The following supplement accompanies the article

Amplification and attenuation of increased primary production in a marine food web

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Documentation of the mixed-layer model with water column ecosystem biological model

Kelly Kearney

This document has been adapted from Kearney (2012, Appendix A). An earlier description of the modeling framework was published in Kearney et al. (2012); since that time a few changes were made to the iron dynamics used in the model, and some parameterization improvements were implemented. We feel it is helpful to publish this description in a more easily-accessible location than Kearney (2012) (a Ph.D. thesis), since in addition to the minor changes just described it offers a more thorough listing of all parameters used for both the physical and food web portions of the model than was possible to include in the already-lengthy appendices to Kearney et al. (2012).

Please note that the food web parameters included in the tables of 2.4.2 make reference to 500 ensemble members. Those 500 ensemble members were generated for other experiments described in the thesis; only 50 of them were used in the study discussed in the article that accompanies this supplement.

1 The one-dimensional physical model

1.1 Description of equations

The physical model used in this study is a Matlab-based code designed to simulate a one-dimensional water column. The code is designed so that a variety of different biological models can be run within the same physical context.

The mixed-layer model simulates the evolution of water column properties under specified forcing by wind, heat, and salinity forcing. Allowance is also made for currents via a depth-independent pressure acceleration. There are six physical state variables in the physical model formulation: U and V are the east to west and south to north current velocities, and T and S are the temperature and salinity. The turbulence closure scheme introduces the remaining two state variables; : q^2 is a turbulent quantity equal to twice the turbulent kinetic energy, and ℓ is a turbulent length scale. These two state variables are used to calculate mixing-related parameters (K_M and K_V) in Eq. (1), Eq. (2), Eq. (3), and Eq. (4).

The momentum equations are standard one-dimensional formulations:

$$\frac{\partial U}{dt} - fV = -\frac{1}{\rho_0}\frac{\partial p}{\partial x} + \frac{\partial}{\partial z}K_M\frac{\partial U}{\partial z} - \epsilon U \tag{1}$$

$$\frac{\partial V}{dt} + fU = -\frac{1}{\rho_0}\frac{\partial p}{\partial y} + \frac{\partial}{\partial z}K_M\frac{\partial V}{\partial z} - \epsilon V \tag{2}$$

where f is the Coriolis parameter, ρ is the density, K_M is the viscosity, $\frac{\partial p}{\partial x}$ is a specified pressure gradient (to impose a mean current) and ϵ is a momentum dissipation term. The dissipation term serves as a surrogate for horizontal momentum divergence. It removes energy from past storm events over a specified time-scale as though energy was being transferred to more quiescent surrounding waters. Energy tends to accumulate unrealistically in one-dimensional water columns without this effect (Mellor, 2001). The value of ϵ was tuned such that the energy in the modeled currents is consistent with that observed. Values comparable to the time scales of storm events (0.33 d^{-1}) yielded reasonable results. The equations are solved using a semi-implicit Crank-Nicolson scheme.

The Mellor-Yamada turbulence closure scheme (Mellor & Yamada, 1982) is used to calculate mixing coefficients. The reader is referred to this reference and Mellor (2004) for the governing equations and other details of this formulation. A k-epsilon formulation (see review by Umlauf & Burchard (2005)) was also tested and yielded similar results to those presented herein. The top and bottom boundary conditions for Eq. (1) and Eq. (2) are provided by the wind stress formulation of Large & Pond (1981) and a quadratic bottom drag law, respectively. Mixing at the surface was augmented by the wave breaking scheme of Mellor & Blumberg (2004).

The temperature and salinity equations are given by:

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z} K_V \frac{\partial T}{\partial z} + ss \tag{3}$$

$$\frac{\partial S}{\partial t} = \frac{\partial}{\partial z} K_V \frac{\partial S}{\partial z} + ss \tag{4}$$

where K_V is the vertical turbulent diffusion coefficient, and ss is used to indicate sources minus sinks.

The salinity source minus sink term is derived via relaxation towards a depth- and time-resolved timeseries on a 7-day timescale, which allows salinity profiles to respond to storm events (2-3 days) but preserves the seasonal evolution of the salinity field. Observed winds are translated to surface wind stresses using the bulk formulae of Large & Pond (1981). Latent and sensible heat fluxes (source minus sink term for temperature) are calculated from the wind speed, air-sea temperature difference, and dew point temperature using the bulk formulae of Friehe & Schmitt (1976). Longwave radiation losses are calculated using the Efimova formula, per Simpson & Paulson (1979). We assume 45% of the incoming shortwave radiation is photosynthetically available, with a background attenuation of 0.15 m^{-1}; self-shading by phytoplankton is applied within the primary production calculations but does not feed back to the physical state variables. Mixing is calculated following the Mellor-Yamada 2.5 algorithm with a background diffusivity of 1.0×10^{-4} m^2s^{-1}, over a water column of 500 m depth with a vertical grid spacing of 10 m

Biological state variables are mixed, where applicable, following the same formulation as Eq. (3), with the source minus sink term representing any additional vertical movement; in the simulations described in this paper, this term was used to apply sinking velocities to the particulate state variables (PON, $Opal$, and $POFe$). The set of equations describing the remaining biological sources and sinks (Section 2) is solved following the mixing calculations at each time step.

1.2 Input variables and datasets for the Eastern Subarctic Gyre

Shortwave radiation, air temperature, and wind speeds were extracted from the Coordinated Ocean-ice Reference Experiments (CORE) normal-year datasets (Large & Yeager, 2009). The CORE datasets provide 6-hourly timeseries of various air-sea fluxes (Figure S1). Dew point temperature was derived from the same dataset. A climatological salinity cycle was derived from the GECCO model's 1950-2000 salinity product. The resulting timeseries was resolved monthly; the modeled salinity relaxation used bilinear interpolation to translate this timeseries to the higher-resolution model grid. Initial profiles for both salinity and temperature were set to the climatological January profiles, also derived from the GECCO product.

2

Process equations for the water column ecosystem model

The water column ecosystem model consists of 7 non-living state variables, and 3 classes of living state variables, coupled together by three sets of ordinary differential equations, one for each of the

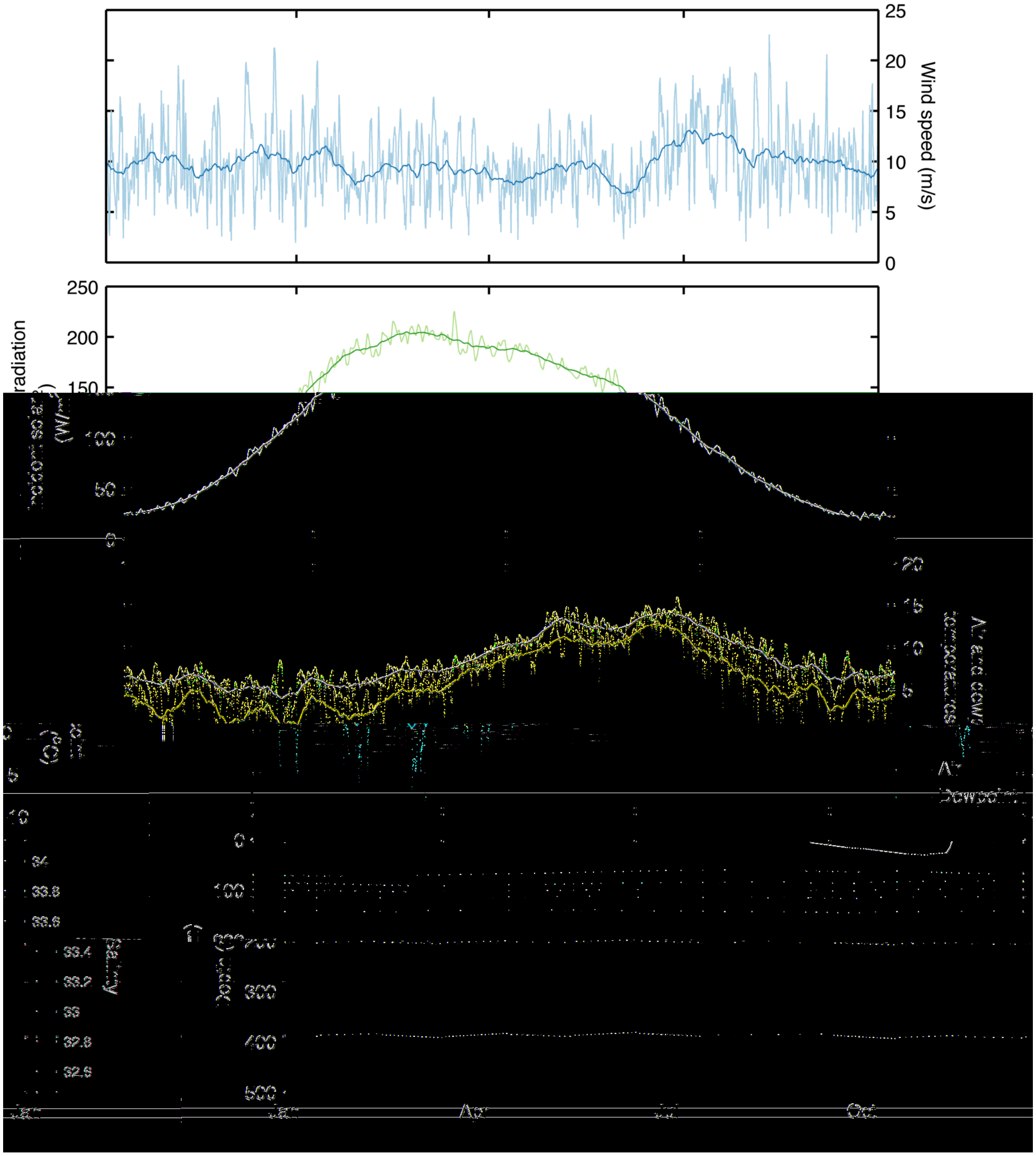

Figure S1: Climatological datasets used to force the physical model, including wind speed, solar radiation, air temperature, dewpoint temperature, and salinity. Light lines in the upper three panels show the high-resolution data used to force the model; dark lines show a weekly running average, and are provided only for visual clarity.

three nutrients included in the model. For simplicity, the following equations omit indicators of depth resolution, but unless otherwise indicated, all equations apply to a single model grid cell.

A note on subscripts, which are plentiful in this documentation: subscripts indicate the index of a functional group to which a given process variable or parameter pertains. I typically use i as this index, and expand to j and k when I need to represent more than one functional group in a single equation. Where variables are related to fluxes between groups, they are denoted by two subscripts (e.g. x_{ij}), with the source group index followed by the sink group index. For clarity I often separate multiple subscripts from each other with commas (e.g. x_{NH_4,NO_3} represents a parameter relating to a flux from the NH_4 state variable to the NO_3 variable); commas also separate parameter-name subscripts from functional group subscripts (e.g. $V_{max,PS}$ is the V_{max} growth rate parameter associated with the PS state variable).

The values of the various biological state variables are referred to as B_i in all the equations below; depending on the particular state variable, these can be thought of as either biomass values or nutrient concentrations. All phytoplankton groups are represented by three state variables: phytoplankton nitrogen (B_i), phytoplankton silica ($B_{Si,i}$), and phytoplankton iron ($B_{Fe,i}$), while zooplankton and nekton groups consist of only nitrogen state variables. The main ODEs are based on the combination of several processes:

- Gpp: gross primary production
- Res: respiration
- Ex: extracellular excretion
- Con (and $ConI$): consumption of prey
- Exc: excretion
- Ege: egestion
- Mor: non-predatory mortality
- Ufe: luxury iron uptake (old Fe model)
- Dec: decomposition
- Qup: uptake of iron (new Fe model)
- Ads: adsorption onto particles (new Fe model)

Further elaboration on these process variables is found in Section 2.1 and Section 2.2. Equations (5), (6), and (7) encompass those used in the originally-published version of this model (Kearney et al., 2012). In later versions of the model, as used in this study, modifications were made to the iron cycle; Eq. (8) describes the new dynamics, and the related process variables are described in Section 2.3.

$$\frac{d(B_i)}{dt} = \begin{cases} Gpp_i - Res_i - Ex_i - \sum_j Con_{ij} - Mor_i & i = \text{phytoplankton} \\ \sum_k Con_{ki} - Ege_i - Exc_i - \sum_j Con_{ij} - Mor_i & i = \text{zooplankton} \\ \sum_k ConI_{ki} - \int_0^{z_{max}} Ege_i - \int_0^{z_{max}} Exc_i - \sum_j ConI_{ij} - MorI_i & i = \text{nekton} \\ Dec_{NH_4,NO_3} + f\left(\sum_j Res_j - \sum_j Gpp_j\right) & i = \text{NO}_3 \\ Dec_{DON,NH_4} + Dec_{PON,NH_4} + \sum_i Exc_i - Dec_{NH_4,NO_3} + & \\ \quad (1-f)\left(\sum_j Res_j - \sum_j Gpp_j\right) & i = \text{NH}_4 \\ Dec_{PON,DON} + \sum_j Ex_j - Dec_{DON,NH_4} & i = \text{DON} \\ \sum_j Mor_j + \sum_j Ege_j - Dec_{PON,DON} - Dec_{PON,NH_4} & i = \text{PON} \end{cases} \tag{5}$$

$$\frac{d(B_{Si,i})}{dt} = \begin{cases} R_{Si:N} \cdot \Big(Gpp_i - Res_i - Ex_i - \sum_j Con_{ij} - Mor_i\Big) & i = \text{phytoplankton} \\ R_{Si:N} \cdot \Big(\sum_{j=\text{diatom}} Res_j + \sum_{j=\text{diatom}} Ex_j - \sum_{j=\text{diatom}} Gpp_j\Big) + & \\ \quad Dec_{Opal,SiOH_4} & i = \text{Si(OH)}_4 \\ R_{Si:N} \Big(\sum_{j=\text{diatom}} Mor_j + \sum_{j=\text{diatom}} \sum_k Con_{jk}\Big) - & \\ \quad Dec_{Opal,SiOH_4} & i = \text{Opal} \end{cases} \tag{6}$$

$$\frac{d(B_{Fe,i})}{dt} = \begin{cases} \frac{B_{Fe,i}}{B_i} \cdot \Big(Gpp_i - Res_i - Ex_i - \sum_j Con_{ij} - Mor_i\Big) + Ufe_i & i = \text{phytoplankton} \\ \sum_j \Big(f_{rem} \cdot \frac{B_{Fe,j}}{B_j} \cdot (Res_j + Ex_j + \sum_k Con_{jk} + Mor_j) - & \\ \quad \frac{B_{Fe,j}}{B_j} \cdot Gpp_j - Ufe_j\Big) & i = \text{Fe} \end{cases} \tag{7}$$

$$\frac{d(B_{Fe,i})}{dt} = \begin{cases} \frac{B_{Fe,i}}{B_i} \cdot \Big(-\sum_j Con_{ij} - Mor_i\Big) + Qup_i & i = \text{phytoplankton} \\ Dec_{POFe,Fe} + \sum_j \frac{B_{Fe,j}}{B_j} \sum_k Con_{jk} \cdot GE_k - \sum_j Qup_j - Ads & i = \text{Fe} \\ Ads + \frac{B_{Fe,j}}{B_j} \sum_j (\sum_k (Con_{jk} \cdot GS_k) + Mor_j) - Dec_{POFe,Fe} & i = \text{POFe} \end{cases} \tag{8}$$

These equations involve a large number of variables and parameters. For clarity and brevity, the parameters are not described within the text, but simply listed and defined in a series of tables at the end of this paper (Section 2.4.2). Table S13 through Table S20 include all parameters related to the biogeochemistry, most of which came from the NEMURO model. The following table, Table S21, defines variables that vary over time in the simulations; these variables are functions of the various state variables in the model. Finally, Table S22 through Table S26 provide parameters that are derived from the Ecopath algorithm.

2.1 Nitrogen flux equations for living state variables

2.1.1 Gross primary production (Gpp)

Gross primary production fluxes flow from the NO_3 and NH_4 variables to each phytoplankton group, following Kishi et al. (2007), with the addition of iron limitation following Fiechter et al. (2009). The uptake of nitrogen is described by:

$$Gpp_i = V_{max,i} \exp(K_{gpp,i}T) \cdot L_{nut,i} \cdot L_{light,i} \cdot B_i \tag{9}$$

where B_i is the nitrogen-based biomass of group i, resolved with depth.

2.1.2 Respiration (Res)

Respiration applies to all phytoplankton groups, and flows from the phytoplankton to the NO_3 and NH_4 groups following the same f-ratio as uptake via primary production:

$$Res_i = Res_{0i} \exp(K_{res,i}T) B_i \tag{10}$$

2.1.3 Extracellular excretion (Ex)

Extracellular excretion applies to all phytoplankton groups, and flows from the phytoplankton to the DON group. Following Kishi et al. (2007), extracellular excretion is proportional to the flux due to gross primary production:

$$Ex_i = \gamma_i \cdot Gpp_i \tag{11}$$

2.1.4 **Consumption (Con)**

Predator/prey interactions between functional groups follow the Aydin version of the foraging arena functional response. The exact form of the functional response varies based on whether the predator and prey groups are planktonic or nektonic. For interactions between two planktonic groups, the flux is resolved with depth for both the predator and prey group, and the uptake rates are temperature-dependent:

$$Con_{ij} = \frac{Q'_{ij}}{\exp(K_{Gra,i} \cdot T_{avg})} \exp(K_{Gra,i} \cdot T) \left(\frac{X_{ij} \cdot \frac{B_j}{B'_j}}{X_{ij} - 1 + \frac{B_j}{B'_j}} \right) \left(\frac{D_{ij} \cdot \left(\frac{B_i}{B'_i}\right)^{\theta_{ij}}}{D_{ij} - 1 + \left(\frac{B_i}{B'_i}\right)^{\theta_{ij}}} \right) \tag{12}$$

where here, the subscripts i and j represent the prey and predator groups, respectively. The biomass and consumption rate parameters are derived from the Ecopath mass balance: $Q' = \frac{Q^*}{MLD}$ and $B' = \frac{B^*}{MLD}$, where Q^* and B^* are the per-area mass-balanced quantities returned directly from Ecopath. The parameters MLD and T_{avg} describe the yearly averaged mixed layer depth and mixed layer temperature, respectively, as simulated by the one-dimensional physical model.

For interactions between two nektonic groups, the functional response follows the same form, but in units of biomass integrated over depth (for shorthand, $ConI$ is depth-integrated consumption, and $Bint$ is depth-integrated biomass). Nektonic consumption does not vary with temperature.

$$ConI_{ij} = Q^*_{ij} \left(\frac{X_{ij} \cdot \frac{Bint_j}{B^*_j}}{X_{ij} - 1 + \frac{Bint_j}{B^*_j}} \right) \left(\frac{D_{ij} \cdot \left(\frac{Bint_i}{B^*_i}\right)^{\theta_{ij}}}{D_{ij} - 1 + \left(\frac{Bint_i}{B^*_i}\right)^{\theta_{ij}}} \right) \tag{13}$$

When a nektonic group preys upon a planktonic group, the total flux is calculated in depth-integrated units. However, the loss on the plankton side is resolved with depth and distributed proportionally to the prey biomass at each depth, while the flow to the predator remains in depth-integrated units:

$$Con_{ij} = Q^*_{ij} \left(\frac{X_{ij} \cdot \frac{Bint_j}{B^*_j}}{X_{ij} - 1 + \frac{Bint_j}{B^*_j}} \right) \left(\frac{D_{ij} \cdot \left(\frac{\int_0^{z_{max}} B_i dz}{B^*_i}\right)^{\theta_{ij}}}{D_{ij} - 1 + \left(\frac{\int_0^{z_{max}} B_i dz}{B^*_i}\right)^{\theta_{ij}}} \right) \cdot \frac{1}{\Delta z} \cdot \frac{B_i \Delta z}{\int_0^{z_{max}} B_i dz} \tag{14}$$

$$ConI_{ij} = Q^*_{ij} \left(\frac{X_{ij} \cdot \frac{Bint_j}{B^*_j}}{X_{ij} - 1 + \frac{Bint_j}{B^*_j}} \right) \left(\frac{D_{ij} \cdot \left(\frac{Bint_i}{B^*_i}\right)^{\theta_{ij}}}{D_{ij} - 1 + \left(\frac{Bint_i}{B^*_i}\right)^{\theta_{ij}}} \right) \tag{15}$$

where $ConI = \int_0^{z_{max}} Con\, dz$.

2.1.5 **Excretion (Exc) and egestion (Ege)**

Egestion and excretion are proportional to the total consumption of prey by a predator. Egestion flows from the predator to the PON group, with the exception of egestion by microzooplankton, where egestion is split between the PON, DON, and NH_4 groups. Excretion flows from the predator group to the NH_4 group. All excretion and egestion by nektonic groups is assumed to take place in the surface layer:

$$Ege_i = GS_i \cdot \left(\sum_{k=plank} Con_{ki} + \frac{\sum_{\ell=nek} ConI_{\ell i}}{\Delta z_1} \right) \qquad z = 1 \tag{16}$$

$$Ege_i = GS_i \cdot \sum_k Con_{ki} \qquad z \neq 1 \tag{17}$$

$$Exc_i = (1 - GE_i - GS_i) \cdot \left(\sum_{k=plank} Con_{ki} + \frac{\sum_{\ell=nek} ConI_{\ell i}}{\Delta z_1} \right) \qquad z = 1 \qquad (18)$$

$$Exc_i = (1 - GE_i - GS_i) \cdot \sum_k Con_{ki} \qquad z \neq 1 \qquad (19)$$

2.1.6 Non-predatory mortality (Mor)

Non-predatory mortality, e.g. loss to old age or disease, is modeled as a quadratic function of biomass. For planktonic groups, this flux is in units of mass per volume:

$$Mor_i = \left(\frac{M_{0i}}{B'_i} \right) \cdot B_i^2 \qquad (20)$$

while for nektonic groups it is in units of mass per area:

$$MorI_i = \left(\frac{M_{0i}}{B^*_i} \right) \cdot Bint_i^2 \qquad (21)$$

As with egestion and excretion by nektonic groups, non-predatory mortality of nektonic groups is assumed to occur in the surface layer, such that in the surface layer,

$$Mor_i = \frac{MorI_i}{\Delta z_1} \qquad (22)$$

when i = nekton.

2.2 Additional fluxes

2.2.1 Proportional-to-nitrogen fluxes of silica and iron

The majority of fluxes between iron- and silica-based state variables occur in proportion to nitrogenous fluxes. Silica fluxes due to gross primary production (*Gpp*), extracellular excretion (*Ex*), and respiration (*Res*) between phytoplankton groups and $SiOH_4$ occur in a constant proportion to the respective fluxes in nitrogen between phytoplankton groups and all dissolved nitrogen pools (NO_3, NH_4, and DON). Similarly, fluxes due to non-predatory mortality (Mor) from phytoplankton groups to the PON group are accompanied by proportional fluxes of silica from the large phytoplankton to particulate opal group. Silica is assumed to be completely egested by phytoplankton grazers, so the proportional flux due to predator consumption (Con) of phytoplankton silica is routed entirely to the particulate opal group, rather than being split between predator, egestion, and excretion as is the case for nitrogenous consumption.

Iron fluxes between the two phytoplankton groups and the dissolved iron group also occur proportionally to nitrogen fluxes, though the ratio between the two elements varies over time (see Section 2.2.2). However, only a fraction of the iron fluxes out of the phytoplankton groups ends up in the dissolved iron pool, with the remainder leaving the system.

2.2.2 Luxury iron uptake (Ufe)

In addition to the proportional-to-nitrogen uptake and loss of iron due to gross primary production, respiration, extracellular excretion, grazing loss, and natural mortality, phytoplankton can also gain and lose iron through a relaxation process following the model of Fiechter et al. (2009). This model allows phytoplankton to take up dissolved iron in order to adjust their internal Fe:C ratios toward a value predicted by the ambient dissolved iron in the surrounding water. This additional uptake term accounts for the fact that iron uptake, unlike macronutrient uptake, is not necessarily a function of dissolved iron concentration, and that iron to carbon ratios within phytoplankton cells can vary widely over time depending on conditions. The luxury uptake in the WCE module is described by:

$$Ufe_i = \frac{R_{0i} - R_i}{t_{Fe,i}} \cdot B_i \cdot R_{C:N} \tag{23}$$

2.2.3 Decomposition (Dec)

Decomposition fluxes follow the model of Kishi et al. (2007), with a decay rate related to temperature:

$$Dec_{ij} = V_{Dec,ij} \exp(K_{Dec,ij}T) \cdot B_i \tag{24}$$

where the subscripts i and j represent the source and sink groups, respectively, and B_i the concentration of the source group.

2.3 Iron dynamics in the quota model

This new iron model is based closely on one developed for the Carbon, Ocean Biogeochemistry and Lower Trophics (COBALT) marine ecosystem model (Stock et al., in press), with only a few adjustments to parameter values in order to tune the dynamics to a one-dimensional water column.

Iron uptake for phytoplankton is based on an internal cell quota, accounting for both requirements and additional luxury uptake. Iron's contribution to overall nutrient limitation, which regulates the uptake of macronutrients, is termed iron deficiency ($D_{Fe,i}$) and is calculated based on the internal ratio of iron to nitrogen. However, uptake of iron is not proportional to uptake of nitrogen, but instead based on a separate limitation term ($L_{Fe,i}$), allowing phytoplankton to increase their internal Fe:N ratios to a preset limit:

$$Qup_i = \begin{cases} V_{max,i} \exp(K_{gpp,i}T) \cdot B_{Fe,i} \cdot L_{Fe,i} \cdot \mu_{Fe:N,i}, & \text{if } R_{Fe:N,i} < R_{Fe:Nmax,i} \\ 0, & \text{otherwise} \end{cases} \tag{25}$$

Iron is not tracked beyond the level of phytoplankton, but upon loss to predation is recycled to the dissolved and particulate iron state variables proportionate to the nitrogenous excretion and egestion fluxes of their predators.

Scavenging of dissolved iron onto particles follows a single ligand model, where only non-ligand-bound iron is available for adsorption onto particles. Light is assumed to greatly reduce the effectiveness of ligand binding through the production of oxygen free radicals (Fan, 2008). This impact is assumed to decay at light levels below 10 W $m-^2$ in a manner consistent with the observed decline of hydrogen peroxide in the water column (Yuan & Shiller, 2001). The free unbound iron, Fe_{free}, is calculated via:

$$K_{Lig} \cdot Fe_{free}^2 + (1 + K_{Lig} \cdot (Lig_{bkg} - Fe)) \cdot Fe_{free} - B_{Fe} = 0 \tag{26}$$

with adsorption onto particles directly proportional to this free iron:

$$Ads = \alpha_{scav} \cdot Fe_{free} \tag{27}$$

Finally, a fraction of particulate iron is remineralized to the dissolved iron pool, proportional to remineralization of particulate nitrogen to ammonium.

$$Dec_{POFe,Fe} = Dec_{PON,NH_4} \cdot \frac{B_{PON}}{B_{POFe}} \cdot r_{eff} \tag{28}$$

2.4 Parameterization for the biological model

2.4.1 Ecopath input data

The majority of the Ecopath data used to construct our food web model came the previously-published Aydin-48 model (Aydin et al., 2003). However, a few modifications were made to this data prior to running the simplification process described briefly in Kearney et al. (2012) and more fully in Kearney (2012).

The first modification made was to eliminate the bacteria functional group from the Aydin-48 model. In the original model, this functional group was included as a prey item for microzooplankton, "preying" itself on the two detrital functional groups. However, in their time-dynamic simulations, Aydin et al. (2003) found that their results were highly sensitive to this representation of the microbial loop, and it led to some lower trophic level dynamics that disagreed with accepted biogeochemical models from the region; they concluded that it was sufficient to assume that bacterial processes occurred within the detrital pools and removed the bacteria group from some of their later simulations. Because we intended to link the Ecopath-derived food web model directly to a biogeochemical model that already included parameterizations for the microbial loop, we decided to eliminate the bacteria group from the food web dynamics entirely, and we replaced the microzooplankton diet with one of 100% small phytoplankton.

Table S1 and Table S2 provide descriptions of the 47 functional groups that remained in the model, including the most common species classified under each functional group. Pertinent information regarding each group's lifecycle is also provided.

After examining the sources of zooplankton data for the Aydin-48 model, we made several adjustments to the data for those groups. Aydin et al. (2003) resolved the zooplankton community into eleven different functional groups: microzooplankton, copepods, euphausiids, pteropods, amphipods, sergestidae (shrimp), chaetognaths, salps, ptenohores, large jellyfish, and a miscellaneous group (mainly larvaceans and polychaetes). Much of the data for these groups was derived from a simulation of the NEMURO biogeochemical model. We found several issues with the assumptions used to translate the NEMURO output data into Ecopath input data.

First, the version of NEMURO used by Aydin et al. (2003) was an early realization of that model (Eslinger et al., 2000; Megrey et al., 2000), and we found we were unable to replicate their results using a version that follows the "official" description (Kishi et al., 2007). For this study, we developed our own biogeochemical model, based very closely on NEMURO, and substituted the values from a simulation of our model in place of those detailed in the Aydin et al. (2003) report.

Second, Aydin et al. (2003) interpreted NEMURO's predatory zooplankton group (ZP) as representing only non-gelatinous omnivores, i.e. euphausiids, pteropods, and amphipods. They gathered data for the gelatinous zooplankton groups (large jellyfish, chaetognaths, salps, and ctenophores) from other sources, and estimated the population of the carnivorous shrimp and miscellaneous groups each as 10% of the ZP value. Overall, this led to a community with a very large mesozooplankton community, more than twice that of the copepod population, despite the fact that copepods should be the dominant mesozooplankton genera (Goldblatt et al., 1999; Harrison et al., 2004). While NEMURO's ZP state variable does have an omnivorous diet, in our opinion it was intended to represent all unresolved predators of the two smaller zooplankton state variables (which correspond to the microzooplankton and copepod populations); in this Ecopath model, this includes not only the nine remaining zooplankton groups but also all other non-planktonic groups. Based on descriptions of the mesozooplankton community in the subarctic gyre (Goldblatt et al., 1999), we decided to distribute 50% of the ZP biomass to the omnivorous, non-gelatinous zooplankton groups (euphausiids, pteropods, and amphipods), 40% to the omnivorous, gelatinous groups (salps and ctenophores), and the remaining 10% to the carnivorous groups (shrimp, ctenophores, and miscellaneous).

The final issue with the NEMURO-derived zooplankton biomass data in the Aydin et al. (2003) report involved the conversion of units between NEMURO, which tracks state variables through their nitrogen content, and Ecopath, which uses total wet weight. While Aydin et al. (2003) detailed the assumptions used to convert the NEMURO data from mmol N m^{-2} to g C m^{-2}, including elemental ratios and mixed layer depth values, no explanation was given for the 0.01 g C/g wet weight conversion factor that was then used to calculate wet weight of both phyto- and zooplankton groups. While this order of magnitude estimate is common in conversions of fish wet weight to carbon content, it is much lower than most measurements for plankton. For example, crustacean zooplankton wet mass to carbon ratios range from 0.06-0.12 g wet mass/gC Harris et al. (2000). We compromised with a conversion factor of 0.03 gC/g wet weight, which we applied throughout this study whenever converting between element-based and weight-based units.

The final adjustment we made to the Aydin-48 data concerned the growth efficiency value applied to the ctenophore group. The value of 0.03 used for this group appeared extremely low, even for a gelatinous group. Aydin et al. (2003) cited Pauly et al. (1996) as the source of this number. However, Pauly et al. (1996) derived their carnivorous jelly data from measurements of the cnidarian *Aglantha*, and even for this species they commented that the consumption rate they were using was "very high, perhaps excessively so." Measured growth efficiencies for ctenophores vary from less than 10% to 45% (Reeve et al., 1978, 1989); we settled on a value of 0.3, in line with that of the other zooplankton groups, in order to resolve Ecopath balance issues that arose as a result of the NEMURO-derived adjustments detailed above.

The final set of Ecopath input data for the 47-group model can be found in Tables S3 through S9. Following the simplification process (Kearney et al., 2012; Kearney, 2012), the food web was reduced to 24 groups. The Ecopath input parameters for this 24-group model are found in Tables S10, S11, and S12.

Table S1: A description of the 47 functional groups included in the unsimplified version of the food web model. Species listed are not exhaustive, but represent the dominant members of each functional group.

Group	Includes	Details
Sperm whales	sperm whales (*Physeter macrocephalus*)	a very large toothed whale, only mature males are found in the subarctic gyre region, and only during the summer months.
Toothed whales	orcas (*Orcinus orca*)	includes the mammal-eating transient subpopulation and some portion of the piscivororous (and typically more coastal) resident subpopulation
Fin whales	fin whales (*Balaenoptera physalus*)	a baleen whale, migrates to the gyre during summer months to feed
Sei whales	sei whales (*Balaenoptera boealis*)	a baleen whale, migrates to the gyre during summer months to feed
Northern fur seals	northern fur seals (*Callorhinus ursinus*)	a large fur seal.
Elephant seals	northern elephant seals (*Mirounga angustirostris*)	large seal, migrates biannually between the Alaska Gyre and California breeding beaches.
Dall's porpoises	Dall's porpoises (*Phocoenoides dalli*)	a porpoise
Pacific white-sided dolphins	Pacific white-sided dolphins (*Lagenorhynchus obliquidens*)	a dolphin
Northern right whale dolphins	Northern right whale dolphins (*Lissodelphis borealis*)	a small dolphin
Albatross	primarily Black-footed albatross (*Phoebastria nigripes*) and Laysan albatross (*Phoebastria immutabilis*)	large seabirds
Shearwaters	primarily sooty shearwaters (*Puffinus griseus*) and short-tailed shearwaters (*Puffinus tenuirostris*)	medium-sized seabirds, the dominant seabird in the Gulf of Alaska region
Storm Petrels	primarily fork-tailed storm petrels (*Oceanodroma furcata*) and Leach's storm petrels (*Oceanodroma leucorhoa*)	small seabirds
Kittiwakes	primarily black-legged kittiwakes (*Rissa tridactyla*)	seabirds in the gull family
Fulmars	northern fulmar (*Fulmarus glacialis*)	a seabird
Puffins	primarily tufted puffins (*Fratercula cirrhata*)	a medium-sized seabird
Skuas	primarily south-polar skuas (*Stercorarius maccormicki*)	a large seabird
Jaegers	primarily Pomarine jaegars	seabird, in the skua family
Sharks	salmon sharks (*Lamna ditropis*)	small shark, approximately 2m long, homeothermic
Large gonatid squid	armhook squid (family Gonatidae)	medium-sized squid

Table S2: A description of the 47 functional groups included in the unsimplified version of the food web model (continued).

Group	Includes	Details
Boreal clubhook squid	boreal clubhook squid (*Onychoteuthis borealijaponica*)	a medium-sized squid
Neon flying squid	neon flying squid (*Ommastrephes bartramii*)	a slightly larger squid
Sockeye salmon	sockeye salmon (*Oncorhynchus nerka*)	the most abundant salmon species in the Eastern Gyre, anadromous
Chum salmon	chum salmon (*Oncorhynchus keta*)	the second-most abundant salmon species in the Easterb Gyre, anadromous
Pink salmon	pink salmon (*Oncorhynchus gorbuscha*)	smallest Pacific salmon, anadromous, have a two-year breeding cycle, with even- and odd-year populations not interbreeding
Coho salmon	coho salmon (*Oncorhynchus kisutch*)	a salmon, anadromous
Chinook salmon	Chinook salmon (*Oncorhynchus tshawytscha*)	the largest Pacific salmon, anadromous
Steelhead	steelhead, or rainbow trout (*Oncorhynchus mykiss*)	salmonid, anadromous
Pomfret	Pacific pomfret (*Brama japonica*)	a large perciform fish
Saury	Pacific saury (*Cololabis saira*)	medium-sized (30-40 cm), highly migratory fish, important commercial fish, especially in Asia
Pelagic forage fish	primarily sticklebacks (*Gasterosteus aculeatus*)	small (4 cm) schooling forage fish
Micronektonic squid	primarily gonatids such as *Berryteuthis anonychus* and *Gonatus onyx*	juvenile squid, few data measurements available
Mesopelagic fish	myctophids, or lanternfishes (family Myctophidae), particularly *Stenobrachius leucopsarus*	small mesopelagic fish
Large jellyfish	phylum Cnidarian	small jellyfish
Ctenophores	phylum Ctenophora	comb jellies, gelatinous
Salps	family Salpidae	planktonic tunicates, gelatinous
Chaetognaths	phylum Chaetognatha	marine worms, gelatinous
Sergestid shrimp	family Sergestidae	shrimp
Miscellaneous predatory zooplankton	mainly Larvaceans and Polychaetes	planktonic tunicates and annelid worms
Amphipods	order Amphipoda	crustacean zooplankton
Pteropods	Thecosomata	planktonic gastropods
Euphausiids	krill (order Euphausiacea)	crustacean zooplankton
Copepods	subclass Copepoda	small crustacean zooplankton
Microzooplankton	any <200 μm	mainly meroplanktonic larva and copepod nauplii
Large phytoplankton	any <5 μm	includes prasinophytes, prymnesiophytes (coccolithophorids), cryptophytes, and cyanobacteria
Small phytoplankton	primarily diatoms	represent large size class, includes silica cycle
DNH3	detritus, dissolved	detritus pool
POM	detritus, particulate	detritus pool

Table S3: Ecopath input variables for the 47-group food web, including biomass (B, tons wet weight m^{-2}), production/biomass (PB, yr^{-1}), consumption/biomass (QB, yr^{-1}), ecotrophic efficiency (EE), growth efficiency (GE), and fraction unassimilated (GS). Where applicable, both value and pedigree (Ped) are listed.

Group	B		PB		QB		EE	GE	GS
	Value	Ped	Value	Ped	Value	Ped			
Sperm whales	0.000929	0.5	0.0596	0.4	6.61	0.2			0.2
Toothed whales	2.8e-05	0.5	0.0252	0.4	11.16	0.2			0.2
Fin whales	0.027883	0.5	0.02	0.4	4.56	0.2			0.2
Sei whales	0.005902	0.5	0.02	0.4	6.15	0.2			0.2
Northern fur seals	0.000246	0.5	0.235	0.4	39.03	0.2			0.2
Elephant seals	0.00043	0.5	0.368	0.4	11.08	0.2			0.2
Dall's porpoises	0.0059864	0.5	0.1	0.4	27.47	0.2			0.2
Pacific white-sided dolphins	0.0039625	0.5	0.14	0.4	25.83	0.2			0.2
Northern right whale dolphins	0.0038973	0.5	0.16	0.4	24.14	0.2			0.2
Albatross	4e-05	0.5	0.05	0.4	81.59	0.2			0.2
Shearwaters	0.0004	0.5	0.1	0.4	100.13	0.2			0.2
Storm Petrels	5.6e-05	0.5	0.1	0.4	152.08	0.2			0.2
Kittiwakes	5.2e-05	0.5	0.1	0.4	123	0.2			0.2
Fulmars	7.4e-05	0.5	0.1	0.4	100.26	0.2			0.2
Puffins	5.8e-05	0.5	0.1	0.4	104.33	0.2			0.2
Skuas	5.4e-05	0.5	0.075	0.4	96.6	0.2			0.2
Jaegers	3.8e-05	0.5	0.075	0.4	96.6	0.2			0.2
Sharks	0.05	0.8	0.2	0.6	10.95	0.4			0.2
Large gonatid squid	0.03	0.8	2.555	0.6	7.3	0.6			0.2
Boreal clubhook squid	0.012	0.8	2.555	0.6	7.3	0.6			0.2
Neon flying squid	0.45	0.8	2.555	0.6	6.205	0.6			0.2
Sockeye salmon	0.089656	0.5	1.27	0.1	10.13	0.1			0.2
Chum salmon	0.054136	0.5	1.93	0.1	14.51	0.1			0.2
Pink salmon	0.023267	0.5	3.37	0.1	18.49	0.1			0.2
Coho salmon	0.0044535	0.5	2.47	0.1	16.55	0.1			0.2
Chinook salmon	0.0093031	0.5	0.8	0.3		0.3		0.15	0.2
Steelhead	0.0093	0.5	0.8	0.3		0.3		0.15	0.2
Pomfret	0.21	0.8	0.75	0.4		0.4		0.20	0.2
Saury	0.45	0.8	1.6	0.6	7.9	0.7			0.2
Pelagic forage fish		0.8	1.5	0.6	5	0.7	0.9		0.2
Micronektonic squid		0.8	3	0.6	15	0.7	0.9		0.2
Mesopelagic fish	4.5	0.8	0.9	0.6	3	0.7			0.2
Large jellyfish	4	0.8	3	0.7	10	0.7			0.2
Ctenophores	1.5488	0.5	4	0.7	13.333	0.7			0.3
Salps	1.5488	0.5	9	0.7	30	0.7			0.3
Chaetognaths	4.1302	0.5	6.9876	0.7	23.292	0.7			0.3
Sergestid shrimp	4.1302	0.8	6.9876	0.7	23.292	0.7			0.3
Miscellaneous predatory zooplankton	4.1302	0.8	6.9876	0.7	23.292	0.7			0.3
Amphipods	5.1628	0.8	6.9876	0.7	23.292	0.7			0.3
Pteropods	5.1628	0.8	6.9876	0.7	23.292	0.7			0.3
Euphausiids	5.1628	0.8	6.9876	0.4	23.292	0.4			0.3
Copepods	20.919	0.1	23.151	0.1	77.169	0.4			0.3
Microzooplankton	16.83	0.1	38.833	0.1	129.44	0.4			0.3
Large phytoplankton	27.029	0.8	41.677	0.1	68.132	0.4			
Small phytoplankton	42.427	0.5	70.621	0.1	101.6	0.4			
DNH3	50	0.1		0.1		0.4			
POM	50	0.1		0.1		0.4			

Table S4: Diet fraction input for the 47-group food web model.

Predator	Prey	Diet fraction	Pedigree
Sperm whales	Large gonatid squid	0.02287	0.7
	Boreal clubhook squid	0.00915	
	Neon flying squid	0.34299	
	Sockeye salmon	0.00208	
	Chum salmon	0.00125	
	Pink salmon	0.00054	
	Coho salmon	0.0001	
	Chinook salmon	0.00022	
	Steelhead	0.00022	
	Pomfret	0.00486	
	Saury	0.01042	
	Pelagic forage fish	0.126	
	Micronektonic squid	0.375	
	Mesopelagic fish	0.10416	
Toothed whales	Fin whales	0.22725	0.7
	Sei whales	0.04811	
	Northern fur seals	0.002	
	Elephant seals	0.00351	
	Dall's porpoises	0.04879	
	Pacific white-sided dolphins	0.03229	
	Northern right whale dolphins	0.03176	
	Albatross	0.00032	
	Shearwaters	0.00326	
	Storm Petrels	0.00046	
	Kittiwakes	0.00042	
	Fulmars	0.00061	
	Puffins	0.00047	
	Skuas	0.00044	
	Jaegers	0.00031	
	Large gonatid squid	0.00305	
	Boreal clubhook squid	0.00122	
	Neon flying squid	0.04573	
	Sockeye salmon	0.0249	
	Chum salmon	0.01504	
	Pink salmon	0.00646	
	Coho salmon	0.00124	
	Chinook salmon	0.00258	
	Steelhead	0.00258	
	Pomfret	0.05833	
	Saury	0.12498	
	Pelagic forage fish	0.264	
	Micronektonic squid	0.05	
Fin whales	Large gonatid squid	0.001524	0.7
	Boreal clubhook squid	0.000609	
	Neon flying squid	0.022866	
	Sockeye salmon	0.001245	
	Chum salmon	0.000752	
	Pink salmon	0.000323	
	Coho salmon	6.19e-05	
	Chinook salmon	0.000129	
	Steelhead	0.000129	
	Pomfret	0.002917	
	Saury	0.00625	
	Pelagic forage fish	0.076	
	Micronektonic squid	0.025	
	Mesopelagic fish	0.062499	
	Chaetognaths	0.054357	
	Sergestid shrimp	0.041179	
	Misc. predatory zooplankton	0.041746	
	Amphipods	0.083492	
	Pteropods	0.083492	
	Euphausiids	0.20873	
	Copepods	0.287004	

Table S5: Diet fraction input for the 47-group food web model (continued).

Predator	Prey	Diet fraction	Pedigree
Sei whales	Large gonatid squid	0.001524	0.7
	Boreal clubhook squid	0.000609	
	Neon flying squid	0.022866	
	Sockeye salmon	0.001245	
	Chum salmon	0.000752	
	Pink salmon	0.000323	
	Coho salmon	6.19e-05	
	Chinook salmon	0.000129	
	Steelhead	0.000129	
	Pomfret	0.002917	
	Saury	0.00625	
	Pelagic forage fish	0.076	
	Micronektonic squid	0.025	
	Mesopelagic fish	0.062499	
	Chaetognaths	0.05435	
	Sergestid shrimp	0.041179	
	Misc. predatory zooplankton	0.041746	
	Amphipods	0.083492	
	Pteropods	0.083492	
	Euphausiids	0.20873	
	Copepods	0.287004	
Northern fur seals	Large gonatid squid	0.00915	0.7
	Boreal clubhook squid	0.00366	
	Neon flying squid	0.1372	
	Sockeye salmon	0.02988	
	Chum salmon	0.01804	
	Pink salmon	0.00775	
	Coho salmon	0.00148	
	Chinook salmon	0.0031	
	Steelhead	0.0031	
	Pomfret	0.06999	
	Saury	0.14998	
	Pelagic forage fish	0.267	
	Micronektonic squid	0.15	
	Mesopelagic fish	0.15	
Elephant seals	Large gonatid squid	0.0122	0.7
	Boreal clubhook squid	0.00488	
	Neon flying squid	0.18293	
	Sockeye salmon	0.01132	
	Chum salmon	0.00683	
	Pink salmon	0.00294	
	Coho salmon	0.00056	
	Chinook salmon	0.00117	
	Steelhead	0.00117	
	Pomfret	0.056	
	Saury	0.12	
	Pelagic forage fish	0.2	
	Micronektonic squid	0.4	
Dall's porpoises	Large gonatid squid	0.01372	0.7
	Boreal clubhook squid	0.00549	
	Neon flying squid	0.20579	
	Sockeye salmon	0.01494	
	Chum salmon	0.00902	
	Pink salmon	0.00388	
	Coho salmon	0.00074	
	Chinook salmon	0.00155	
	Steelhead	0.00155	
	Pomfret	0.035	
	Saury	0.07499	
	Pelagic forage fish	0.208	
	Micronektonic squid	0.225	
	Mesopelagic fish	0.2	

Table S6: Diet fraction input for the 47-group food web model (continued).

Predator	Prey	Diet fraction	Pedigree
Pacific white-sided dolphins	Large gonatid squid	0.00762	0.7
	Boreal clubhook squid	0.00305	
	Neon flying squid	0.11433	
	Sockeye salmon	0.03984	
	Chum salmon	0.02406	
	Pink salmon	0.01034	
	Coho salmon	0.00198	
	Chinook salmon	0.00413	
	Steelhead	0.00413	
	Pomfret	0.09332	
	Saury	0.19997	
	Pelagic forage fish	0.172	
	Micronektonic squid	0.225	
	Mesopelagic fish	0.1	
Northern right whale dolphins	Large gonatid squid	0.01524	0.7
	Boreal clubhook squid	0.0061	
	Neon flying squid	0.22866	
	Sockeye salmon	0.00498	
	Chum salmon	0.00301	
	Pink salmon	0.00129	
	Coho salmon	0.00025	
	Chinook salmon	0.00052	
	Steelhead	0.00052	
	Pomfret	0.01167	
	Saury	0.025	
	Pelagic forage fish	0.053	
	Micronektonic squid	0.25	
	Mesopelagic fish	0.4	
Albatross	Large gonatid squid	0.04573	0.7
	Boreal clubhook squid	0.01829	
	Neon flying squid	0.68598	
	Saury	0.1	
	Pelagic forage fish	0.1	
	Micronektonic squid	0.05	
Shearwaters	Saury	0.275	0.7
	Pelagic forage fish	0.275	
	Micronektonic squid	0.3	
	Amphipods	0.0189	
	Pteropods	0.0189	
	Euphausiids	0.04724	
	Copepods	0.06496	
Storm Petrels	Saury	0.05	0.7
	Pelagic forage fish	0.05	
	Micronektonic squid	0.6	
	Amphipods	0.0378	
	Pteropods	0.0378	
	Euphausiids	0.09449	
	Copepods	0.12992	
Kittiwakes	Saury	0.4	0.7
	Pelagic forage fish	0.4	
	Amphipods	0.0252	
	Pteropods	0.0252	
	Euphausiids	0.06299	
	Copepods	0.08661	
Fulmars	Pelagic forage fish	0.04	0.7
	Micronektonic squid	0.96	
Puffins	Saury	0.4	0.7
	Pelagic forage fish	0.4	
	Micronektonic squid	0.1	
	Amphipods	0.0126	
	Pteropods	0.0126	
	Euphausiids	0.0315	
	Copepods	0.04331	

Table S7: Diet fraction input for the 47-group food web model (continued).

Predator	Prey	Diet fraction	Pedigree
Skuas	Saury	0.5	0.7
	Pelagic forage fish	0.5	
Jaegers	Saury	0.5	0.7
	Pelagic forage fish	0.5	
Sharks	Large gonatid squid	0.01782	0.8
	Boreal clubhook squid	0.00713	
	Neon flying squid	0.26724	
	Sockeye salmon	0.05324	
	Chum salmon	0.03215	
	Pink salmon	0.01382	
	Coho salmon	0.00264	
	Chinook salmon	0.00552	
	Steelhead	0.00552	
	Pomfret	0.12471	
	Saury	0.26724	
	Pelagic forage fish	0.103	
	Micronektonic squid	0.1	
Large gonatid squid	Pelagic forage fish	0.01	0.6
	Micronektonic squid	0.33	
	Chaetognaths	0.04484	
	Sergestid shrimp	0.03397	
	Misc. predatory zooplankton	0.03444	
	Amphipods	0.06888	
	Pteropods	0.06888	
	Euphausiids	0.1722	
	Copepods	0.23678	
Boreal clubhook squid	Pelagic forage fish	0.01	0.6
	Micronektonic squid	0.99	
Neon flying squid	Neon flying squid	0.295	0.6
	Saury	0.058	
	Pelagic forage fish	0.319	
	Micronektonic squid	0.223	
	Mesopelagic fish	0.105	
Sockeye salmon	Pelagic forage fish	0.10982	0.1
	Micronektonic squid	0.07968	
	Mesopelagic fish	0.10982	
	Ctenophores	0.01609	
	Salps	0.01609	
	Misc. predatory zooplankton	0.00171	
	Amphipods	0.29328	
	Pteropods	0.23976	
	Euphausiids	0.10058	
	Copepods	0.03318	
Chum salmon	Pelagic forage fish	0.00802	0.1
	Micronektonic squid	0.03929	
	Mesopelagic fish	0.00802	
	Ctenophores	0.20285	
	Salps	0.20285	
	Chaetognaths	0.00043	
	Misc. predatory zooplankton	0.01474	
	Amphipods	0.07363	
	Pteropods	0.06719	
	Euphausiids	0.08491	
	Copepods	0.29806	

Table S8: Diet fraction input for the 47-group food web model (continued).

Predator	Prey	Diet fraction	Pedigree
Pink salmon	Pelagic forage fish	0.068096	0.1
	Micronektonic squid	0.034823	
	Mesopelagic fish	0.068096	
	Ctenophores	0.003826	
	Salps	0.003826	
	Misc. predatory zooplankton	8.64e-06	
	Amphipods	0.32162	
	Pteropods	0.440933	
	Euphausiids	0.038951	
	Copepods	0.019816	
Coho salmon	Pelagic forage fish	0.367206	0.1
	Micronektonic squid	0.205691	
	Mesopelagic fish	0.367206	
	Ctenophores	7.31e-05	
	Salps	7.31e-05	
	Amphipods	0.008047	
	Pteropods	0.04623	
	Euphausiids	0.002736	
	Copepods	0.002736	
Chinook salmon	Pelagic forage fish	0.367206	0.1
	Micronektonic squid	0.205691	
	Mesopelagic fish	0.367206	
	Ctenophores	7.31e-05	
	Salps	7.31e-05	
	Amphipods	0.008047	
	Pteropods	0.04623	
	Euphausiids	0.002736	
	Copepods	0.002736	
Steelhead	Pelagic forage fish	0.367206	0.1
	Micronektonic squid	0.205691	
	Mesopelagic fish	0.367206	
	Ctenophores	7.31e-05	
	Salps	7.31e-05	
	Amphipods	0.008047	
	Pteropods	0.04623	
	Euphausiids	0.002736	
	Copepods	0.002736	
Pomfret	Saury	0.04	0.5
	Micronektonic squid	0.75	
	Mesopelagic fish	0.08	
	Chaetognaths	0.01	
	Sergestid shrimp	0.01	
	Misc. predatory zooplankton	0.01	
	Amphipods	0.03	
	Pteropods	0.01	
	Euphausiids	0.05	
	Copepods	0.01	
Saury	Chaetognaths	0.05298	0.7
	Sergestid shrimp	0.04014	
	Misc. predatory zooplankton	0.04069	
	Amphipods	0.08138	
	Pteropods	0.08138	
	Euphausiids	0.20344	
	Copepods	0.5	
Pelagic forage fish	Chaetognaths	0.06795	0.7
	Sergestid shrimp	0.05147	
	Misc. predatory zooplankton	0.05218	
	Amphipods	0.10437	
	Pteropods	0.10437	
	Euphausiids	0.26091	
	Copepods	0.35875	

Table S9: Diet fraction input for the 47-group food web model (continued).

Predator	Prey	Diet fraction	Pedigree
Micronektonic squid	Micronektonic squid	0.05	0.7
	Chaetognaths	0.06455	
	Sergestid shrimp	0.0489	
	Misc. predatory zooplankton	0.04957	
	Amphipods	0.09915	
	Pteropods	0.09915	
	Euphausiids	0.24787	
	Copepods	0.34082	
Mesopelagic fish	Chaetognaths	0.15	0.7
	Sergestid shrimp	0.03	
	Misc. predatory zooplankton	0.03	
	Amphipods	0.24	
	Pteropods	0.031	
	Euphausiids	0.171	
	Copepods	0.348	
Large jellyfish	Ctenophores	0.04356	0.7
	Salps	0.03829	
	Chaetognaths	0.03159	
	Sergestid shrimp	0.02393	
	Misc. predatory zooplankton	0.02426	
	Amphipods	0.04852	
	Pteropods	0.04852	
	Euphausiids	0.12131	
	Copepods	0.62	
Ctenophores	Copepods	0.25	0.7
	Microzooplankton	0.25	
	Large phytoplankton	0.5	
Salps	Copepods	0.25	0.7
	Microzooplankton	0.25	
	Large phytoplankton	0.5	
Chaetognaths	Amphipods	0.04444	0.7
	Pteropods	0.04444	
	Euphausiids	0.11111	
	Copepods	0.8	
Sergestid shrimp	Amphipods	0.04444	0.7
	Pteropods	0.04444	
	Euphausiids	0.11111	
	Copepods	0.8	
Misc. predatory zooplankton	Amphipods	0.04444	0.7
	Pteropods	0.04444	
	Euphausiids	0.11111	
	Copepods	0.8	
Amphipods	Copepods	0.4	0.7
	Microzooplankton	0.4	
	Large phytoplankton	0.2	
Pteropods	Copepods	0.4	0.7
	Microzooplankton	0.4	
	Large phytoplankton	0.2	
Euphausiids	Copepods	0.4	0.3
	Microzooplankton	0.4	
	Large phytoplankton	0.2	
Copepods	Microzooplankton	0.3	0.3
	Large phytoplankton	0.4	
	Small phytoplankton	0.3	
Microzooplankton	Small phytoplankton	1	0.3

Table S10: Ecopath input variables for the 24-group simplified food web, including biomass (B, tons wet weight m^{-2}), production/biomass (PB, yr^{-1}), consumption/biomass (QB, yr^{-1}), ecotrophic efficiency (EE), growth efficiency (GE), and fraction unassimilated (GS)

Group	B		PB		QB		EE	GE	GS
	Value	Ped	Value	Ped	Value	Ped			
Albatross	4e-05	0.5	0.05	0.4	81.59	0.2			0.2
Mammals,sharks	0.065451	0.72918	0.18408	0.55279	14.192	0.35279			0.2
Neon flying squid	0.45	0.8	2.555	0.6	6.205	0.6			0.2
Orcas	2.8e-05	0.5	0.0252	0.4	11.16	0.2			0.2
Boreal clubhook squid	0.012	0.8	2.555	0.6	7.3	0.6			0.2
Seabirds 1	0.000166	0.5	0.086145	0.4	98.232	0.2			0.2
Pomfret	0.21	0.8	0.75	0.4		0.4		0.2	0.2
Seabirds 2	0.000566	0.5	0.1	0.4	107.8	0.2			0.2
Gonatid squid	0.03	0.8	2.555	0.6	7.3	0.6			0.2
Salmon	0.19011	0.5	1.6971	0.11957	12.081	0.11957		0.13748	0.2
Baleen whales	0.033785	0.5	0.02	0.4	4.8378	0.2			0.2
Micronektonic squid		0.8	3	0.6	15	0.7	0.9		0.2
Mesopelagic fish	4.5	0.8	0.9	0.6	3	0.7			0.2
Pelagic forage fish		0.8	1.5	0.6	5	0.7	0.9		0.2
Saury	0.45	0.8	1.6	0.6	7.9	0.7			0.2
Jellyfish	4	0.8	3	0.7	10	0.7			0.2
Predatory zooplankton	12.391	0.7	6.9876	0.7	23.292	0.7			0.3
Large zooplankton	15.488	0.8	6.9876	0.6	23.292	0.6			0.3
Gelatinous zooplankton	3.0977	0.5	6.5	0.7	21.667	0.7			0.3
Copepods	20.919	0.1	23.151	0.1	77.169	0.4			0.3
Microzooplankton	16.83	0.1	38.833	0.1	129.44	0.4			0.3
Small phytoplankton	42.427	0.5	70.621	0.1		0.4			
Large phytoplankton	27.029	0.8	41.677	0.1		0.4			
PON	100	0.1		0.1		0.4			

Table S11: Diet fraction input for the 24-group food web model.

Predator	Prey	Diet fraction	Pedigree
Albatross	Neon flying squid	0.68598	0.7
	Boreal clubhook squid	0.01829	
	Gonatid squid	0.04573	
	Micronektonic squid	0.05	
	Pelagic forage fish	0.1	
	Saury	0.1	
Mammals,sharks	Neon flying squid	0.250098	0.776393
	Boreal clubhook squid	0.00667251	
	Pomfret	0.105515	
	Gonatid squid	0.016676	
	Salmon	0.0953397	
	Micronektonic squid	0.133994	
	Mesopelagic fish	0.0502069	
	Pelagic forage fish	0.115384	
	Saury	0.226106	
Neon flying squid	Neon flying squid	0.295	0.6
	Micronektonic squid	0.223	
	Mesopelagic fish	0.105	
	Pelagic forage fish	0.319	
	Saury	0.058	
Orcas	Albatross	0.00032	0.7
	Mammals,sharks	0.11835	
	Neon flying squid	0.04573	
	Boreal clubhook squid	0.00122	
	Seabirds 1	0.00136	
	Pomfret	0.05833	
	Seabirds 2	0.00461	
	Gonatid squid	0.00305	
	Salmon	0.0528	
	Baleen whales	0.27536	
	Micronektonic squid	0.05	
	Pelagic forage fish	0.264	
	Saury	0.12498	
Boreal clubhook squid	Micronektonic squid	0.99	0.6
	Pelagic forage fish	0.01	
Seabirds 1	Micronektonic squid	0.427952	0.7
	Pelagic forage fish	0.29494	
	Saury	0.277108	
Pomfret	Micronektonic squid	0.75	0.5
	Mesopelagic fish	0.08	
	Saury	0.04	
	Predatory zooplankton	0.03	
	Large zooplankton	0.09	
	Copepods	0.01	
Seabirds 2	Micronektonic squid	0.281625	0.7
	Pelagic forage fish	0.277032	
	Saury	0.277032	
	Large zooplankton	0.0931553	
	Copepods	0.0711576	
Gonatid squid	Micronektonic squid	0.33	0.6
	Pelagic forage fish	0.01	
	Predatory zooplankton	0.11325	
	Large zooplankton	0.30996	
	Copepods	0.23678	
Salmon	Micronektonic squid	0.0779714	0.1
	Mesopelagic fish	0.106941	
	Pelagic forage fish	0.106941	
	Predatory zooplankton	0.00512718	
	Large zooplankton	0.468088	
	Gelatinous zooplankton	0.131654	
	Copepods	0.103278	

Table S12: Diet fraction input for the 24-group food web model (continued).

Predator	Prey	Diet fraction	Pedigree
Baleen whales	Neon flying squid	0.022866	0.7
	Boreal clubhook squid	0.000609	
	Pomfret	0.002917	
	Gonatid squid	0.001524	
	Salmon	0.0026399	
	Micronektonic squid	0.025	
	Mesopelagic fish	0.062499	
	Pelagic forage fish	0.076	
	Saury	0.00625	
	Predatory zooplankton	0.137281	
	Large zooplankton	0.375714	
	Copepods	0.287004	
Micronektonic squid	Micronektonic squid	0.05	0.7
	Predatory zooplankton	0.16302	
	Large zooplankton	0.44617	
	Copepods	0.34082	
Mesopelagic fish	Predatory zooplankton	0.21	0.7
	Large zooplankton	0.442	
	Copepods	0.348	
Pelagic forage fish	Predatory zooplankton	0.1716	0.7
	Large zooplankton	0.46965	
	Copepods	0.35875	
Saury	Predatory zooplankton	0.13381	0.7
	Large zooplankton	0.3662	
	Copepods	0.5	
Jellyfish	Predatory zooplankton	0.07978	0.7
	Large zooplankton	0.21835	
	Gelatinous zooplankton	0.08185	
	Copepods	0.62	
Predatory zooplankton	Large zooplankton	0.19999	0.7
	Copepods	0.8	
Large zooplankton	Copepods	0.4	0.566667
	Microzooplankton	0.4	
	Large phytoplankton	0.2	
Gelatinous zooplankton	Copepods	0.25	0.7
	Microzooplankton	0.25	
	Large phytoplankton	0.5	
Copepods	Microzooplankton	0.3	0.3
	Small phytoplankton	0.3	
	Large phytoplankton	0.4	
Microzooplankton	Small phytoplankton	1	0.3

2.4.2 **Tables of parameters**

The following series of tables describe and define all parameters that were used throughout the documentation of the water column ecosystem model.

Table S13: Biogeochemical process-related parameters: Primary production

Parameter	Symbol	Group	Value
Ammonium inhibition constant	ψ	PS	1.5 (mmol N m^{-3})$^{-1}$
		PL	1.5 (mmol N m^{-3})$^{-1}$
Half-saturation constant for ammonium	K_{NH_4}	PS	0.1 mmol N m^{-3}
		PL	0.3 mmol N m^{-3}
Half-saturation constant for nitrate	K_{NO_3}	PS	1 mmol N m^{-3}
		PL	3 mmol N m^{-3}
Half-saturation constant for silica	K_{Si}	PL	6 mmol Si m^{-3}
Initial slope of P-I curve	α	PS	0.017 (W m^{-2})$^{-1}$ d^{-1}
		PL	0.016 (W m^{-2})$^{-1}$ d^{-1}
Light dissipation coefficient of seawater	α_1		0.04 m^{-1}
Maximum uptake rate at 0 deg C	V_{max}	PS	0.4 d^{-1}
		PL	0.8 d^{-1}
Phytoplankton self-shading coefficient	α_2		0.04 m^{-1} (mmol N m^{-3})$^{-1}$
Silica to nitrogen ratio	$R_{Si:N}$		2 mmol Si (mmol N)$^{-1}$
Carbon to nitrogen ratio	$R_{C:N}$		6.625 mol C (mol N)$^{-1}$
Temperature coefficient for photosynthesis	K_{gpp}	PS	0.0693 (deg C)$^{-1}$
		PL	0.0693 (deg C)$^{-1}$
Empirical Fe:C function coefficient	b_{Fe}	PS	28.5 (mol C m^{-3})$^{-1}$
		PL	42.6 (mol C m^{-3})$^{-1}$
Empirical Fe:C function power	α_{Fe}	PS	0.21
		PL	0.46
Fraction of iron remineralized	f_{rem}	PS	0.5
		PL	0.5
Half-saturation constant for Fe:C	$K_{Fe:C}$	PS	12 μmol Fe (mol C)$^{-1}$
		PL	16.9 μmol Fe (mol C)$^{-1}$
Timescale for iron uptake	t_{Fe}	PS	1 d
		PL	1 d

Table S14: Biogeochemical process-related parameters: Iron quota model

Parameter	Symbol	Group	Value
Maximum Fe:N ratio	$R_{Fe:Nmax}$	PS	331.25 μmol Fe (mol N)$^{-1}$
		PL	3312.5 μmol Fe (mol N)$^{-1}$
Half-saturation constant for iron	K_{Fe}	PS	0.6 μmol Fe m^{-3}
		PL	3.0 μmol Fe m^{-3}
Half-saturation constant for internal Fe:N ratio	$K_{Fe:N}$	PS	66.25 μmol Fe (mol N)$^{-1}$
		PL	132.5 μmol Fe (mol N)$^{-1}$
Iron uptake factor	$\mu_{Fe:N}$		100 μmol Fe (mol N)$^{-1}$
Background ligand concentration	Lig_bkg		1.0 μmol m^{-3}
Half saturation constant for light effect on ligand-binding	K_{Iscav}		1.0 W m^{-2}
Lower limit of ligand binding under low-light conditions	K_{LigLo}		300 m^3 (μmol)$^{-1}$
Upper limit of ligand binding under high-light conditions	K_{LigHi}		0.1 m^3 (μmol)$^{-1}$
Iron scavenging coefficient	α_{scav}		50 yr^{-1}
Fraction of iron remineralized, relative to organic nitrogen	r_{eff}		0.25

Table S15: Biogeochemical process-related parameters: Respiration

Parameter	Symbol	Group	Value
Respiration rate at 0 deg C	Res_0	PS	0.03 d^{-1}
		PL	0.03 d^{-1}
Temperature coefficient for respiration	K_{Res}	PS	0.0519 d^{-1}
		PL	0.0519 d^{-1}

Table S16: Biogeochemical process-related parameters: Extracellular excretion

Parameter	Symbol	Group	Value
Ratio of extracellular excretion to photosynthesis	γ	PS	0.135
		PL	0.135

Table S17: Biogeochemical process-related parameters: Grazing

Parameter	Symbol	Group	Value
Grazing inhibition coefficient	ψ_{gr}	ZP on PL	4.605 (mmol N $m^{-3})^{-1}$
		ZP on ZS	3.01 (mmol N $m^{-3})^{-1}$
Grazing threshhold	B_{thresh}	ZS on PS	0.04 mmol N m^{-3}
		ZL on PS	0.04 mmol N m^{-3}
		ZL on PL	0.04 mmol N m^{-3}
		ZP on PL	0.04 mmol N m^{-3}
		ZL on ZS	0.04 mmol N m^{-3}
		ZP on ZS	0.04 mmol N m^{-3}
		ZP on ZL	0.04 mmol N m^{-3}
Ivlev constant	λ	ZS	1.4 (mmol N $m^{-3})^{-1}$
		ZL	1.4 (mmol N $m^{-3})^{-1}$
		ZP	1.4 (mmol N $m^{-3})^{-1}$
Maximum grazing rate at 0 deg C	g_{max}	ZS on PS	0.8 d^{-1}
		ZL on PS	0.1 d^{-1}
		ZL on PL	0.4 d^{-1}
		ZP on PL	0.2 d^{-1}
		ZL on ZS	0.4 d^{-1}
		ZP on ZS	0.2 d^{-1}
		ZP on ZL	0.2 d^{-1}
Temperature coefficient for grazing	K_{Gra}	ZS	0.0693 (deg $C)^{-1}$
		ZL	0.0693 (deg $C)^{-1}$
		ZP	0.0693 (deg $C)^{-1}$
		gel. zoo.	0.0693 (deg $C)^{-1}$
		pred. zoo.	0.0693 (deg $C)^{-1}$
Mixed layer depth, annual average	MLD		80 m
Mixed layer temperature, annual average	T_{avg}		8.26 deg C

Table S18: Biogeochemical process-related parameters: Egestion and excretion

Parameter	Symbol	Group	Value
Assimilation efficiency	α_{eg}	ZS	0.7
		ZL	0.7
		ZP	0.7
Growth efficiency	β_{eg}	ZS	0.3
		ZL	0.3
		ZP	0.3

Table S19: Biogeochemical process-related parameters: Decomposition

Parameter	Symbol	Group	Value
Decomposition (or nitrification) rate	V_{Dec}	NH_4 to NO_3	0.03 d^{-1}
		PON to NH_4	0.1 d^{-1}
		PON to DON	0.1 d^{-1}
		DON to NH_4	0.02 d^{-1}
		Opal to $SiOH_4$	0.04 d^{-1}
Temperature coefficient for decomposition	K_{Dec}	NH_4 to NO_3	0.0693 (deg C)$^{-1}$
		PON to NH_4	0.0693 (deg C)$^{-1}$
		PON to DON	0.0693 (deg C)$^{-1}$
		DON to NH_4	0.0693 (deg C)$^{-1}$
		Opal to $SiOH_4$	0.0693 (deg C)$^{-1}$

Table S20: Biogeochemical process-related parameters: Mortality

Parameter	Symbol	Group	Value
Mortality rate at 0 deg C	Mor_0	PS	0.0585 d^{-1}
		PL	0.029 d^{-1}
		ZS	0.0585 d^{-1}
		ZL	0.0585 d^{-1}
		ZP	0.0585 d^{-1}
Temperature coefficient for mortality	K_{Mor}	PS	0.0693 (deg C)$^{-1}$
		PL	0.0693 (deg C)$^{-1}$
		ZS	0.0693 (deg C)$^{-1}$
		ZL	0.0693 (deg C)$^{-1}$
		ZP	0.0693 (deg C)$^{-1}$

Table S21: Derived parameters used in the equations in Section 2. These parameters vary over time as a function of the state variables from both the physical and biological models.

Parameter Name	Symbol	Definition
Nitrogen limitation	L_N	$\frac{NO_3}{K_{NO_3}+NO_3} \cdot \exp\left(-\psi NH_4\right) + \frac{NH_4}{K_{NH_4}+NH_4}$
Silica limitation	L_{Si}	$\frac{SiOH_4}{K_{SiOH_4}+SiOH_4}$
Iron limitation	L_{Fe}	$\frac{R^2_{Fe:C}}{K^2_{Fe:C}+R^2_{Fe:C}}$
Iron limitation (quota model)	L_{Fe}	$\frac{B_{Fe}}{K_{Fe}+B_{Fe}}$
Iron deficiency	D_{Fe}	$\frac{R^2_{Fe:N}}{K^2_{Fe:N}+R^2_{Fe:N}}$
f-ratio	f	$\frac{\frac{NO_3}{K_{NO_3}+NO_3}\cdot\exp(-\psi NH_4)}{\frac{NO_3}{K_{NO_3}+NO_3}\cdot\exp(-\psi NH_4)+\frac{NH_4}{K_{NH_4}+NH_4}}$
Total nutrient limitation	L_{nut}	$\min\left(L_N, L_{Si}, L_{Fe}\right)$
Total nutrient limitation (quota model)	L_{nut}	$\min\left(L_N, L_{Si}, D_{Fe}\right)$
Light limitation	L_{light}	$1 - \exp\left(\frac{\alpha I_z}{V_{max}}\right)$
Empirical Fe:C ratio	R_{0i}	$b_{Fe,i} Fe_z^{a_{Fe,i}}$
Realized Fe:C ratio	R_i	$\frac{B_{Fe,i}}{B_i \cdot R_{C:N}}$
Realized Fe:N ratio	$R_{Fe:N}$	$\frac{B_{Fe,i}}{B_i}$
Ligand-binding parameter	K_{Lig}	$10^{\left(\log_{10}(K_{LigLo})-\frac{I_z}{K_{Iscav}+I_z}\right)\left(\log_{10}(K_{LigLo})-\log_{10}(K_{LigHi})\right)}$

Table S22: Group-related, Ecopath-derived parameters for the water column ecosystem model, including mass-balanced biomass (B^*), growth efficiency (GE), non-pedatory mortality flux (M0), and unassimilated fraction (GS). Where values vary across ensemble members, mean, standard deviation, minimum, and maximum values, calculated across the 500 ensemble members, are given

Group	B^* (mmol N m^{-2})				GE				M0 (mmol N m^{-2} s^{-1})				GS
	mean	std	min	max	mean	std	min	max	mean	std	min	max	
Albatross	1.48e-08	4.36e-09	7.59e-09	2.26e-08	0.000609	0.000155	0.000323	0.001	2.21e-17	9.08e-18	5.68e-18	4.81e-17	0.2
Mammals,sharks	1.94e-05	9.2e-06	6.69e-06	4.24e-05	0.0143	0.00533	0.00485	0.0299	1.12e-13	6.53e-14	1.79e-14	3.53e-13	0.2
Neon flying squid	0.000171	7.53e-05	3.41e-05	0.000304	0.646	0.276	0.192	1.59	6.14e-12	5.55e-12	3.49e-14	2.73e-11	0.2
Orcas	1.07e-08	3.01e-09	5.32e-09	1.58e-08	0.00232	0.000601	0.0012	0.00385	8.72e-18	3.2e-18	3.05e-18	1.74e-17	0.2
Boreal clubhook squid	4.78e-06	2e-06	9.3e-07	8.14e-06	0.408	0.228	0.0961	1.27	3.24e-13	2.14e-13	6.75e-17	9.84e-13	0.2
Seabirds 1	6.33e-08	1.76e-08	3.13e-08	9.38e-08	0.00089	0.000233	0.000454	0.0015	1.68e-16	6.25e-17	4.74e-17	3.42e-16	0.2
Pomfret	8.64e-05	3.4e-05	1.59e-05	0.000142	0.2	1.75e-15	0.2	0.2	1.21e-12	8.56e-13	8.47e-15	3.77e-12	0.2
Seabirds 2	2.13e-07	6.02e-08	1.07e-07	3.2e-07	0.000941	0.000248	0.000503	0.00156	6.57e-16	2.55e-16	2.05e-16	1.39e-15	0.2
Gonatid squid	1.19e-05	5.11e-06	2.29e-06	2.04e-05	0.403	0.217	0.101	1.25	8.46e-13	5.65e-13	9.28e-15	2.4e-12	0.2
Salmon	7.13e-05	2.02e-05	3.59e-05	0.000107	0.141	0.0138	0.112	0.174	3.06e-12	1.19e-12	1.41e-13	6.03e-12	0.2
Baleen whales	1.28e-05	3.58e-06	6.42e-06	1.91e-05	0.00423	0.00114	0.00213	0.00709	7.14e-15	3.07e-15	8.34e-16	1.54e-14	0.2
Micronektonic squid	0.000391	0.000345	7.6e-05	0.00327	0.27	0.157	0.0527	0.903	3.3e-12	1.91e-12	1.02e-12	1.87e-11	0.2
Mesopelagic fish	0.00168	0.000769	0.000354	0.00304	0.384	0.254	0.0836	1.42	4.03e-11	2.77e-11	2.77e-13	1.27e-10	0.2
Pelagic forage fish	0.000377	0.000253	4.32e-05	0.0015	0.365	0.235	0.0779	1.47	1.55e-12	8.19e-13	2.96e-13	4.75e-12	0.2
Saury	0.000193	6.81e-05	3.93e-05	0.000305	0.281	0.183	0.0554	1.02	6.26e-12	4.68e-12	2.31e-14	2.19e-11	0.2
Jellyfish	0.00141	0.00071	0.000316	0.00271	0.385	0.261	0.0551	1.6	1.34e-10	9.2e-11	1.22e-11	4.31e-10	0.2
Predatory zooplankton	0.00367	0.00171	0.00142	0.00792	0.463	0.287	0.0644	1.6	7.13e-10	5.37e-10	1.29e-11	2.72e-09	0.3
Large zooplankton	0.00613	0.00229	0.00136	0.0105	0.45	0.217	0.0898	1.12	7.65e-10	6.13e-10	1.97e-13	2.85e-09	0.3
Gelatinous zooplankton	0.00117	0.000339	0.000588	0.00175	0.387	0.265	0.06	1.51	2.07e-10	1.25e-10	1.66e-12	5.91e-10	0.3
Copepods	0.00787	0.000478	0.0071	0.00867	0.372	0.0754	0.209	0.537	2.01e-09	1.14e-09	4.75e-12	5.28e-09	0.3
Microzooplankton	0.00637	0.000369	0.00571	0.00698	0.339	0.0816	0.201	0.537	1.62e-09	1.15e-09	2.32e-12	5.11e-09	0.3
Small phytoplankton	0.0189	0.00338	0.00907	0.024	0	0	0	0	1.28e-08	8.25e-09	5.77e-12	3.54e-08	0
Large phytoplankton	0.012	0.00356	0.00448	0.0183	0	0	0	0	8.11e-09	4.83e-09	7.81e-15	1.87e-08	0
PON	0.0379	0.0022	0.034	0.0415	0	0	0	0	0	0	0	0	0

Table S23: Flux-related, Ecopath-derived parameters for the water column ecosystem model, including mass-balanced prey-to-predator flux (Q^*), functional response top-down parameter (X), functional response bottom-up parameter (D), and functional response exponent (θ). Where values vary across ensemble members, mean, standard deviation, minimum, and maximum values, calculated across the 500 ensemble members, are given

Predator	Prey	Q^* (mmol N m^{-2} s^{-1})				X	D				θ
		mean	std	min	max		mean	std	min	max	
Albatross	Neon flying squid	2.57e-14	8.76e-15	9.84e-15	5.46e-14	2	1e+03	0	1e+03	1e+03	2
Albatross	Boreal clubhook squid	7.43e-16	4.24e-16	1.08e-16	2.51e-15	2	1e+03	0	1e+03	1e+03	2
Albatross	Gonatid squid	1.88e-15	1.03e-15	3.42e-16	6.64e-15	2	1e+03	0	1e+03	1e+03	2
Albatross	Micronektonic squid	1.96e-15	1.15e-15	2.92e-16	7.07e-15	2	1e+03	0	1e+03	1e+03	2
Albatross	Pelagic forage fish	4e-15	2.27e-15	5.49e-16	1.33e-14	2	1e+03	0	1e+03	1e+03	2
Albatross	Saury	4.01e-15	2.31e-15	4.61e-16	1.48e-14	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Neon flying squid	2.06e-12	1.32e-12	3.2e-13	7.83e-12	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Boreal clubhook squid	5.42e-14	3.6e-14	4.95e-15	2.02e-13	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Pomfret	8.2e-13	4.73e-13	1.35e-13	2.9e-12	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Gonatid squid	1.41e-13	9.48e-14	1.74e-14	5.69e-13	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Salmon	7.9e-13	4.32e-13	1.51e-13	2.64e-12	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Micronektonic squid	1.14e-12	7.98e-13	1.49e-13	5.9e-12	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Mesopelagic fish	4.18e-13	2.85e-13	3.32e-14	1.76e-12	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Pelagic forage fish	9.59e-13	6.49e-13	1.03e-13	3.9e-12	2	1e+03	0	1e+03	1e+03	2
Mammals,sharks	Saury	1.87e-12	1.27e-12	2.17e-13	7.88e-12	2	1e+03	0	1e+03	1e+03	2
Neon flying squid	Neon flying squid	7.35e-12	4.91e-12	5.37e-13	3.16e-11	2	1e+03	0	1e+03	1e+03	2
Neon flying squid	Micronektonic squid	6.51e-12	4.89e-12	4.39e-13	3.14e-11	2	1e+03	0	1e+03	1e+03	2
Neon flying squid	Mesopelagic fish	3e-12	2.3e-12	1.2e-13	1.25e-11	2	1e+03	0	1e+03	1e+03	2
Neon flying squid	Pelagic forage fish	9.49e-12	7.14e-12	5.08e-13	4.07e-11	2	1e+03	0	1e+03	1e+03	2
Neon flying squid	Saury	1.56e-12	1.2e-12	8.73e-14	8.18e-12	2	1e+03	0	1e+03	1e+03	2
Orcas	Albatross	1.17e-18	6.34e-19	1.7e-19	3.52e-18	2	1e+03	0	1e+03	1e+03	2
Orcas	Mammals,sharks	4.54e-16	2.58e-16	5.37e-17	1.46e-15	2	1e+03	0	1e+03	1e+03	2
Orcas	Neon flying squid	1.76e-16	8.56e-17	3.17e-17	5.03e-16	2	1e+03	0	1e+03	1e+03	2
Orcas	Boreal clubhook squid	4.79e-18	2.31e-18	1.08e-18	1.43e-17	2	1e+03	0	1e+03	1e+03	2
Orcas	Seabirds 1	5.26e-18	2.98e-18	8.76e-19	1.79e-17	2	1e+03	0	1e+03	1e+03	2
Orcas	Pomfret	2.3e-16	9.86e-17	5.73e-17	5.37e-16	2	1e+03	0	1e+03	1e+03	2
Orcas	Seabirds 2	1.76e-17	9.23e-18	2.8e-18	5.51e-17	2	1e+03	0	1e+03	1e+03	2
Orcas	Gonatid squid	1.18e-17	5.71e-18	2.07e-18	3.29e-17	2	1e+03	0	1e+03	1e+03	2
Orcas	Salmon	2.04e-16	7.17e-17	7.5e-17	4.4e-16	2	1e+03	0	1e+03	1e+03	2
Orcas	Baleen whales	1.03e-15	4.88e-16	2.08e-16	3e-15	2	1e+03	0	1e+03	1e+03	2
Orcas	Micronektonic squid	1.94e-16	1.06e-16	3.32e-17	6.35e-16	2	1e+03	0	1e+03	1e+03	2
Orcas	Pelagic forage fish	1.01e-15	4.62e-16	2.13e-16	2.56e-15	2	1e+03	0	1e+03	1e+03	2
Orcas	Saury	4.64e-16	2.35e-16	7.27e-17	1.42e-15	2	1e+03	0	1e+03	1e+03	2
Boreal clubhook squid	Micronektonic squid	1.08e-12	6.07e-13	1.09e-13	2.86e-12	2	1e+03	0	1e+03	1e+03	2
Boreal clubhook squid	Pelagic forage fish	1.45e-14	1.44e-14	5.85e-16	1.18e-13	2	1e+03	0	1e+03	1e+03	2

Table S24: Flux-related, Ecopath-derived parameters for the water column ecosystem model (continued).

Predator	Prey	Q* (mmol N m^{-2} s^{-1})				X	D				θ
		mean	std	min	max		mean	std	min	max	
Seabirds 1	Micronektonic squid	8.28e-14	3.57e-14	1.96e-14	1.94e-13	2	1e+03	0	1e+03	1e+03	2
Seabirds 1	Pelagic forage fish	6.01e-14	2.99e-14	1.07e-14	1.71e-13	2	1e+03	0	1e+03	1e+03	2
Seabirds 1	Saury	5.47e-14	2.84e-14	9.13e-15	1.47e-13	2	1e+03	0	1e+03	1e+03	2
Pomfret	Micronektonic squid	7.36e-12	3.42e-12	1.13e-12	1.81e-11	2	1e+03	0	1e+03	1e+03	2
Pomfret	Mesopelagic fish	9.05e-13	6.44e-13	7.34e-14	4.41e-12	2	1e+03	0	1e+03	1e+03	2
Pomfret	Saury	4.57e-13	3.17e-13	3.06e-14	2.2e-12	2	1e+03	0	1e+03	1e+03	2
Pomfret	Predatory zooplankton	3.41e-13	2.49e-13	2.37e-14	1.59e-12	2	1e+03	0	1e+03	1e+03	2
Pomfret	Large zooplankton	9.92e-13	6.56e-13	6.5e-14	3.67e-12	2	1e+03	0	1e+03	1e+03	2
Pomfret	Copepods	1.13e-13	6.98e-14	1.28e-14	5.13e-13	2	1e+03	0	1e+03	1e+03	2
Seabirds 2	Micronektonic squid	2.02e-13	9.16e-14	4.44e-14	6.04e-13	2	1e+03	0	1e+03	1e+03	2
Seabirds 2	Pelagic forage fish	2.01e-13	1.01e-13	3.58e-14	6.42e-13	2	1e+03	0	1e+03	1e+03	2
Seabirds 2	Saury	1.98e-13	9.4e-14	4.29e-14	5.6e-13	2	1e+03	0	1e+03	1e+03	2
Seabirds 2	Large zooplankton	7.15e-14	3.48e-14	1.22e-14	2.01e-13	2	1e+03	0	1e+03	1e+03	2
Seabirds 2	Copepods	5.44e-14	2.32e-14	1.66e-14	1.65e-13	2	1e+03	0	1e+03	1e+03	2
Gonatid squid	Micronektonic squid	9.02e-13	5.9e-13	5.53e-14	3.25e-12	2	1e+03	0	1e+03	1e+03	2
Gonatid squid	Pelagic forage fish	2.94e-14	2.22e-14	1.26e-15	1.37e-13	2	1e+03	0	1e+03	1e+03	2
Gonatid squid	Predatory zooplankton	3.3e-13	2.3e-13	1.11e-14	1.11e-12	2	1e+03	0	1e+03	1e+03	2
Gonatid squid	Large zooplankton	8.73e-13	5.58e-13	5.5e-14	3.05e-12	2	1e+03	0	1e+03	1e+03	2
Gonatid squid	Copepods	6.87e-13	4.2e-13	6.89e-14	2.22e-12	2	1e+03	0	1e+03	1e+03	2
Salmon	Micronektonic squid	2.25e-12	1.19e-12	3.82e-13	6.51e-12	2	1e+03	0	1e+03	1e+03	2
Salmon	Mesopelagic fish	2.96e-12	1.46e-12	5.14e-13	7.65e-12	2	1e+03	0	1e+03	1e+03	2
Salmon	Pelagic forage fish	3.07e-12	1.61e-12	4.94e-13	9.36e-12	2	1e+03	0	1e+03	1e+03	2
Salmon	Predatory zooplankton	1.46e-13	8.08e-14	2.17e-14	4.81e-13	2	1e+03	0	1e+03	1e+03	2
Salmon	Large zooplankton	1.24e-11	4.48e-12	3.1e-12	2.49e-11	2	1e+03	0	1e+03	1e+03	2
Salmon	Gelatinous zooplankton	3.67e-12	1.88e-12	4.84e-13	1.03e-11	2	1e+03	0	1e+03	1e+03	2
Salmon	Copepods	2.93e-12	1.08e-12	8.73e-13	6.95e-12	2	1e+03	0	1e+03	1e+03	2

Table S25: Flux-related, Ecopath-derived parameters for the water column ecosystem model (continued).

Predator	Prey	Q^* (mmol N m^{-2} s^{-1})				X	D				θ
		mean	std	min	max		mean	std	min	max	
Baleen whales	Neon flying squid	4.62e-14	2.29e-14	7.95e-15	1.32e-13	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Boreal clubhook squid	1.17e-15	6.03e-16	2.71e-16	3.24e-15	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Pomfret	5.82e-15	2.65e-15	1.38e-15	1.56e-14	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Gonatid squid	3.12e-15	1.56e-15	6.28e-16	9.66e-15	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Salmon	5.33e-15	1.86e-15	1.81e-15	1.17e-14	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Micronektonic squid	5e-14	2.71e-14	9.15e-15	1.4e-13	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Mesopelagic fish	1.25e-13	6.71e-14	1.93e-14	3.59e-13	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Pelagic forage fish	1.48e-13	7.72e-14	2.25e-14	4.47e-13	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Saury	1.29e-14	7.32e-15	1.6e-15	4.04e-14	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Predatory zooplankton	2.76e-13	1.46e-13	5.12e-14	8.78e-13	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Large zooplankton	7.11e-13	2.76e-13	2.25e-13	1.78e-12	2	1e+03	0	1e+03	1e+03	2
Baleen whales	Copepods	5.75e-13	2.09e-13	1.72e-13	1.25e-12	2	1e+03	0	1e+03	1e+03	2
Micronektonic squid	Micronektonic squid	1.01e-11	1.49e-11	4e-13	1.35e-10	2	1e+03	0	1e+03	1e+03	2
Micronektonic squid	Predatory zooplankton	3.17e-11	4.28e-11	1.57e-12	4.82e-10	2	1e+03	0	1e+03	1e+03	2
Micronektonic squid	Large zooplankton	8.07e-11	9.26e-11	5.6e-12	9.08e-10	2	1e+03	0	1e+03	1e+03	2
Micronektonic squid	Copepods	6.58e-11	8.2e-11	5.39e-12	8.47e-10	2	1e+03	0	1e+03	1e+03	2
Mesopelagic fish	Predatory zooplankton	3.38e-11	2.58e-11	2.18e-12	1.83e-10	2	1e+03	0	1e+03	1e+03	2
Mesopelagic fish	Large zooplankton	6.77e-11	4.58e-11	3.91e-12	2.31e-10	2	1e+03	0	1e+03	1e+03	2
Mesopelagic fish	Copepods	5.61e-11	3.82e-11	4.06e-12	2.06e-10	2	1e+03	0	1e+03	1e+03	2
Pelagic forage fish	Predatory zooplankton	1.03e-11	9.67e-12	8.2e-13	7.52e-11	2	1e+03	0	1e+03	1e+03	2
Pelagic forage fish	Large zooplankton	2.78e-11	2.35e-11	1.84e-12	1.48e-10	2	1e+03	0	1e+03	1e+03	2
Pelagic forage fish	Copepods	2.22e-11	1.92e-11	1.66e-12	1.58e-10	2	1e+03	0	1e+03	1e+03	2
Saury	Predatory zooplankton	6.17e-12	4.45e-12	3.37e-13	2.5e-11	2	1e+03	0	1e+03	1e+03	2
Saury	Large zooplankton	1.72e-11	1.1e-11	1.74e-12	5.81e-11	2	1e+03	0	1e+03	1e+03	2
Saury	Copepods	2.44e-11	1.45e-11	2.52e-12	7.74e-11	2	1e+03	0	1e+03	1e+03	2
Jellyfish	Predatory zooplankton	3.55e-11	2.93e-11	2.15e-12	1.75e-10	2	1e+03	0	1e+03	1e+03	2
Jellyfish	Large zooplankton	9.09e-11	6.77e-11	4.18e-12	4.12e-10	2	1e+03	0	1e+03	1e+03	2
Jellyfish	Gelatinous zooplankton	3.58e-11	3.17e-11	1.92e-12	1.99e-10	2	1e+03	0	1e+03	1e+03	2
Jellyfish	Copepods	2.67e-10	1.92e-10	2.03e-11	1.01e-09	2	1e+03	0	1e+03	1e+03	2

Table S26: Flux-related, Ecopath-derived parameters for the water column ecosystem model (continued).

Predator	Prey	Q* (mmol N m^{-2} s^{-1})				X	D				θ
		mean	std	min	max		mean	std	min	max	
Predatory zooplankton	Large zooplankton	3.92e-10	2.36e-10	2.98e-11	1.51e-09	1e+03	44.8	26.3	11.3	177	2
Predatory zooplankton	Copepods	1.65e-09	7.99e-10	2.88e-10	4e-09	1e+03	10.6	5.02	3.92	25.6	2
Large zooplankton	Copepods	1.5e-09	7.67e-10	2.24e-10	5.01e-09	1e+03	19.4	7.89	6.78	45.8	2
Large zooplankton	Microzooplankton	1.47e-09	7.21e-10	2.13e-10	3.63e-09	1e+03	19.5	7.79	7.6	45.2	2
Large zooplankton	Large phytoplankton	7.55e-10	3.98e-10	1.25e-10	2.61e-09	1e+03	21.9	14.9	6.45	88.6	2
Gelatinous zooplankton	Copepods	1.96e-10	1.1e-10	2.84e-11	6e-10	1e+03	30.8	16.7	10	114	2
Gelatinous zooplankton	Microzooplankton	1.98e-10	1.08e-10	3.08e-11	6.14e-10	1e+03	31	17.5	10.3	102	2
Gelatinous zooplankton	Large phytoplankton	3.91e-10	2.08e-10	6.52e-11	1.07e-09	1e+03	13	6.39	6.02	39.5	2
Copepods	Microzooplankton	4.61e-09	9.88e-10	2.54e-09	7.3e-09	1e+03	14.8	3.24	8.44	26.9	2
Copepods	Small phytoplankton	4.95e-09	1.42e-09	2.39e-09	1.07e-08	1e+03	3.54	0.939	1.58	6.36	2
Copepods	Large phytoplankton	6.61e-09	1.75e-09	3.18e-09	1.26e-08	1e+03	10.5	2.56	5.07	19.1	2
Microzooplankton	Small phytoplankton	2.46e-08	6e-09	1.46e-08	3.83e-08	1e+03	4.52	1.06	2.89	6.72	2

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