT}	2.0	2.0	µM N
K_{N}^{FLAG}	0.1	0.2	µM N
$a_{\mathrm{Si:N}}^{DIAT}$	1.8	1.8	µM Si (µM N)$^{-1}$
$a_{\mathrm{Si:N}}^{FLAG}$	0.0	0.0	µM Si (µM N)$^{-1}$

Table S2. Parameter values for grazing by the Z1 zooplankton class in the SalishSeaCast model v202111.

Parameter	Current Value	v201905 Value	Units
ν_{max}^{Z1}	2.289e-05	2.48e-05	s^{-1}
α^{Z1}	0.2	0.2	µM N
K^{Z1}	1.25	1.25	µM N
ρ_{DIAT}^{Z1}	0.26	0.27	
ρ_{FLAG}^{Z1}	0.3	0.295	
ρ_{PON}^{Z1}	0.09	0.09	
ρ_{Z1}^{Z1}	0.18	0.18	
α_{DIAT}^{Z1}	0.3	0.1	µM N
α_{FLAG}^{Z1}	0.1	0.05	µM N
α_{PON}^{Z1}	0.6	0.5	µM N
α_{Z1}^{Z1}	0.3	0.2	µM N
K_{DIAT}^{Z1}	1.0	1.0	µM N
K_{FLAG}^{Z1}	1.0	1.0	µM N
K_{PON}^{Z1}	2.0	2.0	µM N
K_{Z1}^{Z1}	0.5	0.5	µM N
ε^{Z1}	0.6	0.6	

Table S3. Parameter values for grazing by the Z2 zooplankton class in the SalishSeaCast model v202111.

Parameter	Current Value	v201905 Value	Units
ν_{max}^{Z2}	1.54e-05	1.37e-05	s^{-1}
α^{Z2}	0.5	0.2	μM N
K^{Z2}	1.0	1.0	μM N
ρ_{DIAT}^{Z2}	0.285	0.28	
ρ_{FLAG}^{Z2}	0.1	0.105	
ρ_{PON}^{Z2}	0.15	0.15	
ρ_{Z1}^{Z2}	0.285	0.28	
α_{DIAT}^{Z2}	0.0	0.0	μM N
α_{FLAG}^{Z2}	0.05	0.0	μM N
α_{PON}^{Z2}	0.0	0.0	μM N
α_{Z1}^{Z2}	0.5	0.2	μM N
K_{DIAT}^{Z2}	0.2	0.3	μM N
K_{FLAG}^{Z2}	0.4	0.4	μM N
K_{PON}^{Z2}	0.4	0.4	μM N
K_{Z1}^{Z2}	1.2	1.2	μM N
ε^{Z2}	0.0	0.0	

Table S4. Parameter values for the Z2 zooplankton class in the SalishSeaCast model v202111.

Parameter	Current Value	v201905 Value	Units
Υ_w	0.41	0.38	μM N
$[\Upsilon_1,\ \Upsilon_2,\ \Upsilon_3]$	[0.50, 0.57, 0.35]	[0.55, 0.55, 0.36]	μM N
$[\sigma_1,\ \sigma_2,\ \sigma_3]$	[35, 65, 44]	[40, 70, 43]	days
$[t_{01},\ t_{02},\ \mathrm{t}_{03}]$	[140, 208, 296]	[130, 206, 290]	year day

Table S5. Parameter values for mortality and excretion/egestion in the SalishSeaCast model v202111.

Parameter	Current Value	v201905 Value	Units
m_{DIAT}	0.0667e-05	0.060e-05	s^{-1}
m_{FLAG}	0.0489e-05	0.044e-05	s^{-1}
m_{Z1}	0.556e-06	0.5e-06	s^{-1}
m_{Z2}	0.0	0.0	s^{-1}
e_{Z1}	0.556e-07	5.0e-07	s^{-1}
e_{Z2}	0.0	0.0	s^{-1}

Table S6. Parameter values for remineralization in the SalishSeaCast model v202111.

Parameter	Current Value	v201905 Value	Units
$b_{\mathrm{NH}}^{\mathrm{NO}}$	4.44e-07	4.0e-07	s^{-1} (μM N)$^{-1}$
$b_{\mathrm{DON}}^{\mathrm{NH}}$	2.56e-07	2.3e-06	s^{-1}
$b_{\mathrm{PON}}^{\mathrm{NH}}$	2.56e-07	2.3e-06	s^{-1}
$b_{\mathrm{bsi}}^{\mathrm{dSi}}$	1.221e-06	1.1e-06	s^{-1}

Table S7. Parameter values for optical model in the SalishSeaCast model v202111.

Parameter	Current Value	v201905 Value	Units
γ	0.091	0.091	m^{-1}
β	0.0433	0.0433	m^{-1}
λ	0.445	0.445	m^{-1}
δ	2.56	2.56	m
$\alpha_{Chl:N}$	2.0	2.0	g Chl $(mol\ N)^{-1}$

Table S8. Parameter values for sinking and bottom boundary condition in the SalishSeaCast model v202111.

Parameter	Current Value	v201905 Value	Units
$\omega_{\mathrm{smin}}^{DIAT}$	5.8e-06 [0.5]	5.8e-06 [0.5]	m s^{-1} [m d^{-1}]
$\omega_{\mathrm{smax}}^{DIAT}$	1.4e-05 [1.2]	1.4e-05 [1.2]	m s^{-1} [m d^{-1}]
ω_s^{PON}	1.0e-04 [8.64]	1.0e-04 [8.64]	m s^{-1} [m d^{-1}]
ω_s^{bSi}	2.5e-04 [21.6]	2.8e-04 [24.2]	m s^{-1} [m d^{-1}]
α_s^{Si}	0.92	0.92	
α_s^{N}	0.45	0.45	

Table S9. Parameter values for detrital transfer coefficients, $X^{i}_{j\to k}$, in the SalishSeaCast model v202111.

	Current Value				v201905 Value			
$j \to k$	i=NH_4^+	i=DON	i=PON	i=bSi	i=NH_4^+	i=DON	i=PON	i=bSi
DIAT → *Z1*	0.05	0.47	0.47	1.0	0.05	0.47	0.47	1.0
FLAG → *Z1*	0.05	0.47	0.47	1.0	0.05	0.47	0.47	1.0
Z1 → *Z1*	0.05	0.47	0.47	-	0.05	0.47	0.47	-
PON → *Z1*	0.0	0.0	1.0	-	0.0	0.0	1.0	-
Z1 → *MORT*	0.05	0.47	0.47	-	0.05	0.47	0.47	-
Z1 → *EXCR*	0.25	0.25	0.5	-	0.25	0.25	0.5	-
DIAT → *Z2*	0.05	0.47	0.47	1.0	0.05	0.47	0.47	1.0
FLAG → *Z2*	0.05	0.47	0.47	1.0	0.05	0.47	0.47	1.0
Z1 → *Z2*	0.05	0.47	0.47	-	0.05	0.47	0.47	-
PON → *Z2*	0.0	0.0	1.0	-	0.0	0.0	1.0	-
Z2 → *MORT*	0.05	0.47	0.47	-	0.05	0.47	0.47	-
Z2 → *EXCR*	0.25	0.25	0.5	-	0.25	0.25	0.5	-

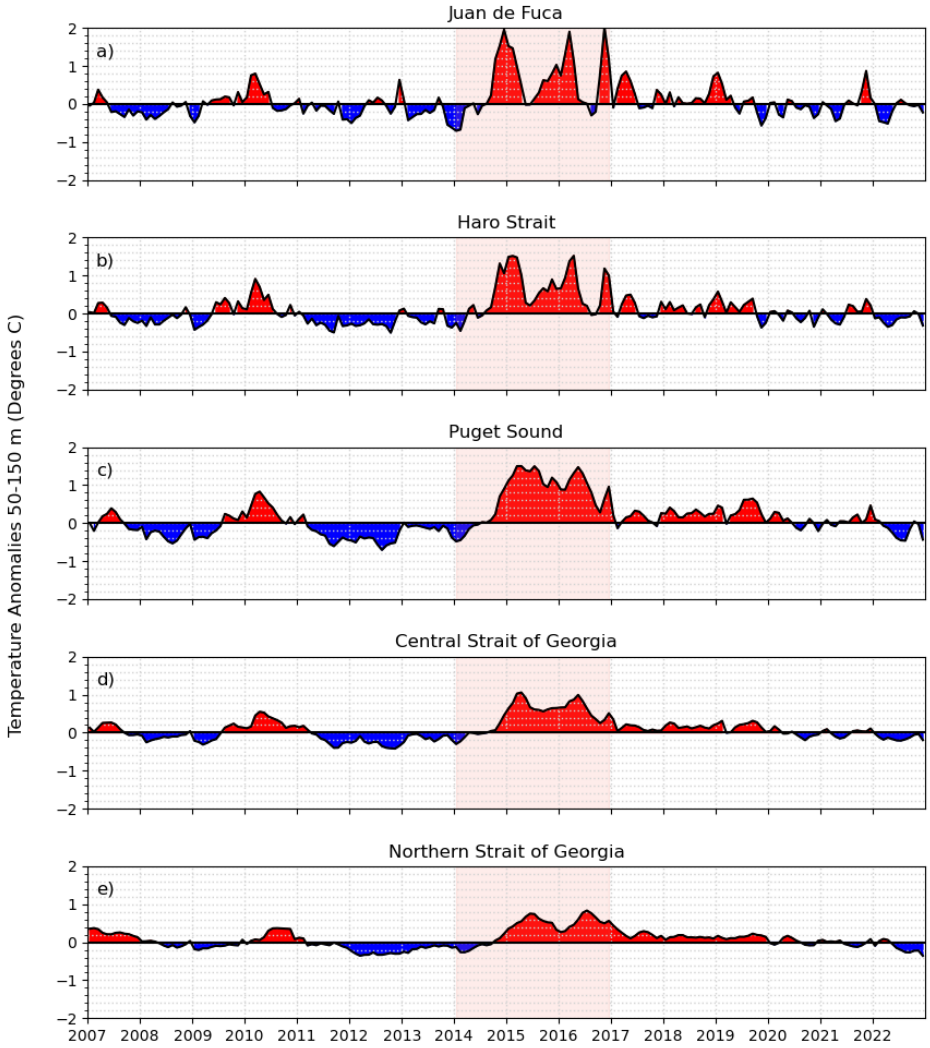

Figure S1. Mean model-based 50-150 m temperature anomalies in the different sub-regions of the Salish Sea from 2007 to 2022.

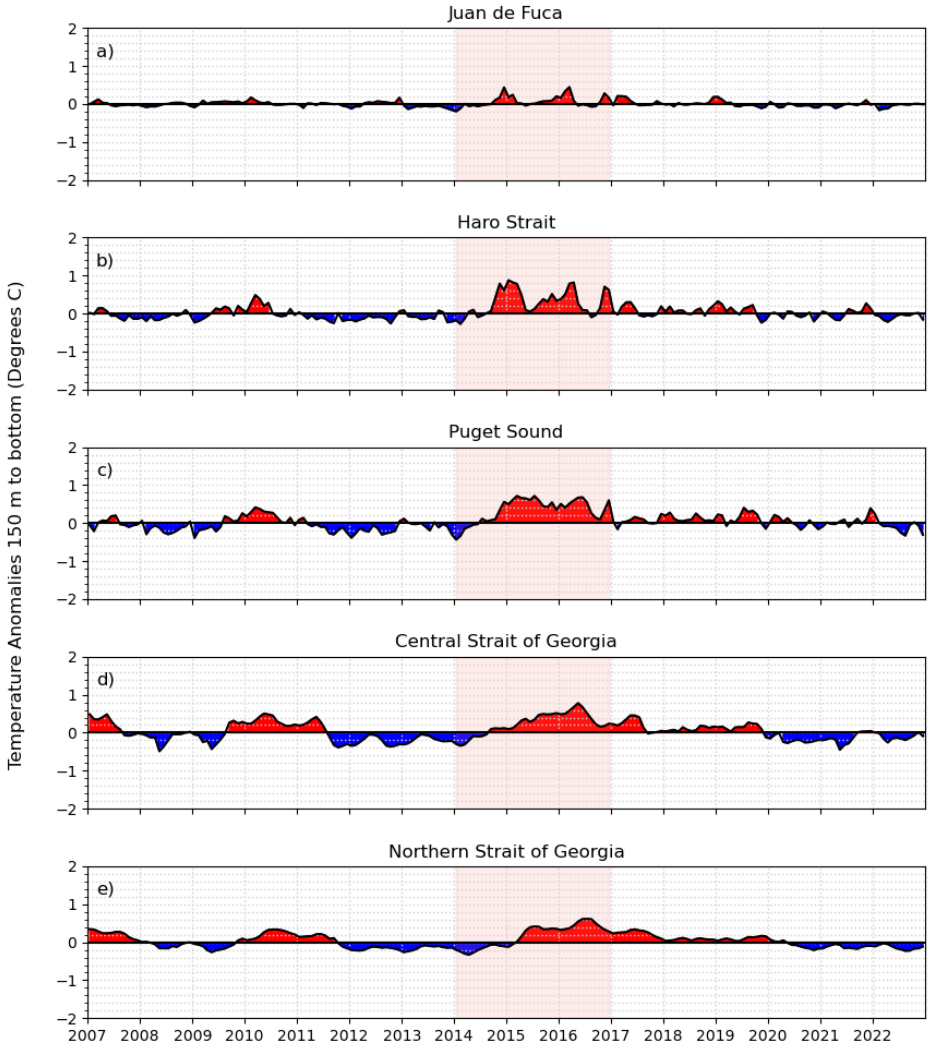

Figure S2. Mean model-based 150 m to bottom temperature anomalies in the different sub-regions of the Salish Sea from 2007 to 2022.

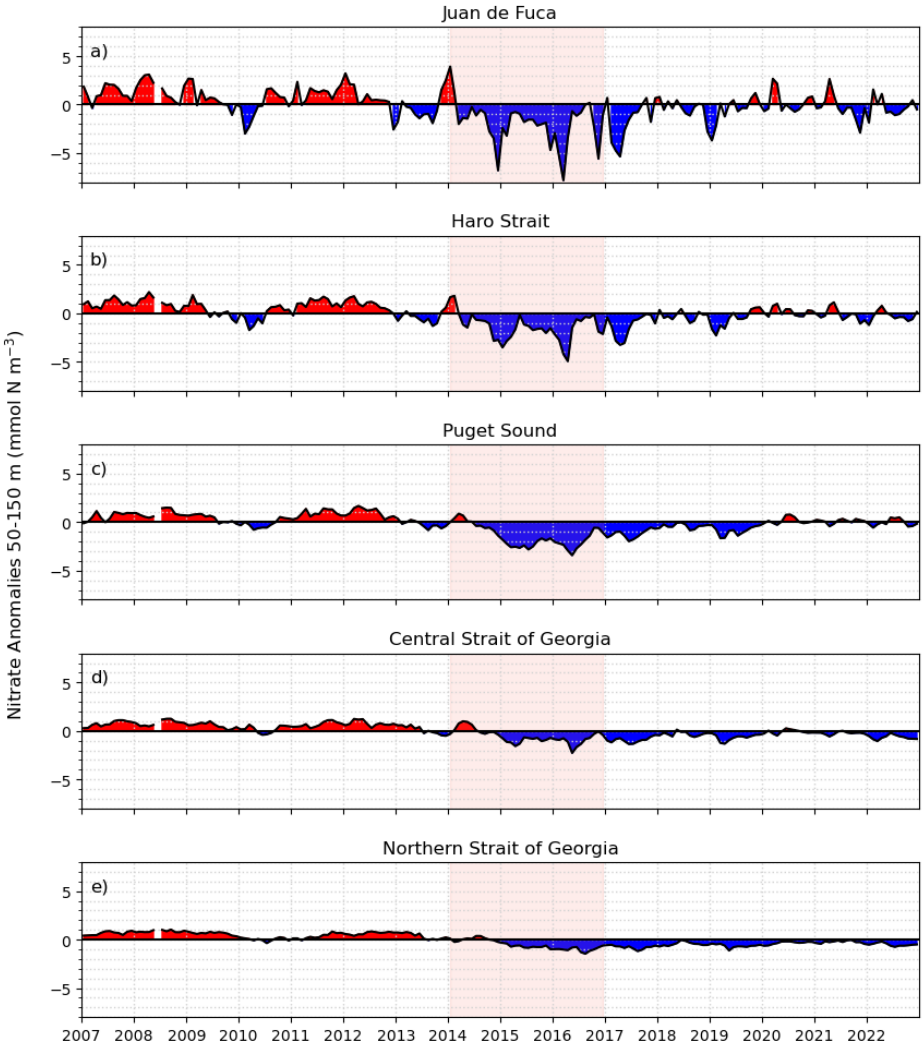

Figure S3. Mean model-based 50-150 m nitrate anomalies in the different sub-regions of the Salish Sea from 2007 to 2022.

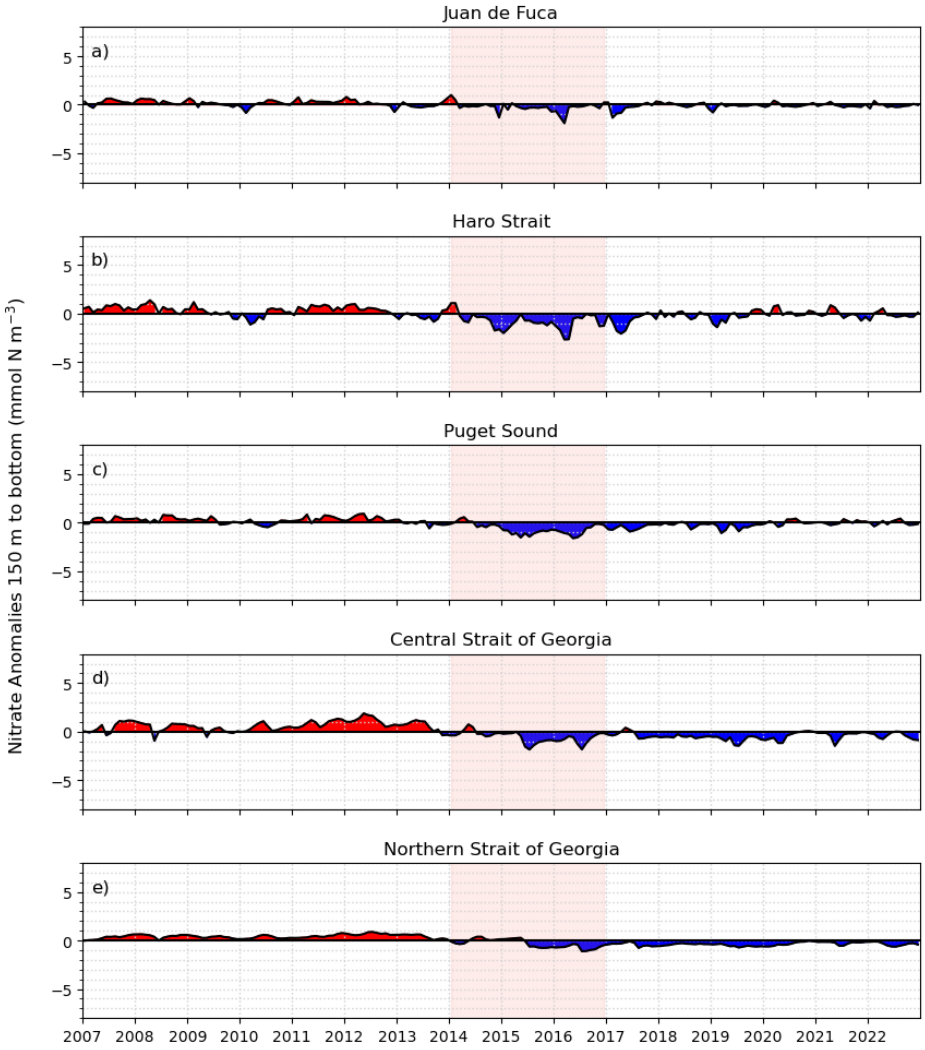

Figure S4. Mean model-based 150 m to bottom nitrate anomalies in the different sub-regions of the Salish Sea from 2007 to 2022.

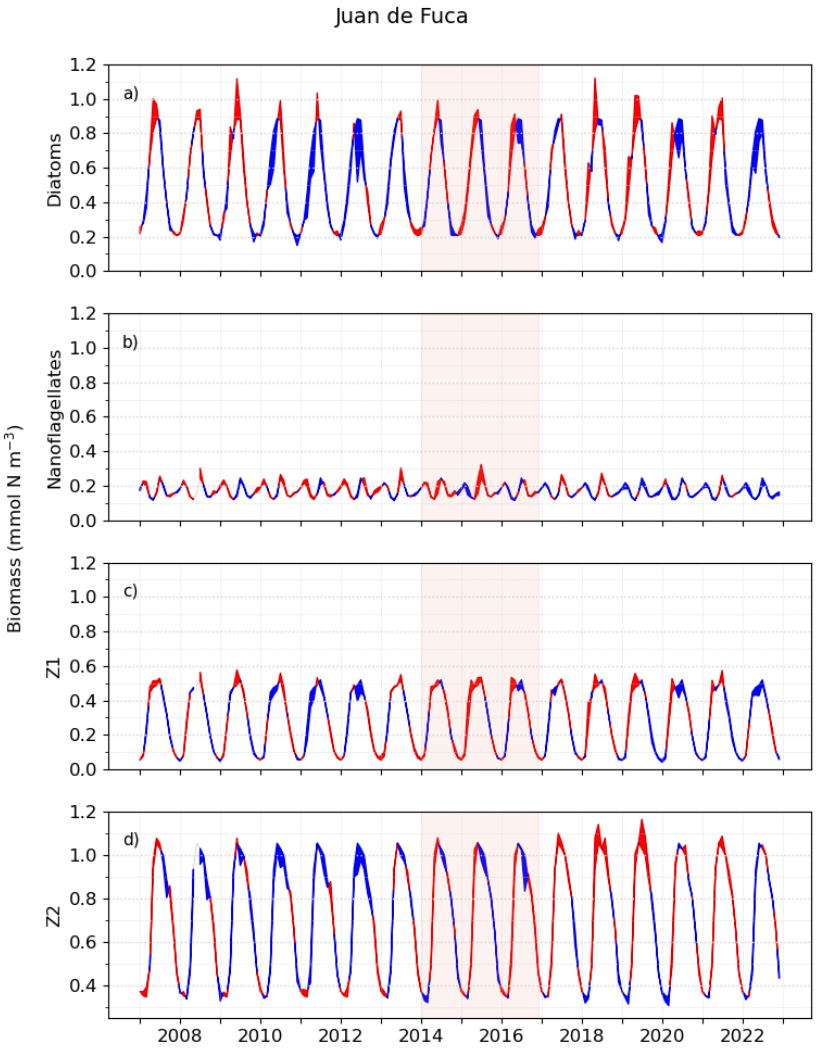

Figure S5. Monthly model-based 0-50 m biological parameters (diatoms, nanoflagellates, Z1, and Z2 zooplankton) compared to interannual mean in the Juan de Fuca region from 2007 to 2022. Positive differences are in red; negative differences in blue.

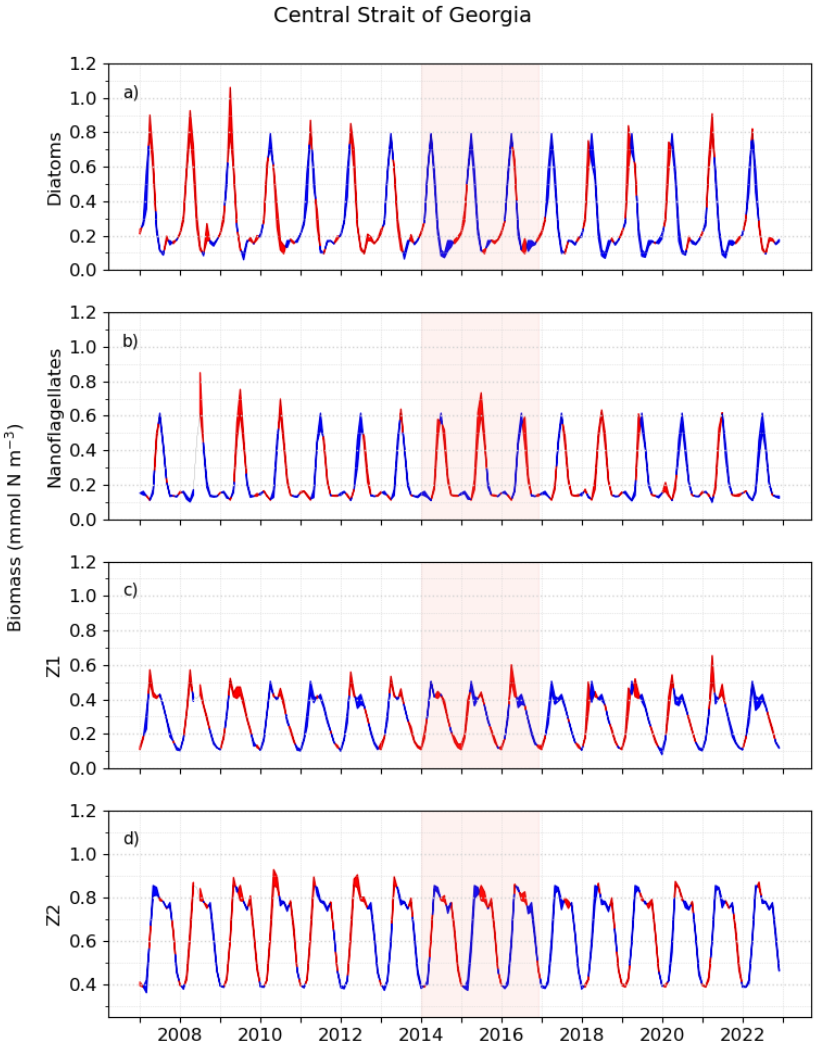

Figure S6. Monthly model-based 0-50 m biological parameters (diatoms, nanoflagellates, Z1, and Z2 zooplankton) compared to interannual mean in the Central Strait of Georgia region from 2007 to 2022. Positive differences are in red; negative differences in blue.

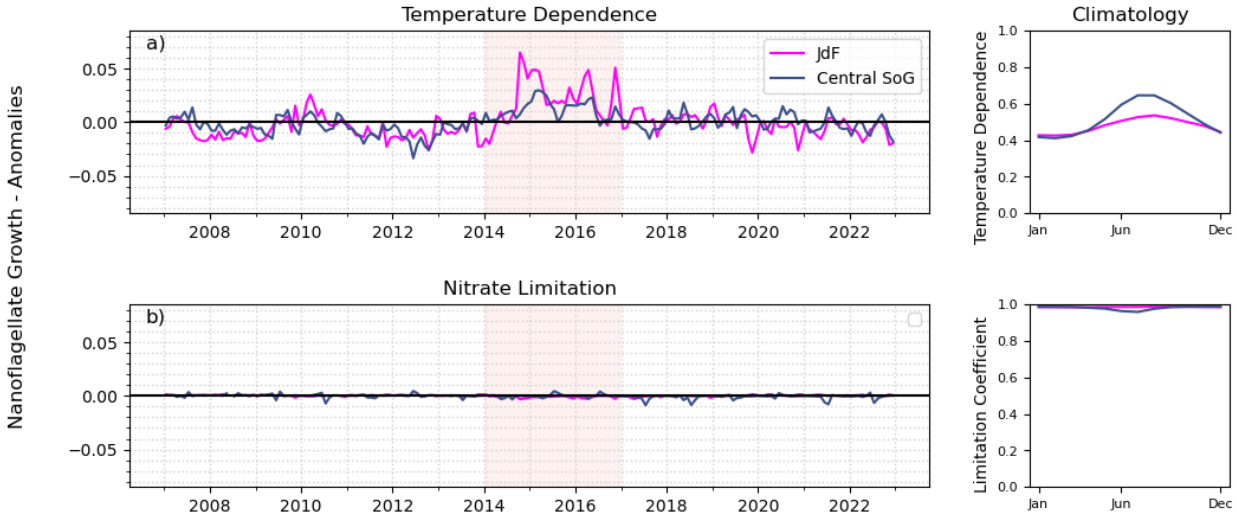

Figure S7. Left panels: anomalies in a) temperature dependence, and b) nitrate limitation on nanoflagellate growth in the 0-50 m depth layer compared to the 16-year climatology (2007-2022; right panels) in the Juan de Fuca and Central Strait of Georgia regions. Positive anomalies mean less limitation or temperature dependence compared to climatology; negative anomalies reflect more limitation or temperature dependence.

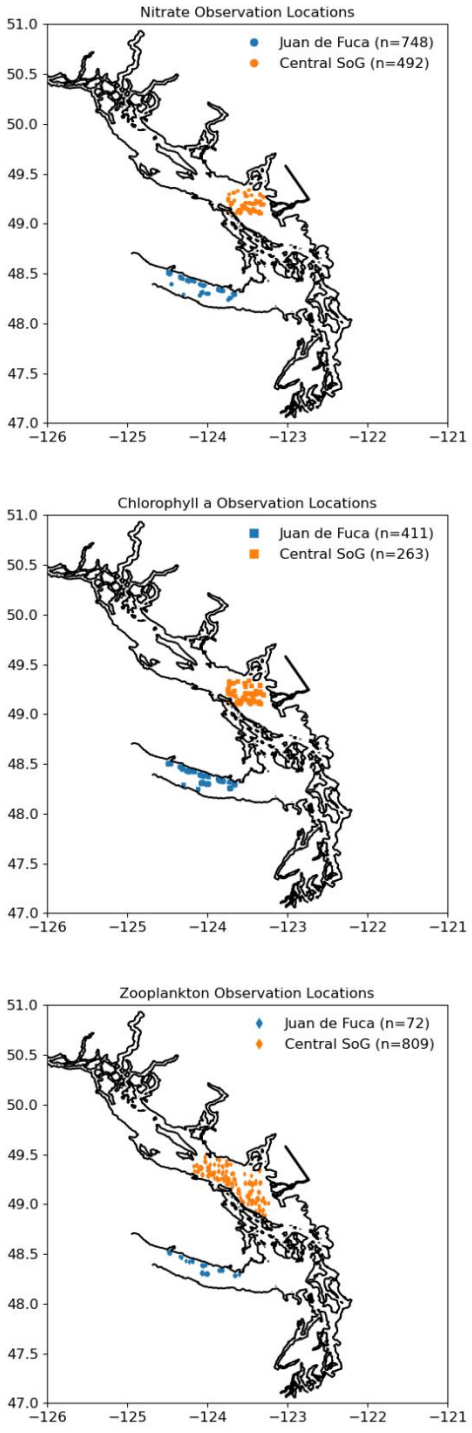

Figure S8. Observation sampling locations for nitrate, chlorophyll a, and zooplankton in the Juan de Fuca and Central Strait of Georgia regions for comparison with model output.