NOAA Technical Memorandum NMFS-AFSC-498

Updating and Extending the Ecopath Model of the Southeastern Bering Sea

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June 2025

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
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Alaska Fisheries Science Center

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This document should be cited as follows:

Whitehouse, G. A., Aydin, K. Y., and McHuron, E. A. 2025. Updating and extending the Ecopath model of the southeastern Bering Sea. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-498, 225 p.

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Updating and Extending the Ecopath Model of the Southeastern Bering Sea

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ABSTRACT

Ecopath mass balance food web models are a type of ecosystem model that describes the network of feeding interactions between species in an ecosystem. Ecopath models that include fisheries are critical tools that can support ecosystem-based fisheries management by improving our understanding of how ecosystems operate and providing a framework for testing and evaluating management strategies. The Ecopath model of the southeastern Bering Sea has seen wide application in ecosystem research and directly contributes model outputs and other indicators to Ecosystem Status Reports that help inform annual quota-setting deliberations of the regional fisheries management council. Presently, the model is included in the Alaska Climate Integrated Modeling Project (ACLIM) of NOAA's Alaska Fisheries Science Center, which uses a suite of models to evaluate the impacts of climate change and alternative fisheries management strategies on fishery resources in the Bering Sea ecosystem. The southeastern Bering Sea Ecopath model has not been updated with new data and rates since originally published in 2007. Here we update this model by extending the model area to better match the existing fishery management regions in the eastern Bering Sea and updating model parameters accordingly to reflect this spatial change. The model area increased in size by 33,569 km^2, for a total area of 533,102 km^2. Additionally, we updated the marine mammal functional groups with improved information on species abundance, distribution, diet composition, and prey consumption rates with estimates utilizing species-specific bioenergetics models to better estimate energy requirements that reflect sex- and age-specific variation in energy needs. We also updated the diet compositions of several benthic invertebrate functional groups. We evaluated the changes made to the model by comparing a number of model metrics with the original model. Overall, the updated model has changed little from the original model. This was expected as the basic model structure, number of functional groups, and taxonomic composition of functional groups has not changed. There are decreases in total production, total consumption, total energy flow, and total biomass. The changes in the updated model are most apparent when examining the parameters of individual functional groups. Most of the changes are a reflection of the larger spatial domain in the updated model, primarily having minor impacts to a group's density and total biomass. Changes in the diet compositions of benthic invertebrates led to lower biomass of benthic microbes, which contributed to the lower total energy flow in the system. Given the updated model domain more closely reflecting fishery management regions and the updated parameters having improved data quality grades, we recommend using this updated Ecopath model over the original model for future modeling studies of the southeastern Bering Sea.

CONTENTS

INTRODUCTION

Marine ecosystems are faced with multiple stressors that can impact the health of ecosystems, the viability of fisheries, and the social and cultural connections people have with marine ecosystems (Allison and Bassett 2015, Pecl et al. 2017). Ecosystem-based fisheries management (EBFM) is an approach to fisheries management that takes into consideration the broader network of connections between organisms in a food web, beyond target species. EBFM considers how impacts from multiple stressors, such as fisheries and climate change, may be transmitted throughout the ecosystem impacting the ecological status and function of the system as a whole, and impacts to human wellbeing (National Marine Fisheries Service 2024). To implement EBFM, it is necessary to utilize modeling to help decision-makers grapple with a range of potential outcomes to policy options in order to make informed decisions, given the uncertainty about future ecosystem states (Walters and Martell 2004, Hill et al. 2007). Ecosystem models are critical tools that can support EBFM by improving our understanding of how ecosystems operate and by providing a framework for testing and evaluating management strategies, the impacts of climate change, and identifying tradeoffs and unintended consequences to both target and non-target species that may arise from different policy options (Townsend et al. 2019, Craig and Link 2023).

Food web models are a type of ecosystem model that describes the network of trophic interactions and material flows between species and across all trophic levels in an ecosystem, including fisheries (Hollowed et al. 2000, Plagányi 2007). Food web models of marine ecosystems in Alaska have been in use since at least the late 1970s, when Laevastu et al. (1979) developed mass-balance ecosystem models to estimate equilibrium biomasses for species in the eastern Bering Sea and Gulf of Alaska. Subsequent analyses with the models of Laevastu et al. (1979) were crucial to the early development of ecosystem considerations in the management of Alaska groundfish fisheries by modeling the consequences of single-species management decisions in a food web framework (Low 1983).

Ecopath (Polovina 1984) is the most widely used food web modeling framework for marine ecosystems globally, with hundreds of published models spanning ecosystems from the tropics to the poles (Colléter et al. 2015). The first Ecopath model of the eastern Bering Sea was developed by Trites et al. (1999) to evaluate hypotheses on why multiple marine mammal stocks had declined between the 1950s and 1980s. This Ecopath model of the eastern Bering Sea was later used to conduct a comparative study with the western Bering Sea to highlight differences in production and major energy pathways (Aydin et al. 2002). Additionally, this model was used to test hypotheses regarding the decline of Steller sea lions (NRC 2003). While the Trites et al. (1999) model of the eastern Bering Sea was useful for a variety of applications, its usefulness to resource managers was limited in part due to a lack of species- or stock-specific information and the geographic resolution of data used to parameterize the model.

Aydin et al. (2007) developed an improved Ecopath model of the eastern Bering Sea using an independent implementation of the Ecopath with Ecosim algorithms. The Aydin et al. (2007) model addressed many of the limitations of the Trites et al. (1999) model with higher species and geographic resolution, and with a spatial domain designed to better coincide with the known distribution of several important commercial groundfish stocks and the existing federal fisheries management regions. This model has been used in a range of studies including comparative analyses with other ecosystems (Aydin et al. 2007, Gaichas et al. 2009, Whitehouse et al. 2014), an examination of food web structure and important energetic pathways (Gaichas et al. 2015), assessing food web resilience (Aydin and Mueter 2007, Whitehouse and Aydin 2020), and in the evaluation of fisheries management strategies under ongoing climate change (Whitehouse et al. 2021). Additionally, a trawl survey index that incorporates catchability coefficients derived from the balanced eastern Bering Sea Ecopath model biomasses is used to calculate a number of ecosystem indicators featured in Ecosystem Status Reports that are presented to the North Pacific Fishery Management Council for consideration during their annual quota-setting deliberations (Boldt 2007, for a more recent example see Siddon 2024). The Aydin et al. (2007) eastern Bering Sea model is presently in use as part of the NOAA Fisheries' Alaska Climate Integrated Modeling Project (ACLIM), which utilizes a suite of biological models of varying complexity to examine the response of the Bering Sea ecosystem to climate change and to evaluate fisheries management strategies (Hollowed et al. 2020).

The spatial domain of the Aydin et al. (2007) eastern Bering Sea Ecopath model (Fig. 1) was in part defined by the spatial boundaries of annual and biennial trawl surveys conducted by NOAA's Alaska Fisheries Science Center (AFSC) of the eastern Bering Sea continental shelf, the eastern Bering Sea upper continental slope, and the continental shelf of the Aleutian Islands region. These trawl surveys provided large amounts of data used to parameterize the model and the survey areas (or portions thereof) closely aligned with known species distributions and fishery management regions. The Aydin et al. (2007) model area included eastern Bering Sea shelf waters between 25 and 200 m depth and the upper continental slope from 200 to 1,000 m depth. Additionally, the model area included a portion of the Aleutian Islands bottom trawl survey area, along the northern side of the archipelago between 170 and 165°W and down to a depth of 500 m (a.k.a., "the horseshoe"). The total model area was approximately 495,218 km^2. This model area did not include the AFSC eastern Bering Sea shelf bottom trawl survey strata 90 and 82, hereafter referred to as the "northwest corner" (Fig. 1). The northwest corner was not sampled in the early years of the eastern Bering Sea shelf groundfish survey and was not added to the annual groundfish survey until 1987. These added stations were intended to better monitor northerly distributions of commercial species and to better align with existing commercial fishing grounds (Markowitz et al. 2023).

Here, we update the eastern Bering Sea Ecopath model of Aydin et al. (2007) and expand the model footprint to include the northwest corner to more closely align with existing fishery management regions in the eastern Bering Sea and areas designated for habitat protection and subject to partial or complete closure to commercial fisheries (Fig. 2). Additionally, the AFSC bottom trawl survey of the upper continental slope has consistently sampled down to 1,200 m depth in surveys conducted since 2002. Thus, we have expanded the model area down to a depth of 1,200 m from 1,000 m. The total area of the updated model is the sum of survey stratum area estimates from Markowitz et al. (2022), Hoff (2016), and von Szalay and Raring (2020), for the eastern Bering Sea shelf, eastern Bering Sea slope, and Aleutian Islands surveys respectively, totaling 533,102.49 km^2. In this updated model footprint, the northwest corner contributed 29,522 km^2, while the deepest strata of the slope survey (1,000–1,200 m depth) added 4,047 km^2. Adding the northwest corner and expanding the lower depth limit of the model area along the eastern Bering Sea slope has required revisions to a number of base model parameters and prompted a review of all other model parameters.

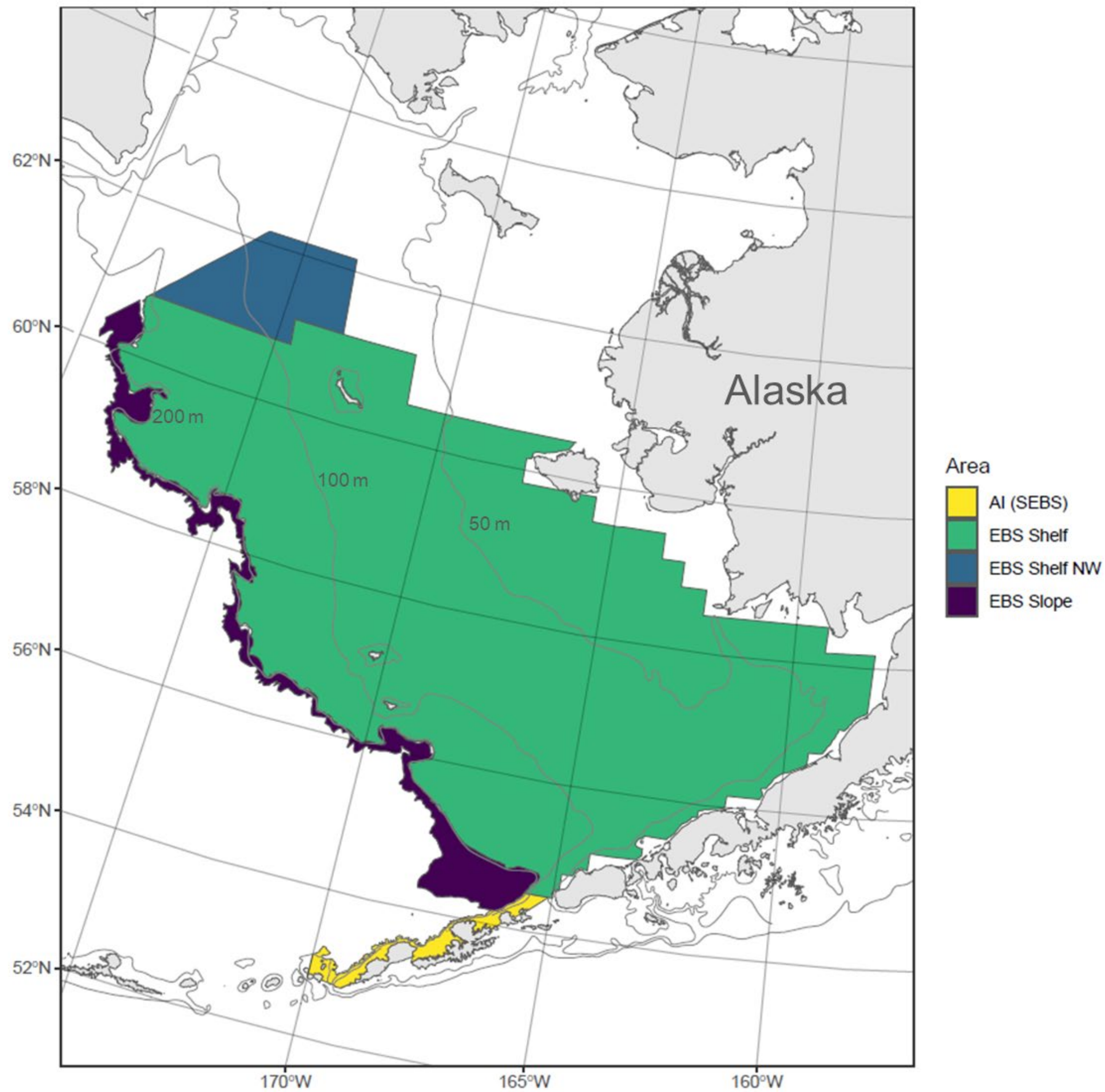

Figure 1. -- The area encompassed by the eastern Bering Sea Ecopath model. The model area includes the southeastern Bering Sea strata of the Aleutian Islands survey (AI SEBS), the eastern Bering Sea continental shelf survey area (EBS shelf), the northwest corner of the EBS shelf survey area (EBS shelf NW), and the eastern Bering Sea upper continental slope survey area (EBS slope).

In the original southeastern Bering Sea Ecopath, a number of simplifying assumptions were necessary in order to parameterize several of the marine mammal groups. For example, marine mammal prey consumption was estimated with generalized relationships, primarily derived from studies of non-reproductive captive animals. In this model update, we revisit the parameterization of marine mammal groups and make updates with improved information, utilizing recent datasets and other advancements. Specifically, we updated: 1) how prey consumption estimates of individual marine mammal species were estimated to attempt to better estimate energy requirements and incorporate sex- and age-specific variation in energy needs, 2) marine mammal diet compositions where new information is available, 3) abundance estimates where new estimates or updated information on distribution is available, and 4) the species compositions of functional groups where improved information is available.

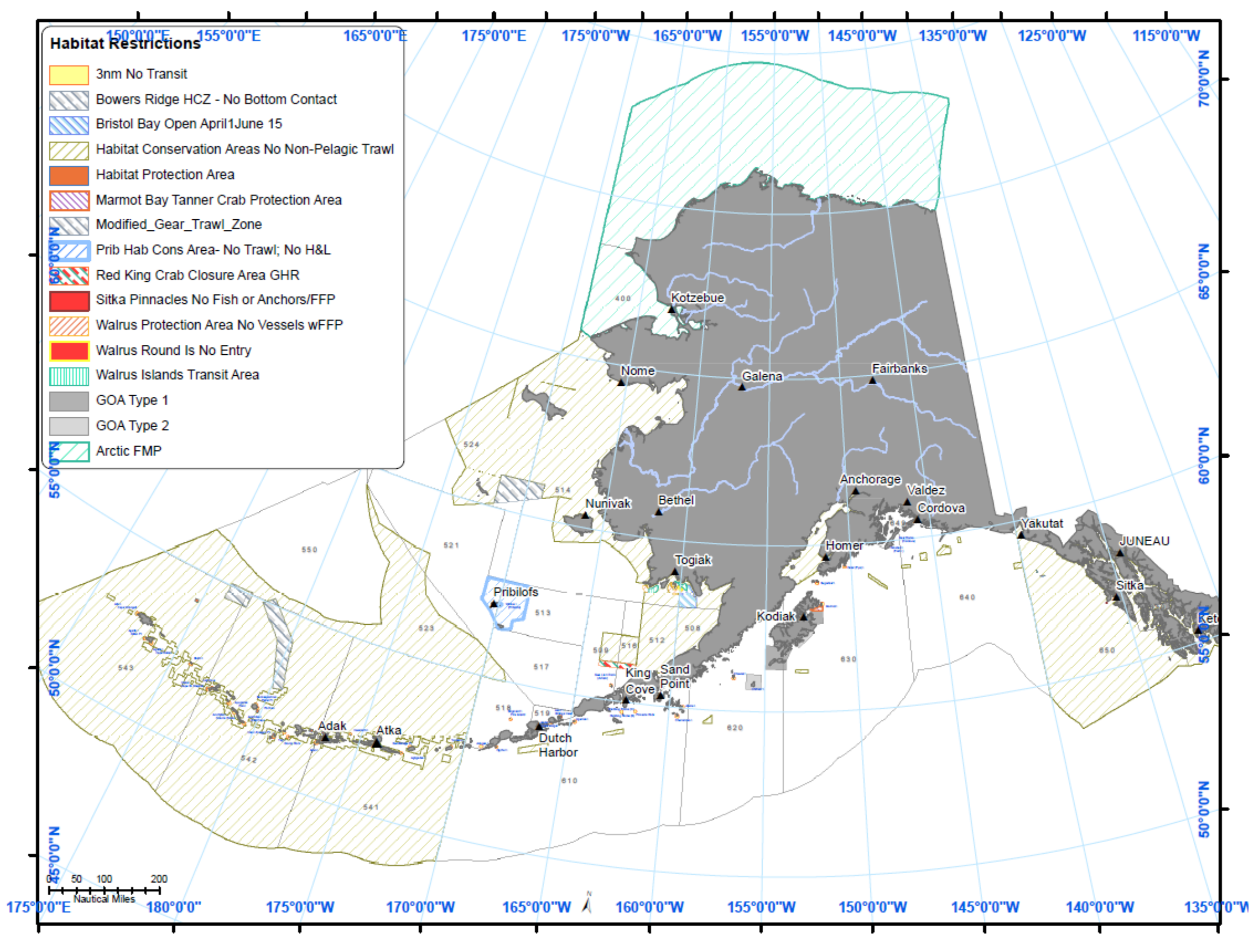

Figure 2. -- Fishery management areas in Alaska along with habitat restrictions, including areas with temporal and/or gear-specific restrictions. Map credit: NOAA Fisheries, https://www.fisheries.noaa.gov/resource/tool-app/habitat-conservation-area-maps

This is the first update of the southeastern Bering Sea Ecopath model since it was published in 2007. The purpose of this report is to detail the process, methods, and results from updating the existing eastern

Bering Sea Ecopath model of Aydin et al. (2007) to reflect the expanded spatial domain, the updated marine mammal parameters, and other updates to model parameters where improved information has become available in the years since the model was first published.

METHODS

General Methodology for Model Update

The general approach to this model update is to follow the same methods used for estimating parameters and inputting data as in the original model (Aydin et al. 2007) wherever possible and to only update parameters when necessary to either accommodate the new spatial boundaries or where improved data or parameter estimates are now available. The Aydin et al. (2007) model was configured around the base time period of the early 1990s and we maintain that reference period in this model update.

Modeling Framework

Ecopath is a static, mass balance food web model that describes the network of material exchanges between groups in a food web (Polovina 1984, Christensen and Pauly 1992). Ecopath was originally developed by Polovina (1984) to describe a coral reef ecosystem and has since been applied to hundreds of ecosystems around the globe, from the tropics to high-latitude ecosystems (Colléter et al. 2015). Ecopath is a biomass compartment model where each compartment represents a species or functional group of multiple species, and describes the energy flows between these groups as mediated by their trophic interactions and through other non-predatory processes such as fisheries and emigration/immigration, among others. The mass balance requirement ensures that production by a functional group is sufficient to match removals by predators, fisheries, and other processes included in the model. The balanced model provides a snapshot of ecosystem structure and energy flow and can be used to calculate metrics that describe ecosystem attributes (Christensen 1995, Fulton et al. 2005, Samhouri et al. 2009). Ecosim is the time-dynamic counterpart of Ecopath which allows for simulations, hypothesis testing, and policy exploration (Walters et al. 1997, Walters et al. 2000, Christensen and Walters 2004). For this Ecopath model update, we use Rpath (Lucey et al. 2020, https://github.com/NOAA-EDAB/Rpath), an independent implementation of the published Ecopath and Ecosim algorithms developed for use with the statistical computing program R (R Core Team 2023). Any differences in model outputs between Ecopath models constructed with Rpath and Ecopath with Ecosim can largely be attributed to rounding differences between the two platforms (Lucey et al. 2020). The focus of this model update and subsequent analyses is on the static, mass-balanced model (i.e., Ecopath) of the eastern Bering Sea. We save dynamic simulations and related analyses, such as sensitivity analysis and model fitting, for future work.

Under the assumption of equilibrium conditions, the interactions between groups are described by a set of linear equations in Rpath. For each group (*i*) with predators (*j*) this is expressed as:

$$B_i * \left(\frac{P}{B}\right)_i * EE_i = \sum_{j=1}^{n} B_j * \left(\frac{Q}{B}\right)_j * DC_{ij} + C_i \, , \qquad (1)$$

where *B* is biomass (t km^{-2}), *P/B* is the rate of production per unit biomass (yr^{-1}), *EE* is ecotrophic efficiency, which is the proportion of a groups production accounted for within the model (*EE ≤ 1*), *Q/B* is the rate of consumption per unit biomass, DC_{ij} is the proportion of prey *i* in the diet of predator *j*, and *C* is fishery catch (t km^{-2}). In Rpath, mass balance is achieved by solving this set of linear equations for one missing parameter, typically *EE*. When a reliable estimate of biomass is unavailable for a group, *EE* can be set to an arbitrary value and the equation solved for biomass. We refer to this as a “top-down balance” because the model is estimating biomass based on top-down pressure from predators and fisheries. *EE* is generally unmeasurable but is thought to be close to 1 for groups that are subject high levels of predation and/or fisheries exploitation, and close to zero for groups that have few predators and low fishing pressure (Christensen and Walters 2024). All top-down balancing in the original eastern Bering Sea Ecopath model was done with EE set equal to 0.8 (Aydin et al. 2007), and we follow that same approach here. An EE of 0.8 means the model is accounting for 80% of the total mortality of a group through predation and fisheries removals included in the model. This implies that other sources of mortality not explicitly represented in the model (a.k.a., $M0_i = 1\text{-}EE_i$), including disease, senescence, and starvation, account for the remaining 20% of total mortality. Other mortality (*M0*) is generally not measurable in nature. Applying a uniform percentage of 20% to unexplained mortality is consistent with dynamic fits of unexplained mortality across a range of species and allows for a standardized analysis (Aydin et al. 2007).

Energy balance within a functional group is ensured with the equation:

$$Q_i = P_i + R_i + U_i \text{ ,} \qquad (2)$$

where Q_i is total consumption, P_i is total production, R_i is respiration, and U_i is the proportion of consumption that is unassimilated. In this equation, the amount of energy "going in" to a functional group is equal to the sum of its growth (production), maintenance and metabolic costs (respiration), and food that is otherwise unassimilated. Parameters Q_i and P_i are derived from Ecopath input parameters (i.e., $Q_i = B_i*[Q/B]_I$ and $P_i = B_i*[P/B]_i$) and U_i is also a model input with a default value of 0.2 (Christensen and Walters 2024). Estimates of the proportion of food that is unassimilated are highly variable and influenced by numerous factors including, the predator species, prey quality, the amount of prey consumed, temperature, and gut passage time (Winberg 1960, Conover 1966, Bayne et al. 1988, Bochdansky et al. 1999, Sreenivasan and Heintz 2016). We use the default value of 0.2 for the unassimilated proportion of consumption (*U/Q*) for most groups. For groups whose diet composition consists of at least 50% benthic detritus, we assume the fraction of unassimilated consumption is higher (Welch 1968) and use a default value of 0.4 (Christensen et al. 2008).

Data Pedigree

Whole ecosystem models like Ecopath require the synthesis of a large body of literature to find suitable data to parameterize the functional groups in the model, much of which will vary in quality. Some data and rates will lend themselves to be directly applied to the model while others may require unit conversion and/or modifications to account for spatial and temporal differences with the model framework. We graded all model parameters and data for quality and uncertainty following the same data pedigree as in the original model documentation (Aydin et al. 2007). The parameter and data grades are based on data source, collection methodology, temporal and spatial coverage of the dataset, and taxonomic relevance (Table 1).

Table 1. -- The data pedigree used to grade model parameter quality. B = biomass, P/B = production/biomass ratio, Q/B = consumption/biomass ratio, DC = diet composition, and C = fishery catch or subsistence harvest. This table recreated from Aydin et al. (2007).

	Data pedigree and corresponding data characteristics		
	B, P/B, Q/B, DC, and C		
1	Assessment data are established and substantial, from more than one independent method (from which the best method is selected) with resolution on multiple spatial scales.		
2	Data are a direct estimate but with limited coverage/corroboration, or established regional estimate is available while subregional resolution is poor.		
3	Data are proxy, proxy may have known but consistent bias.		
4	Direct estimate or proxy with high variation/limited confidence or incomplete coverage.		
	B and C		**P/B, Q/B, and DC**
5	Estimate requires inclusion of highly uncertain scaling factors or extrapolation	5	Estimation based on same species but in "historical" time period, or a general model specific to the area.
6	Historical and/or single study only, not overlapping in area or time.	6	For P/B and Q/B, general life history proxies or other Ecopath model. For DC, same species in adjacent region or similar species in the same region.
7	Requires selection between multiple incomplete sources with wide range.	7	General literature review from a wide range of species, or outside the region. For DC, from other Ecopath model.
8	Estimated by Rpath	8	Functional group represents multiple species with diverse life history traits. For P/B and Q/B, estimated by Rpath.

Data Inputs and Parameter Estimation Methods

Marine mammals

Biomass

The biomass estimates of marine mammal groups were calculated from published estimates of abundance (e.g., stock assessments) and average individual body mass, with adjustments made for migratory behavior and limited use of the model area. In general, published abundance estimates were reduced to account for species making seasonal use of the model area or when the model area only represented a portion of their total range. Biomass was estimated by multiplying the abundance estimates by the average individual body mass, which was weighted by population composition estimates to better account for the often large variation in body size with sex and age class. The specific estimation methods for each group are detailed for each group in the species accounts in the Results section below.

Production

We did not update the P/B ratios for marine mammal groups used in Aydin et al. (2007) and left that for future work. In the original model these were estimated using a variant of Siler's competing risk model (Siler 1979) as modified by Barlow and Boveng (1991). Under equilibrium conditions, P/B is assumed to be equal to the instantaneous mortality rate, Z (Allen 1971). This method uses surrogate life histories scaled by longevity to produce survivorship curves, which are used to estimate P/B (see appendix B in Aydin et al. 2007 for complete details).

Consumption

We built relatively simplistic species-specific bioenergetics models, accounting for ontogenetic, sex, and reproductive influences on energy needs. The general approach was to estimate field metabolic rates using body mass, growth costs from body mass estimates, and pregnancy costs from body mass at birth and composition estimates. This approach replaced the previous one where allometric relationships between body mass and food intake (in kg) were used, which had been derived primarily from non-reproductive animals managed in human care (Perez et al. 1990). There were a few instances when we instead used data from published bioenergetics models, as was the case for northern fur seals, Steller sea lions, and Pacific white-sided dolphins.

Published growth curves were used to estimate body mass at different ages (Fig. 3). When available, we used sex-specific curves to account for the fact that many species exhibit sexual size dimorphism. We also used multi-phase curves because growth trajectories of young animals are often different. When not available, we assumed linear growth between published birth mass estimates and mass at age one as estimated from the growth model. This was because most single phase curves did not appear to do a good job of predicting body mass of very young animals.

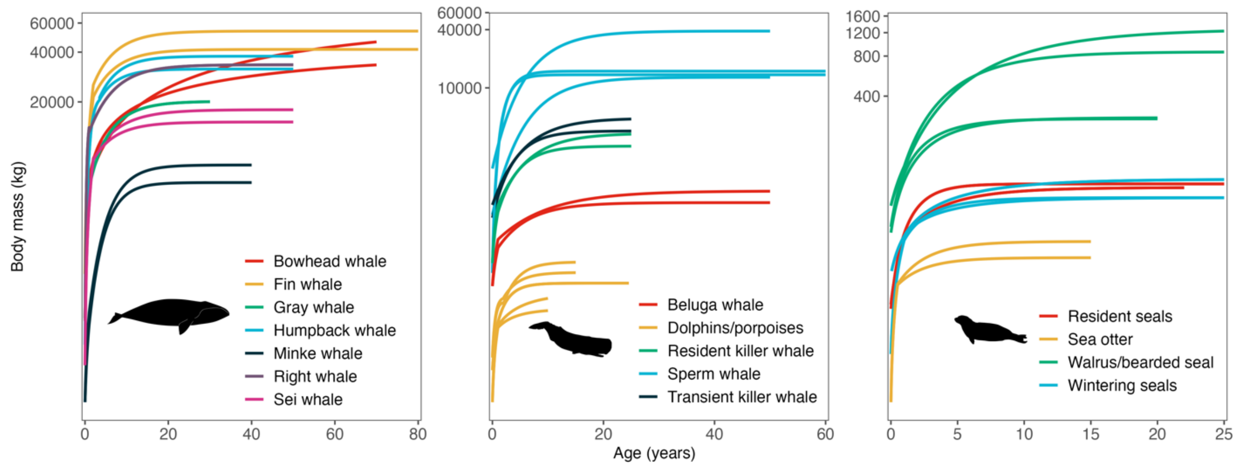

Figure 3. -- Growth curves for marine mammals included in the model, colored by species groupings. Separate curves are provided by sex for species with pronounced sexual dimorphism. Body mass was not always predicted out to the maximum lifespan given the pattern of asymptotic growth made this unnecessary. Image silhouettes are from Phylopic (https://www.phylopic.org, Keesey 2025). Silhouettes were contributed by unknown (PDM 1.0), Margot Michaud (CCO 1.0) and Tracy Heath (CCO 1.0) and accessed via rphylopic (Gearty and Jones 2023).

Field metabolic rate (FMR) was used to represent most of the energetic costs experienced by an individual marine mammal, including costs associated with maintenance, locomotion, digestion, thermoregulation, and growth. To estimate FMR, we used a multiplier on basal metabolic rates (BMR) estimated from Kleiber's curve, except for the species (harbor porpoise, walrus, and sea otters) where these multipliers were calculated from empirical estimates of FMR (Acquarone et al. 2006, Yeates et al. 2007, Rojano-Doñate et al. 2018). We used multipliers of 2.6 (phocid seals), 5.4 (walrus), 6.6 (sea otters), 2.6 (mysticetes), 3.2 (harbor porpoise), and 3.0 (other odontocetes). The value of 2.6 was chosen based on analyses from Williams (2022), FMR estimates from gray seals using doubly labelled water (Sparling et al. 2008), and gray whale calves based on respiratory rates (Sumich 2021). Since mass-specific FMR tends to be higher in juvenile animals compared with adults, we included an additional multiplier based on the growth curve data. This resulted in FMR estimates that were 1.3 – 1.7 times higher than adult estimates for the youngest animals, which declined until the animal reached 70% of its asymptotic mass. Our approach ignores any seasonal variation in FMR; however, we lack the data to incorporate these into the model with any confidence.

The energy invested in growth (the energy stored within the tissue itself) was estimated using differences in mass at yearly intervals (derived from the mass estimates from growth curves) and the energy density of lean tissue, assuming that all structural growth occurred as lean tissue deposition. The composition of lean tissue was assumed to be 2% lipid and 20% protein (Adamczak et al. 2023) with 39.3 MJ kg^{-1} and 24.5 MJ kg^{-1} as the constants for lipid and protein energy density, respectively. This ignores energy deposition in bone, which is largely unknown for marine mammals.

Reproductive costs, which include lactation and gestation costs, were assessed differently depending on whether the population estimate included dependent offspring or not. When it was not explicitly stated, we assumed that population estimates included all age groups. In these cases, we did not include the costs of lactation in estimating costs, since those costs were captured by having dependent-aged animals in the population estimate. Pregnancy costs were included for all species with few exceptions, since those costs are not captured by the dependent offspring. Pregnancy costs were calculated from Brody's equation for the heat increment of gestation, birth mass, and the assumption that newborn marine mammals are comprised of 10% lipid and 20% protein (Brody 1945).

Gross energy intake (GEI) was estimated for each year of life by summing FMR and growth costs across that year and then dividing by metabolizable energy (energy available after urinary and fecal losses). For reproductive-aged females, GEI costs also included pregnancy and lactation (when applicable) costs. We used estimates of pregnancy rates to weight adult female GEI and then used age structure estimates to calculate weighted mean GEI and mass for each species, resulting in a single GEI value for each species.

Age structure of all phocid seal populations was assumed to be 11.6% (age 0), 8.6% (age 1), 7.6% (age 2), 6.7% (age 3), 5.9% (age 4), 5.2% (age 5), and 54.3% (age 6+), which is a reasonable age structure for a stable seal population with 0% growth (Harding and Härkönen 1999), assuming a 1:1 sex ratio. Age structure of small cetaceans (dolphins and phocoenids) was assumed to be 15.9% (ages 0 – 1), 37.4% (juveniles), and 46.7% (adults), assuming a 1:1 sex ratio (Read and Hohn 1995). Age structure of mysticetes was assumed to be 5.8% (ages 0 – 1), 50.5% (juveniles), and 43.7% (adults), assuming a 1:1 sex ratio (Brandon and Wade 2006). Age structure of all other species is described in the species-specific sections below.

Prey energy density

Estimates of prey energy density are needed to convert energy consumption to biomass. Prey energy densities are highly variable, depending on both ecological (e.g., species, location, time of year, sex, age class) and methodological (e.g., storage method) factors. One of the challenges in applying prey energy density values to estimate prey consumption is that they are frequently presented and analyzed in dry weight without the relevant data to accurately convert to wet mass, which is more relevant since this is how marine mammals consume prey. A description of data sources is provided below, with final values for each species provided in Table 2.

Table 2. -- Original and revised energy density estimates for marine mammals.

Marine mammal species	Energy density of diet (MJ kg^{-1})	
	Aydin et al. 2007	This study
Bowhead whale	4.18	6.3
Fin whale	2.93	6.5
Gray whale	2.93	4.0
Humpback whale	2.93	6.6
Minke whale	4.18	5.4
Sei whale	2.93	5.8
Dall's porpoise and Pacific white-sided dolphin	6.27	5.8
Sperm whale	6.27	4.8
Transient killer whale	6.27	12.6
Ringed and bearded seals	6.27	5.02
Sea otter	6.27	4.0
Walrus	6.27	4.4
All other species	6.27	5.4

For all species whose diet was comprised primarily of pelagic and demersal fish, we used a prey energy density value of 5.4 MJ kg^{-1}. This was not only the average prey energy density in Perez (1990) for many of these species, but also the average prey energy density provided for northern fur seals by McHuron et al. (2020). For species that consumed fish and invertebrates, we used a value of 5.02 MJ kg^{-1} (Perez 1990). For most baleen whales, prey energy density estimates were based on weighted generalized diet composition (e.g., 60% euphausiids, 40% copepods) and prey values of benthic amphipods (4.2 MJ kg-1, Perez 1990, Maresh et al. 2022), copepods (4.85 MJ kg-1, Walkusz et al. 2012), euphausiids (7.4 MJ kg-1, Harvey et al. 2012)), and other prey values described here. For walrus, we used a value of 4.4 MJ kg^{-1}, based on data from Born et al. (2003) on the energy content of bivalves consumed by Atlantic walrus. For sea otters, we used a value of 4.0 MJ kg^{-1} because an initial estimate (2.5 MJ kg^{-1}) based on sea otter prey in Glacier Bay, Alaska (Oftedal et al. 2007) resulted in unrealistic estimates of daily prey consumption (> 40% of body mass per day). For Dall's porpoise and Pacific white-sided dolphins, we used an energy density of 5.8 MJ kg^{-1} to represent consumption of energy-dense mesopelagic species in addition to other fish and squid. For sperm whales, we used a value of 4.8 MJ kg^{-1}, calculated from the weighted average using a diet composition of squid (65%, 4.2 MJ kg-1, Sinclair et al. 2015) and fish (35%, assumed to be 6.0 MJ kg^{-1} given consumption of some deep-sea fishes to diet). For transient killer whales, we used a value of 12.6 MJ kg^{-1} based on the average energy density of ringed seal muscle, viscera, skeleton, skin, and blubber (Best 1985).

Diet composition

The diet compositions for marine mammal groups were compiled from multiple literature sources. The taxonomic makeup of prey groups in published diet compositions did not always match functional groups included in our model, for example, “forage fish”. Or alternatively, prey groups were not assigned proportions. In order to accommodate such data sources, we used the preference method, whereby, the proportion of each prey taxa in the diet was weighed proportionally to their biomass.

Harvest

Directed harvests of marine mammal species are included in the Indigenous fishery group. All harvest values are unchanged from the original model, including any discards due to bycatch in other fisheries (see Aydin et al. 2007 for complete details).

Seabirds

Seabirds are represented by 10 multispecies functional groups in this model. We did not update any of the parameters for seabirds in this model version. Please see the original model documentation (Aydin et al. 2007) for functional group species composition and complete details of parameter estimation methods. Briefly, seabird biomass was based on colony counts of seabirds in the region and estimates of average body mass. The P/B of seabirds were estimated from mortality rates taken from the literature. The Q/B and diet compositions of seabirds were taken directly or derived from information in Hunt et al. (2000).

Fish

Biomass

The primary source of information for estimating groundfish biomass was multiple regional bottom trawl surveys conducted by NOAA's Alaska Fisheries Science Center (AFSC): the eastern Bering Sea continental shelf survey, the eastern Bering Sea upper continental slope survey, and the Aleutian Islands survey. These surveys occur during the summer season beginning in approximately the end of May or early June and ending by the end of July or early August. All three of these surveys utilize bottom-trawling gear; however, gear specifications and methods differ slightly between surveys due to different physical characteristics of ecosystems. For detailed descriptions of trawl survey methodology, see Markowitz et al. (2022), Hoff (2016), and von Szalay and Raring (2018), for the eastern Bering Sea shelf, eastern Bering Sea slope, and Aleutian Islands surveys, respectively. All bottom trawling was conducted in accordance with standard NOAA trawling procedures (Stauffer 2004).

The eastern Bering Sea shelf survey has been conducted annually since 1982, except in 2020 due to the COVID 19 pandemic, and samples stations with a systematic 20 nautical mile square grid, with trawl deployments conducted near the center of each grid cell. The survey area extends from the Alaska Peninsula to approximately 61°N and the U.S.-Russia Maritime Boundary (Fig. 1), with station depths ranging from ~15 to 200 m.

The eastern Bering Sea upper continental slope survey was conducted biennially from 2002 to 2016, with survey cancellations in 2006 and 2014, sampling along the upper continental slope at depths from 200 to 1,200 m between the Aleutian Islands and the U.S.-Russia Maritime Boundary (Fig. 1). Surveys of the eastern Bering Sea upper continental slope prior to 2002 were not standardized and did not use consistent methodology (Hoff 2016) and are not considered here.

The Aleutian Islands bottom trawl survey samples stations on the continental shelf and upper continental slope down to 500 m depth in the Aleutian Archipelago between 170°W and 170°E, and on the northern side of the Aleutian chain between 170 and 165°W. With respect to our eastern Bering Sea model area, we only use Aleutian Islands survey data from the southeastern Bering Sea along the northern side of the archipelago between 170 and 165°W and down to a depth of 500 m (hereafter referred to as the southern Bering Sea strata of the AI survey; Fig. 1). From 1991 to 2000 the Aleutian Islands survey was conducted on a triennial basis and has been conducted biennially since 2000, except 2008 and 2020 when the survey was cancelled. Biomass estimates for several stocks from this survey can have considerable variability between survey years which, in addition to demographic processes, can be in part due to the patchy distribution of species and the stratified-random design of the Aleutian Islands survey. Thus, we use the average of the 1991 and 1994 Aleutian Island bottom trawl surveys in biomass calculations.

The primary method for estimating the biomass of fishes was to start with biomass estimates based on the 1991 eastern Bering Sea shelf bottom-trawl survey, the 2002 eastern Bering Sea upper continental slope survey, and the average of the 1991 and 1994 Aleutian Islands survey. Each species/functional group biomass was calculated with area-swept methods (Wakabayashi et al. 1985, Lauth and Kotwicki 2014) and weighted by stratum area. Functional group biomass estimates were summed across the three surveys and converted to density by dividing by the total model area. If data were unavailable or available estimates were otherwise insufficient to balance the model (i.e., EE > 1), a top-down balance with EE = 0.8 was used.

Production

The production-to-biomass ratios for groundfish were not updated in this study. In the original model, for species with abundant data, the P/B ratio was derived from information on the age-structure and numbers-at-age. The weight-at-age was estimated with fits to the generalized von Bertalanffy equations

(Essington et al. 2001). If no stock assessment estimate of numbers-at-age was available, the population was assumed to be in equilibrium and P/B was taken to equal Z (total mortality, Allen 1971).

Consumption

The groundfish consumption-to-biomass ratios were not updated in this study. In the original model, the preferred method for estimating groundfish consumption rates was to use weight-at-age data to fit the generalized von Bertalanffy growth equations (Essington et al. 2001). Q/B values from the literature were used for species lacking requisite data for fitting.

Diet composition

As the base time period for the updated model has not changed from the original model, it was not necessary to update the groundfish diet compositions with new data. The input diet compositions are unchanged from the original model. They were primarily retrieved from the AFSC Groundfish Food Habits Database (Livingston et al. 2017). Diets for species not included in the food habits database were taken from literature sources.

Catch and discards

There are 18 separate fishery/gear groups, including a subsistence group, that harvest fish in the original eastern Bering Sea Ecopath model and we maintain those same fisheries groups in this model update. There are 14 fleets that target federally managed groundfish stocks. The walleye pollock trawl uses pelagic trawl gear. Pacific cod are targeted with three different gear types: the cod trawl which uses bottom trawl gear, cod longline which uses hook and line gear, and cod pots which use trap gear. There are six fleets in this model that target flatfishes with bottom trawling gear: northern rock sole trawl, yellowfin sole trawl, arrowtooth flounder trawl, flathead sole trawl, other flatfish trawl, and Greenland turbot trawl. These flatfish fisheries happen at different times of the year and in different habitats and have distinct bycatch species. The Atka mackerel trawl fishery utilizes non-pelagic trawl gear and primarily occurs in the Aleutian Islands region west of our model area. Within this model, the Atka mackerel trawl fishery represents the small proportion of the fishery that occurs within the model area. The rockfish trawl uses bottom trawling gear to target rockfish. The sablefish longline and Greenland turbot longline use hook-and-line gear to target these two species. The Pacific halibut longline fishery uses hook-and-line gear and is managed separately by the International Pacific Halibut Commission (IPHC). The commercial herring and salmon fisheries are managed by the Alaska Department of Fish and Game (ADF&G) and primarily use purse seine and gillnet gear. The subsistence fishery in this model includes the catch of salmon. Information on subsistence harvest is from ADF&G, who maintains an extensive database on subsistence uses of Alaska communities.

The catch of target and non-target species in federally managed groundfish fisheries was retrieved from the NMFS Alaska Regional Office database, now known as the Catch Accounting System or CAS (Cahalan et al. 2014). Catch data for the Pacific halibut fishery are from the IPHC. Catch data for the salmon, herring, and subsistence fisheries are from the ADF&G. With the exception of the Pacific halibut longline fishery, the amount of directed catch and discards (including non-target groups) in the updated model remains unchanged from the original model. Changes to the directed harvest of the Pacific halibut fishery are detailed in the halibut species account in the results section below. In the original model the retained catch for target species that are processed at-sea was the product of the raw retained catch times the published product recovery rates (e.g., Economic Status Report). The remainder of the raw retained catch (processed fish parts to be discarded) were the fishery offal, and discards were the combination of fishery offal and discards of whole fish.

Benthic invertebrates

Biomass

To account for the increase in model area, we updated biomass for commercial crabs and several other invertebrate functional groups following the same methodology as the original model. Similar to fish groups, initial density estimates for several benthic invertebrate groups were based on biomass estimates from the AFSC summer bottom-trawl surveys of the eastern Bering Sea shelf and upper continental slope. For many benthic invertebrate groups, the trawl survey estimates were insufficient to meet predator demands, and instead, we used a top-down balance with EE = 0.8.

Production

We did not update P/B parameters for benthic invertebrate groups in this model update, but we briefly summarize the methods here. In the original model, P/B estimates for benthic invertebrates were primarily taken from values reported in the literature, were based on growth and longevity studies (e.g., Kimker et al. 1996), or in the case of commercial crabs, were derived from stock assessment information (Trites et al. 1999).

Consumption

With the exception of shrimps and commercial crabs, the Q/B of benthic invertebrate groups were estimated with an assumed P/Q of 0.2 (a.k.a., GE or growth efficiency). For most benthic invertebrate groups, estimates of the rate of consumption per unit body mass are unavailable. Alternatively, Ecopath can calculate Q/B from an assumed value of P/Q. P/Q is calculated as P/B divided by Q/B. Trites et al. (1999) found P/Q to usually range between 0.1 and 0.3 for most groups and to average about 0.2 for most benthic invertebrate groups in the eastern Bering Sea.

Diet composition

The diet compositions of benthic invertebrates in the original model were derived from information in the published literature, though many of these functional groups assumed a common generalized diet composition. This was in part due to a desire to keep trophic levels equivalent between benthic and pelagic tertiary consumers (Aydin et al. 2007). Maintaining equivalent trophic levels between pelagic and benthic invertebrates is not a priority in this model update. Therefore, where supporting information is available in the published literature, we have updated benthic invertebrate diet compositions to be more specific to the predator taxa.

Many benthic invertebrates consume detritus and microbes as a part of their diet and often they do this while filtering prey from the water. While in the real world it is quite possible for microbes and detritus of pelagic origins to find themselves within reach of benthic invertebrate predators, these are dynamics that cannot practically be represented in our food web model. Thus, for the purpose of distinguishing benthic versus pelagic food webs, we assume that all microbes and detritus consumed by bottom dwelling benthic invertebrates come from the benthic microbes and benthic detritus groups.

Catch

The directed catch and bycatch of benthic invertebrates in the original model are maintained in this model update. The catch of target and non-target species were retrieved from species respective stock assessments, the Alaska Catch Accounting System (Cahalan et al. 2014), or appropriate state agencies (e.g., ADF&G). See Aydin et al. (2007) for complete details.

Plankton and microbes

In this model update, we maintain all input parameters from the original model for zooplankton, microbial (pelagic and benthic), and primary production groups. See Aydin et al. (2007) for functional group descriptions and parameterization details. Briefly, the biomasses of zooplankton groups were determined by top-down balance with EE = 0.8. Estimates of P/B, Q/B, and diet composition for zooplankton groups were based on information in the literature, though often not species-specific. The biomass of pelagic microbes was based on values reported in the literature, while benthic microbes were top-down balanced with EE = 0.8. The P/B of pelagic microbes was derived from values in the literature, and the same P/B was assumed for benthic microbes. The Q/B of pelagic and benthic microbes was estimated with an assumed P/Q of 0.35. The diet compositions of pelagic and benthic microbes were based on general descriptions found in the literature. The biomass of primary production groups were top-down balanced with EE = 0.8, and estimates of P/B were derived from values reported in the literature.

The original model of Aydin et al. (2007) included an outside primary production group and a corresponding outside detritus pool. These groups were built into the original model as placeholders to be used later to test specific hypotheses regarding detrital dynamics and are no longer necessary. In the balanced configuration of the original model, outside primary production had no predators and was the only group with a flow to outside detritus. Thus, these two outside groups are removed in this model update as their presence is no longer required and their removal has no measurable effect on any other group.

Adult-Juvenile Split Pool Parameters

The Rpath model framework has the capacity to parameterize distinct groups to account for ontogenetic shifts in species diet and mortality, known as split pools or stanzas (Walters et al. 2000). Rpath calculates the biomass and consumption of the split pool groups based on one leading stage. All split pool groups in this model are divided into two pools, adult and juvenile, with the adult pool as the leading stage.

Thus, the biomass and consumption of the trailing juvenile groups are estimated by calculating the weight at age using the generalized von Bertalanffy growth equation (VBGF) (Essington et al. 2001). Any differences in the estimated biomass or Q/B of trailing stanzas with values estimated by EwE are largely attributed to rounding error between the two programs and/or differences in the calculation of the adult stanza biomass. The full set of equations used in Rpath stanza calculations are detailed in Lucey et al. (2020). The stanza parameter definitions are found in Table 3, and the required input stanza parameters used in this model are in Table 4. The VBGF parameters K, d, and relative weight at maturity, were estimated by fitting to the generalized form of the VBGF (see Appendix B in Aydin et al. 2007 for complete details). Biomass accumulation is a required input and is left at a default value 0. The first month for all juvenile stanzas in this model is 0 and the last month of the adult [trailing] stanza is calculated by Rpath. All stanza parameters used in this model are unchanged from the original model. For groundfish groups, the juvenile pool reflects individuals < 20 cm in length, which roughly corresponds to individuals less than 2 years of age and approximates known ontogenetic shifts in diet composition and predation mortality across a range of species. For northern fur seals and Steller sea lions, juveniles were taken as representing individuals aged 1–3.

Table 3. -- Rpath stanza parameter definitions from Lucey et al. (2020).

Symbol	Units	Parameter	Definition
Ksp	number	Carrying capacity	Carrying capacity from specialized VBGF. Rpath converts to Ksp to k from the generalized VBGF within the code
d	dimensionless	Allometric slope of consumption	Derived from VBGF
Wmat	kg	Relative weight at maturity	Weight at 50% maturity divided by their asymptotic weight (Winfinity)
BAB	yr^{-1}	Biomass accumulation	Rate of change of biomass from initial balance
Z_{juv}	yr^{-1}	Juvenile total mortality	Rate of total loss of biomass as a sum of natural mortality and fishing mortality
Z_{adu}	yr^{-1}	Adult total mortality	Rate of total loss of biomass as a sum of natural mortality and fishing mortality
Juvfirst	number	Month	First month of the juvenile stanza
Juvlast	number	Month	Last month of the juvenile stanza
Adufirst	number	Month	First month of the adult stanza
Adulast	number	Month	Last month of the adult stanza (calculated by Rpath)

Table 4. -- Stanza parameters input to the Rpath model.

Group	Ksp	d	Wmat	Zjuv	Zadu	Juvlast	Adufirst
northern fur seal	0.28697	0.66667	0.44211	0.25191	0.09125	35	36
Steller sea lion	0.392	0.66667	0.58492	0.494	0.10979	23	24
walleye pollock	0.19201	0.64461	0.04646	1.45328	0.66721	23	24
Pacific cod	0.12533	0.65701	0.05769	1.78207	0.41190	23	24
Pacific herring	0.28	0.66667	0.15625	1.05181	0.32	35	36
arrowtooth flounder	0.08775	0.63724	0.28125	0.81014	0.18	25	26
Kamchatka flounder	0.08775	0.63724	0.28125	0.81014	0.18	23	24
Greenland turbot	0.06595	0.57565	0.04587	1.70059	0.18	23	24
Pacific halibut	0.05937	0.66667	0.05404	2.39971	0.19	23	24
yellowfin sole	0.28120	0.79598	0.01167	0.24443	0.17374	71	72
flathead sole	0.18020	0.69043	0.02739	0.39439	0.26	47	48
northern rock sole	0.06174	0.65371	0.00652	0.29170	0.23162	47	48
sablefish	0.38910	0.66667	0.29375	2.26616	0.19	23	24
Atka mackerel	0.55587	0.66667	0.23483	1.9	0.35	23	24

Detrital Pools and Flow to Detritus

In a food web, there are generally two basal resources, one that originates with primary production and another that is based in detritus (Rooney et al. 2006). Aydin et al. (2007) specified five detrital pools in their model of the eastern Bering Sea: pelagic detritus, benthic detritus, fishery discards, offal, and outside detritus. The only link to the outside detritus pool was with the outside production group. These "outside" groups were placeholder groups to be used to test specific hypotheses in their original work. They are no longer necessary and are both removed from the model in this update. The pelagic and benthic detrital pools are intended to distinguish the separate trophic pathways and energy recycling between the pelagic and benthic environments. The fishery discards and offal represent detrital inputs to the food web related to fisheries activity. Discards are whole fish discarded at sea, and offal are processed fish parts and other byproducts of fishery removals, and are estimated from product recovery rates to convert landings to offal (Aydin et al. 2007, Abelman et al. 2024).

In Ecopath, flows to detritus result from mortality not explained by processes explicitly included in the model (i.e., "other" mortality, a.k.a., *M0*) and from unassimilated food (*U*). The flow to each detrital pool from each functional group is specified as a proportion by the user. The eastern Bering Sea has an abundant benthic food web, and Aydin et al. (2007) assumed that flows to detritus generally favored flows to benthic detritus as opposed to pelagic detritus. We maintain all detrital flows as specified in the original model. Offal was initially out of balance in the Aydin et al. (2007) model and was assumed to be the result of prey from stomach contents misidentified as offal when it was actually scarred fish. To correct this, they directed 2% of the detrital flow from fish and cephalopods to offal.

Table 5. -- The percent flow to detrital pools for model groups.

Model groups	Pelagic detritus	Benthic detritus	Offal
Marine mammal	40%	60%	
Seabird	40%	60%	
Sharks	40%	60%	
Fish and cephalopods	39.2%	58.8%	2%
Benthic invertebrates	10%	90%	
Jellies and zooplankton	40%	60%	
Benthic microbes and macroalgae	10%	90%	
Phytoplankton	40%	60%	

Model Balancing

Model balancing is the process of solving the system of linear equations in the Ecopath model by matrix inversion and ensuring the mass balance requirement is met by reconciling any conflicting parameter estimates. Typically, initial attempts to balance an Ecopath model are unsuccessful with a number of functional groups that are out-of-balance (i.e., EE > 1). Groups that are out-of-balance signal that an error may have been made during model development, such as unit conversion, typo, a misplaced decimal point, or more often where model parameters are incompatible. For example, this might happen when initial parameterization has led to predator consumption rates in excess of prey production. When input parameters are determined to be incompatible, the parameters in question and all related parameters need to be re-evaluated to determine how to reconcile the conflicting parameters and bring the model into balance. The data pedigree can be a useful guide to identifying poorly informed parameters that may be a good place to start in reconciling unbalanced groups. Parameters may need to be manually adjusted or recalculated based on new information, or the Ecopath equations can be used to solve for the parameter in doubt (e.g., top-down balance of biomass) to bring groups into balance. All parameter adjustments necessary to bring the model into balance are documented in the Results section below.

Comparisons with the Original Model

We made a number of comparisons between the original model and our updated model to highlight the impact of the updated parameters on model structure and function, and to note where there were no impacts or little change. We look at the percent change in biomass density for individual groups to highlight how individual groups were impacted by the update, including groups that were top-down balanced. Additionally, we examine the percent change in biomass for aggregate groupings of taxonomically related groups to highlight how the updated parameters have impacted the distribution of biomass across the food web. The aggregate groups are marine mammals, seabirds, fish (including cephalopods), benthic invertebrates, pelagic invertebrates (including jellyfish), microbes, and phytoplankton. Additionally, we examine a selection of ecosystem-scale metrics to highlight changes at the ecosystem level resulting from the update, including total energy flow, total production, total consumption, and total living biomass (excluding detritus). These ecosystem scale metrics are intended to highlight changes to ecosystem function and energy flow at the whole-of-ecosystem scale. Total energy flow was measured as total system throughput (TST), which is the sum of total mass flows ($t\ km^{-2}\ yr^{-1}$) for consumption, respiration, flow to detritus, and export (Christensen and Walters 2024).

Total consumption is the sum of food intake (B*Q/B) by all consumer groups. Respiration flow is the fraction of assimilated food that does not lead to production. The flow to detritus from each group is a combination of the unassimilated portion of food that is egested and the portion of the group that is lost to other sources of mortality outside of the predation and fisheries mortality explicitly included in the model. Total ecosystem production is the sum of production (t km^{-2} $year^{-1}$) from all functional groups. Similarly, total biomass is the sum of biomass estimates (t km^{-2}) for all living groups.

RESULTS

Outline

Here, we present descriptions of the updated parameters that resulted from incorporating new information and as a result of model balancing. First, we present functional group (or species) accounts where we note which input parameters were updated with new information and those that remain unchanged from the original model. For the updated parameters, we provide a detailed description of parameter development, the data sources, and the updated data pedigree. For those parameters not updated, they are not discussed at length here, and the reader is directed to the original model documentation for complete details (Aydin et al. 2007). Second, in the model balancing section, we summarize the key adjustments to input parameters made during the model balancing process to bring the model into balance. Last, in the Model Comparison section, we present a selection of metrics and other illustrative comparisons to highlight differences and similarities between this updated model and the original model configuration.

Cetaceans

Killer whales

There are three genetically distinct killer whale (*Orcinus orca*) ecotypes (resident, transient, and offshore) found in the northeast Pacific. Growth of resident whales was characterized using length at age curves derived from whales managed in human care (Williams et al. 2011). Recent data suggests that transient whales may be larger than residents (Kotik 2020); however, not all the parameters needed to recreate the growth curve were reported. Thus, we multiplied resident lengths by 1.15 to approximate asymptotic sizes in Kotik (2020). Mass at length was estimated from a curve derived from live-captured killer whales from British Columbia and Washington (Bigg and Wolman 1975). We used an age structure of 4.9% (< 1 year), 31.59% (<13 years), 30.8% (adult females 13+ years), 19.9% (adult males 13+) derived from the southern Alaska resident population between 1984 and 2005 based on a stable age structure (Matkin et al. 2014). Pregnancy rate was assumed to be 21% for females aged 13+ years (Matkin et al. 2014).

Below we describe the abundance and diet estimates for transient and resident killer whales. We do not include offshore killer whales in this model, even though they have been observed in the Bering Sea, because so little is known about their abundance or distribution. While their diet is not well characterized, fish (predominantly sharks) are believed to be the predominate prey (Jones 2006, Dahlheim et al. 2008, Ford et al. 2011).

Transient killer whales

Transient killer whales found in the model area are part of the Gulf of Alaska, Aleutian Islands, and Bering Sea transient stock, although there is evidence of additional structure within this stock (Parsons et al. 2013, Sharpe et al. 2019). The current population size estimate of 587 whales, based on photo-identification of individuals from 2001 to 2012, is considered a minimum estimate because the entire range has not been surveyed (Muto et al. 2020). The population that resides in the Gulf of Alaska is believed to be stable, but population trajectories for the Aleutian Islands and Bering Sea are unknown. In the absence of additional data, we multiplied the abundance estimate by one-third to reflect that whales use areas outside of the model area. This modified abundance value was further reduced to account for uncertain seasonal use of the model area by multiplying by 0.25. The final abundance estimate was 48 whales. There is some evidence to indicate connectivity between regions, adding uncertainty to the value we have chosen. The final abundance numbers were multiplied by the average weighted body mass of 3.136 t, resulting in a population density of 0.00028 t km^{-2}. The transient killer whale Q/B was estimated with a species-specific bioenergetics model to be 4.1. The P/B is unchanged from the original model and remains 0.025.

The diet of transient whales is comprised of a variety of marine mammals. In Alaska and Russian waters, transients prey on pinnipeds, small odontocetes, and gray (primarily < 2 years of age) and minke whales (Melnikov and Zagrebin 2005, Dahlheim and White 2010). While there are reports of transients harassing humpback whales, predation is a rare occurrence and appears confined to a subpopulation that inhabits the Gulf of Alaska (Saulitis et al. 2015). Based on analysis of rake marks, Mehta et al. (2007) suggested that large baleen whales are not important prey for killer whales in high latitudes. There is increasing evidence of killer whale predation on bowhead whales in the Chukchi and Beaufort seas (Willoughby et al. 2020), but there are no reports of this in the model area and the origin of predating transients is unknown. Based on these studies, we assumed that 90% of the biomass was comprised of pinnipeds and small cetaceans, with an additional 10% comprised of beluga, minke and gray whales (includes all ages because the age class cannot be specified in the model).

The data pedigree for biomass was considered to be 5 (inclusion of uncertain scaling factors). P/B was not updated here and retains the pedigree of 3 because it was based on a species-specific proxy (survival rate). The Q/B value was given a pedigree of 2 (direct estimate with limited corroboration) and diet composition was given a pedigree of 5 (correct species generalized from larger region).

Resident killer whales

Resident killer whales in the model area are part of the Alaska resident stock, which are distributed in southeastern Alaska, the Aleutian Islands, and the Bering Sea. Based on data from 2001 to 2012, the population size of killer whales in western Alaska was 1,475 individuals (Muto et al. 2020). This estimate is much higher than estimates from the early 1990s (Dahlheim 1997) but is primarily believed to be due to discovery of new animals that were previously missed (Muto et al. 2020). Fearnbach et al. (2014) found limited movements in the east-west direction in killer whales in the Gulf of Alaska, Aleutian Islands, and Bering Sea, with whales clustering into one of four regions. There were 388 unique individuals identified within the cluster that encompassed the model area (eastern Aleutian Islands and Bering Sea Shelf). There was some connectivity with the population in the central Aleutians, but killer whales from the central Aleutian cluster did not appear to move into the Bering Sea (Fearnbach et al. 2014). This population estimate is similar to a previous estimate of 391 (95% CI: 171 – 894) individuals from boat surveys of the southeast Bering Sea in 2000 (Waite et al. 2002), although the Waite estimate likely included transients as well. Since it is unclear exactly how whales partition their time within and outside the model area, we used 388 individuals as the final abundance estimate. This abundance was multiplied by the average weighted individual body mass of 2.182 t, resulting in a population density of 0.00159 t km^{-2}. The Q/B of resident killer whales was estimated with a species-specific bioenergetics model to be 10.5. The P/B is unchanged from the original model and remains 0.025.

The diet of resident killer whales is predominantly comprised of fish, regardless of their geographical location (Ford et al. 1998, Saulitis et al. 2000, Hanson et al. 2021), although the diet of killer whales in the model area is largely unresolved. Considerable depredation on sablefish, Pacific halibut, arrowtooth flounder, and Greenland turbot by resident killer whales does occur in the Aleutian Islands and Bering

Sea (Yano and Dahlheim 1995b, Peterson and Hanselman 2017). Whales do not appear to depredate pollock, Pacific cod (in the BS/AI), rockfish, or shortspine thornyhead (Yano and Dahlheim 1995a, Peterson et al. 2013), although mortalities of resident killer whales have occurred in pollock trawls and Pacific cod long-line fisheries in the Aleutian Islands and Bering Sea (Dahlheim et al. 2022). Residents in Prince William Sound ate Pacific herring, salmonids (primarily coho but also Chinook and chum), and Pacific halibut, whereas opportunist observations of residents in the eastern Aleutians were of salmonids and halibut. Walleye pollock is a presumed but unconfirmed prey species (Lowry et al. 1989) and was included in the diet composition in the original R-Path implementation. Based on these studies, we assumed that 70% of the diet was comprised of salmonids, Atka mackerel, sablefish, Pacific halibut, arrowtooth flounder, and Greenland turbot, with the remaining 30% comprised of pollock, Pacific cod, and herring.

A data pedigree of 4 was given to biomass (direct estimate with high variation/limited confidence). P/B was not updated here and retains the pedigree of 3 because it was based on a species-specific proxy (survival rate). The Q/B value was given a pedigree of 2 (direct estimate with limited corroboration) and diet composition was given a pedigree of 5 (correct species generalized from larger region).

Sperm whales

In the original eastern Bering Sea Ecopath model of Aydin et al. (2007), sperm whales (*Physeter macrocephalus*) were a part of the "sperm and beaked whales" functional group. There are at least two types of beaked whales known to occur in the Bering Sea, Stejneger's (*Mesoplodon stejnegeri*) and Baird's (*Berardius bairdii*) beaked whales, with the possibility of a third species (Morin et al. 2017). In the model area, both beaked whale species are each managed as part of an Alaska stock, with no estimates of abundance. Similar, to sperm whales, beaked whales primarily consume squid (Savage et al. 2021).

While this group theoretically includes sperm and beaked whales, there are no abundance estimates for any beaked whale species in the Bering Sea. As a result, they are effectively excluded from the model and the functional group is renamed in this model update to “sperm whales”.

Sperm whales are a cosmopolitan species that typically undertake seasonal migrations between higher latitudes in summer and lower latitudes in winter (Mizroch and Rice 2013). In the model area, sperm whales are managed as part of the North Pacific stock, which encompasses waters from south of 62° N to the equator. There are no reliable estimates of population size for this stock and no new updates since the first implementation of the model, which used an estimate of 930,000 individuals. Thus, we used the same approach as the first implementation, multiplying by 0.0011 to reflect the fact that sperm whales are primarily found in deep waters, with a strong association for slope habitat (Whitehead et al. 1992, Pirotta et al. 2020). It was further modified by 0.5 to represent the seasonal occurrence of sperm whales in the eastern Bering Sea (Mellinger et al. 2004) and then again by 0.5 because females (and immature whales) are typically assumed to not occur in the Bering Sea (but see Fearnbach et al. 2012 and discussion therein). This resulted in an estimate of 256 animals.

Growth was characterized by a single length at age curve since we assume that only larger males are found in the study area, which was based on female growth curves (Evans and Hindell 2004) adjusted for sex-specific differences in asymptotic length (references in Kasuya 1991). Length was converted to mass using the equation from Lockyer (1976). We assumed an age structure that was comprised solely of males aged 10+ years (Ohsumi 1966). The abundance estimate was multiplied by the average weighted individual body mass of 36.17 t, resulting in a population density of 0.01737 t km^{-2}. The Q/B was estimated with a species-specific bioenergetics model to be 5.7. The P/B is unchanged from the original model and remains 0.047.

The diet of sperm whales is predominantly squid, but they eat a variety of fish as well (e.g., Kawakami 1980, Martin and Clarke 1986, Clarke et al. 1993, Flinn et al. 2002, Harvey et al. 2014). In the Bering Sea, 69 of 110 (64.4%) sperm whale stomachs contained only squid, compared with 26.6% that contained fish and squid, and 9.4% that contained only fish. Sperm whales caught farther to the east and north consumed more fish than those from Russian waters, with fish composing between 7 and 29% of the diet in the Bering Sea and Aleutian coasts (Okutani and Nemoto 1964, Kawakami 1980). They are known to depredate sablefish in the Gulf of Alaska, but such depredation was not observed in the Bering Sea (Sigler et al. 2008). Diets in the Gulf of Alaska were comprised of 35.6% sablefish/dogfish followed by skates at 25.4%, and squid and grenadier, a deep-sea fish, generally contributed < 10% to diets (Wild et al. 2020). We assumed that the diet was comprised of 65% squid and 35% fish, including skates, Pacific cod, Pacific lamprey (misc. shallow fish), rockfish, sablefish, greenlings, dogfish, grenadier, sleeper sharks, and miscellaneous deep-sea fishes.

The data pedigree for biomass was considered to be 6 (historical study). P/B was not updated here and retains the pedigree of 6 (general life history proxy). The Q/B value was given a pedigree of 2 (direct estimate with limited corroboration) and diet composition was given a pedigree of 5 (correct species generalized from larger region).

Dolphins and porpoises

Harbor porpoise (*Phocoena phocoena*), Dall's porpoise (*Phocoenoides dalli*), and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) are all represented as a single group in the model. Pacific white-sided dolphins are a new addition to this version in the Bering Sea given recent evidence that their occurrence in the Bering Sea is likely to be more common than previously believed (Waite and Shelden 2018). Recently, Risso's dolphins (*Grampus griseus*) have been detected in the Bering Sea, but this is likely because of recent range expansion (Seger and Miksis-Olds 2019) and so they have not been included here. Below we provide species-specific descriptions of growth, abundance, and diet, which is translated into a group estimate by weighting species-specific values by estimated abundances.

Dall's porpoise

Dall's porpoises are found throughout the North Pacific in oceanic and continental shelf habitats. In the model area, they are part of the Alaska stock, which includes all animals found in Alaska waters. The distribution of animals in this stock extends southward into Canada, as well as northward into Russian waters. Based on surveys in 1999 and 2000, the estimated population size in the eastern Bering Sea is 24,119 (Moore et al. 2002), an estimate that is uncorrected for vessel attraction (Turnock and Quinn 1991), submerged animals during the survey, or missed animals. Correction of this point estimate by multiplying by 0.2 (for vessel attraction) resulted in an abundance estimate of 4,823 Dall's porpoise. This final abundance estimate is still likely an underestimate given it is not corrected for animals underwater or that were missed during the survey.

Growth was characterized by two-phase sex-specific mass to age curves derived from porpoises from the western Aleutian Islands (Ferrero and Walker 1999). Pregnancy rates were estimated at 90% for females aged 7+ years (Ferrero and Walker, 1999). Q/B was estimated with a species-specific bioenergetics model to be 22.3.

The diet of Dall's porpoise is primarily comprised of schooling fishes, mid- and deep-water fish, and squid. In the Bering Sea, Dall's porpoises taken in the basin primarily consumed gonatid squid and myctophid fishes (Ohizumi et al. 2003), whereas those caught coastally in the Sea of Okhotsk primarily consumed Japanese pilchard, pollock, and squid (Ferrero and Walker 1996). Off Washington and California, prey species included salmonids, anchovy, hake, capelin, Pacific saury, Pacific whiting, pollock, Pacific sand lance, eulachon, and squid (Kajimura et al. 1980, Nichol et al. 2013). Kajimura et al.

(1980) concluded that, similar to Pacific white-sided dolphins, Dall's porpoise are opportunistic feeders, preying on available species. Within the model area, Dall's porpoise are sighted along the shelf break and over the continental shelf (Moore et al. 2002). We assumed that the 50% of the diet was comprised of capelin, juvenile pollock, herring, eulachon, salmonids, and Pacific sand lance, and 50% comprised of myctophids and squids.

Harbor porpoise

Harbor porpoise are a small porpoise found in coastal waters. In the model area, they are managed as part of the Bering Sea stock, which encompasses the central and western Aleutian Islands and all areas north of Unimak Pass. The estimated abundance of the Bering Sea stock is 48,215 (95% CI: 31,285 – 74,308) based on aerial surveys conducted in 1999, corrected for perception and availability biases (Hobbs and Waite 2010). This survey did not include the entire model area, but it also included areas in Bristol Bay outside of the model area. Within the model area, harbor porpoise were generally distributed on the continental shelf in areas around the Pribilof Islands, just north of the Aleutian chain, and in Bristol Bay (Moore et al. 2002). Since it is unclear how many animals were outside the model area, and how many were within the model area but excluded from the survey, we left the estimate from Hobbs and Waite (2010) unchanged.

Growth of harbor porpoise was parameterized using sex-specific mass at age curves from animals in Icelandic waters (Ólafsdóttir et al. 2003). Pregnancy rate was assumed to be 93% for females aged 3+ years (Read and Hohn 1995). The harbor porpoise Q/B was estimated to be 30.1 with a species-specific bioenergetics model.

The diet of harbor porpoise is generally dominated by schooling fishes, with diets that often overlap considerably with Dall's porpoise (Santos et al. 2004, Nichol et al. 2013, Andreasen et al. 2017). The diet of harbor porpoise is not well described in the Bering Sea. In Norton Sound, which is north of the model area, saffron cod was found in the stomach of five animals (Lowry et al. 1989). In the Salish Sea, diets consisted of Pacific herring, Pacific sardine, pollock, eulachon, Pacific hake, blackfin sculpin, eelpout, Pacific sanddabs, sole, northern anchovy, shiner perch, myctophids, Pacific sand lance, polychaetes, and squid (Nichol et al. 2013). As a result of these studies, we assumed the diet was comprised of 70% juvenile pollock, juvenile cod, herring, capelin, eulachon, and sand lance, 20% salmonids, small flatfish, small sculpins, eelpout, and 10% squid and myctophids.

Pacific white-sided dolphin

Pacific white-sided dolphins are the largest of three species included in the “Porpoises” group, inhabiting both offshore and coastal habitats. In the model area, they are managed as the North Pacific stock whose range extends from north of Washington to about 150 km north of the Aleutian chain into Bristol Bay. Until recently, the presence of Pacific white-sided dolphins in the Bering Sea was believed to be a rare occurrence, and they were not included in the original model implementation. Recent analyses indicates not only are they likely common year-round in the Bering Sea, but that their range likely extends much farther north than previously believed (Waite and Shelden 2018). Abundance was estimated at 26,880 individuals from surveys conducted in the late 1980s and early 1990s, but this is considered a minimum estimate since not all habitat was surveyed (Muto et al. 2020). We multiplied this abundance estimate by 5% to account for the fact that only a small number of individuals likely use the model area; the actual proportion is unknown.

Growth was characterized by a length at age curve generated from Pacific white-sided dolphins from British Columbia (Heise 1996), converted using a mass to length equation from the same study. We assumed a pregnancy rate of 30% for females aged 11+ years (Ferrero and Walker 1996). Pacific white-sided dolphin Q/B of 47.5 was estimated with a species-specific bioenergetics model (Rechsteiner et al. 2013).

The diet of Pacific white-sided dolphins varies depending on habitat type. When using offshore waters, they primarily feed on mesopelagic fish and squid, whereas in nearshore waters they primarily prey on fish (Heise 1996 and references therein). In Canadian waters, prey consumed included herring, capelin, Pacific sardine, salmonids, cod, sablefish, smelt, squid, and shrimp (Heise 1996, Morton 2000). Dolphins in Korean waters consumed cephalopods, herring, anchovy, and flounders (Lee et al. 2019). In California and Washington, they consumed plainfin midshipman, northern anchovy, rockfish, squid, sanddabs, and shrimp (Kajimura et al. 1980, Black 1994). Most sightings of this species in the Bering Sea have occurred on the continental shelf just north of the Aleutian chain, with a fewer number near the shelf slope further north (Waite and Shelden 2018). We assumed the diet composition was comprised of 60% herring, capelin, salmonids, juvenile cod, juvenile sablefish, juvenile pollock, 30% squid and myctophids, and 10% rockfish, misc. flatfish, pandalid and NP shrimp, and other pelagic smelts.

Dolphin and porpoise composite group parameters

The total abundance of dolphins and porpoises in the model, after accounting for any reductions, was 54,382 individuals. This abundance was multiplied by a weighted-average body mass of 48.1 kg to arrive at a population density of 0.00491 t km^{-2}. The weighted Q/B for dolphins and porpoises was 29.8. The P/B is unchanged from the original model and remains 0.050. The primary prey in the biomass-weighted composite diet of dolphins and porpoises included pollock, squid, myctophids, sand lance, and capelin. Prey of secondary importance included northern rock sole, herring, eulachon, Alaska plaice, other flatfish, other sculpins, Pacific cod, and eelpouts. Prey of lesser importance included salmon, shrimp, other pelagic smelts, and rockfishes.

For dolphins and porpoises, a data pedigree of 5 was given to biomass (uncertain scaling factors). P/B was not updated here and retains the pedigree of 6 because it was based on a general life history proxy. The Q/B value was given a pedigree of 2 (direct estimate with limited corroboration) and diet composition was given a pedigree of 6 (species sampled in neighboring region/limited coverage).

Beluga whale

Beluga whales (*Delphinapterus leucas*) are an Arctic species that often undergo seasonal migrations between foraging and wintering grounds. Beluga whales found in the model area are primarily from the eastern Bering Sea stock, which summers in Norton Sound. The Beaufort Sea stock is also found in the Bering Sea, primarily from January–March, but most of the population is located north of St. Matthew Island, with minimal overlap with the model area (Citta et al. 2017). The Bristol Bay stock exhibits very little movement from summer to winter, primarily residing in Bristol Bay year-round (Citta et al. 2017), with minimal overlap with the model area. In addition, there is evidence to suggest that feeding during winter months is reduced in the Bristol Bay (and potentially other) stock (Cornick et al. 2016). The Beaufort Sea stock was estimated at 39,258 whales in 1992, which was a minimum estimate given the entire study area was not surveyed. This value was multiplied by 0.013 to account for the roughly 3 months they are potentially within the study area and that only a small proportion of their distribution overlaps with the model area (assumed to be 5%). The Bristol Bay stock was estimated at 2,040 whales from aerial surveys in 2016 (Lowry et al. 2019), similar to the estimate of 1,928 whales based on a genetic mark-recapture study from 2002 and 2011 (Citta et al. 2018a). Increases in the number of counted belugas between 1993 and 2016 indicate that the Bristol Bay stock experienced population growth from 1993 to 2005, making it inappropriate to use the most recent abundance estimates. Since most recent counts were roughly double those of 1993, we assumed a Bristol Bay stock population abundance of 1,020 whales in the early 1990s, which was multiplied by 0.017 to account for the fact they are only in the model area for roughly four months (December to April) and that much of the population is likely not even in the model area (assumed to be 5%, Lowry et al. 2019). Population estimates for the eastern Bering Sea stock, based on aerial surveys conducted in 2017, yielded a population size of 9,242 whales that was not significantly different from estimates in 2000. This value was multiple by 0.5 to reflect their seasonal occurrence in the model area. Thus, final abundance estimates were assumed to be 5,148 whales (510 from Beaufort Sea stock, 17 from the Bristol Bay stock, and 4,621 from the Eastern Bering Sea stock).

We characterized beluga growth using sex-specific length at age curves derived from eastern Beaufort Sea belugas (Luque and Ferguson 2010), and a mass to length curve derived from belugas managed in human care (Robeck et al. 2005). Age composition was based on a stable population age structure from Mosnier et al. (2015) and was 7% (0 – 1 years), 4.5% (1 – 2 years), 6% (2 – 3 years), 5% (3- 4 years), 4.5% (4 – 5 years), 5% (5 – 6 years), 4% (6 – 7 years), 5% (7 – 8 years), and 59% (aged 9+ years), assuming a 1:1 sex ratio. Pregnancy rate was assumed to be 56% for females aged 9+ years (Suydam 2009). Multiplying the abundance by an estimated mean weighted body mass of 551 kg resulted in a density of 0.00532 t km^{-2}. The beluga Q/B was estimated with a species-specific bioenergetics model to be 15.3. The P/B is unchanged from the original model and remains 0.112.

Beluga whales eat a wide diversity of fish and invertebrate species, such as salmon, schooling fish, and shrimp (Heide-Jørgensen and Teilmann 1994, Loseto et al. 2009, Quakenbush et al. 2015, Breton-Honeyman et al. 2016). The diet of the eastern Bering Sea stock has been characterized from stomach contents of animals collected primarily from May to September when they are outside of the model area. They frequently consumed gadids (Arctic cod, saffron cod, and pollock), with lesser contribution from other species including flatfishes, rainbow smelt, capelin, herring, Pacific sand lance, slender eelblenny, sculpins, polychaetes, mysids, bivalves, and shrimp (Quakenbush et al. 2015). Salmonids were the primary prey consumed by Bristol Bay belugas, but these samples were not representative of the time that whales are potentially within the model area. During summer months, Beaufort Sea stock whales primarily consumed arctic cod and capelin (Loseto et al. 2009, Choy et al. 2020). Based on these studies, we assumed a diet, proportioned relative to biomass, comprised of juvenile pollock, adult herring, misc. shallow fish, juvenile Pacific halibut, small flatfishes (yellowfin sole, flathead sole, northern rock sole, misc. flatfish), small sculpins, capelin, sand lance, shrimp, mysids, gastropods, octopus, benthic urochordata, benthic amphipods, snow crab, Tanner crab, misc. crabs, polychaetes, and misc. worms. We did not include salmonids in their diet since they appear to primarily be important during summer months when adults return to rivers to spawn and thus not relevant during winter months.

The data pedigree for beluga biomass was considered to be 4 (proxy with high variance, limited confidence or incomplete coverage). P/B is unchanged in this model update and retains the pedigree of 6 (general life history proxy). Q/B was given a pedigree of 2 (direct estimate with limited corroboration) and the diet composition was given a pedigree of 6 (correct species in an adjacent region).

Gray whales

Gray whales (*Eschrichtius robustus*) in U.S. waters are managed as a single stock, the Eastern North Pacific stock. They migrate between low latitude breeding grounds in Baja California to high latitude feeding grounds in the Bering, Chukchi, and Beaufort seas. There is also a small group of whales that feed in waters from northern California to southeast Alaska (Lagerquist et al. 2019). The most recent population estimate, from surveys conducted in 2019/2020 during the southbound migration, is 20,580 whales (95% CI: 18,700 – 22,870, Stewart and Weller 2021). Abundance estimates from surveys conducted between 1992 and 1996 ranged from 15,762 and 20,944 whales (Laake et al. 2012). A small proportion of the gray whale population does not migrate into the Bering Sea, estimated at 872 based on the number of unique individuals identified in surveys from southern California to Kodiak, AK, between 1998 and 2008 (Calambokidis et al. 2010). This is likely an overestimate because these surveys likely captured some whales migrating to high-latitude feeding grounds, but such uncertainty is unlikely to be influential as the time spent within the model area is relatively short, limited to individuals on their north and southbound migration. For example, it took a single migrating gray whale on her northbound migration about one month to travel from the Gulf of Alaska to the Chirikov Basin, which is north of the model area. Whales typically enter the Bering Sea in April and May and exit through Unimak Pass in late October. Some feeding does occur while in the model area based on observations on the northbound migration (Gill and Hall 1983). Observations of migratory gray whales elsewhere indicate that little feeding occurs on the southbound migration (Pike 1962). To estimate abundance, we multiplied the maximum abundance estimate between 1992 and 1996 (20,944) by 0.08 (representing 15 days within the roughly 6-month period spent in the Bering, Beaufort, and Chukchi seas), and 0.958 (to account for the small proportion of whales not migrating through the model area), resulting in an estimate of 1,605 whales.

Growth was characterized using age-specific length at age curves followed by a length to mass conversion (Agbayani et al. 2020). Pregnancy rates were assumed to be 44% for females aged 8+ years (Jones 1990). Multiplying abundance by the mean weighted body mass of 14.4 t resulted in a density of 0.04338 t km^{-2}. The gray whale Q/B was estimated to be 7.9 using a species-specific bioenergetics model. The P/B is unchanged from the original model and remains 0.063.

Gray whales primarily feed on benthic (or epibenthic) prey including amphipods, polychaete worms, cumaceans, bivalves, ghost shrimp, and mysids, as well as planktonic crab larvae (Nerini and Oliver 1983, Oliver et al. 1984, Dunham and Duffus 2002, Moore et al. 2007, Budnikova and Blokhin 2012, Burnham and Duffus 2016). In general, gray whales tend to be associated with areas of high amphipod abundance (Moore et al. 2003, Brower et al. 2017). We assumed a diet composition comprised of 90% benthic amphipods and 10% other benthic and epibenthic species (polychaetes, bivalves, misc. crustaceans, mysids).

The pedigree for gray whale biomass was 2 (data are a direct estimate but with limited coverage/corroboration). P/B is unchanged and maintains the pedigree of 6 (general life history proxy).

Q/B was given a pedigree of 2 (direct estimate with limited corroboration) and the diet composition was given a pedigree of 5 (correct species generalized from larger region).

Humpback whales

Humpback whales (*Megaptera novaeangliae*) seasonally migrate between lower latitude breeding grounds and higher latitude feeding grounds. The previous model version used a starting abundance value of 394 whales, which appears to be derived from the number of animals using breeding grounds in Japan (Calambokidis et al. 1997). This may have been because a few animals with discovery tags from Japan were recaptured in the area. More recent photo-identification studies indicates that humpback whales that use the Aleutian Islands and Bering Sea use breeding grounds in Mexico, Hawaii, the western Pacific, and likely an unsampled and unknown location (Calambokidis et al. 2008, Barlow et al. 2011). Recent estimates of population size for humpback whales in the model area are 6,000 – 14,000 individuals (excluding calves), based on photo-identification efforts from 2004 to 2006 (Calambokidis et al. 2008). These estimates include whales in the Commander Islands and Gulf of Anadyr, the Western and Eastern Aleutians, and the Bering Sea, although many of the observations were concentrated in areas within the model area (Barlow et al. 2011). These estimates are considerably higher than surveys in the eastern Bering Sea from 2002 to 2010 that resulted in uncorrected abundance estimates of 231 – 675 humpback whales (Friday et al. 2013). A 2017 survey of the eastern Bering Sea in July and August indicated an abundance of 4,539 whales (Inai et al. 2018). Using this value, adjusted to account for the increasing population assuming an annual growth rate of 6.6% (Zerbini et al. 2006), results in a population estimate of 1,788 whales in the early to mid-1990s. While there is evidence that some humpback whale populations feed outside of the foraging grounds (Stamation et al. 2007, Owen et al. 2017, Pirotta et al. 2021), most of the energy to support their yearly energy budget still comes from summer foraging grounds. Thus, we did not make a time adjustment to this population estimate. This estimate assumes that the number of whales using the model area is consistent across the foraging season, which is currently unknown.

Growth was modeled using sex- and age-specific length at age curves (Chittleborough 1965, Boye et al. 2020) and a length-weight conversion (Lockyer 1976). We used a pregnancy rate of 42% based on an average inter-birth interval of 2.38 years (Barlow and Clapham 1997). Multiplying the estimated abundance by a weighted average body mass of 25.2 t results in a modeled density of 0.08463 t km^{-2}. The Q/B was estimated with a species-specific bioenergetics model to be 4.2. The P/B is unchanged from the original model and remains 0.038.

Humpback whales feed on zooplankton (especially euphausiids) and small forage fishes (Witteveen et al. 2006, Stamation et al. 2007, Friedlaender et al. 2009, Witteveen et al. 2012, Witteveen and Wynne 2016, Straley et al. 2018). In the Bering Sea, humpback whale distribution overlaps with areas of consistent high euphausiid abundance (Sigler et al. 2012), and euphausiid abundance was an important predictor of whale abundance (Zerbini et al. 2016). We assumed a diet composition of 60% euphausiids and 40% fish (capelin, sand lance, eulachon, herring, and juvenile pollock).

The data pedigree for biomass was considered to be 4 (direct estimate or proxy with high variation/limited confidence or incomplete coverage). P/B is unchanged and keeps the pedigree of 2 (direct regional estimate). The pedigree for Q/B is 2 (species-specific bioenergetics model) and diet composition is given a pedigree of 5 (correct species generalized from the larger region).

Fin whales

Fin whales (*Balaenoptera physalus*) are the most abundant baleen whale observed within the model area and the second largest whale behind blue whales. Worldwide, there are both migratory and resident populations of fin whales (Mizroch et al. 2009, López et al. 2019). In the fall, there is some indication that whales in the Bering Sea represent a mixing of two stocks, those from the Aleutian Islands and those from the Chukchi Sea (Mizroch et al. 2009, Archer et al. 2020). High call frequencies of fin whales have been detected from July to December in the Bering Sea, with a smaller peak occurring in mid-February to April (Stafford et al. 2010, Širović et al. 2013). Uncorrected counts from summer surveys in 1999-2000 in the model area resulted in an abundance estimate of 4,051 fin whales (Moore et al. 2002). Since fin whale populations have been recovering with the cessation of commercial whaling, we corrected these counts back to the early 1990s using an annual rate of increase of 4.8% (Zerbini et al. 2006). This resulted in an estimate of 3,160 whales.

Growth was characterized using sex-specific length at age curves derived from north Atlantic fin whales, and a length to mass conversion (Lockyer 1976, Lockyer and Waters 1986). Pregnancy rates were assumed to be 45% for females aged 8+ years, based on an assumed inter-birth interval of 2.24 years (Agler et al. 1993). We multiplied the abundance estimate by a weighted average body mass of 35.6 t to result in a density of 0.21120 t km^{-2}. Q/B was estimated to be 3.9 using a species-specific bioenergetics model. The P/B is unchanged from the original model and remains 0.027.

Fin whale diets are dominated by euphausiids, with lesser consumption of copepods, amphipods, squid, and fish such as capelin, herring, and sand lance (Nemoto 1956, Christensen et al. 1992, Flinn et al. 2002, Jory et al. 2021), although diets may vary temporally or among individuals (Jory et al., 2021). Euphausiid biomass was one of the predictors of fin whale distribution in the Bering Sea (Zerbini et al. 2016). We assumed that fin whale diet was comprised of 60% euphausiids, 20% copepods, and the remaining 20% comprised of pelagic amphipods, squid, capelin, herring, and sand lance.

The data pedigree for biomass was considered to be 4 (direct estimate or proxy with high variation/limited confidence or incomplete coverage). The P/B is unchanged from the original model and keeps the pedigree of 6 (general life history proxy). Q/B has a pedigree of 2 (direct estimate with limited corroboration) the diet composition pedigree is 6 (species sampled in neighboring region/limited coverage).

Sei whales

Sei whales (*Balaenoptera borealis*) are broadly distributed in subtropical, temperate, and subarctic waters in both hemispheres. The movements of sei whales in the North Pacific are not well understood and there are no estimates of abundance in the Bering Sea. Recent estimates of the population in the central and eastern North Pacific (south of Alaska) were 29,632 (95% CI: 18,576–47,267; Hakamada et al. 2017). Surveys conducted within the model area have observed sei whales, but those observations have been limited to a few individuals (Moore et al. 2002, Friday et al. 2013). Observations of the number of sei whales were on average 2.2% of those of fin whales, whose abundance was estimated at 4,051 based on surveys on the central and southeastern Bering Sea shelf in 1999 and 2000. Because of this, we assumed that sei whales are relatively uncommon within the model area, using an estimate of 89 whales (2.2% of the estimated fin whale abundance).

Growth was characterized using sex-specific length at age curves from North Pacific sei whales (Bando and Maeda 2020) and a mass at length conversion (Lockyer and Waters 1986). Pregnancy rates were assumed to be 36% for females aged 8+ years (references in Prieto et al. 2012). Multiplying the abundance estimate by a weighted average body mass of 12.6 t results in a density of 0.0021 t km^{-2}. Q/B was estimated with a species-specific bioenergetics model to be 5.5. The P/B is unchanged from the original model and remains 0.040.

Sei whales eat a wide variety of prey, including zooplankton, fish, decapods, and squid (Prieto et al. 2012, Burkhardt-Holm and N'Guyen 2019). In the western North Pacific, sei whales consumed copepods, euphausiids, fish, and squids, with copepods and pelagic fish/euphausiids comprising roughly 40% and

50% of the diet, respectively (Takahashi et al. 2022). In contrast, Kawamura (1982) found that copepods dominated the diet of sei whales caught across the North Pacific, with lesser inputs from euphausiids, amphipods, fish, and cephalopods. Off British Columbia, sei whales primarily consumed copepods and euphausiids, with lesser contribution from fish such as pollock, saury, and lanternfish (Flinn et al. 2002). We assumed a diet comprised of 75% copepods and euphausiids, 24% fish (sand lance, capelin, juvenile pollock, myctophids, herring, misc. shallow fish), and 1% squid.

The data pedigree for biomass was considered to be 7 (incomplete source(s) with a wide range). P/B is unchanged from the original model and remains 6 (general life history proxy). Q/B was given a data pedigree of 2 (direct estimate with limited corroboration) and the pedigree for diet composition was considered 6 (species sampled in neighboring region/limited coverage).

North Pacific right whales

North Pacific right whales (*Eubaleana japonica*) are one of the most endangered marine mammals today (Wade et al. 2011). Historically they were distributed across the entire North Pacific. Current critical habitat for the eastern population occurs in the Bering Sea (within the model area) and the Gulf of Alaska. Most observations in the past few decades have been confined to the southeastern Bering Sea, although recently more detections have occurred outside the critical habitat area (McDonald and Moore 2002, Wade et al. 2006, Wright et al. 2019, Matsuoka et al. 2022). North Pacific right whales are seasonally present in the model area from May through December. They migrate out of the Bering Sea to unknown breeding locations during the winter. The first and most recent estimate of abundance was 28 (95% CI: 24–42) or 31 (95% CI: 23–54) whales based on genotyping or photographic methods, respectively (Wade et al. 2011). The authors noted that this estimate may only pertain to a Bering Sea subpopulation and may not represent abundance of the entire eastern North Pacific population. Here we use an estimate of 31 whales. Since North Atlantic and Southern right whales are capital breeders, we assume that North Pacific right whales follow this strategy. Thus, we did not adjust population estimates for time since annual energy needs are acquired on summer foraging grounds.

Growth was characterized by using age-specific length at age curves followed by a length-mass conversion (Fortune et al. 2021). Pregnancy rates were assumed to be 25% for females aged 8+ years, derived from North Atlantic right whales (Stewart et al. 2022). We multiplied the abundance estimate by a weighted average body mass of 25.3 t to arrive at a density of 0.00147 t km^{-2}. The right whale Q/B of 5.6 was estimated with a species-specific bioenergetics model. The P/B is unchanged from the original model and remains 0.033.

Right whales almost exclusively consume copepods (Omura et al. 1969, Baumgartner and Mate 2003, Gregr and Coyle 2009, Baumgartner et al. 2013). We assumed their diet was comprised of 95% copepods and 5% pelagic amphipods, pteropods, and mysids.

The data pedigree for biomass was considered to be 2 (data are a direct estimate but with limited coverage/corroboration). P/B is unchanged and keeps the data pedigree of 6 (general life history proxy). Q/B is given a pedigree of 2 (direct estimate with limited corroboration) and the diet composition pedigree is 6 (species sampled in neighboring region/limited coverage).

Minke whales

Minke whales (*Balaenoptera acutorostrata*) are a small baleen whale, following the general baleen whale migratory pattern of summer months in high latitude feeding grounds and winter months in lower latitude breeding grounds (Towers et al. 2013, Risch et al. 2014). There are no abundance estimates for the entire Alaska stock of minke whales. In the eastern Bering Sea, uncorrected counts ranged from 389 to 2,020 whales (Moore et al. 2002, Friday et al. 2013). Surveys in 1999 and 2000 indicated there were 810 in the central-eastern Bering Sea in 1999 and 1,003 in the southeastern Bering Sea in 2000 (Moore et al. 2002). We used estimates from the 1999-2000 surveys of 1,813 since this was closest to the model start time. Since minke whales exhibit large mass gains on summer feeding grounds (Christiansen et al. 2013) with little feeding occurring on breeding grounds, we have left the abundance estimate unchanged even though they are only in the model area seasonally.

Minke whale growth was modeled using sex-specific mass at age curves derived from Northeast Atlantic minke whales (Markussen et al. 1992). We used a 90% pregnancy rate derived from Antarctic minke whales for females aged 6+ (Bando and Hakamada 2014). We multiplied the estimated abundance by a weighted average body mass of 4.6 t to arrive at a density of 0.01551 t km^{-2}. Q/B was estimated to be 8.0 with a species-specific bioenergetics model. The P/B is unchanged from the original model and remains 0.051.

Minke whales consume a variety of species, primarily schooling fishes and swarming zooplankton. In the western Pacific, the diet of minke whales as dominated by fish, with lesser inputs from krill, copepods, and squid (Tamura and Fujise 2002). In the North Atlantic, whales primarily consume euphausiids, capelin, herring, and sandeels, with regional, seasonal, and annual variation in diets (Haug et al. 1996, Olsen and Holst 2001, Windsland et al. 2007). They can consume a wide variety of prey size classes, with consumption primarily dictated by availability (Windsland et al. 2007). We assumed the diet was comprised of 50% fishes (juvenile pollock, herring, capelin, eulachon, and sand lance), 45% euphausiids, and 5% squid and copepods, with importance within each group driven by available biomass.

The biomass data pedigree was considered to be 4 (direct estimate or proxy with high variation/limited confidence or incomplete coverage). P/B was not updated here and maintains the pedigree of 6 (general life history proxy). Q/B was given a pedigree of 2 (direct estimate with limited corroboration) and the diet composition was given a pedigree of 6 (species sampled in neighboring region/limited coverage).

Bowhead whales

There is only a single stock of bowhead whales in U.S. waters, the Western Arctic or Bering-Chukchi-Beaufort Stock. Bowhead whales are only present in the Bering Sea for 4–5 months of the year, typically entering in late November or December from the Beaufort and Chukchi seas and migrating northwards in April (Braham et al. 1980). Data from satellite-tagged bowhead whales between 2006 and 2011 indicated that whales were only found in the model area from January – April, using only a very small area of the model around and north of St. Matthews Island and one farther south of Nunivak Island (Citta et al. 2015). Biochemical tracers indicate that bowhead whales likely feed year-round (Pomerleau et al. 2018). In 1993, the stock size was estimated at 8,167 whales (references in Muto et al. 2020), which is consistent with more recent population size and growth estimates (Givens et al. 2013). We multiplied this value by 0.33 (for time), and then further by 0.05 since most of the habitat use in the Bering Sea is concentrated outside of the model area. This resulted in an estimate of 135 whales.

Growth was characterized using sex-specific length at age curves, which were then converted to mass using a length at mass equation (George 2009, Lubetkin et al. 2012). Pregnancy rates were assumed to be 20% for females aged 25+ based on calving intervals (Rugh et al. 1992). We multiplied the estimated abundance by a weighted average body mass of 24.3 t resulting in a density of 0.00617 t km^{-2}. The Q/B was estimated to be 4.5 using a species-specific bioenergetics model. The P/B is unchanged from the original model and remains 0.010.

Bowhead whales feed primarily on euphausiids, copepods, and other zooplankton, with some small proportion of the diet composed of benthic invertebrates (Lowry et al. 1978, Hazard and Lowry 1984, Pomerleau et al. 2011). In the model area, bowheads were assumed to feed on 40% copepods, 55% euphausiids, pelagic amphipods, mysids, and pteropods, and 5% benthic invertebrates (crabs, polychaetes, shrimps, and amphipods).

The data pedigree for biomass was considered to be a 5 (estimate requires inclusion of highly uncertain scaling factors or extrapolation). P/B is not updated here and maintains the pedigree of 1 as it was derived from a direct independent method specific to this stock of bowheads. Q/B is given a pedigree of 2 (direct estimate with limited corroboration) and the pedigree for diet composition is 6 (species sampled in neighboring region/limited coverage).

Table 6. -- Summary of information for individual species and species groupings of cetaceans, including abundance estimates, average body mass, and biomass. Biomass density was calculated using a model area of 533,102 t km^{-2}. Conversion values reduce the total number of animals to account for limited spatial or temporal use of the model area and other miscellaneous reductions (e.g., sex-specific use of model area, alternative migration routes). *Species grouping values were calculated by weighting based on abundance estimates.

			Conversion							
Functional group	**no. animals**	**no. reference**	**area**	**time**	**misc.**	**no. in model**	**body wt. (kg)**	**MJ day^{-1}**	**Biomass (t km^{-2})**	**Q/B**
transient killer whales	587	Muto et al. (2020)	0.33	0.25	1	48	3,136	445.6	0.00028	4.1
sperm whales	930,000	ref in Muto et al. 2020	0.0011	0.5	0.5	256	36,170	2,719.5	0.01737	5.7
resident killer whales	388	Fearnbach et al. (2014)	1	1	1	388	2,182	338.8	0.00159	10.5
dolphins and porpoises						54,382	48.1*	21.3	0.00491	29.8*
Dall's porpoise	24,119	Moore et al. (2002)	1	1	0.2	4,823	94.1	33.3		22.3
harbor porpoise	48,215	Hobbs and Waite (2010)	1	1	1	48,215	42.4	18.9		30.1
Pacific white-sided dolphin	26,880	Muto et al. (2020)	0.05	1	1	1,344	86.3	65.1		47.5
belugas	See text	Lowry et al. (2019)				5,148	551	124.5	0.00532	15.3
gray whales	20,944	Laake et al. (2012)	1	0.08	0.958	1,605	14,408	1,254.0	0.04338	7.9
humpback whales	4,539	Inai et al. (2017)	1	1	0.394	1,788	25,233	1,904.9	0.08463	4.2
fin whales	4,051	Moore et al. (2002)	1	1	0.78	3,160	35,630	2,453.0	0.21120	3.9
sei whales	89	See text	1	1	1	89	12,599	1,109.0	0.00210	5.5
right whales	31	Wade et al. (2011)	1	1	1	31	25,325	1,891.0	0.00147	5.6
minke whales	1,813	Moore et al. (2002)	1	1	1	1,813	4,561	540.6	0.01551	8.0
bowhead whales	8,167	see Muto et al. (2020)	0.05	0.33	1	135	24,374	1,883.0	0.00617	4.5

Caniformia

Sea otter

Sea otters (*Enhydra lutris*) are one of the smallest marine mammals and the only marine mustelid found in US waters. Sea otters in the model area are part of the Southwest stock, which includes the Alaska Peninsula and Bristol Bay coasts, and the Aleutian, Barren, Kodiak, and Pribilof islands (Gorbics and Bodkin 2001). Abundance estimates of the North Alaska Peninsula (from Unimak Island to Cape Seniavin) indicated a population size of 11,253 otters in 2000 (Burn and Doroff 2005, USFWS 2014). Abundance estimates of sea otters on the Pribilof Islands are presumably small given observations in the 1970s and 1980s numbered from 1 to 3 individuals (Frost et al. 1983). Sea otters along the North Alaska Peninsula experienced a population decline from 1986 to 2000 by 27 – 49% (Burn and Doroff 2005). We therefore used the same estimate of 15,000 otters to represent abundance in the early 1990s as that used in Aydin et al. (2007).

Growth was characterized using sex-specific mass at age curves derived from sea otters from the Aleutian Islands (Laidre et al. 2006). Age structure data were from female otters at Bering Island, Russia, resulting in an age structure of 63% adults and 36% juveniles (Bodkin et al. 2000). We used a pregnancy rate of 83% for females aged 4+ years (Monson et al. 2000). Multiplying the abundance estimate by a weighted average body mass of 24.3 kg results in a density of 0.00068 t km^{-2}. The Q/B was estimated to be 111.5 using a species-specific bioenergetics model. The P/B is unchanged from the original model and remains 0.117.

Sea otters forage in nearshore benthic communities, primarily on invertebrates but in some cases fish (Green and Brueggeman 1991, Watt et al. 2000, Oftedal et al. 2007, Wolt et al. 2012). The diet of sea otters in the North Alaska Peninsula has been characterized by two studies with limited sample sizes (n = 9 and n = 50 scats). Green and Brueggeman (1991) found the diet was dominated by mussels, followed by clams, crabs, and sand dollars. These results are consistent with an earlier study with a much smaller sample size. Based on these results, we assumed a diet that was comprised of 75% bivalves, 10% crabs, 10% sand dollars, and 5% gastropods and fish (sand lance, greenling, misc. shallow fish, and other managed forage).

The data pedigree for biomass was considered a 4 (direct estimate or proxy with high variation/limited confidence or incomplete coverage). We did not update P/B and maintain the pedigree of 6 (general life history proxy). The Q/B pedigree is 2 (direct estimate with limited corroboration) and the diet composition pedigree is 6 (species sampled in neighboring region/limited coverage).

Walrus/bearded seals

Pacific walrus

Walruses (*Odobenus rosmarus*) are a large, sexually dimorphic pinniped with a discontinuous circumpolar distribution. The Pacific walrus is comprised of a single population that inhabits the Bering and Chukchi seas. Between 1975 and 2006, population size estimates of walruses in the Bering Sea ranged from 129,000 to ~ 400,000 individuals, with lower and upper confidence intervals of 55,000 and 500,000 individuals (Udevitz et al. 2001, Speckman et al. 2011, Taylor et al. 2018). Much of this variation is due to methodological differences and uncertainty in estimates. For example, the estimate of 129,000 from aerial surveys conducted in 2006 is likely to be biased low, since several areas known to be important to walruses were not surveyed (Speckman et al. 2011). Taylor et al. (2018) found that there was likely a population decline that began on or before 1981, increased in severity in the mid-1980s, and moderated in the 1990s. We used an estimate of 200,000 animals based on estimates of the population size in the early 1990s from the most recent study of population size (Taylor et al. 2018). We multiplied this estimate by 0.25 since walruses are seasonal residents of the model area during the winter from January to March, with much of the population migrating northward in April into the Bering Strait and Chukchi Sea. This was further multiplied by 0.5 to reflect that the winter distribution of walrus is not entirely within the model area (Sheffield and Grebmeier 2009). Adult males remain in the Bering Sea during other times of the year, primarily around Bristol Bay (Jay and Hills 2005); we did not account for these additional animals but this omission may be offset somewhat by the fact that breeding males may exhibit limited foraging during winter when they are within the model area (Freitas et al. 2009). This results in a final modeled abundance of 25,000 walruses.

Growth was characterized using sex-specific mass at age equations derived from Bering Sea walruses (Knutsen and Born 1994). Age structure was estimated at 5.2% (YOY), 6.4% (age 1), 5.7% (age 2), 7.8% (age 3), 7.8% (ages 4 – 5), and 67% (ages 6+) based on age composition of female walruses from 2013 (Taylor and Udevitz 2015, Taylor et al. 2018). This assumes that male and female age structure is the same. The age composition of the population has changed over time, with adult females comprising 86% of the sampled female population in 1981 – 1984, 79% in 1998 – 1998, and 68% in 2013 – 2015 (Taylor et al. 2018). Given this change, and the fact that adult male survival of sexually dimorphic species is often less than adult females, we chose an estimate that was less adult biased. We used a pregnancy rate of 83%, which was the average of pregnancy rates of harvested walrus at St. Lawrence Island between 2012 and 2016 (Quakenbush et al. 2016). We multiplied the abundance estimate by the weighted average individual body mass of 701.7 kg, resulting in a biomass density of 0.03291 t km^{-2}. Q/B was estimated with a species-specific bioenergetics model to be 31.0.

Walrus primarily feed on a variety of benthic invertebrates, with limited reports of fish, seal, and seabird consumption (Lowry et al. 1980b, Lowry and Fay 1984, Dehn et al. 2007, Maniscalco et al. 2020). Early reports of prey consumption in the southeastern Bering Sea during the winter indicated walruses consumed cockles, whelks, shrimps, crabs, and mollusks (Fay et al. 1984). A more recent study by

Sheffield and Grebmeier (2009) indicated that bivalves may have been overestimated in the diet previously because soft-bodied prey were digested quickly. In their study, walruses from the Bering Sea consumed a wide variety of species that presumably reflected local benthic communities; bivalves, gastropods, and polychaete worms were the most frequently consumed species, but echiurid and priapulid worms, decapods, sea cucumbers, amphipods, cnidarians, tunicates, cephalopods, fish, and pinnipeds were all found in stomachs collected in the Bering Sea. Based on these studies, we assumed that 70% of the diet was comprised of bivalves, gastropods, and polychaetes, 29% from other species listed above (excluding pinnipeds), and 1% from phocid seals. We did not include seabirds in diet estimates because reported interactions between walrus and seabirds in the Bering Sea had a very low kill rate (Lovvorn et al. 2010, Giljov et al. 2017).

Bearded seals

Bearded seals (*Erignathus barbatus*) are a circumpolar, pagophilic species. Bearded seals that use the model area are managed as the Alaska stock, which is the portion of the Beringia distinct population segment in U.S. waters. Preliminary estimates of the number of bearded seals in the Bering Sea by Conn et al. (2014) were 301,836 seals (95% CI: 238,195-371,147). The population trajectory is unknown. Bearded seals migrate to the Bering Sea during the winter months (Citta et al. 2018b, Olnes et al. 2020), with acoustic detections from January – May (MacIntyre et al. 2015). Abundance was multiplied by 0.42 to reflect that bearded seals only spend approximately 5 months of the year in the Bering Sea, and then further by 0.5 because many of the hotspots of use in the Bering Sea are outside of the model area (Citta et al. 2018b), resulting in an abundance of 63,386 seals.

We used sex-specific mass at age equations to characterize growth, which were derived from seals from bearded seals from Norway (Andersen et al. 1999). While growth was characterized separately, asymptotic sizes were similar between males and females, at 269 kg and 274 kg, respectively. Pregnancy rates were assumed to be 93.9% (Quakenbush et al. 2011a). We multiplied the abundance estimate by a weighted average body mass of 213.7 kg, resulting in a bearded seal density of 0.02541 t km^{-2}. Bearded seal Q/B was estimated with a species-specific bioenergetics model to be 17.9.

Bearded seals are generalist foragers that primarily consume benthic species, although schooling fishes may also be consumed in certain parts of their range (Lowry et al. 1980b, Antonelis et al. 1994, Cameron et al. 2010, Quakenbush et al. 2011a, Crawford et al. 2015). In the late 1970s, bearded seals from the Bering Sea primarily consumed clams, shrimp, crabs, and sculpins (Lowry et al. 1980b). In the early 1980s, bearded seals from the central Bering Sea primarily consumed capelin, cod, eelpouts, pricklebacks, crab, clams, snails, and amphipods, with no differences in diet with sex or age class (Antonelis et al. 1994). Similar to other pagophilic species, the importance of fish in the diet of bearded seals from the Bering Sea increased in more recent samples (2000s) compared with during the 1960s and 1970s, with sculpin, Arctic and saffron cod, and flatfish being the dominant species consumed (Quakenbush et al. 2011a). Other fish species consumed included pollock, prickleback, Pacific sand lance, herring, eelpout, poacher, and snailfish. Crustaceans and mollusks dominated invertebrate consumption. Based on these studies, we assumed 45% of the diet was comprised of capelin, sculpin, and flatfish, 45% comprised of crab, clams, snails, shrimps, worms, and amphipods, and the remaining 10% comprised of a mixture of fish and invertebrate species (e.g., juvenile pollock, prickleback, sand lance, Herring, eelpout, poacher, snailfish, smelt, lumpsucker, octopus).

Walrus/bearded seals composite group parameters

The combined abundance of walrus and bearded seals in the model after accounting for any reductions was 88,386 individuals. This abundance was multiplied by a weighted-average body mass of 351.7 kg to arrive at a population density of 0.05831 t km^{-2}. The weighted Q/B for walrus/bearded seals was 21.6. The P/B is unchanged from the original model and remains 0.051. The primary prey in the biomass weighted composite diet included bivalves, polychaetes, benthic amphipods, non-pandalid shrimp, capelin, other sculpins, and Alaska plaice. Prey of secondary importance included miscellaneous worms, sand lance, juvenile pollock, pandalid shrimp, miscellaneous flatfish, and snow crabs. Prey of lesser importance (< 1%) included other managed forage fish, juvenile flathead sole, hermit crabs, miscellaneous shallow fish, snails, herring, rex sole, other pelagic smelt, octopus, urochordata, wintering seals, walrus/bearded seals, resident seals, tanner crab, miscellaneous crabs, eelpouts, anemones, urchins-dollars-cucumbers, and dover sole.

For walrus/bearded seals, a data pedigree of 5 was given to biomass (requires inclusion of highly uncertain scaling factors or extrapolation). P/B was not updated here and retains the pedigree of 6 because it was based on a general life history proxy. The Q/B value was given a pedigree of 2 (direct estimate with limited corroboration) and diet composition was given a pedigree of 5 (correct species, includes information from outside the model area).

Northern fur seals

Northern fur seals (*Callorhinus ursinus*) are a sexually dimorphic species that only come ashore during the breeding season, spending the rest of the year in pelagic waters throughout the North Pacific. Northern fur seals that breed in Alaska are managed as the Eastern Pacific stock, which includes Bogoslof and the Pribilof Islands. Only fur seals breeding on the Pribilof Islands are within the model area. Based on the population model described in McHuron et al. (2020), which provides yearly age- and sex-specific estimates at each island, the number of fur seals from the Pribilof Islands in 1991 was estimated at 531,496 (excluding pups and reflecting the absence of many juveniles until the age of two). Since the model is separated into juveniles and adults, we partitioned this estimate into juvenile (1 – 3 years, 94,170) and non-juvenile (4+ years, 414,567) estimates. While they largely forage within the model area, there are some animals that forage in the basin (Kuhn et al. 2014), which is outside of the model area. We assumed that 25% of the population uses the basin. Population estimates were further reduced since fur seals only spend an average of 25% (juveniles) or 32% (age 4+) of their time in the Bering Sea (McHuron et al. 2020). This resulted in abundance estimate of 17,545 (juveniles) and 99,496 (age 4+) fur seals.

Age- and sex-specific energy intake of Pribilof Island fur seals has already been described (McHuron et al. 2020), and we used these estimates instead of estimating from growth curves and allometric relationships. The age structure of this population is 22.3% (juveniles, 1 – 3-years), 15.6% (sub adult males, 4 – 7 years), 9.7% (adult males, 8+), 17.9% (non-reproductive adult females, 4+ years), and 33.8% (lactating females, 4+ year). This age structure accounts for the fact that many juveniles do not return to the Bering Sea until the age of 2 and is derived from the population model mentioned above. Since juveniles are part of their own model, the modified age structure is 20.3% (sub adult males), 12.6% (adult males), 23.2% (non-reproductive adult females), and 43.9% (lactating females). We do not include the costs of pregnancy here since females are generally not pregnant while in the Bering Sea. This estimate does not account for potential consumption by weaned pups once they leave the Pribilof Islands. It is largely unknown how much prey they actually consume during this period, which can be as short as a few weeks (Lea et al. 2009, Zeppelin et al. 2019), and so we have not included those costs here. Multiplying the abundance estimate by a weighted average body mass of 55.9 kg for adults resulted in a density estimate of 0.1043 t km^{-2}. The Q/B of adult northern fur seals was estimated with a species-specific bioenergetics model to be 48.7. The biomass and Q/B of the trailing juvenile group was calculated by the Rpath stanza equations to be 0.00027 t km^{-2} and 104.5, respectively. The P/B ratios for juvenile and adult pools are unchanged from the original model and remain 0.252 and 0.091, respectively.

The diet of northern fur seals in the Pribilof Islands is temporally and spatially variable (Antonelis et al. 1997, Zeppelin and Ream 2006), with little evidence for age-specific variation in diet (Call and Ream 2012). In general, pollock is a dominant prey species when fur seals forage on the continental shelf, whereas squid dominates the diet when fur seals forage in the basin. Despite early beliefs that fur seals only eat juvenile pollock, mature pollock are also consumed (Call and Ream 2012, McHuron et al. 2020), potentially when juvenile pollock are less abundant. At St Paul Island, where fur seals spend considerable time foraging on the continental shelf, approximately 70% of the diet by biomass is comprised of pollock, with the remaining 30% comprised primarily of squid, Atka mackerel, sablefish, greenlings, Pacific herring, Pacific sand lance, salmonids, and northern smoothtongue (MML unpublished data, but see McHuron et al. 2020). We assumed the diet was comprised of 50% juvenile pollock, 20% adult pollock, 28% of squid, Atka mackerel, sablefish, greenlings, herring, sand lance, salmonids, and northern smoothtongue, and 2% misc. flatfish, juv. Pacific halibut, Dover sole, juv. Arrowtooth flounder, northern rock sole, other managed forage, large sculpins, rockfish, capelin, eulachon. The diets were the same for the juvenile and adult fur seal models.

The biomass pedigrees for juvenile and adult northern fur seals are considered to be 2 (data are a direct estimate but with limited coverage/corroboration). P/Bs are not updated here and retain their pedigree of 4 (proxy with known but consistent bias). The pedigrees for juvenile and adult Q/B are both 2 (direct estimate with limited corroboration). The data pedigree assigned to both juvenile and adult diet compositions is 4 (direct estimate or proxy with high variation/limited confidence or incomplete coverage).

Steller sea lions

Sea lions in the model area are managed as part of the western U.S. stock, which was in decline from the late 1970s – the early 2000s. The stock encompasses sea lions west of 144°W, in the Gulf of Alaska, Aleutian Islands, and Bering Sea. There are only a few haulouts in the Bering Sea itself, outside of those on the northern side of the Aleutian Islands, near the Pribilof Islands, Bristol Bay, St. Matthews, and farther north outside the model area on St. Lawrence Island. To estimate abundance within the model area, we used estimates from sites in the eastern Aleutian Islands and Bering Sea from 1990 (Johnson and Fritz 2014), corrected for the fact that only about 67% of animals are ashore during summer surveys (Olesiuk 2018). This resulted in a total of 8,720 non-pups (Sweeney et al. 2017). Based on age composition data (see below), we assumed that 40% of these animals were juveniles and 60% subadult and adult animals, which was necessary since juveniles are modeled separately from adults. Thus, estimate population size was 5,232 subadult/adult animals, and 3,488 juveniles. We did not adjust this estimate further because while not all animals in the Aleutian Islands forage in the Bering Sea, subadult and adult males from other areas, such as Southeast Alaska, will forage in the Bering Sea during certain times of the year.

We used age- and sex-specific energy intake of Steller sea lions from an existing bioenergetics model (McHuron et al. 2024) rather than use growth curves to estimate GEI. Age structure of Steller sea lions was assumed to be 40% juveniles (ages 1 – 3), 12% sub adult males (ages 4 – 7), 7.6% adult males (ages 8+), and 40.4% adult females (ages 4+), which were derived from data from Holmes et al. (2007) and data from northern fur seals, which share a similar life history strategy. These data were renormalized to reflect that juveniles and adults were modeled separately. Pregnancy rates were assumed to be 63.3% for females aged 4+ years (Holmes et al. 2007). Multiplying the abundance estimates by a weighted average body mass of 319.4 kg for adults, resulted in a density estimates of 0.00313 t km^{-2}. Q/B was estimated with a species-specific bioenergetics model to be 27.9 for adults. The biomass and Q/B of the trailing juvenile group was calculated by the Rpath stanza equations to be 0.00005 t km^{-2} and 65.3, respectively. The P/B ratios for juvenile and adult pools are unchanged from the original model and remain 0.494 and 0.110, respectively.

Steller sea lions are opportunistic predators whose diets tend to reflect the local availability of prey, largely species that occupy demersal and semi-demersal habitats as adults (Sinclair and Zeppelin 2002, Womble and Sigler 2006, Sigler et al. 2009, Tollit et al. 2017). In the eastern Aleutian Islands, diet was comprised of gadids, salmonids, other schooling fish, flatfish and other demersal fish, Atka mackerel, and squid/octopus (Merrick et al. 1997). A recent study using DNA in the western Aleutian Islands revealed that Pacific cod (FL 38 – 79 cm), Atka mackerel, and cephalopods (primarily octopus) had the greatest contribution to the diet. Other species consumed included Irish lord, salmon, greenling, flatfish, rock sole, pollock, and smooth lumpsucker (Tollit et al. 2017). In the only study on diets in the Bering Sea, Sinclair et al. (2019), who compiled data from stomach contents of adult males and juveniles shot at sea in the spring of 1985 (n = 13) and fall of 1985 – 1986 (n = 9), found that pollock was the most frequently consumed prey in spring (69% FO), followed by herring (62%), and shorthorn sculpin (54%), whereas in fall northern rock sole (78%), cod (56%), and pollock (44%) were the most frequently consumed prey. Other species that were consumed included other sculpins, snailfish, eelpout, giant wrymouth, halibut and flathead sole, skates, salmonids, octopus, snow crabs, and bivalves (Sinclair et al. 2019). While sample sizes were smaller than studies from other regions, comparisons with over 7,000 scat samples from females in the Aleutian Islands and Gulf of Alaska revealed the occurrence of similar prey species, particularly walleye pollock, among regions. Males consumed both adult and juvenile pollock, with larger pollock consumed in the fall (average of 17 cm in length) and smaller pollock in the spring (49 cm in length). Based on these studies, we assumed a diet composition of 70% pollock, herring, cod, northern rock sole, and large sculpins, with the remaining 30% from octopus, misc. shallow fish, eelpout, halibut, flathead sole, misc. flatfish, greenlings, snow crab, salmon, and skates.

The data pedigree for juvenile and adult Steller sea lion biomass is 2 (direct estimate but with limited coverage/corroboration). P/B is unchanged in this model update and the pedigree for juveniles and adults stays as a 4 (proxy with known but consistent bias). The pedigree for Q/B is 2 for both juvenile and adults (direct estimate with limited corroboration). Diet compositions were given a pedigree of 4 (direct estimate or proxy with high variation/limited confidence or incomplete coverage).

Resident seals (harbor and ribbon seals)

Harbor seal

Harbor seals (*Phoca vitulina*) are a cosmopolitan phocid found nearshore habitats throughout the northern hemisphere. The model area encompasses habitat used by two stocks of harbor seals, the Pribilof Island stock and the Bristol Bay stock. Harbor seals typically forage within 30 km of haul out sites so their abundance is concentrated close to the Pribilof Islands and Bristol Bay (Cordes et al. 2017). Abundance was based on counts that were corrected to account for seals that were at sea or otherwise unobserved during surveys. The Pribilof Island stock was estimated to contain 515 harbor seals based on a comprehensive aerial survey conducted in 2018 and a correction factor of 2.25 (Muto et al. 2020). Counts from the mid-1980s and 1990s were within this range (119 – 232 seals). The current population trend of this stock is unknown. The most recent abundance estimate for the Bristol Bay stock was 44,781 seals (Muto et al. 2020), which is the value we used since it was within the range of abundance estimates from the 1990s. The nearshore range of this stock falls outside the model area, but we do not know what proportion of the population this might encompass and so have assumed 100% overlap between the model area and harbor seal foraging. Thus, the total abundance of harbor seals that use the model area was estimated at 45,296 seals.

Harbor seals are slightly sexually dimorphic, with males being about 9 cm longer than females at asymptotic length (Hall et al. 2019). Given such mild sexual dimorphism, we characterized growth using a single mass at age curve derived from female harbor seals in the Gulf of Alaska (Hutchinson et al. 2016). We used a pregnancy rate of 92% for females aged 5+ years (Pitcher and Calkins 1979). Q/B was estimated with a species-specific bioenergetics model to be 22.4.

Harbor seal diet data from the model area are sparse, but across their Pacific range harbor seals feed on a variety of fish and invertebrate species, with temporal and spatial variability in diet (Steingass 2017).

Lowry and Frost (1981) noted that harbor seals from the Bering Sea primarily consumed pollock, Pacific cod, and octopus. Pollock consumption included both young and mature pollock (Frost and Lowry 1986). In other areas in Alaska, harbor seals consumed a wide variety of fish and cephalopods, but diets tended to be dominated by a fewer number of species. Depending on the region and time, these species included pollock, Pacific cod, salmon, Irish lord, giant Pacific octopus, greenling, rockfish, and capelin (Pitcher 1980, Herreman et al. 2009, Geiger et al. 2013). Using data from multiple studies, Perez et al. (1990) estimated that diet of harbor seals in the eastern Bering Sea was comprised of pollock (12%) followed by other fishes (75% of total diet), with the remaining 25% primarily comprised of octopus. Given such variability in the diet, we assumed that 75% of the diet came from pollock, juvenile Pacific cod, large sculpins, sand lance, salmon, flatfish, capelin, Pacific herring, and greenlings, and 25% came from octopus.

Ribbon seal

Ribbon seals (*Histriophoca fasciata*) occur throughout the North Pacific and into the Chukchi Sea, with seasonal associations with ice during reproduction and the annual molt. The model area encompasses habitat used by the single U.S. stock of ribbon seals, the Alaska stock. The most recent estimate of this stock in the Bering Sea was 184,697 (95% CI: 139,617–240,225) seals based on a survey conducted in 2012 (Conn et al. 2014). There are no data to indicate trends in population abundance, but Boveng et al. (2013) discuss that strong trends in the recent past appear unlikely. Ribbons seals are broadly distributed in the Bering Sea, with an estimated 21% (Boveng et al. 2017) of seals using the Chukchi Sea during the open water season (July – October). We multiplied the population abundance estimate by 0.93 to account for this seasonal shift in spatial distribution, and then further multiplied this number by 0.7 since ribbon seals also use other areas in the Bering Sea, outside of the model (Boveng et al. 2017), resulting in a final estimate of 120,238 seals.

A single growth curve was used to characterize ribbon seal length at age (Quakenbush and Citta 2008). Mass at age was estimated using the mass-length equation from harbor seals (Markussen et al. 1989). Pregnancy rates were assumed to be 91.7% for females aged 3+ years (Quakenbush and Citta 2008). The Q/B was estimated to be 21.4 with a species-specific bioenergetics model.

Ribbon seal diet data are sparse as most harvested seals have empty stomachs because sampling occurs during the reproductive and molting period when they spend much of their time hauled out on land (London et al. 2022). Lowry et al. (1980c) found that seals from the southcentral Bering Sea (n = 9), the region with greatest overlap with the model area, consumed primarily pollock (49.7% by mass), followed by eelpout (45.1%), with the remaining 5.2% comprised of capelin, prickleback, sculpin, flatfish, poacher, and snailfish. Pollock consumption in other regions varied (Lowry et al. 1996). Seals mainly consumed age-1 pollock (< 20 cm in fork length), indicating a lack of preference since this age class was also the most abundant in trawl samples. In contrast, ribbon seals from the central and northern Bering Sea preferred pollock and cod over more abundant species, such as sculpins and capelin. Shustov (1965), as cited in Lowry et al. (1980c), found shrimps, mysids, crabs, cephalopods, Arctic cod, pricklebacks, Pacific sand lance, Pacific herring, and saffron cod. A more recent study by Quakenbush and Citta (2008) found pollock, arctic and saffron cod, and crangonid and pandalid shrimp in the stomachs (n = 7) of seals harvested in the Bering Strait. We assumed that 50% of the diet came from juvenile pollock, with the remaining 50% coming from eelpout, capelin, sculpins, prickleback (other managed forage), flatfish, poacher and snailfish (misc. shallow fish), Pacific herring, sand lance, cephalopods, and shrimp.

Resident seals composite parameters

The combined abundance of harbor seals (45,296) and ribbon seals (120,238) was multiplied by a weighted mean body mass of 70.8 kg to arrive at a biomass density of 0.02198 t km^{-2}. The weighted Q/B for resident seals is 21.6. The P/B is unchanged from the original model and remains 0.083. The primary prey in the composite resident seal diet are juvenile pollock (40.8%), non-pandalid shrimp (16.1%), adult pollock (11.1%), pandalid shrimp (8.6%), octopus (6.1%), sand lance (4.9%), capelin (2.4%), and Alaska plaice (2%). Prey of secondary importance (~1%) include miscellaneous shallow fish, other sculpins, other managed forage fish, squids, and herring. Other prey taxa accounting for trace portions of the diet included large sculpins, multiple flatfish species, multiple rockfish species, juvenile Pacific cod, juvenile herring, salmon returning, and greenlings.

The pedigree for biomass was considered a 5 (highly uncertain scaling factors or extrapolation). Resident seal P/B is unchanged in this model update and remains a 6 (general life history proxy). The Q/B pedigree is 2 (direct estimate with limited corroboration) and the diet composition is 5 (correct species generalized from larger region).

Wintering seals (spotted and ringed seals)

Spotted seal

Spotted seals (*Phoca largha*) are found year-round in the Bering Sea on the continental shelf. Their distribution is concentrated in the northern Bering Sea and Chukchi Sea from May to November, whereas from December to April they are concentrated in Bristol Bay and the northern and southeastern Bering Sea in close association with the ice edge (Citta et al. 2018b). In the model area, spotted seals are part of the Alaska stock, defined as the portion of seals from the Bering Distinct Population segment in U.S. waters. There have been few estimates of population size and no indication of the direction of trends in population abundance. We used an estimate of 461,625 seals (95% CI: 388,732–560,348), which represents an estimate of the number of spotted seals in the U.S. Bering Sea from aerial surveys in 2012 (Conn et al. 2014). Spotted seal distribution from July to October encompasses very little of the model area, whereas they are more broadly distributed in the model area from December to April. Because of this, we multiplied this abundance estimate by 0.42 to account for primarily using the model from December to April, then further multiplied by 0.9 to reflect that they are found in areas outside of the model area from December–April, resulting in a value of 174,494 seals.

Growth was modeled using length at age curves derived from harvested spotted seals in Alaska (Quakenbush et al. 2009) and a mass-length equation derived from harbor seals (Markussen et al. 1989) in the absence of a species-specific one. We used a pregnancy rate of 75% for females aged 4+ years (Boveng et al. 2009). The Q/B was estimated with a species-specific bioenergetics model.

Spotted seals are generalist predators whose diet reflects spatial and temporal changes in prey availability (reviewed in Boveng et al. 2009). Stomach content and chemical analyses suggest that pelagic fish dominate the diet of spotted seals (Dehn et al. 2007, Cooper et al. 2009). In the Bering Sea, they prey on pollock, Pacific herring, Pacific cod, Pacific sand lance, capelin, saffron cod, Japanese smelt, greenlings, mackerel, eelpout, sculpin, flatfish, cephalopods, and crustaceans (Bukhtiyarov et al. 1984, Quakenbush et al. 2009). Fish consumption was higher in more recent years (2000s) compared with the 1960s -1970s (Quakenbush et al. 2009). In the southeastern Bering Sea, spotted seals primarily consumed capelin, followed by pollock and herring (Bukhtiyarov et al. 1984). Based on these studies, we assumed that 70% of biomass was from capelin, rainbow smelt, juvenile pollock, and Pacific herring, with the remaining 30% coming from juvenile Pacific cod, cephalopods, shrimp, flatfish, sculpins, pricklebacks, sand lance, eelpout, misc. shallow fish, mysids, greenlings, amphipods, and euphausiids. In the Bering Sea, spotted seals are primarily reported to eat juvenile pollock, although elsewhere they consume larger pollock (Lowry et al. 1996).

Ringed seal

Ringed seals (*Pusa hispida*) are a small, pagophilic seal with a circumpolar distribution. The model area encompasses habitat used by the Alaska stock of ringed seals, with a preliminarily estimate by Conn et al. (2014) of 171,418 ringed seals (95% CI: 141,588–201,090). This estimate does not include animals in the shorefast ice zone nor does it correct for animals at sea, and population estimates may be up to two times higher than this value (Muto et al. 2020). Ringed seals typically migrate from more northern waters into the Bering Sea during the winter months. Crawford et al. (2012) found a distinct separation in habitat use between adult and sub adult ringed seals, with adults remaining in northern waters well outside of the model area. Other tracking studies have not detected such clear delineations in habitat use between age classes (Von Duyke et al. 2020), and so we have not considered this segregation here. Ringed seals are typically in the Bering Sea during the winter months, with seals on their southward migration detected in the Bering Strait in November. Thus, we multiplied the biomass estimate by 0.42 to reflect their presence from December – April. We further reduced this estimate by multiplying by 0.5, to correct for the fact that many ringed seals are still located north of the study area during the winter months (Citta et al. 2018b). This resulted in an estimate of 35,998 ringed seals.

Growth was modeled using sex-specific mass to age curves derived from ringed seals from Norway (Krafft et al. 2006), which were similar in asymptotic length to ringed seals harvested in Alaska after 1977 (Quakenbush et al. 2011b). We used a pregnancy rate of 76.8% for females aged 5+ years (Quakenbush et al. 2011b). Q/B was estimated with a species-specific bioenergetics model to be 24.4.

Ringed seals consume a variety of fish and invertebrate species (Kelly et al. 2010, Quakenbush et al. 2011b). While they may consume upwards of 10 – 15 species in any given area, there only appear to be 2 – 4 species that are of importance at any given time and region (Weslawski et al. 1994). Wathne et al. (2000) found that ringed seals preferred fish over pelagic crustaceans, as evidenced by mismatches between prey availability and stomach contents. Ringed seals generally consume prey that range in length from 5 to 10 cm (fish) and from 2 to 6 cm (crustaceans) (Weslawski et al. 1994). In the Bering Sea, ringed seals consume pollock, sculpin, Arctic cod, saffron cod, rainbow smelt, amphipods, and shrimp (Quakenbush et al. 2011b); other prey included flatfish, polychaetes, mollusks, and euphausiids. Ringed seals in the northern Bering Sea primarily consumed saffron cod and shrimp, with lesser contributions from Arctic cod, amphipods, and mysids (Lowry et al. 1980a). The diet of ringed seals in the Bering Sea changed slightly between the 1960s–1980s and late 1990s – 2010, with fish increasing in occurrence and invertebrates decreasing slightly. We assumed a diet composition of 70% from juvenile pollock, juvenile herring, sculpin, eelpout, and pelagic smelt, 25% from amphipods and shrimp, and 5% allocated to lesser consumed species (sand lance, euphausiids, flatfish, polychaetes, mollusks, mysids, and misc. shallow fish).

Wintering seals composite parameters

We combined the estimated abundances of spotted seals (174,494) and ringed seals (35,998) and multiplied by an average weighted body mass of 68.7 kg to arrive at a density of 0.02713 t km^{-2}. The weighted Q/B was 22.2. The P/B is unchanged from the original model and remains 0.069. The primary prey in the composite diet of wintering seals includes juvenile pollock (47%), non-pandalid shrimp (11.6%), other sculpins (6.9%), pandalid shrimp (6.2%), capelin (5.9%), euphausiids (5.6%), and other pelagic smelt (5.2%). Prey of secondary importance included adult herring (2.9%), juvenile herring (1.8%), pelagic amphipods (1.5%), and bivalves (1.5%). Prey of least importance (< 1%) included sand lance, eelpouts, polychaetes, mysids, miscellaneous shallow fish, Alaska plaice, other managed forage fish, squids, and others.

The biomass pedigree for wintering seals was considered a 5 (estimate requires inclusion of highly uncertain scaling factors or extrapolation). P/B is not updated here and maintains the pedigree of 6 (general life history proxy). The Q/B pedigree is considered to be 2 (direct estimate with limited corroboration) and the diet composition is given a pedigree of 5 (correct species generalized from larger region).

Table 7. -- Summary of information for individual species and species groupings of caniforms, including abundance estimates, average body mass, and biomass. Biomass density was calculated using a model area of 533,102 t km^{-2}. Conversion values reduce the total number of animals to account for limited spatial or temporal use of the model area and other miscellaneous reductions (e.g., seasonal shift in distribution). *Species grouping values were calculated by weighting based on abundance estimates. Biomass and Q/B in parentheses for trailing juvenile stanzas are calculated by Rpath stanza equations.

Functional group	Number animals	Number reference	Conversion			No. in model	Body wt. (kg)	MJ day^{-1}	Biomass (t km^{-2})	Q/B
			Area	Time	Misc.					
Sea otter	15,000	Burns and Doroff (2005)	1	1	1	15,000	24.3	29.6	0.00068	111.5
Walrus/bearded seal						88,386	*351.7	111.9	0.05831	*21.6
Bearded seal	301,836	Conn et al. (2014)	0.5	0.42	1	63,386	213.7	52.6	0.02541	17.9
Pacific walrus	200,000	Taylor et al. (2018)	0.5	0.25	1	25,000	701.7	262.3	0.03291	31.0
Northern fur seal - juv	94,170	McHuron et al. (2020)	0.75	0.25	1	17,545	19.6	40.3	(0.00027)	(104.5)
Northern fur seal - adu	414,567	McHuron et al. (2020)	0.75	0.32	1	99,496	55.9	19.0	0.01043	48.7
Steller sea lion - juv	3,488	Sweeney et al. (2017)	1	1	1	3,488	143.0	91.6	(0.00005)	(65.3)
Steller sea lion - adu	5,232	Sweeney et al. (2017)	1	1	1	5,232	319.4	131.7	0.00313	27.9
Resident seals						165,534	*70.8	22.6	0.02198	*21.6
Harbor seal	45,296	Muto et al. (2020)	1	1	1	45,296	63.7	21.1	0.00541	22.4
Ribbon seal	184,697	Conn et al. (2014)	0.7	1	0.93	120,238	73.5	23.2	0.01658	21.4
Wintering seals						210,492	*68.7	22.3	0.02713	*22.2
Spotted seal	461,625	Conn et al. (2014)	0.9	0.42	1	174,494	71.3	23.0	0.02334	21.8
Ringed seal	171,418	Conn et al. (2014)	0.5	0.42	1	35,998	56.2	18.8	0.00379	24.4

Fish

Sharks

Pacific sleeper sharks (*Somniosus pacificus*) are commonly found on the eastern Bering Sea continental slope and shelf and are the only shark species included in this model. While salmon sharks (*Lamna ditropsis*) and Pacific spiny dogfish (*Squalus suckleyi*) are observed in adjacent ecosystems, they are infrequently observed in the eastern Bering Sea and are assumed to have trace or zero biomass in the eastern Bering Sea model area (Aydin et al. 2007). Little is known about Pacific sleeper sharks in part due to their lack of commercial value, general difficulty sampling them in their selected habitat with traditional sampling methods, and challenges associated with landing and handling such a large animal in the field (Matta et al. 2024). While fisheries-independent trawl surveys conducted by the AFSC were not designed to catch sleeper sharks and vary in their ability to do so, they do appear to provide some indication of long-term variation in abundance (Tribuzio et al. 2022). The biomass of eastern Bering Sea Pacific sleeper sharks is the sum of the 1991 eastern Bering Sea shelf survey biomass, the 2002 eastern Bering Sea slope survey biomass, and the mean of the 1991 and 1994 biomass estimates from the southern Bering Sea strata of the Aleutian Islands survey (0.04862 t km^{-2}). The data pedigree for biomass was originally considered a 4 (survey with limited catchability) but it was downgraded to a 5 due to the main deepwater concentrations of this species not being surveyed.

The Pacific sleeper shark P/B of 0.1 and Q/B of 3 are unchanged from the original model. The P/B was based on the assumption of slow growth and relatively low mortality rates, and Q/B was adapted from a similar group in a model of a Prince William Sound (Okey and Pauly 1999). P/B and Q/B are both given a data pedigree of 7 (general literature review from a range of species).

The diet composition was based on a study conducted in the western Bering Sea (Orlov and Moiseev 1999). Their major prey items include pollock, squids, and grenadiers (20% each). Prey of secondary importance include arrowtooth flounder (12%), fisheries offal (10%), Greenland turbot (4.4%), salmon returning (5%), and Pacific halibut (2.8%). Prey of lesser importance (≤ 2%) include miscellaneous shallow fish, octopus, Kamchatka flounder, Pandalid shrimp, non-pandalid shrimp, snails, and hermit crabs. The diet composition was given a pedigree of 6 (species sampled in neighboring regions/limited coverage).

Walleye pollock

Walleye pollock (*Gadus chalcogrammus*) are medium-sized groundfish in the family Gadidae (cods) and are found throughout the north Pacific Ocean with their largest concentrations in the eastern Bering Sea (Ianelli et al. 2023). They are an economically significant species with annual commercial catches in the eastern Bering Sea averaging 1.2 million t since the 1970s (Ianelli et al. 2023). Additionally, pollock are a significant node in the eastern Bering Sea food web, both as a prey for piscivorous predators and as abundant predators themselves (Lang et al. 2000, Aydin and Mueter 2007). Pollock primarily prey upon zooplankton, particularly euphausiids and copepods and may incorporate more fish in their diet at increasing sizes, including cannibalism (Dwyer et al. 1987, Boldt et al. 2012, Buckley et al. 2016). Due to the economic and ecological significance of pollock in the eastern Bering Sea they are represented in the model by separate adult and juvenile pools. As in the original model, the split between adult and juvenile was taken to be age 2, which corresponds to about 20 cm.

Pollock are found in both the demersal and pelagic environment with older fishes having a more demersal orientation and younger fish being more common in midwater (Karp and Walters 1994). Therefore, bottom trawl surveys alone do not adequately capture their total biomass in the eastern

Bering Sea (Kotwicki et al. 2015). Thus, we use the stock assessment estimated biomass for ages 2 through 10+ for the adult pool estimated biomass. The stock assessment estimated abundance by age in 1991 (Table 1-28 in Ianelli et al. 2021) was multiplied by the mean weight at age from the fishery in 1991 (Table 1-24 in Ianelli et al. 2021) to arrive at a total biomass of ~8.602 million tons, or a density of 16.136 t km^{-2}. The biomass of the juvenile pool is estimated by Rpath through the stanza calculations as a proportion of the group's multi-stanza total biomass. The adult pollock biomass data pedigree is a 1 (assessment data is established and substantial) and for juveniles it is 8 (estimated by Rpath).

The P/B's of adult and juvenile pollock are 0.667 and 1.453, respectively, and are unchanged from the original model. The Q/B of the adult pool is 3.170 and also remains unchanged. The data pedigree for adult pollock P/B and Q/B are 3 (proxy with known and consistent bias) and the pedigree for juvenile pollock P/B is 4 (proxy with high variation). Because the juvenile Q/B is estimated by the stanza equations it differs slightly from the original model at 8.499 compared to 8.405. The juvenile pollock data pedigree for Q/B is 4 (proxy with high variation). The diet compositions of both juvenile and adult pools are the same as in the original model and were estimated from collections made during the 1991 eastern Bering Sea shelf bottom trawl survey and both are given a data pedigree of 1 (data established and substantial with resolution on multiple spatial scales).

Pacific cod

Pacific cod (*Gadus macrocephalus*) are large, demersal, predatory members of the family Gadidae (cods). They are found from the nearshore down to 875 m depth and ranging across the north Pacific Ocean from southern California, north to the Bering and Chukchi seas, east through the Aleutian Islands, the Russian Far East, and the Yellow Sea (Pietsch and Orr 2019a). They are found throughout the eastern Bering Sea, predominantly occupying shelf waters in summer and moving to deeper waters near the outer continental shelf and upper continental slope during winter (Shimada and Kimura 1994). At post-settlement life history stages Pacific cod are benthic-generalists, consuming a wide range of vertebrate and invertebrate prey (Lang et al. 2005, Yang et al. 2006). Pacific cod is the second largest commercial groundfish fishery in Alaska by catch and is caught with a diversity of gears, including trawls, longlines, pot gear, and jigs (Barbeaux et al. 2023).

Pacific cod may be found in demersal and pelagic habitats, so the stock assessment was considered a better estimate of the biomass than the bottom trawl surveys alone. The biomass of adult Pacific cod is the 1991 stock assessment estimated biomass for fish over 20 cm in length (i.e., ages 2–20+). The 1991 stock assessment estimated numbers at age from the preferred ensemble model (Table 2.33 in Thompson et al. 2021) were multiplied by the 1991 estimated mean weight at age from the preferred ensemble model (Table 2.27a [page 5 of 5] in Thompson et al. 2021) to arrive at a total biomass of ~1.285 million tons, or density of 2.4096 t km^{-2}. The biomass of the juvenile pool is 0.18262 t km^{-2} and was estimated by Rpath through the stanza calculations as a proportion of the group's multi-stanza total biomass. The data pedigree for adult cod biomass is 2 (data are a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B's of adult and juvenile Pacific cod are 0.412 and 1.782, respectively, and are unchanged from the original model. The adult Q/B is 2.280 and is also unchanged. The juvenile Q/B of 8.882 was estimated by Rpath. The pedigree for adult P/B and Q/B is 3 (proxy with known and consistent bias) because they were estimated using age structure information from the stock assessment and weight-at-age data collected on AFSC bottom-trawl surveys. The pedigree for juvenile Pacific cod P/B and Q/B is 4 (proxy with high variation). Diet compositions for adult and juvenile pools are unchanged from the original model and were estimated from food habits collections made on the 1991 eastern Bering Sea shelf bottom trawl survey and were given a data pedigree of 1 (data established and substantial, with resolution on multiple spatial scales).

Pacific herring

Pacific herring (*Clupea pallasii*, hereafter referred to as herring) is a schooling fish in the family Clupeidae that has multiple spawning populations in the eastern Bering Sea. Herring form spawning aggregations in nearshore coastal waters of the eastern Bering Sea during spring, after which they move offshore to feed and overwinter in the outer domain of the eastern Bering Sea continental shelf (Tojo et al. 2007). Pacific herring commercial fisheries in Alaska are managed by the Alaska Department of Fish and Game (ADF&G) and occur in ADF&G districts in the southeastern Bering Sea, including Dutch Harbor, Port Moller, and Togiak, and in the Kuskokwim management area.

There was insufficient data to account for the presence of Pacific herring in the northwest corner of the model area. Pacific herring are not well sampled by the AFSC bottom trawling gear and nearshore stock size estimates from ADF&G aerial surveys cannot resolve herring use of offshore habitats, such as the northwest corner. Therefore, we were unable to update the 1991 biomass estimate for the adult pool of herring or improve their data pedigree for biomass (pedigree 3, proxy data from assessed stocks and applied to entire area). Thus, we maintain the density estimate from the original model of 0.61156 t km^{-2}. The biomass of the juvenile pool is 0.17201 t km^{-2} as estimated by Rpath through the stanza calculations as a proportion of the group's multi-stanza total biomass (pedigree 8, estimated by Rpath).

The P/B and diet compositions for both adult and juvenile herring, and the fisheries catch of the adult pool are unchanged from the original model. The P/B of adult and juvenile pools were estimated using age structure information from the stock assessment and weight-at-age data collected by ADF&G and given data pedigrees of 3 for adults (proxy with known and consistent bias) and 4 for juveniles (proxy with high variation). Diet composition was estimated from food habits collections made on the 1991 eastern Bering Sea shelf bottom trawl survey. The data pedigree for adult herring diet composition was

4 (direct estimate but with high variation due to poor selectivity of trawl sampling) and 5 for juvenile herring (direct estimate from trawl surveys but downgraded for small sample size).

The adult herring Q/B of 3.520 was estimated using weight-at-age data fit to a generalized von Bertalanffy growth function (Essington et al. 2001) and scaled to the 1991 age structure from the eastern Bering Sea stock assessment (pedigree 3, proxy with known and consistent bias). The juvenile herring Q/B of 7.843 was estimated by the stanza equations and given a pedigree of 4 (proxy with high variation).

Arrowtooth flounder

Arrowtooth flounder (*Atheresthes stomias*) are large piscivorous flatfish found in the eastern Bering Sea, found on the continental shelf and upper continental slope from about 20 m down to more than 800 m depth. As adults they primarily consume pollock (47%) and juvenile pollock (20%). They are a federally managed commercial species in Alaska. However, they are rarely targeted and are primarily captured in fisheries targeting higher value species (Shotwell et al. 2022)

Initial attempts to balance the model with AFSC bottom trawl survey estimated biomass of 0.64841 t km^{-2} for the adult pool of arrowtooth flounder were insufficient to balance the model (EE=1.252). Arrowtooth flounder can be found on the eastern Bering Sea shelf and continental slope, and throughout the Aleutian Islands. Given the extent of their range they may not be well sampled by the trawl surveys in all years. So, the stock assessment was considered a better estimate of biomass. The total biomass of adult arrowtooth flounder was the model estimated age 1+ biomass of 484,989 t for the BSAI in 1991 (Table 6.13 in Shotwell et al. 2022). This total was reduced to reflect the proportion of biomass by survey strata within the model area (Table 6.1 in Shotwell et al. 2022) resulting in a biomass density of 0.86244 t km^{-2} and an EE of 0.924. The biomass of the juvenile pool was estimated by Rpath through the stanza calculations as a proportion of the group's multi-stanza total biomass to be 0.00769 t km^{-2}. The data pedigree for arrowtooth flounder adult biomass is 2 (data are a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B and diet compositions for both adult and juvenile arrowtooth flounder, and the fisheries catch of the adult pool are unchanged from the original model. The adult P/B and Q/B were estimated using age structure information from the stock assessment and weight-at-age data collected on AFSC bottom-trawl surveys and both parameters were given a pedigree of 4 (proxy for combined Bering Sea-Aleutian Islands region). The juvenile Q/B of 5.787 was estimated by the stanza equations and given a pedigree of 5 (proxy with high variation and downgraded from adult pedigree of 4). Adult and juvenile diet composition was estimated from food habits collections made on the 1991 eastern Bering Sea shelf bottom trawl survey. The diet compositions were give a data pedigree of 1 because the data are established and substantial, with resolution on multiple spatial scales.

Kamchatka flounder

Kamchatka flounder (*Atheresthes evermanni*) is a piscivorous flatfish found on continental shelf and upper continental slope of the eastern Bering Sea. A congener of arrowtooth flounder, the two species are morphologically similar (Yang 1988) and were not reliably identified in AFSC trawl surveys until 2002 (Stevenson and Hoff 2009). Prior to 2011, arrowtooth flounder and Kamchatka flounder were managed collectively as a two-species complex in federal groundfish fisheries in Alaska. However, due to the emergence of directed fisheries for these species they have been managed separately since 2011 (Bryan et al. 2022).

The biomass estimate of Kamchatka flounder is based on estimates from the 2002 eastern Bering Sea shelf and 2002 eastern Bering Sea slope surveys to help ensure correct identification, along with the average of the 1991 and 1994 Aleutian Islands trawl survey of southern Bering Sea strata. Summing across the three surveys, the combined biomass was 0.08116 t km^{-2}, which is higher than the original model biomass of 0.05607 t km^{-2}. The biomass of the juvenile pool was estimated by Rpath through the stanza calculations as 0.00054 t km^{-2}, increasing from 0.00037 t km^{-2} in the original model. The data pedigree for adult Kamchatka flounder biomass is 3 (data are proxy, proxy may have known but consistent bias) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B and diet composition for both adults and juveniles, and the Q/B and fisheries catch of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation to be 6.152, up slightly from 6.139 in the original model.

Greenland turbot

Greenland turbot (*Reinhardtius hippoglossoides*) are large, benthic, predatory flatfish that can be found on the eastern Bering Sea shelf and continental slope, and throughout the Aleutian Islands. Given the extent of their range, they may not be sampled well by AFSC bottom trawl surveys in all years, so the stock assessment was considered a better estimate of biomass. Adult Greenland turbot biomass is the stock assessment estimated age 1+ biomass for the BSAI in 1991 (Table 5.22 in Bryan et al. 2020). We estimated the portion of the total BSAI biomass attributed to the eastern Bering Sea by proportioning the biomass based on trawl survey estimates in the AI and eastern Bering Sea, resulting in a final biomass of 0.5147 t km^{-2}. This is an increase over the original model which had an adult pool biomass of 0.34930 t km^{-2}. The juvenile biomass of 0.01101 t km^{-2} was estimated by the Rpath stanza calculations. The data pedigree for adult Greenland turbot biomass is 2 (data are a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B and diet composition for both adults and juveniles along with the Q/B and fisheries catch of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation to be 7.9118, up slightly from 7.8846 in the original model.

Pacific halibut

Pacific halibut (*Hippoglossus stenolepis*, hereafter referred to as halibut) are large predatory flatfish found across the eastern Bering Sea continental shelf and upper continental slope. As adults they are primarily piscivorous with fish constituting more than 80% of the diet composition, pollock in particular account for 52% of their diet. In contrast, juveniles are primarily benthivorous with non-pandalid shrimp accounting for 69% of the diet composition. Additionally, halibut are an economically important species managed by the International Pacific Halibut Commission which was created by a convention between Canada and the United States.

Adult halibut biomass is the sum of biomass estimates from the 1991 eastern Bering Sea shelf survey, the 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This results in a biomass estimate of 0.22128 t km^{-2} which is a modest decrease from 0.22199 t km^{-2} in the original model. Similarly, the juvenile halibut biomass of 0.00185 t km^{-2} is down slightly from 0.00187 t km^{-2} in the original model. The data pedigree for adult halibut biomass is 2 (data is a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B and diet composition for both adults and juveniles along with the Q/B of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation to be 9.33371, up slightly from 9.30319 in the original model.

The total landings and discards for Pacific halibut in 1991 are 1406.06 t and 4193.94 t, respectively (Hare 2011). The landings were attributed to the Pacific halibut directed fishery and the discards were attributed to several trawl, longline, and pot fisheries, following the allocation of Pacific halibut discards to different fishery/gear combinations in the original model (Aydin et al. 2007).

Yellowfin sole

Yellowfin sole (*Limanda aspera*) are a commercially important small-mouth flatfish found on the continental shelf from the nearshore down to about 250 m depth during summer, and have been observed as deep as 600 m during winter (Pietsch and Orr 2019b). They are benthivorous and their dominant prey include, but not limited to, polychaete worms, bivalves, miscellaneous worms, and miscellaneous crustaceans.

The biomass of 4.50123 t km^{-2} for adult yellowfin sole was estimated from the 1991 eastern Bering Sea shelf survey and the average of the 1991 and 1994 Aleutian Islands bottom trawl survey. This is down from the biomass of 4.83331 t km^{-2} in the original model. The biomass of the juvenile pool is estimated by the stanza calculations as 0.39437 t km^{-2}, which is down from 0.42466 t km^{-2} in the original model. The data pedigree for adult yellowfin sole biomass is 2 (data are a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B and diet composition for both adults and juveniles along with the Q/B and fisheries catch of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation to be 1.53580, up from 1.53072 in the original model.

Flathead sole

Flathead sole (*Hippoglossoides elassodon*) is a medium-sized commercially important flatfish found on the eastern Bering Sea continental shelf and upper continental slope. They are primarily benthivores as both adults and juveniles with more than 60% of their diet coming from benthic prey, including brittle stars, benthic amphipods, non-pandalid shrimp, and pandalid shrimp.

The adult flathead sole biomass of 1.0244 t km^{-2} is the sum of biomass estimates from the 1991 eastern Bering Sea shelf survey, 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Island survey of southern Bering Sea strata. This is down slightly from 1.19385 t km^{-2} in the original model. The biomass of juveniles was estimated by the stanza calculations as 0.1270 t km^{-2}, down from 0.14733 t km^{-2} in the original model. The data pedigree for adult flathead sole biomass is 2 (data are a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B and diet composition for both adults and juveniles along with the Q/B and fisheries catch of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation as 4.16175, up from 4.14483 in the original model.

Northern rock sole

The northern rock sole (*Lepidopsetta polyxystra*) is a commercially important small-mouth flatfish found on the eastern Bering Sea continental shelf from 3 to 517 m depth, with juveniles generally found at shallower depths than adults (Pietsch and Orr 2019b). Both adult and juvenile pools are primarily benthivorous with more than 50% of their diet in the eastern Bering Sea consisting of benthic worms.

Adult northern rock sole biomass is the sum of biomass estimates from the 1991 eastern Bering Sea shelf survey, the 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This results in a biomass estimate of 3.02498 t km^{-2} which is down from 3.22571 t km^{-2} in the original model. Similarly, the juvenile northern rock sole biomass of 0.14783 t km^{-2} is down slightly from 0.15731 t km^{-2} in the original model. The data pedigree for adult northern rock sole biomass is 2 (data are a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath).

The P/B and diet composition for both adults and juveniles along with the Q/B and fisheries catch of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation as 3.49551, up from 3.48249 in the original model.

Alaska plaice

The Alaska plaice (*Pleuronectes quadrituberculatus*) is a commercial small-mouth flatfish species inhabiting continental shelf waters of the eastern Bering Sea. Alaska plaice, the most regal of Alaska's flatfish, is easily distinguished from other small-mouth flatfish by the four bony tubercules on its head and their yellow colored blind side (Mecklenburg et al. 2002). Alaska plaice are benthivores with a particular fondness for polychaetes who account for 58% of their diet composition. The diet composition was estimated from food habits collections made on the 1991 eastern Bering Sea shelf bottom trawl survey. The biomass of Alaska plaice is estimated from the 1991 eastern Bering Sea shelf and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata as 0.99298 t km^{-2}. This is down from 1.06840 t km^{-2} in the original model. The data pedigree for Alaska plaice biomass is 2 (data are a direct estimate but with limited coverage/corroboration). The P/B, Q/B, diet composition, and fisheries catch are unchanged from the original model.

Dover sole

Dover sole (*Microstomus pacificus*) is a small-mouth flatfish found on the outer continental shelf and upper continental slope of the eastern Bering Sea down to about 1,400 m depth (Pietsch and Orr 2019b). They are benthivores whose primary prey includes polychaetes (28%), non-pandalid shrimp (26%), pandalid shrimp (22%), and benthic amphipods (9%). The Dover sole biomass of 0.00038 t km^{-2} was estimated from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata, and is up from 0.00023 t km^{-2} in the original model. The data pedigree for dover sole biomass is 2 (data are a direct estimate but with limited coverage/corroboration). The P/B, Q/B, diet composition, and fisheries catch are unchanged from the original model.

Rex sole

Rex sole (*Glyptocephalus zachirus*) is a small-mouth flatfish that occurs in the middle and outer domains for the eastern Bering Sea continental shelf and upper continental slope down to more than 1,000 m depth (Pietsch and Orr 2019b). Like other small-mouth flatfish, they primarily prey on benthic invertebrates including, non-pandalid shrimp (55%), polychaetes (20%), and benthic amphipods (12%), among others. The rex sole biomass of 0.04733 t km^{-2} was estimated from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata, and is up from 0.04063 t km^{-2} in the original model. The data pedigree for rex sole biomass is 2 (data are a direct estimate but with limited coverage/corroboration). The P/B, Q/B, diet composition, and fisheries catch are unchanged from the original model.

Miscellaneous flatfish

Miscellaneous flatfish is a composite group that consists of all remaining species of flatfish that are generally less abundant than those included as single species in this model and includes, starry flounder (*Platichthys stellatus*), longhead dab (*Limanda proboscidea*), Sakhalin sole (*L. sakhalinensis*), among others. As in the original model, trawl survey estimates of the biomass for this group were insufficient meet the demands of predators (EE > 1). Therefore, a top-down balance was used instead with EE = 0.8. This resulted in a balanced biomass 0.25525 t km^{-2} which is up from 0.22169 t km^{-2} in the original model. The data pedigree for miscellaneous flatfish biomass is 8 (estimated by Rpath). The P/B, Q/B, diet composition, and fisheries catch are unchanged from the original model.

Alaska skate

The Alaska skate (*Bathyraja parmifera*) is the most abundant, and truly most majestic, skate species in the eastern Bering Sea. They are benthic-oriented and inhabit waters across the eastern Bering Sea continental shelf and upper continental slope down to 1,425 m depth (Mecklenburg et al. 2002). They have a diverse diet, consuming several fish species, including pollock (40%), northern rock sole (8.5%), and eelpouts (8.7%), and a number of benthic invertebrates, including non-pandalid shrimp (6.5%) and snow crab (3.1%), and fisheries offal (15%). The Alaska skate biomass of 0.79112 t km^{-2} was estimated from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata, and is up from 0.68045 t km^{-2} in the original model. The data pedigree for Alaska skate biomass is 2 (data are a direct estimate but with limited coverage/corroboration). The P/B, Q/B, diet composition, and fisheries catch are unchanged from the original model.

Other skates

Other skates is a composite group that consists of skate species found on the shelf and upper continental slope in the eastern Bering Sea, including the Aleutian skate (*Bathyraja aleutica*), Bering skate (*B. interrupta*), commander skate (*B. lindbergi*), whiteblotched skate (*B. maculata*), whitebrow skate (*B. minispinosa*), mud skate (*B. taranetzi*), roughtail skate (*B. trachura*), and big skate (*Raja binoculata*), among others. They consume a wide range of prey including both fish and invertebrates, with pollock (45%) and hermit crabs (20%) as leading components of their diet composition. The other skate biomass of 0.19267 t km^{-2} was estimated from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata, and is up from 0.09293 t km^{-2} in the original model. The data pedigree for other skate biomass is 3 (data is proxy, proxy may have known but consistent bias). The P/B, Q/B, diet composition, and fisheries catch are unchanged from the original model.

Sablefish

Sablefish (*Anoplopoma fimbria*, a.k.a., black cod) is a commercially important species in the family Anoplopomatidae, and are found throughout the north Pacific from Japan to Mexico, primarily along the outer continental shelf and upper continental slope down to about 900 m depth (Pietsch and Orr 2019b). Juveniles more commonly occupy shallower shelf waters including the nearshore (Pietsch and Orr 2019b). Adult sablefish consume a range of fish and invertebrate prey, including pollock (46%), other managed forage fish (31%, see description below for taxonomic composition), and squids (11%). Juveniles are zooplanktivorous primarily preying upon euphausiids (50%).

Sablefish biomass was estimated from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata to be

0.02909 t km^{-2}, which is down from 0.03145 t km^{-2} in the original model. The biomass of juveniles was estimated as 0.00347 t km^{-2} by the stanza calculations, which is down slightly from 0.00385 t km^{-2} in the original model. The data pedigree for adult sablefish biomass is 2 (data are a direct estimate but with limited coverage/corroboration) and for juvenile biomass it is 8 (estimated by Rpath). The P/B and diet composition for both adults and juveniles along with the Q/B and fisheries catch of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation as 3.00864, up from 2.96415 in the original model.

Eelpouts

Several species from the family Zoarcidae comprise the eelpouts group, including representatives from the genera *Lycodes*, *Lycodapus*, *Lycodopsis*, *Lycenchelys*, *Bothrocara*, and *Gymnelis*. Eelpouts can be found throughout the eastern Bering Sea continental shelf and upper continental slope from about 10 m to more than 1,000 m depth. They primarily consume invertebrate prey including benthic amphipods (33%), polychaetes (24%), brittle stars (18%), and snow crabs (9%), and to a lesser extent consume fish, including cannibalism of other eelpouts (1.8%) and predation on other sculpins (1.4%).

Eelpouts are not well sampled by bottom-trawling gear and their biomass from AFSC trawl surveys (0.11083 t km^{-2}) was not sufficient to meet predator demands. Thus, a top-down balance was used with EE = 0.8 resulting in a biomass of 2.01106 t km^{-2} (pedigree 8, estimated by Rpath). This is less than the top-down balanced biomass of 2.37153 t km^{-2} in the original model. The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Grenadiers

Grenadiers is a composite group consisting of species from the family Macrouridae, a.k.a., rattails. The dominant species in this group are the giant grenadier (*Albatrossia pectoralis*), popeye grenadier (*Coryphaenoides cinereus*), and Pacific grenadier (*C. pacificus*). Grenadiers are typically not found on the continental shelf and primarily occupy deeper waters (> 200 m) along continental slope to depths well beyond the maximum depths sampled by the AFSC eastern Bering Sea slope survey (1,200 m). Their diets are poorly known but in the eastern Bering Sea they are assumed to feed primarily on squids and non-pandalid shrimp (50% each) based on samples collected on AFSC eastern Bering Sea trawl surveys (Aydin et al. 2007).

Grenadiers were not present in the 1991 eastern Bering Sea shelf survey. So, their biomass estimate of 0.89343 t km^{-2} is based on the 2002 eastern Bering Sea slope survey and the 1991 Aleutian Islands survey of the southern Bering Sea strata (grenadiers not present in 1994 Aleutian survey). This is less than their biomass of 0.96810 t km^{-2} in the original model. The data pedigree for grenadier biomass is 3 (data are proxy, proxy may have known but consistent bias). Their P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Miscellaneous fish, deep

Miscellaneous fish, deep is a composite group consisting of relatively uncommon deep-dwelling species including viperfishes and dragonfishes (Stomiidae), hatchetfishes (Sternoptychinae), tubesnouts (Aulorhynchidae), slickheads (Alepocephalidae), pearleyes (Scopelarchidae), and bigscales (Melamphaidae), among others. There is no biomass estimate available for this group. We used a top-down balance with EE = 0.8, resulting in a biomass of 0.00756 t km^{-2} (pedigree 8, estimated by Rpath).

This is lower than the top-down biomass of 0.00809 t km^{-2} in the original model. Their P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Pacific ocean perch

Pacific ocean perch (*Sebastes alutus*) is a commercially important stock of schooling rockfish (family Scorpaenidae) inhabiting waters along the outer domain of the eastern Bering Sea continental shelf and upper continental slope down to 825 m, but more commonly found between 100 and 400 m depth (Pietsch and Orr 2019a). They primarily consume zooplankton, including mysids (71%), euphausiids (21%), and copepods (5%). The Pacific Ocean perch biomass of 0.15215 t km^{-2} is estimated from the 2002 eastern Bering Sea slope survey and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This is less than their biomass of 0.16664 t km^{-2} in the original model. The data pedigree for Pacific Ocean perch biomass is 3 (data are proxy, proxy may have known but consistent bias). Their P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Sharpchin rockfish

Sharpchin rockfish (*Sebastes zacentrus*) are from the family Scorpaenidae and are found in the north Pacific from Attu Island in the Aleutian archipelago to southern California. They are commonly found between 100 and 300 m depth but have been observed as deep as 660 m (Pietsch and Orr 2019a). Their biomass estimates from trawl survey data were too low compared to predator demands. Thus, we used a top-down balance (EE = 0.8) which resulted in an estimated biomass of 0.00142 t km^{-2}, slightly less than their biomass of 0.00153 t km^{-2} in the original model (data pedigree 8, estimated by Rpath). Their P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Northern rockfish

Northern rockfish (*Sebastes polyspinis*) are a commercially important species of rockfish found along the outer domain of the eastern Bering Sea continental shelf and upper continental slope, primarily between 100 and 300 m depth but have been found as deep as 740 m (Mecklenburg et al. 2002). Northern rockfish biomass estimated from trawl surveys was insufficient to balance the model (EE > 1). Thus, we used a top-down balance to estimate a biomass of 0.02222 t km^{-2}, which is less than the top-down estimated biomass of 0.02793 t km^{-2} in the original model (data pedigree 8, estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Dusky rockfish

The dusky rockfish (*Sebastes variabilis*) is a commercial species of rockfish found in the north Pacific from Japan and Russia, east through the Aleutian Islands and Bering Sea, and south to British Columbia, primarily inhabiting depths of 100–300 m (Butler et al. 2012). They are primarily zooplanktivorous with their diet composition dominated by euphausiids (68%) and copepods (19%). Their biomass was estimated to be 0.00182 t km^{-2} from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This is greater than their biomass of 0.00061 t km^{-2} in the original model which was estimated by scaling stock assessment estimated biomass to survey areas (Aydin et al. 2007). The data pedigree for dusky rockfish biomass is 3 (data are proxy, proxy may have known but consistent bias). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Shortraker rockfish

The shortraker rockfish (*Sebastes borealis*) is a commercial rockfish species that ranges from Japan and Russia, east through the Aleutian Islands and Bering Sea, and south to British Columbia, primarily at depths between 300 and 600 m (Butler et al. 2012). They are a large and long-lived rockfish with an estimated maximum age greater than 150 years (Munk 2001). Their primary prey are pandalid shrimp (83%) and mysids (13%), as estimated from AFSC trawl surveys conducted in the early 1990s (Aydin et al. 2007). The shortraker biomass was estimated to be 0.01066 t km^{-2} from the 2002 eastern Bering Sea slope survey and the mean of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata (shortrakers were not present in the 1991 eastern Bering Sea shelf survey). This is greater than the estimate of 0.00949 t km^{-2} in the original model. The data pedigree for shortraker rockfish biomass is 3 (data is proxy, proxy may have known but consistent bias). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Rougheye and blackspotted rockfish

Historically, “rougheye” rockfish (*Sebastes aleutianus*) were treated as a single species but are now recognized as consisting of two species, rougheye rockfish (*S. aleutianus*) and blackspotted rockfish (*S. melanostictus*) (Orr and Hawkins 2008). Both species are targeted commercial stocks and over the history of their exploitation in Alaska they have been categorized and managed under multiple stock complex definitions, including “other red rockfish” and “shortraker/rougheye” (Spencer et al. 2022). Beginning in 2008 “rougheye” rockfish were managed as a two species complex in the BSAI region consisting of rougheye and blackspotted rockfish (Spencer et al. 2008) and are similarly treated as a two-species functional group in this model. Rougheye, are a long-lived commercial species of rockfish reaching ages greater than 200 years (Munk 2001). Rougheye and blackspotted rockfish have maximum sizes of 73 cm and 69 cm, respectively (Love 2011). In the eastern Bering Sea these two species occupy waters along the outer margins of the outer domain and along the upper continental slope down to more than 700 m (Butler et al. 2012).

The combined biomass of blackspotted and rougheye rockfish from AFSC bottom trawl surveys was not sufficient to balance the model (EE > 1). Blackspotted and rougheye rockfish are found in demersal and pelagic environments and often over untrawlable bottom substrate (Krieger and Ito 1999), and therefore may be inadequately sampled by the bottom trawl surveys. Thus, we used model estimated AFSC survey biomass from the stock assessment (Table 14.15 in Spencer et al. 2022) to estimate a density of 0.0028 t km^{-2} in the model area. The data pedigree for rougheye/blackspotted rockfish biomass is 3 (data is proxy, proxy may have known but consistent bias). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Shortspine thornyhead

Shortspine thornyheads (*Sebastolobus alascanus*) are a roundfish in the family Scorpaenidae which can be found around the rim of the north Pacific from Japan to Russia, through the Aleutian Islands and Bering Sea, and south to Mexico, inhabiting depths down to 1,524 m but most commonly between 200 and 850 m (Pietsch and Orr 2019a). Their primary prey includes mysids (48%), benthic amphipods (36%), and non-pandalid shrimp (15%). Shortspine thornyhead biomass of 0.03229 t km^{-2} was estimated from the 1991 eastern Bering Sea slope survey and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This is greater than their biomass of 0.00461 t km^{-2} in the original model. The data pedigree for shortspine thornyhead biomass is 3 (data are proxy, proxy may have known but consistent bias). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Other Sebastes

"Other *Sebastes*" is a multispecies functional group that consists of all remaining species of the genus *Sebastes* and *Sebastolobus* that are not included in the aforementioned rockfish groups and are known to occur in the eastern Bering Sea. The species included in this group are infrequently encountered in the model area and are mainly found along the eastern Bering Sea slope and the southern Bering Sea strata of the Aleutian Islands survey. This includes, the harlequin rockfish (*S. variegatus*), redbanded rockfish (*S. babcocki*), broadfin thornyhead (*Sebastolobus macrochir*), and longspine thornyhead (*S. altivelis*). Other *Sebastes* biomass as estimated from trawl surveys was insufficient to balance the model (EE > 1). Thus, we used a top-down balance to estimate a biomass of 0.00882 t km^{-2}, which is less than the top-down estimated biomass of 0.01114 t km^{-2} in the original model (biomass pedigree 8, estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Atka mackerel

Atka mackerel (*Pleurogrammus monopterygius*) is a commercially important medium-sized schooling species in the family Hexagrammidae (a.k.a., greenling family). They are found in continental shelf waters extending from the Kuril Islands in Asia eastward through the Aleutian Archipelago and the Gulf of Alaska (McDermott 2010). The overall abundance and schooling nature of Atka mackerel has helped make them an important prey species for the endangered Steller sea lion, among other predators (McDermott 2010). Concerns that fisheries may be competing with Steller sea lions for fish has led to multiple fisheries regulations in the Bering Sea/Aleutian Islands regions designed to ensure the maintenance of critical prey resources for Steller sea lions (e.g., Atka mackerel), including trawl exclusion zones near rookeries and a modified harvest control rule prohibiting directed fishing should fish biomass drop below a threshold biomass (20% of unfished biomass), among other regulations (Fritz et al. 1995, 67 FR 56692). Both adult and juvenile Atka mackerel are zooplanktivorous primarily feeding upon euphausiids and copepods (Rand et al. 2010).

Given the patchy distribution of Atka mackerel, trawl surveys were not regarded as reliable estimates of biomass for Atka mackerel. We use the same biomass for adult Atka mackerel as in the original model (0.10685 t km^{-2}). The estimated biomass used by Aydin et al. (2007) was derived from information contained in the Atka mackerel stock assessment (Lowe et al. 2006). The biomass of juvenile Atka mackerel was estimated by Rpath through the stanza calculations to be 0.03682 t km^{-2}, which is nearly equal to the value of 0.03713 t km^{-2} in the original model. The data pedigree for adult Atka mackerel biomass is 4 (direct estimate or proxy with high variation/limited confidence or incomplete coverage), and for juvenile biomass, it is 8 (estimated by Rpath). The P/B and diet composition for both adults and juveniles along with the Q/B and fisheries catch of the adult pool remains unchanged from the original model. The juvenile Q/B was estimated through the stanza calculation as 12.18512, up slightly from 12.01878 in the original model.

Greenlings

Greenlings are benthic fishes belonging to the genus *Hexagrammos* (family Hexagrammidae) and are represented here by the kelp greenling (*H. decagrammus*), rock greenling (*H. lagocephalus*), masked greenling (*H. octogrammus*), and the white spotted greenling (*H. stelleri*). The biomass of greenlings was estimated from the 1991 eastern Bering Sea shelf survey and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata to be 0.00126 t km^{-2}. This group was top-down balanced (EE = 0.8) in the original model which resulted in a lower biomass estimate of 0.00119 t km^{-2}. The data pedigree for greenling biomass is 2 (data are a direct estimate but with limited coverage/corroboration). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Large sculpins

The large sculpins (suborder Cottoidei) functional group includes a number of common species that achieve large sizes in Alaska, including the bigmouth sculpin (*Hemitripterus bolini*), Irish lords (*Hemilepidotus* spp.), and multiple species of the genus *Myoxocephalus*. Species in this functional group can be found across the eastern Bering Sea continental shelf and upper continental slope (Love 2011). Their biomass is estimated from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata to be 0.51568 t km^{-2}, which is lower than the estimated biomass of 0.54032 t km^{-2} in the original model. The data pedigree for large sculpin biomass is 2 (data are a direct estimate but with limited coverage/corroboration). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Other sculpins

Other sculpins (suborder Cottoidei) is a composite group containing all other species of sculpins not included in the aforementioned large sculpin group. This speciose functional group includes representatives from the genera *Icelus, Triglops, Artediellus, Enophrys, Gymnocanthus, Icelinus, Leptocottus, Malacocottus, Blepsias, Dasycottus*, Psychrolutes, and *Nautichthys*, among others. While other sculpins are frequently encountered by AFSC trawl surveys, their size and affinity for untrawlable habitat make survey derived estimates of biomass unreliable. Thus, as was done in the original model, we use a top-down balance (EE = 0.8) to estimate other sculpin biomass as 1.20064 t km-2

(1.13669 t km^{-2} in the original model). The data pedigree for other sculpin biomass is 8 (estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Miscellaneous shallow fish

Miscellaneous shallow fish is a composite group that brings together demersal fishes from multiple families including poachers (Agonidae), lumpsuckers (Cyclopteridae), snailfishes (Liparidae), Arctic and saffron cod (Gadidae), ronquils (Bathymasteridae), wolffishes (Anarhichadidae), prowfish (Zaproridae), lampreys (Petromyzodontidae), hagfish (Myxinidae), among others. Species in this group are infrequently encountered by trawl surveys, are too small to be effectively caught by survey gear, or inhabit untrawlable areas. Thus, their biomass of 0.76752 t km^{-2} was estimated with a top-down balance, as was done in the original model (1.16769 t km^{-2}). The data pedigree for miscellaneous shallow fish biomass is 8 (estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Octopus

Octopus includes multiple species from the order Octopoda, most notably the giant Pacific octopus (*Enteroctopus dofleini*). Trawl surveys do not efficiently capture octopus leading to high variance in biomass estimates and limited understanding of spatial variation (Cronin-Fine et al. 2023). Beginning in 2012 the North Pacific Fishery Management Council adopted a method of estimating octopus biomass based on consumption estimates by Pacific cod (Conners et al. 2011). An examination of Pacific cod food habits data from the eastern Bering Sea indicated higher densities of octopus may be present in the middle and outer domains of the eastern Bering Sea continental shelf (Rohan and Buckley 2017). Octopus biomass was estimated with a top-down balance (EE = 0.8) to be 0.14262 t km^{-2}, down from

0.19248 t km^{-2} in the original model (biomass pedigree 8, estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Squids

Squids includes cephalopods from the order Teuthoidea. Several squid species inhabit the eastern Bering Sea including, *Berryteuthis magister, B. anonychus, Gonatopsis borealis*, and *Gonatus middendorfi*, among others. In July of 2018, the regional fishery management council implemented Amendment 117 to the Bering Sea and Aleutian Islands Fishery Management Plan (FMP), which prohibited directed fishing for squids and moved the squid complex into the Ecosystem Component category (50 CFR 679, https://www.federalregister.gov/d/2018-14457). Prior to Amendment 117, squids were managed as a target fishery stock complex with annual harvest specifications (Ormseth 2018).

Squid biomass cannot be estimated from AFSC trawl survey data because the trawl surveys do not deploy gear appropriate to adequately sample squids (Ormseth 2016). Thus, we used a top-down balance to estimate squid biomass as 0.73158 t km^{-2}, which is less than the top-down balanced estimate of 0.92700 t km^{-2} in the original model (data pedigree 8, estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Salmon

Salmon are represented in this model (and the original model) in two distinct groupings, large mature salmon returning through the continental shelf environment on their way to spawning grounds (**Salmon returning**) and small outmigrating smolts just entering the oceanic environment (**Salmon smolts**). Salmon returning and salmon smolts are composite groups representing salmon from the genus *Oncorhynchus*, including pink (*O. gorbuscha*), chum (*O. keta*), coho (*O. kisutch*), sockeye (*O. nerka*), and

Chinook (*O. tshawytscha*). These anadromous salmonids spawn in freshwater where fry and small juveniles spend varying amounts of time rearing in freshwater before migrating to the open ocean where they grow and mature. These five *Oncorhynchus* species exhibit a variety of life history strategies, spending from 1 to 5 years at sea before returning to their natal streams to spawn and die. Given the complexity of these numerous life history strategies involving multiple life history stages occurring outside the model domain, salmon returning and salmon smolts are treated as separate functional groups and not linked as adult and juvenile pools through stanzas.

We maintain the biomass estimate of 0.16377 t km^{-2} for Salmon returning from the original model. This estimate was based on the 1991 catch plus escapement of salmon for western Alaska (Rogers 2001) and proportioned to model area by eastern Bering Sea trawl survey biomass for 1991 (Aydin et al. 2007). The biomass of salmon smolts was estimated with a top-balance to be 0.00051 t km^{-2}, which is less than the top-down balanced biomass of 0.01453 t km^{-2} in the original model. The data pedigree for salmon returning biomass is 6 (historical information) and the pedigree for juvenile biomass is 8 (estimated by Rpath). The P/B, Q/B, and diet composition for salmon returning and salmon smolts, and the fisheries mortality for salmon returning are unchanged from the original model. The model does not include and fisheries related mortality for salmon smolts.

Bathylagidae

Bathylagidae is a family of pelagic deepsea smelts, including the northern smoothtongue (*Leuroglossus schmidti*). In the eastern Bering Sea, bathylagids inhabit deep continental slope waters down to 1,800 m depth (Love 2011). Biomass was estimated with a top-down balance (EE = 0.8) to be 0.18313 t km^{-2}, which is similar to the original model's top-balanced biomass of 0.16164 t km^{-2} (biomass pedigree of 8, estimated by Rpath). The P/B, Q/B, and diet composition are unchanged from the original model.

Myctophidae

Myctophidae is a composite group representing laternfishes found in the eastern Bering Sea. A defining feature of myctophids are the light-emitting blue-green photophores that can be found on their body. Myctophids are mesopelagic fishes that can be found at depths greater than 1,000 m, but they are known to vertically migrate to near-surface waters where they are an important prey resource for seabirds, marine mammals, and fishes (Love 2011). In the eastern Bering Sea, they are represented by species from the genera *Diaphus, Lampanyctus, Stenobrachius, Nannobranchium*, and *Protomyctophum*. Myctophid biomass was estimated with a top-down balance (EE = 0.8) to be 0.67008 t km^{-2} (biomass data pedigree 8, estimated by Rpath). This is less than the top-down balanced biomass of 0.79695 t km^{-2} in the original model. The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Capelin

Capelin (*Mallotus villosus*) are a small schooling fish in the family Osmeridae (smelts) with a maximum length of 25 cm (Love 2011). In the eastern Bering Sea, they can be found across the continental shelf down to about 200 m depth, though typically in the upper 100 m of the water column (Love 2011). Capelin are not well sampled by AFSC trawl survey gear. So, their biomass was estimated with a top-down balance (EE = 0.8) to be 0.90463 t km^{-2}. This is less than the top-down balanced biomass of 1.23928 t km^{-2} in the original model. Their data pedigree for biomass is 8 (estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Sand lance

Sand lance or sand eels (Ammodytidae) are slender forage fishes found in continental shelf waters throughout the north Pacific. Based on an examination of genetic and morphological data, there are two species present in the eastern Bering Sea, *Ammodytes personatus*, and *A. hexapterus* (Orr et al. 2015). Sand lance are not well sampled by AFSC trawl survey gear, so their biomass was estimated with a top-down balance (EE = 0.8) to be 2.33574 t km^{-2}. This is less than the top-down balanced biomass of 2.48365 t km^{-2} in the original model. Their biomass data pedigree is 8 (estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Eulachon

Eulachon (*Thaleichythys pacificus*) are smelts (family Osmeridae) that school near the seafloor over continental shelf waters (Love 2011). Their generally demersal orientation makes them more available to AFSC bottom trawling gear than other smelts. However, there presently are no reliable estimates of biomass for this stock (Szuwalski et al. 2023). Thus, their biomass was estimated with a top-down balance (EE = 0.8) to be 0.41558 t km^{-2}, down from 0.55245 t km^{-2} in the original model (biomass pedigree 8, estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Other managed forage

Amendment 36 to the Bering Sea/Aleutian Islands Fishery Management Plan established a forage fish category and prevented the development of a directed fishery for forage fish in recognition of their critical role as prey for marine mammal, seabird, and piscivorous fishes (63 FR 13009). The “other” managed forage functional group is a composite group that consists of fish (euphausiids were also designated as forage by Amendment 36 but are treated separately below) whom are members of the Amendment 36 designated forage fish group, aside from those more common taxa already listed separately above, including capelin, sand lance, eulachon, bathylagids, and myctophids. The other managed forage functional group includes Pacific sandfish (*Trichodon trichodon*), pricklebacks (Stichaeidae), gunnels (Pholidae), and bristlemouths (Gonostomatidae). There is no reliable estimate of biomass for this group. Thus, we estimated a biomass of 0.81220 t km^{-2} with a top-down balance (EE = 0.8). This is less than the top-down estimate of 1.05387 t km^{-2} from the original model. Their biomass data pedigree is 8 (estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Other pelagic smelt

Other pelagic smelt is a composite group that consists of argentines (Argentinidae), rainbow smelt (*Osmerus mordax*), and other osmerids that are less common in the eastern Bering Sea. There is no reliable estimate of biomass for this group, so their biomass was estimated with a top-down balance to be 0.40069 t km^{-2}, which is less than the top-down estimate of 0.49905 t km^{-2} from the original model. The data pedigree for biomass is 8 (estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Benthic Invertebrates

Tanner crab

Tanner crabs (*Chionoecetes bairdi*) are a large, commercially important species of brachyuran crab (Infraorder Brachyura, true crabs) from the Majidae family (spider crabs). Their biomass was estimated from the 1991 eastern Bering Sea shelf survey, 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Island surveys to be 0.35824 t km^{-2}. However, this biomass estimate was insufficient to meet predator and fishery demands (EE > 1.0). Pacific cod are the primary predator of tanner crabs, however the exact percentage of tanner crabs in Pacific cod diet varies in both time and space. In consideration of the uncertainty in Pacific cod diet composition, we reduced the proportion of tanner crabs in the diet of Pacific cod by 0.5% and added that 0.5% to the dominant prey group in the Pacific cod diet, walleye pollock. This was sufficient to bring tanner crabs into balance with EE = 0.960. In the original model, tanner crab biomass was estimated to be 0.52185 t km^{-2} from a report to industry on the status of commercial crab resources in the eastern Bering Sea (Stevens et al. 2002). To maintain consistent methods for biomass estimation with other groups in our updated model, we use our survey-derived estimate of biomass as input for this group. The tanner crab biomass pedigree is 2 (direct regional estimate with poor subregional resolution). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

King crabs

King crabs is a composite group that consists of Anomuran crabs from the family Lithodidae including the commercial species, red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), and golden king crab (*Lithodes aequispina*). King crab biomass was estimated to be 0.20454 t km^{-2} from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This is less than the biomass of 0.23839 t km^{-2} from the original model. The king crab biomass pedigree is 2 (direct regional estimate with poor subregional resolution). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Snow crab

Snow crab (*Chionoecetes opilio*) is a commercially important species of brachyuran crab from the family Majidae (spider crabs). They are typically found in relatively cooler and shallower water than their congener, tanner crabs (*C. bairdi*), though there is considerable spatial overlap in the eastern Bering Sea (Murphy 2020). The snow crab biomass of 1.51625 t km^{-2} was estimated from the 1991 eastern Bering Sea shelf and 2002 eastern Bering Sea slope bottom trawl surveys. This is less than the estimated biomass of 2.17883 t km^{-2} from the original model which was derived from information in Stevens et al. (2002). The snow crab biomass pedigree is 2 (direct regional estimate with poor subregional resolution). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Pandalid shrimp

The Pandalid shrimp group consists of species from the commercial shrimp family Pandalidae, including several species from the *Pandalus* and *Pandalopsis* genera. Shrimps have low catchability in the AFSC trawl surveys, so a top-down balance (EE = 0.8) was used to estimate biomass (pedigree 8, estimated by Rpath). Their biomass in this model update is 6.15653 t km^{-2} compared to 6.72695 t km^{-2} in the original model. The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Non-pandalid shrimp

The non-pandalid shrimp functional group consists of all (non-commercial) shrimp species outside of the Pandalidae family. This includes representatives from several shrimp families, including Sergestidae, Hippolytidae, Crangonidae, Pasiphaeidae, and Oplophoridae. Shrimps are not well sampled by AFSC trawl surveys, so non-pandalid shrimp biomass was estimated by top-down (EE = 0.8) to be 12.31677 t km^{-2} (pedigree 8, estimated by Rpath). This is slightly less than the top-down estimate of

12.82204 t km^{-2} in the original model. The P/B, Q/B, and diet composition are unchanged from the original model.

Sea stars

Sea stars is an abundant group of benthic invertebrates that contains all members of the class Asteroidea found in the eastern Bering Sea. Sea star biomass was estimated from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands surveys of southern Bering Sea strata as 2.3169 t km^{-2}. This is only slightly less than their biomass of 2.47136 t km^{-2} in the original model.

Sea stars are generalist predators that consume a wide range of benthic invertebrate taxa. Sea star prey in the Bering Sea includes sea urchins, sand dollars, shrimp, bivalves, snails, barnacles, tunicates, crabs, polychaetes, and echiurans (Feder and Jewett 1978, 1980, Feder and Jewett 1981, Shah and Surati 2013). The diet composition of sea stars in the Aydin et al. (2007) model of the eastern Bering Sea consisted of 91% bivalves, 2% polychaetes, 1% miscellaneous worms, 3% brittle stars, and 0.5% each of tanner crabs, snow crabs, pandalid shrimp, non-pandalid shrimp, snails, and hermit crabs. We largely maintain that diet composition in this update but with a few modifications: 1) bivalves are reduced from 91% to 80%, 2) we add urchins, dollars, cucs to the diet and attribute 10% to them, 3) we add benthic tunicates to the diet (0.5%), and 4) the portion attributed to polychaetes was increased from 2.0% to 2.5%.

The biomass data pedigree for sea stars is 3 (direct sampling but poor catchability). The pedigree for diet composition is 6 (general diet description from the same region). The P/B, Q/B, and fisheries mortality are unchanged from the original model.

Brittle stars and basket stars

The brittle stars functional group includes all members of the class Ophiuroidea found in the eastern Bering Sea. This includes brittle stars from the order Ophiurida, such as the notched brittle star (*Ophiura sarsi*) and the ubiquitous brittle star (*Ophiopholis aculeata*), among others, and also includes basket stars from the order Euryalida, such as *Gorgonocephalus eucnemis*. Brittle stars are not well sampled by bottom trawling gear and their biomass from the trawl surveys was insufficient to meet predator demands. Therefore, we used a top-down balance (EE = 0.8) resulting in a biomass of 2.47795 t km^{-2}, which is less than their biomass of 3.08653 t km^{-2} in the original model.

In the original eastern Bering Sea Ecopath of Aydin et al. (2007), they assumed a diet of 90% benthic detritus and 10% benthic amphipods for brittle stars and basket stars. Brittle stars utilize multiple feeding methods including deposit feeding, suspension feeding, scavenging, and predation (Warner 1982). Common prey of brittle stars include detritus, carrion, benthic amphipods, polychaetes, bivalves, and diatoms (Warner 1982, Ambrose et al. 2001, Harris et al. 2009). Basket stars feed by catching planktonic prey with the spines and hooks that arm their highly branched arms (Patent 1970, Warner 1982, Emson et al. 1991, Rosenberg et al. 2005). Frequently reported prey of basket stars includes mysids, euphausiids, other crustacean zooplankton, and bottom-dwelling crustaceans (Patent 1970, Emson et al. 1991), though Warner (1982) described their diet as consisting of virtually all planktonic prey. We assume a composite diet for brittle stars and basket stars that consists of 60% benthic detritus and 40% equally divided (5% each) among miscellaneous crustaceans, benthic amphipods, bivalves, polychaetes, euphausiids, mysids, copepods, and large phytoplankton.

The biomass data pedigree is 8 (estimated by Rpath). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B and Q/B are unchanged from the original model.

Urchins, dollars, and cucumbers

Urchins, dollars, and cucumbers is a composite group that brings together echinoderms from the orders Echinoidea (sea urchins and dollars) and Holothuroidea (sea cucumbers). Sea urchins, sand dollars, and sea cucumbers are not efficiently sampled with standard bottom trawling used during the AFSC summer bottom trawl surveys. Thus, their survey estimated biomass was inadequate to balance the model and we used a top-down balance instead (EE = 0.8) resulting in a biomass of 3.87265 t km^{-2}. This is greater than their top-down estimated biomass of 1.11966 in the original model. This increase is largely due to changes in the diet compositions of predators of this group, resulting in increased predation pressure and higher biomass.

In the original Ecopath model of the eastern Bering Sea, the urchins, dollars, and cucumbers group's diet composition consisted of 75% benthic detritus and 25% macroalgae. The common sand dollar (*Echinarachnius parma*) is a deposit feeder, consuming detritus and phytoplankton (DeRiddler and Lawrence 1982, Ables 2000). The green sea urchin (*Strongylocentrotus droebachiensis*) primarily consumes plant material (DeRiddler and Lawrence 1982). Sea cucumbers includes both suspension feeders and deposit feeders, consuming plankton and detritus (Massin 1982). We assume a diet for this group that consists of 60% benthic detritus, 20% macroalgae, and 20% large phytoplankton.

The biomass data pedigree is 8 (estimated by Rpath). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B and Q/B are unchanged from the original model.

Snails

The snail functional group includes all gastropods except pteropods (pelagic snails). The biomass of snails was estimated to be 0.59967 t km^{-2} from the 1991 eastern Bering Sea shelf, 2002 eastern Bering

Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This is different from the original model where they top-down balanced (EE = 0.8) snails to have a biomass of 0.8222 t km^{-2}. As our survey-derived biomass estimate was sufficient to balance the model, we elected to use that estimate over a top-down balanced estimate, which improved the data pedigree from 8 to 3 (direct sampling but poor catchability). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Hermit crabs

The hermit crab functional group includes anomuran crabs from the family Paguridae who encase their abdomens within empty gastropod shells (Ruppert and Barnes 1994). The hermit crab biomass from the AFSC trawl surveys was not sufficient to meet predator demands. So, a top-down balance (EE = 0.8) was used resulting in a biomass of 1.64234 t km^{-2} (data pedigree 8, estimated by Rpath). This is down slightly from the top-down balanced biomass of 1.78518 t km^{-2} in the original model. The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Miscellaneous crabs

Miscellaneous crabs is a composite group that consists of all non-commercial crab species, except for hermit crabs, which are a separate group listed above. This group includes both brachyuran and anomuran crabs, including crabs from the families Lithodidae, Majidae, and Pinnotheridae. Additionally included in this group are mud shrimps (family Axiidae), though technically not crabs. The AFSC bottom trawl survey biomass estimate for miscellaneous crabs (0.11216 t km^{-2}) was insufficient to meet predator demands and a top-down balance (EE = 0.8) was used instead resulting in a biomass estimate of 0.56725 t km^{-2} (pedigree 8, estimated by Rpath). The P/B, Q/B, diet composition, and fisheries mortality are unchanged from the original model.

Miscellaneous crustaceans

The miscellaneous crustaceans group consolidates many of the remaining crustaceans that are not members of other functional groups, including barnacles, ostracods, cladocerans, isopods, cumaceans, and pycnogonids. In general, these animals are benthic in orientation living either on, within, or in waters just above the surface sediments. There are no reliable estimates of biomass for this group. So, a top-down balance was used (EE = 0.8) resulting in a biomass of 1.70913 t km^{-2}. This density is less than their top-down estimated biomass of 8.84222 t km^{-2} in the original model and is largely due to changes in predator diet compositions in this model update.

In the Aydin et al. (2007) eastern Bering Sea Ecopath model, the diet of miscellaneous crustaceans was divided evenly between benthic detritus and benthic microbes. The taxa in this functional group include suspension feeders, deposit feeders, scavengers, and predators. Barnacles are suspension feeders that filter plankton from the water (Ruppert and Barnes 1994). Pycnogonids (a.k.a., sea spiders) as a group include multiple feeding methods, such as parasitism, predation, herbivory, and detritivory (Wyer and King 1974, Mercier and Hamel 1994, Soler-Membrives et al. 2013, Wicksten 2017, Dietz et al. 2018). Ostracods are primarily detritivores but some species may be predators or parasites (Vannier et al. 1998). Cladocerans feed upon detritus, microbes, phytoplankton, and small zooplankton (Turner et al. 1988, Modig et al. 2000, Lehtiniemi and Gorokhova 2008). Isopods are primarily detritivores and scavengers but also includes species that are predators or are parasitic (Würzberg et al. 2011, Poore and Bruce 2012). Cumaceans feed upon detritus, phytoplankton, and microbes (Blazewicz-Paszkowycz and

Ligowski 2002, Würzberg et al. 2011). We assume a diet for miscellaneous crustaceans that consists of 50% benthic detritus, 45% benthic microbes, and 5% large phytoplankton.

The data pedigree for biomass is 8 (estimated by Rpath). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B and Q/B are unchanged from the original model.

Benthic amphipods

Benthic amphipods consists of crustacean species from the suborders Gammaridea and Caprellidea. They are relatively small benthic crustaceans that are an important prey resource for groundfish, marine mammals, and seabirds (Grebmeier and Harrison 1992, Highsmith and Coyle 1992, Lang et al. 2005). There is no reliable estimate of biomass for benthic amphipods, so biomass was estimated with a top-down balance to be 5.09950 t km^{-2} with EE = 0.8. This is less than their top-down estimated biomass of 12.63702 t km^{-2} in the original model and is largely attributable to changes in the diets of predators, in particular, the diets of other benthic invertebrates.

Benthic amphipods as a group exhibit multiple feeding strategies, including scavenging, deposit feeding, suspension feeding, and carnivory (Legeżyńska et al. 2012, Rodkina et al. 2020). Common prey items of benthic amphipods include carrion, detritus, phytoplankton (diatoms), bacteria, copepods, and polychaetes (Thomson 1986, Legeżyńska 2008, Nygård et al. 2012, Connelly et al. 2014, Guerra-García et al. 2014, Legeżyńska et al. 2014, Dischereit et al. 2024). We assume a benthic amphipod diet that consists of 60% benthic detritus and 10% each of large phytoplankton, benthic microbes, copepods, and polychaetes.

The data pedigree for biomass is 8 (estimated by Rpath). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B and Q/B are unchanged from the original model.

Anemones

The anemones functional group consists of Cnidarians from the Order Actinaria. Some of the most frequently encountered species in the eastern Bering Sea are *Liponema brevicorne*, *Urticina crassicornis*, *Stomphia coccinea*, and *Metridium* sp. The biomass of anemones was estimated to be 0.10471 t km^{-2} from the 1991 eastern Bering Sea shelf, 2002 eastern Bering Sea slope, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata. This is slightly less than the similarly derived biomass estimate of 0.10952 t km^{-2} in the original model.

Sea anemones are predators who can feed on a range of benthic and pelagic taxa, including, but not limited to, bivalves, polychaetes, gastropods, amphipods, cumaceans, ostracods, isopods, copepods, crustacean larvae, mollusk larvae, and detritus (Purcell 1977, Chintiroglou and Koukouras 1992, Dalby 1992, Acuña and Zamponi 1996, Kruger and Griffiths 1998, Quesada et al. 2014, Sun et al. 2022, Wells et al. 2022, Vazquez et al. 2023). Lacking region-specific anemone diet descriptions, we assume a diet that consists of equal parts (16.667%) miscellaneous crustaceans, benthic amphipods, bivalves, polychaetes, benthic microbes, and benthic detritus.

The biomass data pedigree is 3 (direct sampling but poor catchability). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B, Q/B, and fisheries mortality are unchanged from the original model.

Corals

The corals group consists of Anthozoan cnidarians, including soft corals, cup corals, sea fans, hydrocorals, and black corals. Sea raspberries (*Gersemia* sp.) are among the most frequently encountered coral on the eastern Bering Sea shelf. In the Aleutian Islands and eastern Bering Sea upper continental slope other frequently encountered corals include, *Paragorgia* sp., *Fanellia* sp., *Primnoa* sp., and *Stylaster* sp. The biomass of corals was estimated from the 1991 eastern Bering Sea shelf survey, 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata to be 0.01216 t km^{-2}.

The original eastern Bering Sea Ecopath model assumed a generalized benthic invertebrate diet composition that consisted of benthic detritus (60%), benthic microbes (15%), miscellaneous crustaceans (12.5%) and benthic amphipods (12.5%). Corals feed by filtering prey from the water. They consume a wide range of prey, including microbes, phytoplankton, zooplankton (e.g., copepods), and detritus, with the specific contributions of different prey types to their overall diet compositions being variable (Slattery et al. 1997, Sherwood et al. 2008, Carlier et al. 2009, Mueller et al. 2014, McMahon et al. 2018, Parzanini et al. 2018, van Oevelen et al. 2018, Luo et al. 2024, Greenman et al. 2025, Rodkina and Dautova 2025). We assume the dominant component of the coral diet to consist of benthic detritus (75%). Prey of lesser importance include, benthic microbes (20%), copepods (1.667%), large phytoplankton (1.667%), and small phytoplankton (1.667%).

The biomass data pedigree is 3 (direct sampling but poor catchability). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B, Q/B, and fisheries mortality are unchanged from the original model.

Benthic hydroid

Benthic hydroid consists of cnidarians from the class Hydrozoa. Hundreds of hydroid species have been identified in Alaskan waters (O'Clair and O'Clair 1998) and the family Sertulariidae has been identified as a prey item in Alaska groundfish diets (Aydin et al. 2007). Benthic hydroids are commonly found among the epifaunal community in association with deep sea corals (Henry 2001). There are no reliable estimates of biomass for this group, so biomass was estimated with a top-down balance to be 0.21073 t km^{-2}. This is less than their top-down estimated biomass of 0.25977 t km^{-2} in the original model.

The original eastern Bering Sea Ecopath model assumed a generalized benthic invertebrate diet composition for hydroids that consisted of benthic detritus (60%), benthic microbes (15%), miscellaneous crustaceans (12.5%) and benthic amphipods (12.5%). Hydrozoans are primarily carnivorous preying upon small zooplankton (e.g., copepods, mysids, chaetognaths,), larvae and eggs from multiple taxa (including, crustaceans, molluscs, and fish), worms (e.g., polychaetes, sipunculans), diatoms, and organic matter (Coma et al. 1995, Gili and Hughes 1995, Di Camillo et al. 2012, Di Camillo et al. 2017, Dutto et al. 2019, Huang et al. 2020). Lacking a quantitative diet composition for benthic hydroids in the Bering Sea, we divide their diet composition evenly (7.692% each) among miscellaneous crustaceans, benthic amphipods, bivalves, polychaetes, miscellaneous worms etc., fish larvae, chaetognaths, mysids, gelatinous filter feeders, copepods, benthic microbes, large phytoplankton, and benthic detritus.

The data pedigree for biomass is 8 (estimated by Rpath). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B and Q/B are unchanged from the original model.

Benthic urochordata

Benthic urochordata (Phylum Urochordata) includes tunicates from the Class Ascidiacea. Sessile adult tunicates are an abundant component of the benthic community on the eastern Bering Sea continental shelf. Common genera include *Boltenia* (sea onion), *Halocynthia* (sea peach), and *Styela* (sea potato). The biomass of benthic urochordata was estimated from the 1991 eastern Bering Sea shelf survey, 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata to be 0.33122 t km^{-2}. This is slightly less than their survey estimated biomass of 0.35450 t km^{-2} in the original model.

Benthic tunicates feed by filtering plankton and detritus from the water (Ruppert and Barnes 1994). The original eastern Bering Sea Ecopath model assumed a generalized benthic invertebrate diet composition for benthic tunicates that consisted of benthic detritus (60%), benthic microbes (15%), miscellaneous crustaceans (12.5%) and benthic amphipods (12.5%). Their food habits are not well known but observed prey include bacteria, protozoans, phytoplankton, organic matter, and invertebrate larvae (Bingham and Walters 1989, Ribes et al. 1998, Coma et al. 2001). We assume a diet composition for benthic tunicates that consists of benthic detritus (50%), benthic microbes (45%), large phytoplankton (2.5%), and small phytoplankton (2.5%).

The biomass data pedigree is 3 (direct sampling but poor catchability). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B, Q/B, and fisheries mortality are unchanged from the original model.

Sea pens

Sea pens groups together benthic cnidarians from the Class Octocorallia, commonly known as sea pens (Order Pennatulacea) and sea whips (Order Alcyonacea). Sea pen biomass was estimated from the 1991 eastern Bering Sea shelf survey, 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata to be 0.00153 t km^{-2}. This is less than their survey estimated biomass of 0.01342 t km^{-2} in the original model.

Sea pens and whips feed by filtering small plankton and detritus from the water. The original eastern Bering Sea Ecopath model assumed a generalized benthic invertebrate diet composition for sea pens that consisted of benthic detritus (60%), benthic microbes (15%), miscellaneous crustaceans (12.5%) and benthic amphipods (12.5%). This generalized diet was intended to maintain comparable trophic levels with pelagic tertiary consumers (e.g., euphausiids). Trophic studies of sea pens and sea whips that examined their fatty acid and lipid profiles and stable isotope compositions indicated a diet that primarily consisted of phytoplankton and detritus (Sherwood et al. 2008, Servetto et al. 2017, Salvo et al. 2018). We assume a diet composition for sea pens and sea whips that consists of 60% benthic detritus, 20% large phytoplankton, and 20% small phytoplankton.

The biomass data pedigree is 3 (direct sampling but poor catchability). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B, Q/B, and fisheries mortality are unchanged from the original model.

Sponge

Sponges (Phylum Porifera) are a diverse and abundant group that can be found throughout the eastern Bering Sea with higher abundances along the upper continental slope and in the Aleutian Islands (Stone et al. 2019). Sponges are important live substrates, forming benthic structures that provide habitat and protection for numerous other taxa from predators (Marliave et al. 2009, Miller et al. 2012). The biomass of sponge was estimated from the 1991 eastern Bering Sea shelf survey, 2002 eastern Bering Sea slope survey, and the average of the 1991 and 1994 Aleutian Islands survey of southern Bering Sea strata to be 0.05496 t km^{-2}, which is approximately equal to their biomass of 0.05449 t km^{-2} in the original model.

The original eastern Bering Sea Ecopath model assumed a generalized benthic invertebrate diet composition for sponge that consisted of benthic detritus (60%), benthic microbes (15%), miscellaneous crustaceans (12.5%) and benthic amphipods (12.5%). We updated that diet composition here with information from the literature specific to sponge. Sponges feed by actively filtering water for bacteria, phytoplankton, and other particles as water passes through their bodies (Pile et al. 1996, Totti et al. 2005, Yahel et al. 2007, Perea-Blázquez et al. 2013). We attribute 50% of the sponge diet to benthic detritus, 25% to benthic microbes, 20% to small phytoplankton, and 5% to large phytoplankton.

The biomass data pedigree is 3 (direct sampling but poor catchability). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B, Q/B, and fisheries mortality are unchanged from the original model.

Bivalves

The bivalves functional group consists of species from the mollusk Class Bivalvia, including clams, mussels, cockles, and scallops, and additionally, scaphopods from the Class Scaphopoda. Bivalves are an abundant part of the benthic community and may lie on the sea floor or live within the sediment. There are few regional estimates of bivalve biomass in the eastern Bering Sea and we maintain the biomass estimate of 61.87307 t km^{-2} from the original model. This estimate was taken from a study of the eastern Bering Sea benthic community conducted in the 1970s (McDonald et al. 1981), however, remains a best region-wide estimate.

The original eastern Bering Sea Ecopath model assumed a generalized benthic invertebrate diet composition for bivalves that consisted of benthic detritus (60%), benthic microbes (15%), miscellaneous crustaceans (12.5%) and benthic amphipods (12.5%). Bivalves are deposit and suspension feeders, consuming phytoplankton, microbes, and detritus (Ruppert and Barnes 1994). In the Bering Sea, they consume ice algae, pelagic diatoms, phytodetritus, and microbes (Weems et al. 2012, Oxtoby et al. 2016, Koch et al. 2025). We update the bivalve diet composition to be 60% benthic detritus, 20% benthic microbes, and 20% large phytoplankton.

The data pedigree for biomass is 7 given the date of the estimate and high variance. The pedigree for diet composition is 6 (general diet description from the same region). The P/B, Q/B, and fisheries mortality are unchanged from the original model.

Polychaetes

Polychaetes (Class Polychaeta) are a diverse group of annelid worms found throughout the study region. They are an important prey taxa for a variety of predators, including marine mammals, fishes, and benthic invertebrates. At least 37 families of polychaetes have been identified from the stomach contents of Alaska groundfishes (Aydin et al. 2007). The biomass estimate of 21.68738 t km^{-2} for polychaetes in the original model was averaged from benthic grab samples collected across the eastern Bering Sea and reported in Feder et al. (1981). This remains a best region-wide density estimate for polychaetes and we maintain this biomass in this update.

The original eastern Bering Sea Ecopath model assumed a diet composition for polychaetes that was divided evenly between benthic detritus and benthic microbes. In the Bering Sea, there are both carnivorous and deposit feeding polychaetes (Feder and Jewett 1981, Stoker 1981, Oxtoby et al. 2016, Charrier et al. 2023) who consume a range of prey including, miscellaneous crustaceans, benthic amphipods, bivalves, polychaetes, microbes, phytoplankton, and detritus (Jumars et al. 2015 and references cited therein). Based on qualitative diet descriptions, we assume the diet of the polychaete functional group to consist of 60% benthic detritus, 5% small phytoplankton, 5% large phytoplankton, 10% benthic microbes, 10% bivalves, 5% polychaetes, 2.5% benthic amphipods, and 2.5% miscellaneous crustaceans.

The data pedigree for biomass is 7 due to the high variance of the estimate and because the study was conducted in the 1970s. The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B and Q/B are unchanged from the original model.

Miscellaneous worms etc.

Miscellaneous worms, etc. is a composite group consisting of taxa from multiple phyla, including Annelida (including, sipunculans, echiurans, oligochaetes, leeches, and flatworms), Priapulida, Nemertea, Bryozoa, and Brachiopoda. There are no reliable estimates of biomass for this functional group, so we estimated biomass to be 8.17770 t km^{-2} with a top-down balance (EE = 0.8).

This functional group includes carnivores, deposit feeders, and filter feeders. In the original eastern Bering Sea Ecopath model a generalized invertebrate diet was assumed for this group which consisted of 50% benthic detritus and 50% benthic microbes. We update their diet composition in this model update with taxa-specific diet information. Echiurans are deposit feeders primarily consuming benthic detritus (McConnaughey and McRoy 1979, Ruppert and Barnes 1994). Sipunculans are deposit feeders or suspension feeders, preying upon detritus, bacteria, protozoans, and algae (Maiorova and Adrianov 2013). Priapulans include carnivores and deposit feeders. Carnivorous priapulans primarily prey upon polychaete worms, other priapulans, and other invertebrates, while deposit feeding priapulans consume detritus (Ruppert and Barnes 1994). Nemerteans are carnivorous feeding primarily on annelid worms (e.g., polychaetes), mollusks, and crustaceans (McDermott and Roe 1985, Thiel and Kruse 2001). Bryozoans and brachiopods are both filter feeders who consume detritus, microbes, and phytoplankton

(Richelle et al. 1994, Dhar et al. 1997, Peck et al. 2005, Wood 2021). In consideration of the qualitative diet descriptions for this functional group, we assume a general diet composition that consists of 50% benthic detritus, 28% benthic microbes, 10% polychaetes, 10% miscellaneous worms etc. (cannibalism), 1% large phytoplankton, and 1% small phytoplankton.

The data pedigree for biomass is 8 (estimated by Rpath). The pedigree for diet composition is 7 (general literature for a range of species, or outside the region). The P/B and Q/B are unchanged from the original model.

Plankton and Microbes

Scyphozoid jellies

Scyphozoid jellies (Class Scyphozoa, a.k.a., jellyfish) are gelatinous predators of the phylum Cnidaria. They have a bell-shaped body with trailing tentacles that possess stinging cells that can be used to capture prey and be used in defense (Ruppert and Barnes 1994). Jellyfish abundance is influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, sea ice phenology, wind-mixing, ocean currents, and prey abundance (Brodeur et al. 2008, Decker et al. 2023). The jellyfish biomass of 0.33793 t km^{-2} is unchanged from the original model and reflects a time of high jellyfish density in the eastern Bering Sea during the early 1990s (Brodeur et al. 2002). P/B, Q/B, diet composition, and fisheries mortality are also unchanged from the original model.

Macrozooplankton

There are eight functional groups that can broadly be referred to as macrozooplankton, including **fish larvae, chaetognaths, euphausiids, mysids, pelagic amphipods, gelatinous filter feeders, pteropods**, and **copepods**. Fish larvae are not taxa-specific and are intended to represent all planktonic life history stages of fish and are not quantitatively linked to other fish groups. Chaetognaths (Phylum Chaetognatha, a.k.a., arrow worms) are a predatory group of planktonic worms. Euphausiids (family Euphausiidae, a.k.a., krill) are an abundant shrimp-like zooplankton group that is designated as critical forage for marine mammals, seabirds, and fishes by Amendment 36 of the BSAI FMP (63 FR 13009). Among other things, Amendment 36 prohibits the development of targeted fisheries on taxa designated as "forage" by the amendment. This is intended to protect and maintain sufficient forage biomass to support higher trophic levels. Mysids consist primarily of species from the Order Mysidacea, in particular the families Mysidae and Eucopiidae. Several families of pelagic amphipods comprise the pelagic amphipods group, including Hyperiidae. Gelatinous filter feeders is a composite group that includes salps (Class Thaliacea), larvaceans (Class Appendicularia), and ctenophores (Phylum Ctenophora, a.k.a., comb jellies). Pteropods (Order Pteropoda) consists of pelagic, free-swimming mollusks known as sea butterflies. Copepods (Order Copepoda) are an abundant group of crustacean zooplankton.

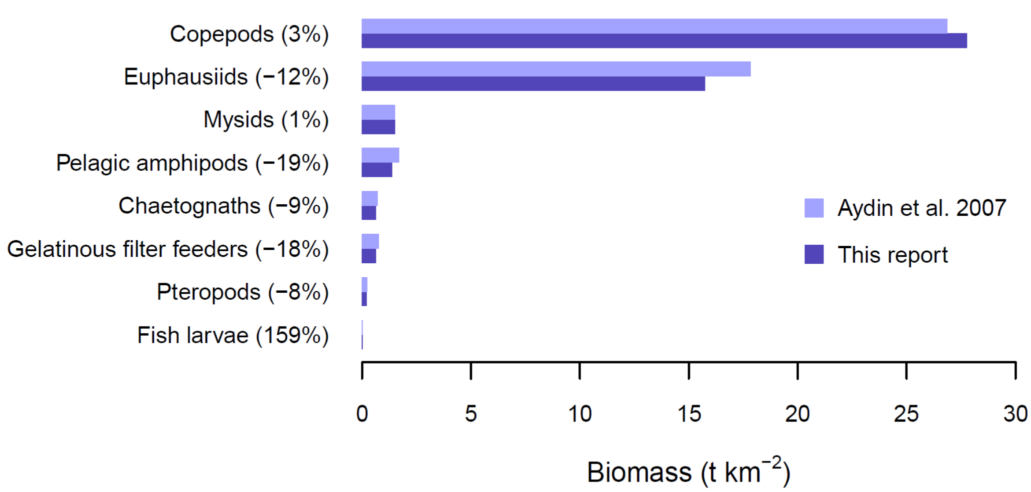

Figure 4. -- Top-down balanced biomass (t km^{-2}) of macrozooplankton groups in this report and in the Aydin et al. (2007) version of the model. The percent change in biomass (t km^{-2}) from the original to the updated model is shown in parentheses.

There are no reliable biomass estimates for any of the macrozooplankton functional groups and all were top-down balanced (EE= 0.8). The top-down balanced biomass estimates for five of the eight macrozooplankton groups are lower in this model update than from the original model (Fig. 4). We did not update P/B, Q/B, or diet composition for any macrozooplankton groups. The P/B of pelagic amphipods was estimated from western Bering Sea information (Aydin et al. 2002). The P/B for copepods was derived from values reported by Trites et al. (1999). The P/B of euphausiids was estimated from values reported by Smith (1991) for both warm and cool years. In lieu of taxa-specific estimates, the P/Bs of fish larvae, chaetognaths, mysids, gelatinous filter feeders, and pteropods were all assumed equal to that of euphausiids. The diet composition of copepods was based on multiple sources summarized by Kishi et al. (2007). The diet composition of euphausiids was based on Mauchline (1980), but modified to include microzooplankton. The diet compositions of fish larvae, chaetognaths, mysids, pelagic amphipods, gelatinous filter feeders, and pteropods were based on the diet composition of euphausiids.

Microzooplankton

Microzooplankton (pelagic microbes) is a composite group consisting of protozoan zooplankton that is intended to represent processes of the pelagic microbial loop. The biomass, P/B, Q/B, and diet composition are unchanged from the original model. The biomass of microzooplankton was estimated for 1999 (Olson and Strom 2002), both in and out of bloom. The P/B was derived from a conservative estimated daily rate of 0.2 (Sorokin et al. 1995), which translates to 36.5 over an assumed half year growing season. Q/B was estimated with an assumed growth efficiency of 0.35. The diet composition of microzooplankton was assumed to consist of 70% small phytoplankton and 30% pelagic detritus.

Benthic bacteria

Benthic bacteria (benthic microbes) is a composite group consisting of benthic protozoans and is intended to represent processes within the benthic microbial group. The P/B, Q/B, and diet composition are unchanged from the original model. There is no biomass estimate available for this group, so benthic bacteria was top-down balanced (EE = 0.8). The P/B of benthic bacteria is assumed to be equal to that of microzooplankton. Q/B, also assumed equal to that of microzooplankton, was estimated using a growth efficiency of 0.35. The diet composition of benthic bacteria is assumed to consist entirely of benthic detritus.

Primary producers

Primary production is represented by three functional groups in this model: **algae** (a.k.a., macroalgae), **large phytoplankton**, and **small phytoplankton**. The algae group consists of all macroscopic, non-planktonic primary producers. Large phytoplankton consists of pelagic primary producers above the size threshold of cells > 10 micrometers (Olson and Strom 2002), and generally consists of diatoms and large dinoflagellates. Small phytoplankton consists of primary producers below the same size threshold (< 10 micrometers, based on Olson and Strom 2002). We maintain all P/B parameters for primary producers from the original model. The P/B of algae is a generalized value from the literature (Lüning et al. 1990). The P/B of large and small phytoplankton was derived from growth rates for each cell size class reported in the literature (Strom et al. 2001, Olson and Strom 2002). There are no ecosystem-wide estimates of standing stock or biomass for these groups, so a top-down balance (EE = 0.8) was used on all primary producers.

Model Balancing

There were few parameter adjustments necessary to bring the updated model into balance. This was largely due to the model update beginning with a model that was already balanced and because most of the parameter updates were minor changes to biomass, reflecting the change in model area, which resulted in minimal changes to model outputs (e.g., EE).

In our initial attempt to balance the model, wintering seals (i.e., ringed seals and spotted seals) were out of balance. An examination of their mortality sources indicated the walrus/bearded seal group accounted for ~80% of their mortality. Pacific walruses are known to prey on other pinnipeds, including wintering seals, but quantitative estimates of this predation are not available. The initial estimate of 0.4% wintering seals in the composite, weighted diet composition of walrus/bearded seals was too high, driving wintering seals out of balance (EE = 2.73). We reduced the proportion of wintering seals in the diet of walrus/bearded seals in steps of 0.1% until wintering seals could be brought back into balance (EE < 1), which resulted in a diet proportion of 0.1% wintering seals. The 0.3% of diet composition subtracted from wintering seals was added to bivalves, which is the dominant prey taxa in the walrus/bearded seal diet.

Tanner crabs had an EE > 1 during initial attempts to balance the model. Their biomass was estimated from AFSC bottom trawl surveys, consistent with other commercial crab stocks in the model (snow and king crabs). However, this biomass estimate was insufficient to meet predator and fishery demands (EE = 1 .01). Pacific cod account for about 45% of tanner crab mortality in the food web model, while the directed fishery accounted for 8% of their mortality. The consumption of tanner crabs by Pacific cod is well established and supported by data (Lang et al. 2005). However, the exact percentage that tanner crabs represent in Pacific cod diet composition is less precise and varies in both spatial and temporal dimensions. Thus, to bring tanner crabs back into balance, given the uncertainty in Pacific cod diet composition, we reduced the proportion of tanner crabs in the diet of Pacific cod from 4.8% to 4.3%, and added 0.5% to Pacific cod's dominant prey type, adult pollock. This reduction in tanner crab predation by Pacific cod was sufficient to reduce the tanner crab EE to 0.96.

Model Comparisons

There were numerous parameters updated in this report that have contributed to some differences in metrics at the ecosystem scale. We calculated ecosystem metrics that describe the overall size, production, and energy flow in the food web to capture those differences where they exist (Table 6). Total system throughput (TST) quantifies the overall flow of energy in the food web and is lower in the updated model. TST is the sum of mass flows for consumption, respiration, and flow to detritus, and is dominated by energy flows through nodal prey groups near the base of the food web that contribute substantially to total energy flow, including zooplankton, microbes, and primary producers. In this update, the top-down balanced biomass estimates are lower for benthic microbes (-71%), euphausiids (-12%), pelagic amphipods (-19%), benthic amphipods (-60%), and miscellaneous crustaceans (-81%), which has led to lower consumption, respiration, and flow to detritus for these important prey groups, contributing to the decrease in TST. Additionally, updates to the diet compositions of several benthic invertebrate groups coupled with, in some cases, lower predator biomass has contributed to the decrease in TST. Many benthic invertebrate taxa are known to consume benthic microbes but quantitative consumption estimates or diet descriptions that easily translate into our food web model are generally unavailable. For example, in the original Aydin et al. (2007) model, they assumed a common generalized diet composition for many of these benthic invertebrate functional groups. While the updated benthic invertebrate diet compositions included in this model update still maintain a great deal of uncertainty, we believe these are improved diet compositions based on a stronger literature review. Our updated benthic invertebrate diet compositions have resulted in lower overall consumption of benthic microbes, and thus, lower benthic microbe biomass and lower total energy flow through this nodal group. Similarly, there are decreases in the total production, total consumption, and total biomass in the updated model compared to the original model. These decreases are largely attributed to the aforementioned changes to nodal groups at the base of the food web.

Table 8. – Ecosystem metrics comparing the original Aydin et al. (2007) model to the updated model in this report.

System metrics	This report	Aydin et al. (2007)
Total system throughput (t km^{-2} yr^{-1})	15,522.19	19,363.61
Biomass (excluding detritus, t km^{-2})	327.36	359.32
Production (t km^{-2} yr^{-1})	7,413.15	7,936.04
Consumption (t km^{-2} yr^{-1})	7,785.22	9,954.37
Model area (km^{2})	533,102	495,218

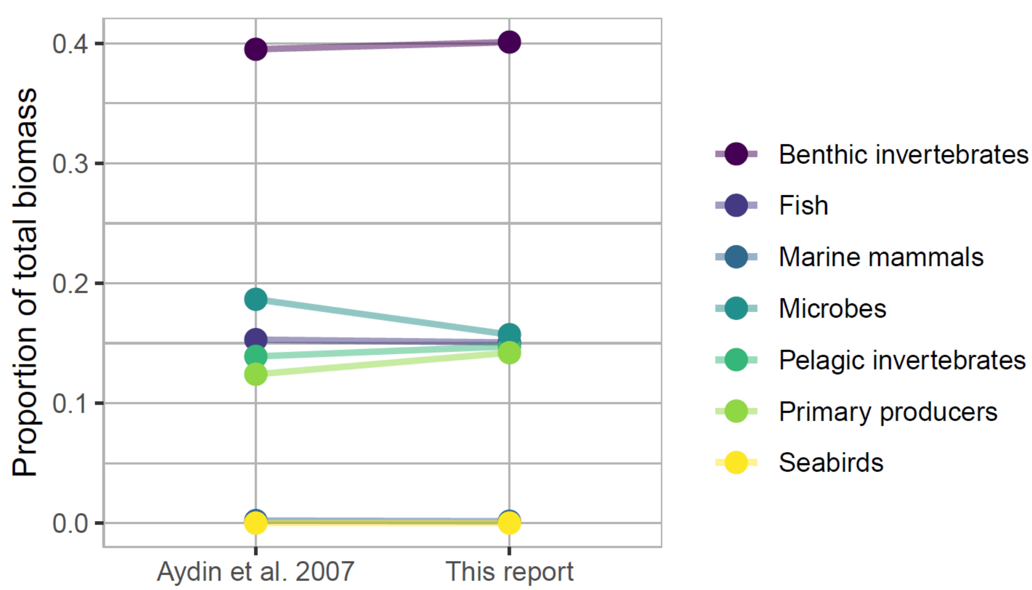

Figure 5. -- The proportion of total living biomass represented by aggregate groups in this report versus the Aydin et al. (2007) model.

To examine where in the food web there were changes in biomass and in which direction, we examined the proportion of total biomass represented by aggregated groups (Fig. 5). We found in the updated model there were decreases in the proportion of total biomass accounted for by fish (-0.24%), marine mammals (-0.06%), and microbes (-2.95%). While there were increases in the proportion of total biomass for seabirds (< 0.0001%), benthic invertebrates (0.6%), pelagic invertebrates (0.8%), and primary producers (1.8%). Both seabirds and marine mammals represent small proportions of the total biomass rendering their changes undetectable in Figure 5. Additionally, seabird biomass (density) is unchanged from the original model. However, as the total biomass decreased in the updated model their contribution to total biomass thusly increased slightly.

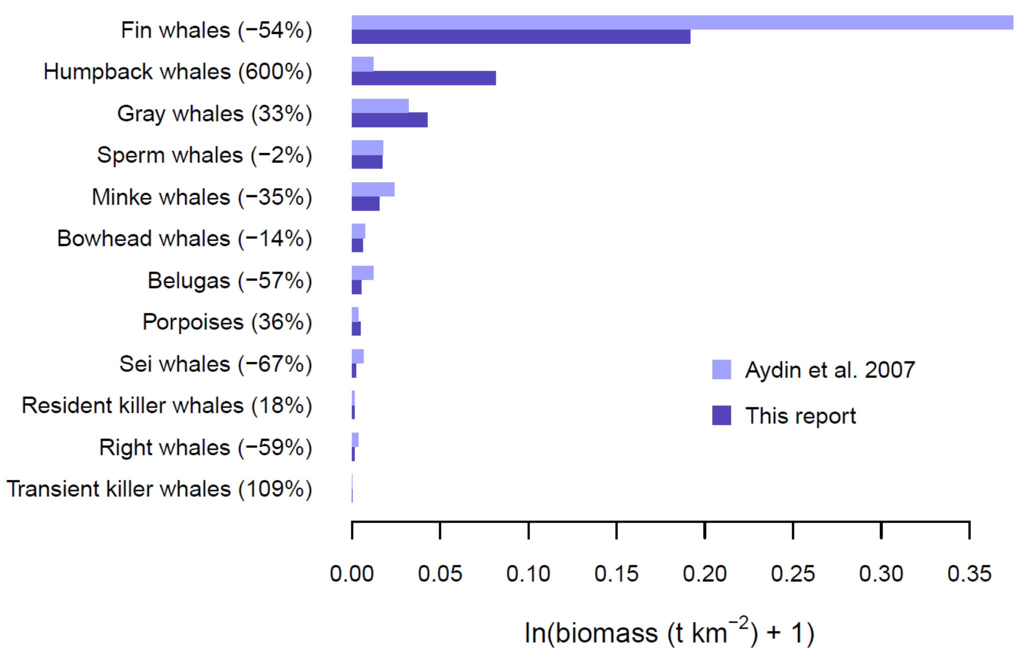

Figure 6. – The log biomass of cetaceans in the updated and original model. The percent change in biomass (t km^{-2}) from the original to the updated model is shown in parentheses.

Within these larger aggregations from Figure 5, the changes in biomass are more visible by looking at the individual groups. For several of the marine mammal groups, their changes in biomass from the original model to the updated model were substantial (Figs. 6 and 7). These changes primarily arose from three sources: 1) improved estimates of abundance from newer studies and different methods of estimation; 2) an improved understanding of animal behavior and uses of the model area leading to changes in the conversion factors for reducing total abundance to account for temporal, spatial, and other miscellaneous considerations impacting time spent in the model area; and 3) updated estimates of individual body mass reflecting an improved understanding of sexual dimorphism and sex ratio, size-at-age, numbers-at-age, and seasonal variation in body mass. In most cases it was a combination of the aforementioned sources that led to the changes in the biomass of marine mammal groups. For example, humpback whales increased to nearly six times their biomass in the original model (Fig. 6). This was due to an improved estimate of abundance, changes to the abundance modifiers reflecting a better understanding of their use of the model area, and a better estimate of individual body mass. Collectively, this resulted in the humpback whale biomass data pedigree improving from five in the original model to a four in this update. The biomass estimates for many of the marine mammal groups were given poor data pedigree scores relative to trawl caught animals (e.g., commercial fish and crabs). However, the change in biomass estimates for marine mammals in this update reflect an overall improved understanding of species abundance and their use of the model area, despite the relatively poor data pedigree.

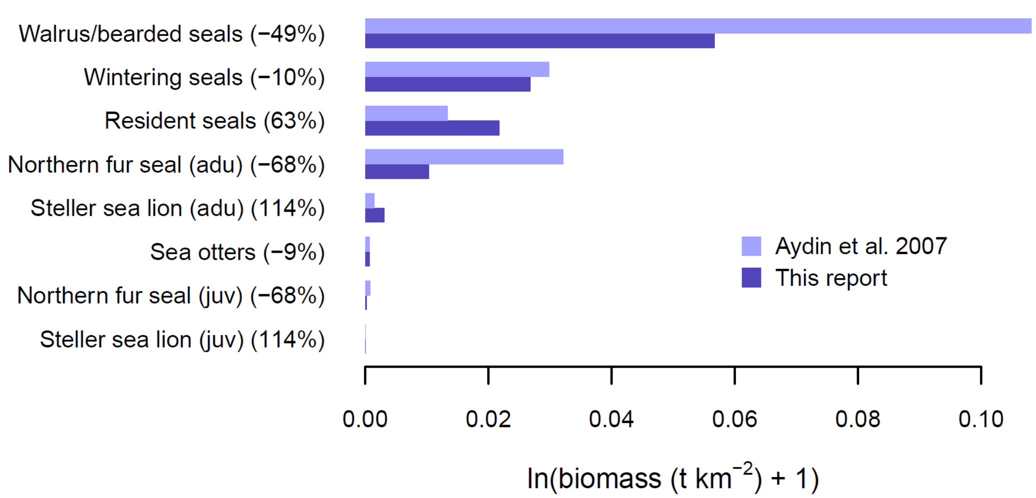

Figure 7. -- The log biomass of pinnipeds and sea otters in the updated and the original model. The percent change in biomass (t km^{-2}) from the original to the updated model is shown in parentheses.

The biomass estimates for fish groups were primarily derived from bottom-trawl surveys conducted by the AFSC. Where possible, we employed the same methodology for estimating the biomass of fish groups but still arrived at some estimates that are different from the original model (Fig. 8). The largest change in biomass was for adult walleye pollock who decreased from 18.5 to 16.1 t km^{-2}. In both the original model and in this model update, the biomass of adult walleye pollock was derived from the stock assessment. The difference in these biomass estimates reflects the increase in total model area in the update and changes in the values presented in the specific stock assessment documents (Ianelli et al. (2021) in this report versus Ianelli et al. (2003) in the original model). In absolute terms, biomass changes for other fish groups were smaller, as walleye pollock have the highest biomass amongst fishes. However, some fish groups had substantial changes in biomass relative to their biomass in the original model (Fig. 8). For example, adult Kamchatka flounder and adult Greenland turbot increased by 45% and 47%, respectively, over their biomass in the original model. Both of these species tend towards deeper/slope waters; for Kamchatka flounder, we used all three trawl surveys to estimate their biomass in this update, while only the shelf survey was used in the original model. In the case of Greenland turbot, the biomass estimates were derived from equivalent information in the stock assessments. However, the stock assessments have evolved over time as new information becomes available and the estimated values for the early 1990s have changed. These minor differences in methodology along with the change in total model area account for the majority of differences in the biomass estimates of fish.

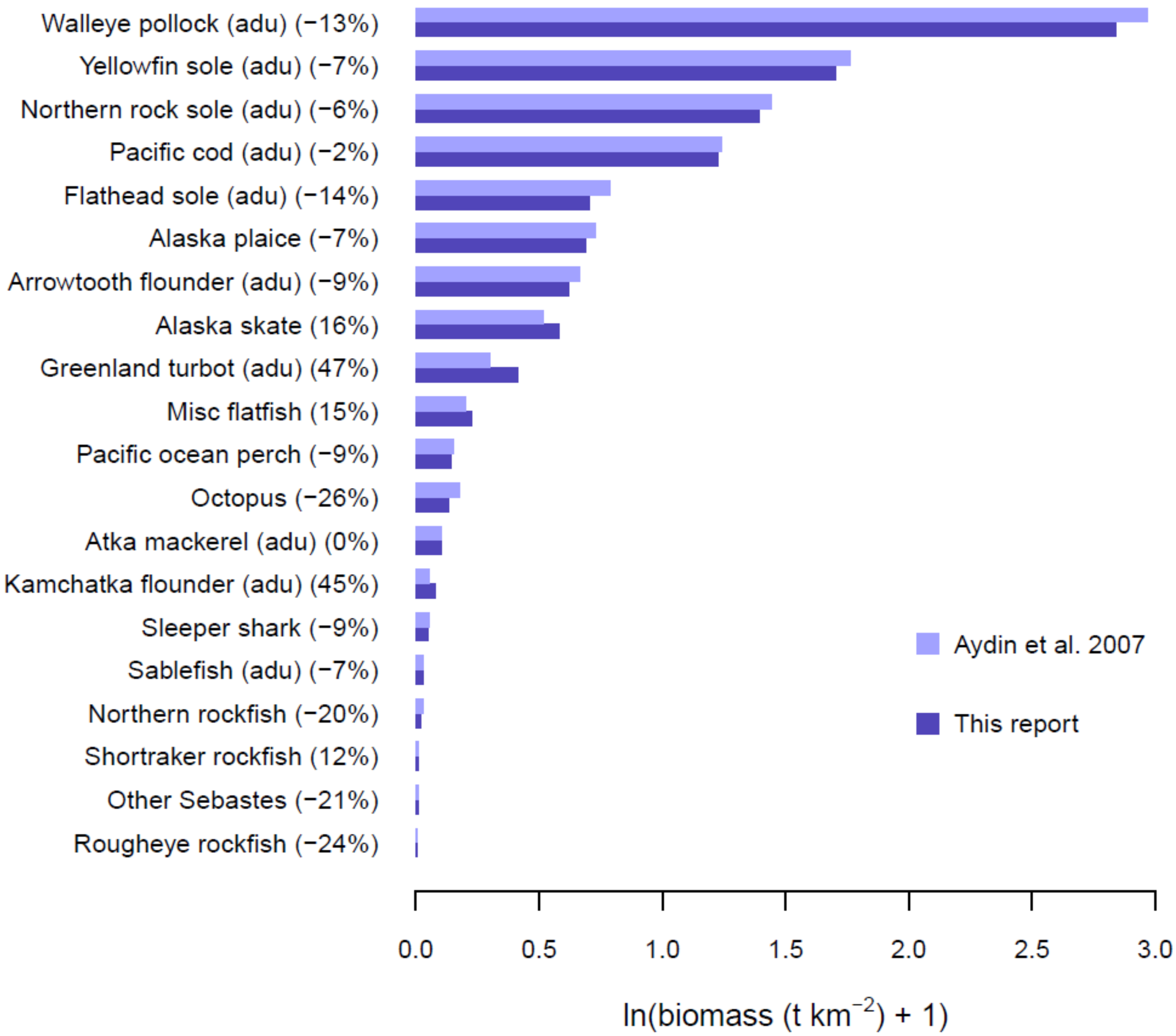

Figure 8. – The log biomass of federally managed groundfish stocks. The percent change in biomass ($t\ km^{-2}$) from the original to the updated model is shown in parentheses.

There was a decrease in the combined biomass of benthic invertebrate groups in the new model versus the original model, with decreases for 17 functional groups, biomass increases for three groups, and two groups whose biomass remained unchanged (Fig. 9). Bivalves and polychaetes are the two biomass dominant groups among benthic invertebrates and their biomasses, which is input to the model, were unchanged. The urchins-dollars-cucs group and the miscellaneous worms, etc. group had the largest increases in biomass relative to their biomass in the original model (Fig. 9). Both of these groups were top-down balanced (EE = 0.8) and their increase in biomass is in part driven by the updated diet compositions for benthic invertebrates. In particular, urchins-dollars-cucs have been added to the diet composition of sea stars in the updated model which has contributed to their increased biomass. The miscellaneous worms, etc. group has been added to the diet composition of hydroids and is subject to cannibalism in the updated model. In particular, it is the cannibalism that is driving the increase in miscellaneous worms, etc. biomass.

The biomass of the three commercial crab stocks all decreased in the updated model (Fig. 9). In the case of tanner and snow crabs, we were unable to reproduce their biomass estimates from the original model with the reference cited in Aydin et al. (2007). Alternatively, we used biomass estimates derived from the regional AFSC bottom trawl surveys. For king crabs, our methods were generally similar to the original model with the exception that we included the southeastern Bering Sea strata from the Aleutian Islands survey in our biomass estimates. In the case of tanner crabs, an additional adjustment to the diet composition of Pacific cod was necessary to bring them into balance. It is also important to note that the model area is larger in the updated model, which may contribute to the lower biomass [density] estimates.

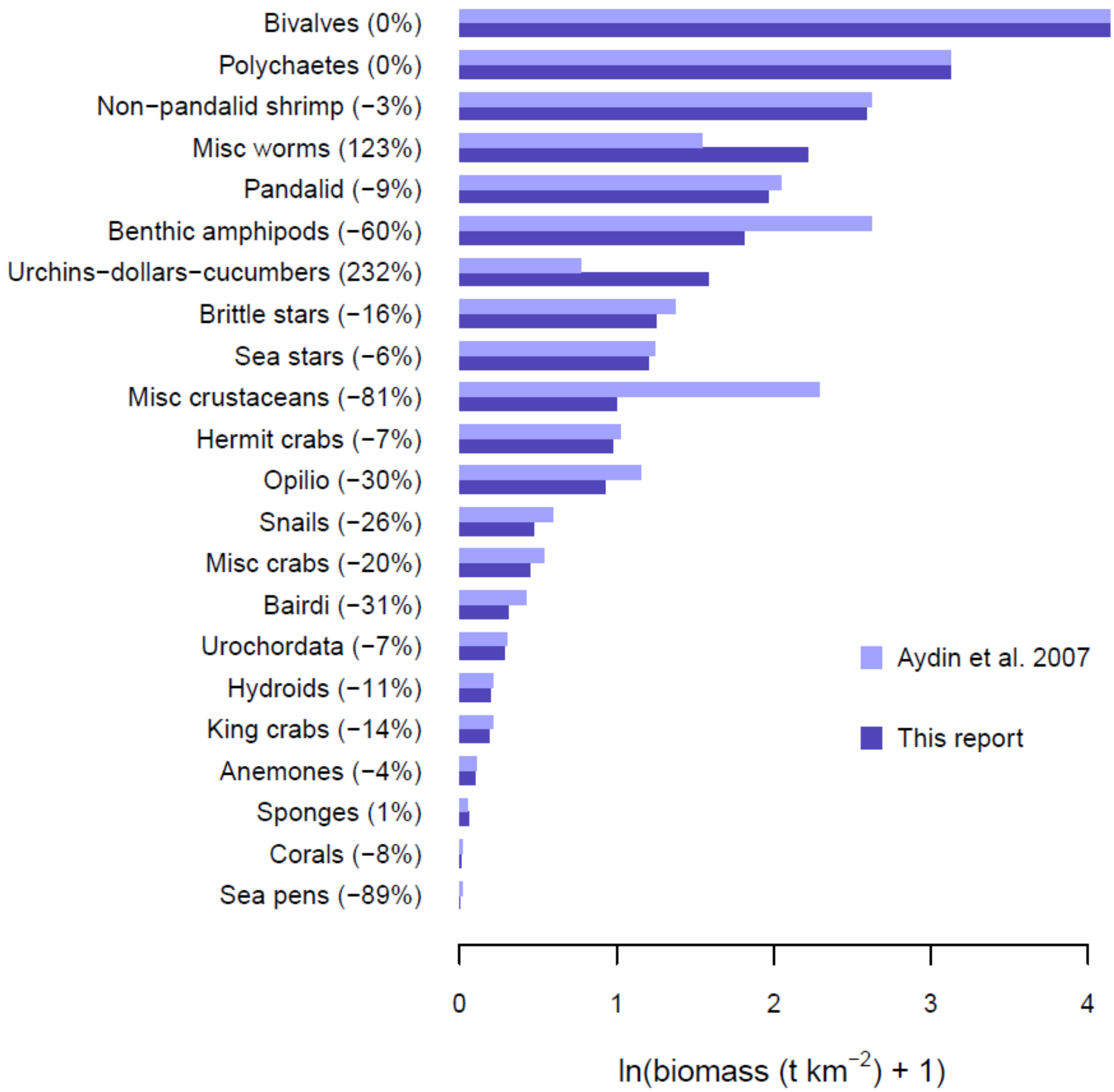

Figure 9. – Log biomass (t km^{-2}) of benthic invertebrate groups in this updated model and the Aydin et al. (2007) model. The percent change in biomass (t km^{-2}) from the original to the updated model is shown in parentheses.

SUMMARY AND CONCLUSIONS

The updated model is very similar to the original model in terms of overall model structure and function, as evidenced by the ecosystem system metrics and aggregate biomasses (Table 8 and Fig. 5). However, the lower values for energy flow, production, and consumption highlight how sensitive these ecosystem-scale metrics are to changes at the base of the food web, in this case, particularly sensitive to the decreased energy flow routed through benthic microbes. The generally similar food web model topology was expected as the basic model structure, number of functional groups, and taxonomic composition of functional groups has not changed. Most of the changes in the updated model are only apparent when examining the parameters of individual functional groups, and many of these changes are quite small. Most of the changes are a reflection of the larger spatial domain in the updated model, primarily having minor impacts to a group's density and total biomass. In other cases, the changes additionally reflect improved information which has led to higher quality parameter estimates (i.e., improved data pedigree). We improved the biomass data pedigree for 12 functional groups (six marine mammals, five fish, and one benthic invertebrate group), the Q/B data pedigree for all 20 marine mammal groups, and the diet composition data pedigree for eight marine mammal groups.

Ecosystem models updated at regular intervals can be used to evaluate changes in the food web and are better positioned to inform resource management deliberations. Models can be updated with new data allowing for better estimates of temporal trends and improved model calibration. Additionally, new modeling approaches can provide improved parameter estimates. As the next steps for this updated model of the eastern Bering Sea, we recommend calibrating the updated model to time series of biomass and commercial catch data to ensure the model is capable of reproducing observed ecosystem dynamics. Though reproduction of past dynamics does not equate to predictive power (Planque 2016), such demonstrations are key to improving model uptake and to providing insightful outputs (Heymans et al. 2016, Olsen et al. 2016). Given that the updated model domain more closely aligns with fishery management regions and the updated parameters having improved data quality grades, we recommend using this updated Ecopath model over the original model for future mass balance food web modeling studies of the southeastern Bering Sea.

ACKNOWLEDGMENTS

The authors extend their thanks and appreciation to the AFSC Groundfish Assessment Program and the Marine Mammal Laboratory for their efforts to survey the abundance and biomass of animals in the eastern Bering Sea, and for the collection of an array of biological samples and measurements over many years that were vital to the completion of this work. This study is part of NOAA's Alaska Climate Integrated Modeling project (ACLIM). We would like to thank the entire ACLIM team for feedback and discussions on the broader application of this work. Multiple NOAA National Marine Fisheries Service programs provided support for ACLIM including NOAA COCA (ACLIM phase 2), Fisheries and the Environment (FATE), Stock Assessment Analytical Methods (SAAM) Science and Technology North Pacific Climate Regimes and Ecosystem Productivity, the Integrated Ecosystem Assessment Program (IEA), the NOAA Economics and Social Analysis Division, NOAA Research Transition Acceleration Program (RTAP), the Alaska Fisheries Science Center (ASFC), the Office of Oceanic and Atmospheric Research (OAR) and the National Marine Fisheries Service (NMFS). We thank Bridget Ferriss (AFSC) and Beatriz S. Dias (UW/CICOES) for reviewing an earlier version of this manuscript. Thanks to Sean Rohan (AFSC) for assistance with mapping. The scientific views, opinions, and conclusions expressed herein are solely those of the authors and do not represent the views, opinions, or conclusions of NOAA or the U. S. Department of Commerce. This publication is [partially] funded by the Cooperative Institute for Climate, Ocean, & Ecosystem Studies (CICOES) under NOAA Cooperative Agreement NA20OAR4320271, Contribution No. 2024-1421. This study was funded in part by the NOAA Integrated Ecosystem Assessment Program, Contribution No. 2025_1.

CITATIONS

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APPENDIX A: Balanced Model Parameters

Appendix A: Balanced model parameters and trophic level for the updated eastern Bering Sea Rpath model. Parameters that are estimated by Rpath are bold and italicized. TL is Trophic Level, B is Biomass, P/B is production to biomass ratio, Q/B is consumption to biomass ratio, EE is ecotrophic efficiency, GE is growth efficiency, and U/Q is the unassimilated fraction of consumed food. B is in t km^{-2}; P/B, Q/B, and GE are in $year^{-1}$, and EE and U/Q are dimensionless.

Appendix Table A1. -- Balanced model parameters.

Group	TL	Biomass	P/B	Q/B	EE	GE	U/Q
Transient killer whales	***5.357***	0.00028	0.025	4.100	***0.00000***	***0.0062***	0.2
Sperm whales	***4.801***	0.01737	0.047	5.700	***0.00000***	***0.0082***	0.2
Resident killer whales	***5.110***	0.00159	0.025	10.500	***0.13424***	***0.0024***	0.2
Porpoises	***4.560***	0.00491	0.050	29.800	***0.64367***	***0.0017***	0.2
Belugas	***3.568***	0.00532	0.112	15.300	***0.15593***	***0.0073***	0.2
Gray whales	***3.374***	0.04338	0.063	7.900	***0.00789***	***0.0080***	0.2
Humpback whales	***3.927***	0.08463	0.038	4.200	***0.00486***	***0.0090***	0.2
Fin whales	***3.700***	0.21120	0.027	3.900	***0.00000***	***0.0068***	0.2
Sei whales	***3.769***	0.00210	0.040	5.500	***0.00000***	***0.0073***	0.2
Right whales	***3.501***	0.00147	0.033	5.600	***0.00000***	***0.0059***	0.2
Minke whales	***4.028***	0.01551	0.051	8.000	***0.03391***	***0.0064***	0.2
Bowhead whales	***3.517***	0.00617	0.010	4.500	***0.00000***	***0.0022***	0.2
Sea otters	***3.336***	0.00068	0.117	111.500	***0.54265***	***0.0010***	0.2
Pacific walrus/bearded seals	***3.679***	0.05831	0.051	21.600	***0.37244***	***0.0024***	0.2
Northern fur seal juv.	***4.573***	***0.00027***	0.252	***104.510***	***0.74968***	***0.0024***	0.2
Northern fur seal adult	***4.573***	0.01043	0.091	48.700	***0.33768***	***0.0019***	0.2
Steller sea lion juv.	***4.670***	***0.00005***	0.494	***65.339***	***0.37439***	***0.0076***	0.2
Steller sea lion adult	***4.670***	0.00313	0.110	27.900	***0.19011***	***0.0039***	0.2
Resident seals	***4.392***	0.02198	0.083	21.600	***0.79463***	***0.0038***	0.2
Wintering seals	***4.329***	0.02713	0.069	22.200	***0.71052***	***0.0031***	0.2
Shearwaters	***4.536***	0.00040	0.100	73.000	***0.08238***	***0.0014***	0.2
Murres	***4.418***	0.00814	0.169	72.000	***0.04852***	***0.0024***	0.2
Kittiwakes	***4.387***	0.00066	0.077	110.000	***0.10696***	***0.0007***	0.2
Auklets	***3.568***	0.00175	0.169	110.000	***0.04851***	***0.0015***	0.2
Puffins	***4.393***	0.00047	0.040	73.000	***0.20573***	***0.0005***	0.2
Fulmars	***4.584***	0.00052	0.055	73.000	***0.14954***	***0.0008***	0.2
Storm petrels	***4.277***	1.75E-06	0.120	144.000	***0.06814***	***0.0008***	0.2
Cormorants	***4.483***	0.00015	0.159	73.000	***0.05173***	***0.0022***	0.2
Gulls	***4.466***	0.00010	0.166	73.000	***0.04969***	***0.0023***	0.2
Albatross/jaegers	***4.604***	0.00010	0.068	75.000	***0.12185***	***0.0009***	0.2
Sleeper shark	***4.670***	0.04862	0.100	3.000	***0.19569***	***0.0333***	0.2
Walleye pollock juv.	***3.538***	***3.98638***	1.453	***8.498***	***0.87482***	***0.1710***	0.2
Walleye pollock adult	***3.674***	16.13562	0.667	3.170	***0.89644***	***0.2105***	0.2
Pacific cod juv.	***3.556***	***0.18262***	1.782	***8.882***	***0.72988***	***0.2006***	0.2
Pacific cod adult	***4.061***	2.40963	0.412	2.280	***0.50430***	***0.1807***	0.2
Pacific herring juv.	***3.522***	***0.17201***	1.052	***7.843***	***0.27746***	***0.1341***	0.2
Pacific herring adult	***3.524***	0.61156	0.320	3.520	***0.92221***	***0.0909***	0.2
Arrowtooth flounder juv.	***3.941***	***0.00769***	0.810	***5.787***	***0.59890***	***0.1400***	0.2
Arrowtooth flounder adult	***4.309***	0.86244	0.180	1.160	***0.92444***	***0.1552***	0.2
Kamchatka flounder juv.	***4.088***	***0.00054***	0.810	***6.152***	***0.01407***	***0.1317***	0.2
Kamchatka flounder adult	***4.473***	0.08116	0.180	1.160	***0.11557***	***0.1552***	0.2
Greenland turbot juv.	***3.538***	***0.01101***	1.701	***7.912***	***0.59133***	***0.2149***	0.2
Greenland turbot adult	***4.576***	0.51469	0.180	1.160	***0.37309***	***0.1552***	0.2

Appendix Table A1. Continued. -- Balanced model parameters.

Group	TL	Biomass	P/B	Q/B	EE	GE	U/Q
Pacific halibut juv.	***3.744***	***0.00185***	2.400	***9.334***	***0.85453***	***0.2571***	0.2
Pacific halibut adult	***4.532***	0.22128	0.190	1.100	***0.50524***	***0.1727***	0.2
Yellowfin sole juv.	***3.430***	***0.39437***	0.244	***1.536***	***0.48606***	***0.1592***	0.2
Yellowfin sole adult	***3.473***	4.50123	0.174	0.930	***0.38825***	***0.1868***	0.2
Flathead sole juv.	***3.554***	***0.12700***	0.394	***4.162***	***0.81363***	***0.0948***	0.2
Flathead sole adult	***3.725***	1.02440	0.260	1.970	***0.24143***	***0.1320***	0.2
Northern rock sole juv.	***3.369***	***0.14783***	0.292	***3.496***	***0.29209***	***0.0834***	0.2
Northern rock sole adult	***3.561***	3.02498	0.232	1.140	***0.50047***	***0.2032***	0.2
Alaska plaice	***3.374***	0.99298	0.200	2.000	***0.56928***	***0.1000***	0.2
Dover sole	***3.629***	0.00038	0.200	2.000	***0.34729***	***0.1000***	0.2
Rex sole	***3.648***	0.04733	0.200	2.000	***0.47910***	***0.1000***	0.2
Misc. flatfish	***3.647***	***0.25525***	0.200	2.000	0.80000	***0.1000***	0.2
Alaska skate	***4.157***	0.79112	0.200	2.000	***0.29944***	***0.1000***	0.2
Other skates	***4.375***	0.19267	0.200	2.000	***0.25408***	***0.1000***	0.2
Sablefish juv.	***3.625***	***0.00347***	2.266	***3.009***	***0.02222***	***0.7532***	0.2
Sablefish adult	***4.508***	0.02909	0.190	1.030	***0.58061***	***0.1845***	0.2
Eelpouts	***3.542***	***2.01106***	0.400	2.000	0.80000	***0.2000***	0.2
Grenadiers	***4.260***	0.89343	0.150	2.000	***0.28845***	***0.0750***	0.2
Misc. fish deep	***4.260***	***0.00756***	0.200	2.000	0.80000	***0.1000***	0.2
Pacific ocean perch	***3.548***	0.15215	0.100	2.000	***0.81309***	***0.0500***	0.2
Sharpchin rockfish	***3.741***	***0.00142***	0.100	2.000	0.80000	***0.0500***	0.2
Northern rockfish	***3.600***	***0.02222***	0.100	2.000	0.80000	***0.0500***	0.2
Dusky rockfish	***3.500***	0.00182	0.100	2.000	***0.21699***	***0.0500***	0.2
Shortraker rockfish	***3.809***	0.01066	0.100	2.000	***0.30753***	***0.0500***	0.2
Rougheye rockfish	***4.286***	0.00280	0.100	2.000	***0.64075***	***0.0500***	0.2
Shortspine thornyhead	***3.524***	0.03229	0.150	0.500	***0.03744***	***0.3000***	0.2
Other Sebastes	***3.741***	***0.00882***	0.100	2.000	0.80000	***0.0500***	0.2
Atka mackerel juv.	***3.523***	***0.03682***	1.900	***12.185***	***0.00376***	***0.1559***	0.2
Atka mackerel adult	***3.529***	0.10685	0.350	5.650	***0.58740***	***0.0619***	0.2
Greenlings	***4.179***	0.00126	0.400	2.000	***0.85168***	***0.2000***	0.2
Large sculpins	***3.975***	0.51568	0.400	2.000	***0.12109***	***0.2000***	0.2
Other sculpins	***3.831***	***1.20064***	0.400	2.000	0.80000	***0.2000***	0.2
Misc. fish shallow	***3.649***	***0.76752***	0.400	2.000	0.80000	***0.2000***	0.2
Octopus	***3.635***	***0.14262***	0.800	3.650	0.80000	***0.2192***	0.2
Squids	***3.679***	***0.73158***	3.200	10.670	0.80000	***0.2999***	0.2
Salmon returning	***3.827***	0.16377	1.650	11.600	***0.83556***	***0.1422***	0.2
Salmon smolts	***3.513***	***0.00051***	1.280	13.560	0.80000	***0.0944***	0.2
Bathylagids	***3.523***	***0.18313***	0.800	3.650	0.80000	***0.2192***	0.2
Myctophids	***3.523***	***0.67008***	0.800	3.650	0.80000	***0.2192***	0.2
Capelin	***3.523***	***0.90463***	0.800	3.650	0.80000	***0.2192***	0.2
Sand lance	***3.523***	***2.33574***	0.800	3.650	0.80000	***0.2192***	0.2
Eulachon	***3.523***	***0.41558***	0.800	3.650	0.80000	***0.2192***	0.2
Other managed forage fish	***3.523***	***0.81220***	0.800	3.650	0.80000	***0.2192***	0.2
Other pelagic smelt	***3.523***	***0.40069***	0.800	3.650	0.80000	***0.2192***	0.2

Appendix Table A1. Continued. -- Balanced model parameters.

Group	TL	Biomass	P/B	Q/B	EE	GE	U/Q
Tanner crab	***3.241***	0.35824	1.601	3.092	***0.96022***	***0.5178***	0.2
King crabs	***3.317***	0.20454	0.659	3.207	***0.67629***	***0.2054***	0.2
Snow crabs	***3.173***	1.51625	1.295	3.117	***0.69226***	***0.4155***	0.2
Pandalids	***2.841***	***6.15653***	0.576	2.409	0.80000	***0.2389***	0.2
Non-pandalid shrimp	***2.841***	***12.31677***	0.576	2.409	0.80000	***0.2389***	0.2
Sea stars	***3.222***	2.31690	1.210	***6.050***	***0.00621***	0.2000	0.2
Brittle stars	***2.497***	***2.47795***	1.210	***6.050***	0.80000	0.2000	0.2
Urchins, dollars, cucumbers	***2.000***	***3.87265***	0.610	***3.050***	0.80000	0.2000	0.2
Snails	***2.826***	0.59967	1.810	***9.050***	***0.76986***	0.2000	0.2
Hermit crabs	***3.033***	***1.64234***	0.820	***4.100***	0.80000	0.2000	0.2
Misc. crabs	***3.033***	***0.56725***	0.820	***4.100***	0.80000	0.2000	0.2
Misc. crustaceans	***2.450***	***1.70913***	7.400	***37.000***	0.80000	0.2000	0.2
Benthic amphipods	***2.386***	***5.09950***	7.400	***37.000***	0.80000	0.2000	0.2
Anemones	***3.066***	0.10471	1.000	***5.000***	***0.09236***	0.2000	0.4
Corals	***2.225***	0.01216	0.046	***0.230***	***0.03109***	0.2000	0.4
Hydroids	***3.227***	***0.21073***	1.000	***5.000***	0.80000	0.2000	0.4
Urochordata	***2.450***	0.33122	3.580	***17.900***	***0.09984***	0.2000	0.4
Sea pens	***2.000***	0.00153	0.092	***0.461***	***0.04595***	0.2000	0.4
Sponges	***2.250***	0.05496	1.000	***5.000***	***0.38495***	0.2000	0.4
Bivalves	***2.200***	61.87307	1.300	***6.500***	***0.69753***	0.2000	0.4
Polychaetes	***2.359***	21.68738	2.970	***14.850***	***0.88362***	0.2000	0.4
Misc. worms	***2.573***	***8.17770***	2.230	***11.150***	0.80000	0.2000	0.4
Scyphozoid jellies	***3.429***	0.33793	0.880	3.000	***0.47200***	***0.2933***	0.2
Fish larvae	***2.525***	***0.03017***	5.475	***15.643***	0.80000	0.3500	0.2
Chaetognaths	***2.906***	***0.63999***	5.475	***15.643***	0.80000	0.3500	0.2
Euphausiids	***2.525***	***15.72988***	5.475	***15.643***	0.80000	0.3500	0.2
Mysids	***2.525***	***1.52276***	5.475	***15.643***	0.80000	0.3500	0.2
Pelagic amphipods	***2.525***	***1.36991***	2.500	***7.143***	0.80000	0.3500	0.2
Gelatinous filter feeders	***2.525***	***0.63102***	5.475	***15.643***	0.80000	0.3500	0.2
Pteropods	***2.525***	***0.21364***	5.475	***15.643***	0.80000	0.3500	0.2
Copepods	***2.500***	***27.77506***	6.000	27.740	0.80000	***0.2163***	0.2
Pelagic microbes	***2.0***	45.00000	36.500	***104.286***	***0.26228***	0.3500	0.25
Benthic microbes	***2.0***	***6.45213***	36.500	***104.286***	0.80000	0.3500	0.25
Macroalgae	***1.0***	***1.08914***	4.000		0.80000		
Large phytoplankton	***1.0***	***5.70618***	101.794		0.80000		
Small phytoplankton	***1.0***	***39.72676***	110.919		0.80000		
Discards	***1.0***	***1.12278***	0.5		***0.06586***		
Offal	***1.0***	***5.31798***	0.5		***0.55009***		
Pelagic detritus	***1.0***	***3086.3759***	0.5		***0.91230***		
Benthic detritus	***1.0***	***5636.3174***	0.5		***0.47520***		

APPENDIX B: Fisheries Removals and Discards

Appendix B: Total removals (t) as retained catch and discards. Retained catch for target species processed at sea is the product of the raw retained catch times the published product recovery rate for that species; processing waste ("offal") calculated by this method was added to Discards.

Appendix Table B1. -- Marine mammal harvests (t) as retained catch.

Group	Harvest (t)
Transient killer whales	0
Sperm whales	0
Resident killer whales	0
Porpoises	0
Belugas	12.475
Gray whales	0
Humpback whales	0
Fin whales	0
Sei whales	0
Right whales	0
Minke whales	0.091
Bowhead whales	0
Sea otters	0.015
Pacific walrus/bearded seals	15.300
Northern fur seal juv.	0
Northern fur seal adult	18.232
Steller sea lion juv.	0
Steller sea lion adult	24.256
Resident seals	7.303
Wintering seals	15.673

Appendix Table B2. -- Total removals as retained catch (t). Groups with zero catch not shown.

Fishery	Sleeper shark	Walleye pollock adult	Pacific cod adult	Pacific herring adult	Arrowtooth flounder adult	Greenland turbot adult	Pacific halibut adult	Yellowfin sole adult	Flathead sole adult
Pollock trawl	7.090	193,872.994	14,681.837	0	1,615.444	25.003	0	212.554	580.435
Pacific cod trawl	0	2,637.450	28,893.469	0	311.060	7.304	0	529.067	162.656
Pacific cod pots	0	0.007	4,527.152	0	0.276	1.034	0	0.006	0.032
Pacific cod longline	0.055	218.881	50,124.134	0	474.234	72.530	0	0.300	7.037
Atka mackerel trawl	0	15.620	56.361	0	11.302	5.251	0	0.026	4.862
Northern rock sole trawl	0	1,128.352	3,567.391	0	38.597	2.937	0	1,259.571	343.626
Yellowfin sole trawl	0	1,935.663	7,708.073	0	145.677	38.757	0	64,134.296	1,079.006
Arrowtooth flounder trawl	0	14.767	11.195	0	75.631	1.322	0	0.586	6.610
Flathead sole trawl	1.49E-04	330.112	1,009.191	0	7.410	7.463	0	1,896.381	962.599
Other flatfish trawl	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	0	0.090	22.497	0	83.391	902.375	0	0.007	1.375
Greenland turbot longline	0.525	1.333	53.257	0	71.866	942.202	0	0.008	0.189
Sablefish longline	0	0	14.554	0	4.441	14.980	0	0	0.014
Rockfish trawl	0	3.161	294.943	0	74.181	27.615	0	7.250	38.330
Pacific halibut longline	0	0	0	0	0	0	1,306.139	0	0
Crab pots	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	10,659.676	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0

Appendix Table B2. Continued. -- Total removals as retained catch (t). Groups with zero catch not shown.

Fishery	Northern rock sole adult	Alaska plaice	Dover sole	Rex sole	Misc. flatfish	Alaska skate	Other skates	Sablefish adult	Grenadiers
Pollock trawl	1,296.016	613.387	0.007	42.328	146.253	101.689	16.420	3.625	15.780
Pacific cod trawl	813.985	171.890	0	84.807	40.996	29.640	4.798	7.250	0
Pacific cod pots	0.026	0.033	0	0	0.008	0.105	0.017	7.197	0.009
Pacific cod longline	2.223	7.410	0	0	1.775	1,540.142	249.033	95.648	0
Atka mackerel trawl	2.564	5.150	0	22.497	1.221	0	0	23.723	0
Northern rock sole trawl	13,821.069	363.135	0	14.234	86.584	24.736	4.004	9.543	0
Yellowfin sole trawl	2,958.065	1,140.264	0	13.594	271.879	92.693	14.980	1.338	0.088
Arrowtooth flounder trawl	3.620	6.984	0.119	2.207	1.663	0.960	0.156	1.525	0.008
Flathead sole trawl	799.570	1,017.249	0.045	34.705	242.547	17.699	2.857	3.721	0
Other flatfish trawl	0	0.762	0	0	0	0	0	0	0
Greenland turbot trawl	0.015	1.455	0	25.216	0.347	5.811	0.938	166.790	0.090
Greenland turbot longline	0	0.199	0	0	0.048	0.858	0.138	260.042	2.015
Sablefish longline	0	0.015	0	0	0.004	0	0	575.006	0
Rockfish trawl	3.716	40.516	0	13.061	9.649	15.567	2.511	2.927	0
Pacific halibut longline	0	0	0	0	0	0	0	166.119	0
Crab pots	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0

Appendix Table B2. Continued. -- Total removals as retained catch (t). Groups with zero catch not shown.

Fishery	Pacific ocean perch	Sharpchin rockfish	Northern rockfish	Dusky rockfish	Shortraker rockfish	Rougheye rockfish	Shortspine thornyhead	Other Sebastes	Atka mackerel adult
Pollock trawl	42.861	0.864	16.366	1.157	4.228	0.276	2.116	5.544	26.282
Pacific cod trawl	200.963	3.188	60.566	1.013	0.469	0.062	3.337	3.838	10.022
Pacific cod pots	0.020	4.95E-04	0.009	0.007	3.47E-04	0	0.002	0.484	0.048
Pacific cod longline	2.058	0.661	12.528	1.040	4.862	3.017	0.602	27.188	0.082
Atka mackerel trawl	56.058	0.050	0.949	0	3.300	2.266	1.637	4.947	808.297
Northern rock sole trawl	6.610	0.077	1.450	0	0	0	0	3.742	7.144
Yellowfin sole trawl	0.613	0.001	0.024	0.046	0.005	0.003	0.128	1.136	0.077
Arrowtooth flounder trawl	0.500	0.184	3.492	0.007	0.544	0.301	0.645	3.327	5.917
Flathead sole trawl	12.421	0.002	0.045	0	0.858	0.353	1.775	1.631	3.657
Other flatfish trawl	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	0.027	0.002	0.033	0	11.568	7.304	12.048	32.839	60.595
Greenland turbot longline	1.104	0.137	2.607	0.042	3.822	1.893	6.077	15.886	0
Sablefish longline	0.223	0.291	5.544	0.021	1.903	1.349	34.865	25.056	0
Rockfish trawl	3,791.191	30.600	581.728	0	89.114	58.713	0	38.810	83.050
Pacific halibut longline	0	0	0	0	0	0	0	0	0
Crab pots	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0

Appendix Table B2. Continued. -- Total removals as retained catch (t). Groups with zero catch not shown.

Fishery	Large sculpins	Misc. fish shallow	Octopus	Squids	Salmon returning	Myctophids	Capelin	Sand lance	Eulachon	Other managed forage fish	Other pelagic smelt
Pollock trawl	39.876	4.713	0.720	177.064	0	0.115	0.006	1.98E-04	0.800	0.199	28.521
Pacific cod trawl	6.344	0.442	3.060	47.659	0	0	0	0	0	0	0
Pacific cod pots	1.050	0.005	21.164	0	0	0	0	0	0	0	0
Pacific cod longline	4.766	0.041	1.471	0	0	0	0	0	0	0	0
Atka mackerel trawl	0	0	0	0.003	0	0	0	0	0	0	0
Northern rock sole trawl	8.316	0.014	12.848	0	0	0	0	0	0	0	0.008
Yellowfin sole trawl	221.062	0.358	0.327	0.041	0	0	0	0	0	0	0.049
Arrowtooth flounder trawl	0	0	0	2.97E-04	0	0	0	0	0	0	0
Flathead sole trawl	2.500	0	0	0.323	0	0	0	0	0	0	8.42E-04
Other flatfish trawl	0	0	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	0.080	0	0	0.167	0	0	0	0	0	0	0
Greenland turbot longline	2.97E-04	0	0.003	0	0	0	0	0	0	0	0
Sablefish longline	0	0	0	0	0	0	0	0	0	0	0
Rockfish trawl	0	0	0	0.048	0	0	0	0	0	0	0
Pacific halibut longline	0	0	0	0	0	0	0	0	0	0	0
Crab pots	0	0	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	83,764.491	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0.997	0	0	0	0	0	0

Appendix Table B2. Continued. -- Total removals as retained catch (t). Groups with zero catch not shown.

Fishery	Tanner crab	King crabs	Snow crabs	Pandalids	Sea stars	Urchins, dollars, cucumbers	Snails	Hermit crabs	Misc. crabs
Pollock trawl	0	0	0	0.080	2.068	0.020	0.003	0.073	0
Pacific cod trawl	0	0	0	0	0.015	0.011	0	0.027	0
Pacific cod pots	0	0	0	4.95E-05	0.010	0.000	0.009	0.042	0
Pacific cod longline	0	0	0	0	0.126	0	0	0.002	0
Atka mackerel trawl	0	0	0	0	0	0	0	0	0
Northern rock sole trawl	0	0	0	0	4.041	0.021	0	0.656	0
Yellowfin sole trawl	0	0	0	0.021	12.688	0.120	0.080	0.821	0
Arrowtooth flounder trawl	0	0	0	0	0	0	0	0	0
Flathead sole trawl	0	0	0	0.010	0.101	0	0	0.010	0
Other flatfish trawl	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	0	0	0	0	0.103	0	0	0	0
Greenland turbot longline	0	0	0	0	1.09E-03	0	0	0	0
Sablefish longline	0	0	0	0	0	0	0	0	0
Rockfish trawl	0	0	0	0	0	0	0	0	0
Pacific halibut longline	0	0	0	0	0	0	0	0	0
Crab pots	23,486.917	9,310.990	148,906.952	0	0	0	0	0	171.136
Salmon fishery	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0

Appendix Table B2. Continued. -- Total removals as retained catch (t). Groups with zero catch not shown.

Fishery	Anemones	Corals	Urochordata	Sea pens	Sponges	Bivalves	Scyphozoid jellies
Pollock trawl	0.063	0	0	0.089	0.001	0	1,649.645
Pacific cod trawl	0	0.010	0	0	0.730	0	0.388
Pacific cod pots	0	0	0	0	0.005	0.012	0.012
Pacific cod longline	0.075	0	0	0	0	0	0
Atka mackerel trawl	0	0	0	0	0	0	0
Northern rock sole trawl	0.062	0	0.970	0	0	0	1.845
Yellowfin sole trawl	0.013	0.062	1.988	0	0.215	0	14.394
Arrowtooth flounder trawl	0	0	0	0	0	0	0
Flathead sole trawl	9.90E-04	0	0.053	0	2.47E-04	0	0.005
Other flatfish trawl	0	0	0	0	0	0	0
Greenland turbot trawl	0	0	0	0	0	0	0
Greenland turbot longline	0	0	0	0	0	0	0
Sablefish longline	0	0	0	0	0	0	0
Rockfish trawl	0	0	0	0	0	0	0
Pacific halibut longline	0	0	0	0	0	0	0
Crab pots	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0

Appendix Table B3. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Resident killer whales	Porpoises	Belugas	Humpback whales	Minke whales	Pacific walrus/bearded seals	Northern fur seal adult	Steller sea lion adult	Resident seals	Wintering seals
Pollock trawl	1.136	0.173	0	4.137	0.592	1.466	0.030	1.215	0.046	0.065
Pacific cod trawl	0.284	0.043	0	1.034	0.149	0.367	0.008	0.303	0.012	0.016
Pacific cod pots	0	0	0	0	0	0	0	0	0.016	0
Pacific cod longline	0.613	0.090	0	0	0	0	0	0.111	0.022	0.012
Atka mackerel trawl	0.026	0.004	0	0.093	0.013	0.033	0.001	0.027	0.001	0.001
Northern rock sole trawl	0.310	0.047	0	1.130	0.163	0.401	0.008	0.332	0.013	0.018
Yellowfin sole trawl	0.388	0.059	0	1.413	0.204	0.500	0.010	0.415	0.016	0.022
Arrowtooth flounder trawl	0.019	0.003	0	0.071	0.010	0.025	5.45E-04	0.021	7.92E-04	0.001
Flathead sole trawl	0.059	0.009	0	0.212	0.030	0.075	0.002	0.062	0.002	0.003
Other flatfish trawl	0	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	0.025	0.004	0	0.089	0.013	0.032	6.44E-04	0.026	9.90E-04	0.001
Greenland turbot longline	0.004	4.95E-04	0	0	0	0	0	6.93E-04	1.49E-04	4.95E-05
Sablefish longline	2.97E-04	4.95E-05	0	0	0	0	0	4.95E-05	0	0
Rockfish trawl	0.026	0.004	0	0.094	0.013	0.033	6.93E-04	0.028	0.001	0.001
Pacific halibut longline	0	0	0	0	0	0	0	0	0	0
Crab pots	0	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0	0
Indigenous	0	0	0.012	0	9.90E-05	0.015	0.018	0.024	0.007	0.016
Subsistence	0	0	0	0	0	0	0	0	0	0

Appendix Table B3. Continued. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Shearwaters	Murres	Kittiwakes	Auklets	Puffins	Fulmars	Storm petrels	Cormorants	Gulls	Albatross/ jaegers
Pollock trawl	0.023	0.478	0.039	0.103	0.028	0.030	9.90E-05	0.009	0.006	0.006
Pacific cod trawl	0.003	0.061	0.005	0.013	0.004	0.004	0	0.001	7.92E-04	7.43E-04
Pacific cod pots	0.001	0.030	0.002	0.007	0.002	0.002	0	5.45E-04	3.96E-04	3.47E-04
Pacific cod longline	0.720	14.607	1.189	3.145	0.853	0.933	0.003	0.268	0.188	0.179
Atka mackerel trawl	7.43E-04	0.015	0.001	0.003	8.91E-04	9.41E-04	0	2.97E-04	1.98E-04	1.98E-04
Northern rock sole trawl	0	0	0	0	0	0	0	0	0	0
Yellowfin sole trawl	0.001	0.029	0.002	0.006	0.002	0.002	0	5.45E-04	3.47E-04	3.47E-04
Arrowtooth flounder trawl	0	0	0	0	0	0	0	0	0	0
Flathead sole trawl	0	0	0	0	0	0	0	0	0	0
Other flatfish trawl	0	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	7.92E-04	0.016	0.001	0.003	9.41E-04	9.90E-04	0	2.97E-04	1.98E-04	1.98E-04
Greenland turbot longline	0.013	0.274	0.022	0.059	0.016	0.017	4.95E-05	0.005	0.004	0.003
Sablefish longline	0.007	0.138	0.011	0.030	0.008	0.009	4.95E-05	0.003	0.002	0.002
Rockfish trawl	0	0	0	0	0	0	0	0	0	0
Pacific halibut longline	0	0	0	0	0	0	0	0	0	0
Crab pots	0	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0	0

Appendix Table B3. Continued. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Sleeper shark	Walleye pollock adult	Pacific cod adult	Pacific herring adult	Arrowtooth flounder adult	Greenland turbot adult	Pacific halibut adult	Yellowfin sole adult	Flathead sole adult
Pollock trawl	118.141	972,788.411	6,150.236	3,149.990	3,262.623	142.493	830.789	673.631	2,270.606
Pacific cod trawl	14.980	24,276.300	30,742.519	1.541	2,951.112	41.529	1,375.075	665.861	1,178.844
Pacific cod pots	0	5.001	4,443.882	0	1.871	3.247	2.287	12.741	0.246
Pacific cod longline	89.431	2,928.633	49,961.009	0	1,619.359	234.832	283.026	66.356	97.911
Atka mackerel trawl	0	113.470	12.635	0	121.334	20.471	6.877	46.327	21.857
Northern rock sole trawl	0	15,868.097	2,277.001	24.843	1,613.847	16.846	704.207	2,874.614	1,510.649
Yellowfin sole trawl	0.084	22,207.685	3,780.143	557.658	1,480.603	15.087	411.017	42,978.014	4,785.839
Arrowtooth flounder trawl	0.251	52.564	0.399	0.039	50.431	1.322	31.346	2.436	2.148
Flathead sole trawl	2.426	3,762.423	345.549	31.560	2,126.092	131.388	32.519	1,563.633	1,040.724
Other flatfish trawl	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	4.297	7.677	0.261	0	496.303	380.054	161.104	0.018	4.787
Greenland turbot longline	23.776	0.468	2.735	0	179.386	411.521	0.455	0.009	14.340
Sablefish longline	12.528	0.229	1.610	0	115.582	966.472	18.872	0.029	0.304
Rockfish trawl	28.254	384.775	45.474	0.192	808.341	19.831	72.858	6.664	35.984
Pacific halibut longline	50.058	0	452.092	0	113.557	0	69.852	0	0
Crab pots	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	10.662	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0

Appendix Table B3. Continued. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Northern rock sole adult	Alaska plaice	Dover sole	Rex sole	Misc. flatfish	Alaska skate	Other skates	Sablefish adult	Grenadiers
Pollock trawl	4,331.641	2,399.515	0.005	36.677	572.127	420.324	67.966	1.951	44.834
Pacific cod trawl	3,949.334	1,245.769	0.034	11.035	297.034	817.978	132.263	0.282	3.033
Pacific cod pots	0.265	0.260	0	0.001	0.062	0.014	0.002	0.017	3.455
Pacific cod longline	14.820	103.470	0.004	0	24.683	7,156.346	1,157.145	10.289	365.569
Atka mackerel trawl	31.133	23.083	4.46E-04	4.467	5.491	4.718	0.762	4.585	0.912
Northern rock sole trawl	20,439.994	1,596.412	0.003	6.184	380.640	538.147	87.016	1.706	0
Yellowfin sole trawl	6,502.554	5,057.543	0.298	4.654	1,205.893	913.000	147.627	0.008	0.730
Arrowtooth flounder trawl	2.570	2.271	0.038	0.688	0.538	3.934	0.634	0.597	0.360
Flathead sole trawl	748.082	1,099.809	0.034	12.315	262.232	161.214	26.069	6.984	3.865
Other flatfish trawl	0	1.231	0	0	0	0	0	0	0
Greenland turbot trawl	0.380	5.054	0.007	9.329	1.205	24.576	3.966	12.155	34.492
Greenland turbot longline	0.944	15.140	0.005	0	3.614	46.646	7.517	2.564	799.951
Sablefish longline	0.017	0.321	0	0	0.077	58.818	9.489	3.156	528.192
Rockfish trawl	9.169	38.064	0.027	0	9.063	36.198	5.864	2.452	320.134
Pacific halibut longline	0	0	0	0	0	3.439	58.412	0	0
Crab pots	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0

Appendix Table B3. Continued. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Pacific ocean perch	Sharpchin rockfish	Northern rockfish	Dusky rockfish	Shortraker rockfish	Rougheye rockfish	Shortspine thornyhead	Other Sebastes	Atka mackerel adult
Pollock trawl	219.871	1.120	21.271	1.701	4.95E-05	4.95E-05	1.759	19.885	606.306
Pacific cod trawl	259.402	3.534	67.169	1.530	0	0	0.351	44.621	158.670
Pacific cod pots	0.004	0.004	0.076	0.001	0	0	0	0.757	39.9
Pacific cod longline	4.259	0.367	6.984	0.264	2.97E-04	1.98E-04	0.092	29.214	148.726
Atka mackerel trawl	19.991	2.084	39.556	0.933	9.90E-05	4.95E-05	0	34.225	356.490
Northern rock sole trawl	36.784	0.034	0.640	0.070	1.98E-04	1.49E-04	0	3.113	23.350
Yellowfin sole trawl	2.383	4.46E-04	0.009	0	0	0	0	0.874	2.303
Arrowtooth flounder trawl	0.246	0.112	1.269	0	0	0	0.012	0.586	1.189
Flathead sole trawl	104.822	0.012	0.235	0.205	4.95E-05	4.95E-05	0.087	1.253	7.997
Other flatfish trawl	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	0.144	0.013	0.251	0	0	0	0.104	4.057	1.599
Greenland turbot longline	0.132	0.001	0.022	0	9.90E-05	4.95E-05	0.165	1.866	0
Sablefish longline	0.039	0.176	3.348	0	1.49E-04	9.90E-05	0.160	20.738	0.032
Rockfish trawl	321.280	3.529	67.069	0	8.42E-04	5.45E-04	0	26.069	191.971
Pacific halibut longline	1.930	1.930	1.930	1.930	1.930	1.930	1.930	1.930	0
Crab pots	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0	0

Appendix Table B3. Continued. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Greenlings	Large sculpins	Misc. fish shallow	Octopus	Squids	Salmon returning	Myctophids	Capelin	Sand lance	Eulachon	Other managed forage fish	Other pelagic smelt
Pollock trawl	1.98E-04	157.571	4.873	1.130	388.719	208.041	0.090	1.98E-04	6.93E-04	0.954	0.081	20.578
Pacific cod trawl	0	1,447.654	1.391	36.144	28.947	26.708	0	0	0	0	1.114	0.661
Pacific cod pots	0	186.014	0.030	33.319	0.085	0	5.45E-04	0	0	0	0	0
Pacific cod longline	0	749.956	0.067	15.460	0.007	0.392	0	0	0	0	0.005	0
Atka mackerel trawl	0	15.727	2.964	0.056	0.960	0.012	0	0	0	0.002	0	0
Northern rock sole trawl	0	384.608	3.161	25.322	0.071	4.627	0	0	0.005	0	0.454	1.093
Yellowfin sole trawl	0	1,537.098	0.279	1.125	1.701	4.393	0.005	0	0.016	0.002	0.216	2.868
Arrowtooth flounder trawl	0	1.839	0	0.033	0.237	0.236	0	0	0	0	0	0.010
Flathead sole trawl	0	95.766	0.131	0.337	1.509	0.255	1.49E-04	0	0	0	0.525	0.187
Other flatfish trawl	0	0	0	0	0	0	0	0	0	0	0	0
Greenland turbot trawl	0	12.794	4.830	0.250	3.977	0.052	0.005	0	0	0	0	0.008
Greenland turbot longline	0	0.592	0.008	0.029	2.97E-04	0	0	0	0	0	0	0
Sablefish longline	0	2.516	0	0.014	0.002	0.004	0	0	0	0	0	0
Rockfish trawl	0	48.352	0	0	7.197	3.055	0	0	0	0	0	0
Pacific halibut longline	0	11.888	0	0	0	0	0	0	0	0	0	0
Crab pots	0	0	0	0	0	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	83.765	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0.995	0	0	0	0	0	0

Appendix Table B3. Continued. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Tanner crab	King crabs	Snow crabs	Pandalids	Sea stars	Urchins, dollars, cucumbers	Snails	Hermit crabs
Pollock trawl	254.041	39.503	1,298.502	0.036	14.074	0.784	0.189	2.260
Pacific cod trawl	161.741	6.984	76.874	0.057	105.644	12.208	0.416	7.997
Pacific cod pots	62.545	99.592	11.568	3.96E-04	13.594	0.351	0	1.050
Pacific cod longline	2.255	0.380	17.539	9.90E-05	154.569	0.869	0	0.454
Atka mackerel trawl	0.012	0.072	0.221	0.005	0.361	0.624	0	0.272
Northern rock sole trawl	203.984	185.947	497.066	0.074	623.422	13.328	0.283	27.508
Yellowfin sole trawl	180.678	46.860	1,001.778	0.549	2,217.560	3.577	7.997	101.336
Arrowtooth flounder trawl	0.538	0.746	1.306	0.011	1.674	0.009	0	0.048
Flathead sole trawl	64.911	5.251	261.507	0.165	67.555	0.326	0	3.231
Other flatfish trawl	0	0	0	0	0	0	0	0
Greenland turbot trawl	2.804	1.263	70.557	0.051	5.491	0.249	0	0.094
Greenland turbot longline	1.49E-04	0.005	4.95E-04	0	0.156	0.014	0	0.007
Sablefish longline	8.42E-04	0.212	0.029	0	0.436	0.120	0	1.98E-04
Rockfish trawl	1.183	0.186	1.386	0.037	7.997	0.015	0	0.147
Pacific halibut longline	0	0	0	0	0.821	0	0	0
Crab pots	23.457	9.329	148.907	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0

Appendix Table B3. Continued. -- Total removals as discards (t). Groups with zero discards not shown.

Fishery	Misc. crabs	Anemones	Corals	Urochordata	Sea pens	Sponges	Bivalves	Scyphozoid jellies
Pollock trawl	0	2.244	0.061	0.826	0.251	5.384	0	6,155.119
Pacific cod trawl	0	13.434	1.349	25.429	0.223	45.900	0	577.460
Pacific cod pots	0	0.018	0.032	0.005	0	0.137	0.018	3.380
Pacific cod longline	0	109.761	1.088	1.104	2.602	1.152	0.037	9.063
Atka mackerel trawl	0	0.148	0.005	0.020	0.037	0.773	0	12.741
Northern rock sole trawl	0	34.652	0.634	42.488	0.119	239.866	0	378.972
Yellowfin sole trawl	0	24.576	5.544	659.819	0	23.616	0	412.132
Arrowtooth flounder trawl	0	0.087	0	0.002	0	0.029	0	0.525
Flathead sole trawl	0	3.311	0.103	15.353	0.005	0.938	0	12.475
Other flatfish trawl	0	0	0	0	0	0	0	0
Greenland turbot trawl	0	1.221	0.044	0.251	0.004	0.013	0	0.417
Greenland turbot longline	0	0.046	0.014	0	4.46E-04	0.005	0	0.001
Sablefish longline	0	1.013	0.122	9.90E-05	0	0.003	0	0
Rockfish trawl	0	0.015	0.213	0.415	0.121	2.708	0	0.358
Pacific halibut longline	0	0	0	0	0	0	0	0
Crab pots	0.171	0	0	0	0	0	0	0
Salmon fishery	0	0	0	0	0	0	0	0
Pacific herring fishery	0	0	0	0	0	0	0	0
Subsistence	0	0	0	0	0	0	0	0

APPENDIX C: Diet Matrices

Appendix C: The diet compositions of functional groups with prey proportions expressed as proportion by weight. Columns may total to slightly more or less than one due to rounding.

Appendix Table C1. -- Cetacean diet compositions.

Prey	Transient killer whales	Sperm whales	Resident killer whales	Porpoises	Belugas	Gray whales	Humpback whales	Fin whales	Sei whales	Right whales	Minke whales	Bowhead whales
Dolphins and porpoises	0.13570											
Belugas	0.06010											
Gray whales	0.01874											
Minke whales	0.02117											
Sea otters	0.03743											
Northern fur seal juv.	0.04378											
Northern fur seal adult	0.24800											
Steller sea lion juv.	0.00870											
Steller sea lion adult	0.01306											
Resident seals	0.41306											
Sleeper shark		0.00294										
Walleye pollock juv.			0.05500	0.27014	0.03044		0.18720		0.09765		0.23400	
Walleye pollock adult			0.20284									
Pacific cod juv.			0.00228	0.00572								
Pacific cod adult		0.14884	0.03029									
Pacific herring juv.			0.00210	0.01029			0.00713	0.00409	0.00372		0.00891	
Pacific herring adult			0.00749	0.03677	0.00414		0.02548	0.01460	0.01329		0.03185	
Arrowtooth flounder juv.			0.00265									
Arrowtooth flounder adult			0.23804									
Greenland turbot juv.			0.00317									
Greenland turbot adult			0.22407									
Pacific halibut juv.			0.00079		0.00001							
Pacific halibut adult			0.08055									
Yellowfin sole juv.					0.00288							
Yellowfin sole adult					0.03131							
Flathead sole juv.					0.00100							
Flathead sole adult					0.00678							
Northern rock sole juv.				0.00216	0.00107							
Northern rock sole adult				0.04231	0.02091							
Alaska plaice				0.01397	0.00691							
Dover sole				4.00E-06	1.98E-06							
Rex sole				0.00064	0.00031							
Misc. flatfish				0.00255	0.00125							
Alaska skate		0.04885						0.01940				
Other skates		0.01183						0.00470				
Sablefish juv.		0.00023	0.00163	6.63E-06								
Sablefish adult		0.00179	0.01261									
Eelpouts				0.00156								
Grenadiers		0.05547										
Misc. fish deep		0.00049										

Appendix Table C1. Continued. -- Cetacean diet composition.

Prey	Transient killer whales	Sperm whales	Resident killer whales	Porpoises	Belugas	Gray whales	Humpback whales	Fin whales	Sei whales	Right whales	Minke whales	Bowhead whales
Pacific ocean perch		0.00842		0.00001								
Sharpchin rockfish		0.00009		1.49E-07								
Northern rockfish		3.85E-06		6.25E-09								
Dusky rockfish		0.00010		1.66E-07								
Shortraker rockfish		0.00032		5.19E-07								
Rougheye rockfish		0.00010		1.66E-07								
Shortspine thornyhead		0.00019		3.11E-07								
Other Sebastes		1.50E-06		2.44E-09								
Atka mackerel juv.			0.01574									
Atka mackerel adult			0.04530									
Greenlings		0.00007										
Other sculpins				0.01558	0.00770							
Misc. fish shallow		0.07025			0.00791				0.02538			
Octopus					0.00130							
Squids		0.65000		0.17642				0.02220	0.01000		0.00167	
Salmon returning			0.06944	0.00734				0.00392				
Salmon smolts			0.00602	0.00064				0.00034				
Myctophids				0.15724					0.01796			
Capelin				0.07484	0.00843		0.05186	0.02976	0.02705		0.06483	
Sand lance				0.14762	0.01713		0.10532	0.06044	0.05494		0.13165	
Eulachon				0.03224	0.00374		0.02300				0.02875	
Other managed forage fish					0.00712							
Other pelagic smelt				0.00005								
Tanner crab					0.00247							0.00032
King crabs												0.00018
Snow crabs					0.01053							0.00135
Pandalids				0.00066	0.04568							0.00585
Non-pandalid shrimp				0.00124	0.08606							0.01102
Snails					0.00414							0.00053
Hermit crabs												0.00075
Misc. crabs					0.00063							0.00008
Misc. crustaceans						0.00946						
Benthic amphipods					0.08670	0.90000						0.01110
Urochordata					0.00228							
Bivalves					0.41920	0.06586						
Polychaetes					0.14694	0.02308						0.01882
Misc. worms					0.02486							
Euphausiids							0.60000	0.60000	0.29926	0.04194	0.45000	0.46133
Mysids					0.01016	0.00160				0.00353		0.03882
Pelagic amphipods								0.04053		0.00399		0.04385
Pteropods										0.00055		0.00600
Copepods								0.20000	0.45074	0.95000	0.04833	0.40000

Appendix Table C2. -- Caniform diet composition

Prey	Sea otters	Pacific walrus bearded seals	Northern fur seal juv.	Northern fur seal adult	Steller sea lion juv.	Steller sea lion adult	Resident seals	Wintering seals
Pacific walrus/bearded seals		0.00086						
Resident seals		0.00076						
Wintering seals		0.00103						
Walleye pollock juv.		0.01807	0.50000	0.50000	0.11330	0.11330	0.40826	0.47039
Walleye pollock adult			0.20000	0.20000	0.41782	0.41782	0.11103	
Pacific cod juv.							0.00269	0.00054
Pacific cod adult					0.06240	0.06240		
Pacific herring juv.		0.00069	0.01025	0.01025			0.00217	0.01792
Pacific herring adult		0.00246	0.03663	0.03663	0.01542	0.01542	0.00776	0.02882
Arrowtooth flounder juv.			0.00002	0.00002				
Pacific halibut juv.			5.36E-06	5.36E-06	0.00010	0.00010		
Pacific halibut adult					0.01032	0.01032		
Flathead sole juv.		0.00764					0.00286	0.00046
Flathead sole adult					0.05434	0.05434		
Northern rock sole juv.			0.00045	0.00045				
Northern rock sole adult			0.00887	0.00887	0.07784	0.07784		
Alaska plaice		0.05287					0.01977	0.00320
Dover sole		0.00002	8.39E-07	8.39E-07			5.66E-06	9.15E-07
Rex sole		0.00241					0.00090	0.00015
Misc. flatfish		0.01041	0.00053	0.00053	0.01003	0.01003	0.00358	0.00058
Alaska skate					0.04412	0.04412		
Other skates					0.01068	0.01068		
Sablefish juv.			0.00023	0.00023				
Eelpouts		0.00046			0.00619	0.00619		0.00689
Pacific ocean perch			0.00040	0.00040			0.00094	
Sharpchin rockfish			4.39E-06	4.39E-06			0.00001	
Northern rockfish			1.84E-07	1.84E-07			4.29E-07	
Dusky rockfish			4.89E-06	4.89E-06			0.00001	
Shortraker rockfish			0.00002	0.00002			0.00004	
Rougheye rockfish			4.89E-06	4.89E-06			0.00001	
Shortspine thornyhead			9.16E-06	9.16E-06			0.00002	
Other Sebastes			7.18E-08	7.18E-08			1.68E-07	

Appendix Table C2. Continued. -- Caniform diet composition.

Prey	Sea otters	Pacific walrus bearded seals	Northern fur seal juv.	Northern fur seal adult	Steller sea lion juv.	Steller sea lion adult	Resident seals	Wintering seals
Atka mackerel adult			0.00640	0.00640	0.00581	0.00581		
Greenlings	0.00001		0.00007	0.00007	0.00007	0.00007	8.34E-06	3.60E-06
Large sculpins			0.00151	0.00151	0.01322	0.01322	0.00351	
Other sculpins		0.05894					0.01443	0.06874
Misc. fish shallow	0.01089	0.00470			0.06344	0.06344	0.01482	0.00366
Octopus		0.00165			0.01046	0.01046	0.06092	0.00005
Squids			0.05552	0.05552			0.01177	0.00291
Salmon returning			0.00981	0.00981			0.00110	
Salmon smolts							0.00010	
Bathylagids			0.00968	0.00968				
Capelin		0.06454	0.00358	0.00358			0.02414	0.05865
Sand lance	0.02358	0.02163	0.15140	0.15140			0.04902	0.00792
Eulachon			0.00159	0.00159				
Other managed forage fish	0.00981	0.00899	0.00302	0.00302			0.01334	0.00304
Other pelagic smelt		0.00201						0.05221
Tanner crab		0.00071						
Snow crabs	0.06201	0.01005			0.08444	0.08444		
Pandalids		0.01305					0.08558	0.06158
Non-pandalid shrimp		0.08218					0.16122	0.11601
Urchins, dollars, cucumbers	0.10000	0.00018						
Snails	0.00571	0.00406						0.00015
Hermit crabs	0.03427	0.00556						
Misc. crabs	0.00372	0.00060						
Benthic amphipods		0.08278						
Anemones		0.00045						
Urochordata		0.00152						
Bivalves	0.75000	0.41321						0.01488
Polychaetes		0.10182						0.00521
Misc. worms		0.02374						
Euphausiids								0.05588
Mysids								0.00470
Pelagic amphipods								0.01548

Appendix Table C3. -- Seabird diet composition.

Group	Shearwaters	Murres	Kittiwakes	Auklets	Puffins	Fulmars	Storm petrels	Cormorants	Gulls	Albatross & jaegers
Shearwaters						0.00005				
Murres						0.00099				
Kittiwakes						0.00008				
Auklets						0.00021				
Puffins						0.00006				
Fulmars						0.00006				
Storm petrels						2.13E-07				
Cormorants						0.00002				
Gulls						0.00001				
Albatross/jaegers						0.00001				
Walleye pollock juv.		0.27031	0.22324	0.00255	0.11147	0.29278	0.01627	0.02434	0.00191	0.17300
Pacific cod juv.		0.19971	0.00973	0.00011	0.00486	0.01277	0.00071	0.00106	0.00008	0.00754
Pacific herring juv.		0.00005	0.00253					0.12701		0.00093
Pacific ocean perch		0.00076	0.00076	0.00077	0.00076	0.00076	0.00076	0.00065	0.00076	
Sharpchin rockfish		5.67E-06	5.67E-06	5.69E-06	5.67E-06	5.66E-06	5.67E-06	4.80E-06	5.67E-06	
Northern rockfish		0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00009	0.00010	
Dusky rockfish		2.80E-06	2.80E-06	2.81E-06	2.80E-06	2.80E-06	2.80E-06	2.38E-06	2.80E-06	
Shortraker rockfish		0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	
Rougheye rockfish		0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00001	0.00002	
Shortspine thornyhead		0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	
Other Sebastes		0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00003	0.00004	
Atka mackerel juv.		4.94E-07	4.94E-07	4.96E-07	4.94E-07	4.94E-07	4.94E-07	4.19E-07	4.94E-07	
Squids	0.25951	0.03450	0.00722	0.00074	0.03814	0.58512	0.60639			0.50000

Appendix Table C3. Continued. -- Seabird diet composition.

Group	Shearwaters	Murres	Kittiwakes	Auklets	Puffins	Fulmars	Storm petrels	Cormorants	Gulls	Albatross & jaegers
Salmon smolts										7.78E-08
Bathylagids	0.01353							0.02490		0.01238
Myctophids	0.04817	0.00215	0.11972					0.08864		0.04406
Capelin	0.40585	0.05202	0.07088	0.00755	0.09935	0.00996	0.00585	0.07354	0.13404	0.03655
Sand lance	0.14118	0.18374	0.25038	0.02666	0.35095	0.03517	0.02067	0.42337	0.47347	0.12913
Eulachon	0.02660	0.03463	0.04718	0.00502	0.06613	0.00663	0.00390	0.04895	0.08922	0.02433
Other managed forage fish	0.05545	0.07217	0.09834	0.01047	0.13785	0.01382	0.00812	0.10203	0.18597	0.05072
Other pelagic smelt	0.02336	0.03040	0.04143	0.00441	0.05807	0.00582	0.00342	0.04298	0.07834	0.02136
Tanner crab								0.00033		
King crabs								0.00012		
Snow crabs								0.00121		
Pandalids								0.00325		
Non-pandalid shrimp								0.00539		
Misc. crabs								0.00033		
Misc. crustaceans	0.00976	0.00604	0.00381	0.00072	0.06267	0.00008	0.00115	0.00445	0.00131	
Benthic amphipods			0.00520	0.00099		0.00011	0.00157	0.00608	0.00179	
Bivalves			0.02672	0.00506		0.00057	0.00804		0.00919	
Polychaetes			0.00936	0.00177		0.00020	0.00282		0.00322	
Misc. worms			0.00139	0.00026		0.00003	0.00042		0.00048	
Euphausiids	0.00671	0.04315	0.03118	0.35522	0.02647	0.01312	0.12175	0.00857	0.00342	
Mysids		0.00262	0.00189	0.02156	0.00161	0.00080	0.00739		0.00021	
Pelagic amphipods		0.00408	0.00295	0.03360	0.00250	0.00124	0.01152		0.00032	
Copepods	0.00987	0.06344	0.04585	0.52230	0.03892	0.01929	0.17902	0.01260	0.00503	
Discards									0.01099	

Appendix Table C4. -- Diet composition for sharks, gadids, herring, arrowtooth and Kamchatka flounder.

Prey	Sleeper shark	Walleye pollock juv.	Walleye pollock adult	Pacific cod juv.	Pacific cod adult	Pacific herring juv.	Pacific herring adult	Arrowtooth flounder juv.	Arrowtooth flounder adult	Kamchatka flounder juv.	Kamchatka flounder adult
Walleye pollock juv.		0.00978	0.04407	0.00668	0.02866			0.21853	0.46915	0.42284	0.58052
Walleye pollock adult	0.20000		0.08513		0.26428				0.19477		0.21294
Pacific cod juv.			0.00030		0.00041				2.50E-06		
Pacific cod adult			0.00067		0.00537				1.21E-06		
Pacific herring juv.			1.63E-06		0.00178						
Pacific herring adult			0.00089		0.00036				0.01343		
Arrowtooth flounder juv.					0.00004				0.00342		0.00001
Arrowtooth flounder adult	0.12017		0.00084		0.00068				2.48E-06		
Kamchatka flounder juv.									6.11E-06		
Kamchatka flounder adult	0.00714		1.69E-07		0.00006						
Greenland turbot juv.		0.00010	0.00014		0.00006						
Greenland turbot adult	0.04445		0.00031		0.00003						
Pacific halibut juv.			1.87E-06		0.00014			0.00060			
Pacific halibut adult	0.02824		2.66E-06		0.00086						
Yellowfin sole juv.					0.00016						
Yellowfin sole adult			3.87E-07		0.00756				0.00029		
Flathead sole juv.			5.07E-07		0.00055			0.00133	0.01133		0.00006
Flathead sole adult			0.00023		0.00289				0.00021		0.00087
Northern rock sole juv.			0.00002		0.00020			0.00001	0.00001		
Northern rock sole adult			0.00002		0.01326				2.92E-06		
Alaska plaice			1.21E-08		0.00011						
Misc. flatfish			4.96E-07		0.00127						
Alaska skate					6.70E-07						
Eelpouts			0.00070	0.00007	0.04001			0.00036	0.04295		0.05253
Grenadiers	0.20000								5.04E-06		
Misc. fish deep			7.96E-07								
Pacific ocean perch					0.00011						
Other Sebastes					6.06E-07						
Atka mackerel adult					0.00198				0.00042		
Greenlings					0.00005						
Large sculpins			0.00001		0.00152						
Other sculpins		4.29E-06	0.00053	0.00971	0.01072			0.02618	0.00855		0.00283
Misc. fish shallow	0.02000	2.46E-06	0.00014	0.00026	0.00411			0.00195	0.00002		0.00818
Octopus	0.02000		0.00004		0.00648				0.00007		
Squids	0.20000	0.00025	0.00250		0.00093				0.00879		0.00207
Salmon returning	0.05000				0.00165						

Appendix Table C4. Continued. -- Diet composition for sharks, gadids, herring, arrowtooth and Kamchatka flounder.

Prey	Sleeper shark	Walleye pollock juv.	Walleye pollock adult	Pacific cod juv.	Pacific cod adult	Pacific herring juv.	Pacific herring adult	Arrowtooth flounder juv.	Arrowtooth flounder adult	Kamchatka flounder juv.	Kamchatka flounder adult
Bathylagids			0.00104		1.35E-06						
Myctophids		0.00089	0.00252		1.77E-07				0.00342		0.00123
Capelin		0.00039	0.00075	0.00002	0.00416				0.01203		
Sand lance		0.00136	0.00170	0.00579	0.02393				0.00042		
Eulachon			9.61E-06		0.00014				0.02119		
Other managed forage fish			0.00059	0.00329	0.00754			0.00424	0.00587	0.00772	0.02961
Other pelagic smelt			9.39E-08								
Tanner crab			0.00016	3.90E-06	0.04309						0.00123
King crabs		6.51E-07	2.24E-06	0.00017	0.00971						
Snow crabs		3.58E-08	0.00003	0.00127	0.07392				3.70E-09		
Pandalids	0.00250	0.00054	0.03578	0.01000	0.05304			0.05432	0.03865	0.02761	0.02346
Non-pandalid shrimp	0.00250	0.00488	0.01496	0.17659	0.07605			0.41884	0.02208	0.40321	0.03911
Sea stars			0.00005		0.00016						
Brittle stars		4.75E-07	0.00006	0.00013	0.00020			0.00005	0.00009		0.00003
Urchins, dollars, cucumbers			2.05E-07		0.00014						
Snails	0.00250		0.00030	0.00005	0.00604			0.00022	0.00004		
Hermit crabs	0.00250	0.00037	0.00098	0.00723	0.07027			0.00548	0.00018		0.00007
Misc. crabs		0.00004	0.00026	0.00017	0.01415						
Misc. crustaceans		0.01628	0.00111	0.00708	0.00056				3.68E-06	0.00004	0.00006
Benthic amphipods		0.05699	0.02049	0.39205	0.02819		0.00004	0.00187	0.00104	0.02608	0.00723
Hydroids					6.21E-08				5.96E-07		
Urochordata			0.00003		0.00071				9.54E-07		
Sponges			0.00009		0.00006				1.60E-09		
Bivalves		0.00053	0.00047	0.00001	0.00214				0.00018		0.00031
Polychaetes		0.00614	0.00208	0.04110	0.03594		0.00041	0.00021	0.00088	0.02860	0.00248
Misc. worms		9.22E-07	0.00222	0.00204	0.03435						0.00078
Scyphozoid jellies			0.00005		4.86E-06				2.34E-06		
Fish larvae			7.16E-07		0.00002				0.00017		
Chaetognaths		0.04844	0.00976		8.36E-06			3.75E-07	0.00001		
Euphausiids		0.32899	0.34964	0.03308	0.02190	0.87855	0.95662	0.24589	0.09170	0.07843	0.03045
Mysids		0.09381	0.01181	0.29685	0.02456			0.01961	0.00097	0.00547	0.00095
Pelagic amphipods		0.00522	0.01591	0.00021	0.00011		0.00042	6.91E-07	3.10E-07		
Gelatinous filter feeders		0.00577	0.01450		1.01E-07				0.00013		
Pteropods		4.57E-06	0.00060	2.60E-08	3.67E-07				3.14E-07		
Copepods		0.41922	0.36423	0.00611	0.00006	0.12145	0.04250	0.00031	9.09E-06		
Pelagic microbes			3.17E-06	0.00004	8.05E-07						
Macroalgae					0.00002						
Offal	0.10000		0.01129	6.41E-06	0.07253				0.04751		0.00301

Appendix Table C5. -- Diet compositions for Greenland turbot, Pacific halibut, yellowfin sole, flathead sole, and northern rock sole.

Prey	Greenland turbot juv.	Greenland turbot adult	Pacific halibut juv.	Pacific halibut adult	Yellowfin sole juv.	Yellowfin sole adult	Flathead sole juv.	Flathead sole adult	Northern rock sole juv.	Northern rock sole adult
Walleye pollock juv.	0.01199	0.27150		0.01901		0.00998	0.00050	0.16766		0.00093
Walleye pollock adult		0.10534		0.52104						
Pacific cod juv.				0.00001		0.00002	7.49E-07	0.00011		
Pacific cod adult		0.00125		0.04738						
Pacific herring juv.										0.00177
Pacific herring adult		0.01223		0.00263						
Arrowtooth flounder juv.						1.30E-06				
Arrowtooth flounder adult				0.00090						
Greenland turbot juv.						0.00004		4.38E-06		
Pacific halibut juv.				1.73E-06		0.00015				
Pacific halibut adult				0.00004						
Yellowfin sole adult				0.03314						
Flathead sole juv.				0.00052		4.45E-07		0.00162		
Flathead sole adult		7.56E-06		0.01079						
Northern rock sole juv.				0.00015	0.00001	0.00041		0.00001		
Northern rock sole adult				0.03237						
Alaska plaice				0.00493		0.00035		2.10E-09		
Rex sole				0.00097						
Misc. flatfish				0.02682		0.00001				
Alaska skate				0.00002						
Other skates				0.00010						
Sablefish adult				0.00103						
Eelpouts		0.07286		0.00926		0.00007	0.00348	0.00189		0.00070
Grenadiers		6.21E-06								
Shortspine thornyhead		8.30E-09								
Atka mackerel adult				0.00489						
Greenlings				0.00042						
Large sculpins				0.00165		0.00006				
Other sculpins		0.02167		0.02235		0.00190	0.00820	0.00060	0.00090	3.51E-07
Misc. fish shallow		0.00954		0.01547	4.85E-06	0.00003		0.00511		
Octopus		0.00005		0.00474		0.00012		0.00022		
Squids		0.32266		0.00322			0.00292	0.00003		0.00002
Bathylagids		0.09117						2.39E-06		
Myctophids		0.05182		0.00012				5.35E-06		

Appendix Table C5. Continued. -- Diet compositions for Greenland turbot, Pacific halibut, yellowfin sole, flathead sole, and northern rock sole.

Prey	Greenland turbot juv.	Greenland turbot adult	Pacific halibut juv.	Pacific halibut adult	Yellowfin sole juv.	Yellowfin sole adult	Flathead sole juv.	Flathead sole adult	Northern rock sole juv.	Northern rock sole adult
Capelin				0.03864		2.09E-08		0.00096		
Sand lance				0.03442	0.00198	0.00633		0.00349		0.14135
Eulachon				0.00004						
Other managed forage fish		0.00959		0.00263		0.00103		0.00790		0.00061
Tanner crab		1.60E-09		0.02602	4.43E-06	0.00276	4.82E-06	0.00736		0.00004
King crabs		1.26E-06		0.00182		0.00015				
Snow crabs		2.41E-06		0.03394		0.00655	5.84E-07	0.00960		0.00053
Pandalids		0.00255		0.00958	0.00001	0.00016	0.06149	0.10845	0.00164	0.00029
Non-pandalid shrimp	0.00373	0.00437	0.69298	0.00458	0.06074	0.07338	0.11120	0.10151	0.01020	0.03103
Sea stars				8.23E-08		0.00001		4.00E-08		4.79E-07
Brittle stars	1.08E-06	0.00002		0.00008	0.01018	0.03185	0.14160	0.24769	0.00090	0.01256
Urchins, dollars, cucumbers				0.00004	0.02205	0.04618		0.00029	0.00612	0.02270
Snails				0.00241	0.00668	0.01046		0.02002	0.00019	0.00141
Hermit crabs		0.00222	0.00044	0.04664	0.00023	0.02586	0.00005	0.01602	1.26E-07	0.00561
Misc. crabs				0.00744	0.00066	0.00179	1.17E-06	0.00123		0.00114
Misc. crustaceans	7.69E-08	9.70E-07		0.00018	0.43516	0.00939	0.01233	0.00133	0.00444	0.01221
Benthic amphipods	0.00232	0.00133	0.00002	0.00015	0.20847	0.07529	0.27429	0.02340	0.34858	0.09572
Hydroids					0.00004	0.00005		3.10E-09		1.15E-06
Urochordata				0.00002	0.00504	0.00529	8.96E-06	0.00132	0.00093	0.00071
Sponges						0.00029				2.83E-06
Bivalves				0.00365	0.05328	0.11518	0.00176	0.02424	0.06125	0.07306
Polychaetes		1.00E-10	0.00009	0.00014	0.14231	0.25270	0.01162	0.03877	0.53626	0.47237
Misc. worms				0.00189	0.00845	0.15616	0.01009	0.00546	0.00645	0.10999
Scyphozoid jellies						0.00505		2.81E-06		0.00006
Fish larvae				0.00006	0.00003	8.21E-06				
Chaetognaths						0.00007	0.00254	0.00087		2.20E-06
Euphausiids	0.97435	0.01925		0.00338	0.02618	0.13826	0.15214	0.11665	0.00526	0.01245
Mysids	6.26E-06	0.00012	0.30647	0.00086	0.01089	0.00493	0.19591	0.04602	0.01687	0.00125
Pelagic amphipods	0.00755	0.00018			0.00002	0.00043	0.00012	0.00024	4.24E-06	0.00001
Gelatinous filter feeders	7.30E-07				3.80E-06	0.00192	5.80E-06	1.80E-06		0.00051
Pteropods	0.00004	1.15E-06			0.00002	0.00424	0.00584	3.76E-08		0.00055
Copepods					0.00439	0.00016	0.00390	0.00013	0.00002	0.00010
Pelagic microbes					0.00024	0.00037	8.76E-07	0.00002	5.03E-06	0.00032
Macroalgae				1.39E-06						2.28E-08
Offal		0.00027		0.01743	0.00292	0.01054		0.03979		5.22E-06

Appendix Table C6. -- Diet compositions of Alaska plaice, dover sole, rex sole, misc. flatfish, Alaska skate, other skates, sablefish (juv), sablefish (adu), eelpouts, grenadiers, and misc. fish deep.

Prey	Alaska plaice	Dover sole	Rex sole	Misc. flatfish	Alaska skate	Other skates	Sablefish juv.	Sablefish adult	Eelpouts	Grenadiers	Misc. fish deep
Walleye pollock juv.				0.03177	0.00161				0.00001		
Walleye pollock adult					0.40470	0.44883		0.45916	0.00394		
Pacific cod juv.				0.00032		0.00387					
Pacific cod adult					0.00639						
Pacific herring adult					0.00191			0.00037	0.00074		
Arrowtooth flounder juv.								0.00017			
Arrowtooth flounder adult					0.02629						
Pacific halibut juv.	0.00007				0.00134						
Pacific halibut adult					3.08E-07						
Yellowfin sole juv.					0.00011						
Yellowfin sole adult					0.00683	0.04248					
Flathead sole juv.									7.38E-06		
Flathead sole adult					0.00001						
Northern rock sole juv.					0.00024						
Northern rock sole adult					0.08494	0.02030					
Misc. flatfish					0.00166						
Eelpouts	0.00004			0.04198	0.08713	0.03171		0.00034	0.01846		
Large sculpins					0.00002						
Other sculpins					0.02358	0.00179			0.01351		
Misc. fish shallow					0.00371	0.03346		0.00007	0.00099		
Octopus				0.00006				0.03883			
Squids					0.00003		0.10000	0.11109		0.50000	0.50000
Salmon returning					0.02555						
Bathylagids								0.01787			
Myctophids								0.00106			
Capelin				0.04553					0.00026		
Sand lance	0.00735				0.02921	0.00009					
Eulachon	0.00013										
Other managed forage fish				0.00816	0.00257	0.00039		0.30811	0.01207		

Appendix Table C6. Continued. -- Diet compositions of Alaska plaice, dover sole, rex sole, misc. flatfish, Alaska skate, other skates, sablefish (juv), sablefish (adu), eelpouts, grenadiers, and misc. fish deep.

Prey	Alaska plaice	Dover sole	Rex sole	Misc. flatfish	Alaska skate	Other skates	Sablefish juv.	Sablefish adult	Eelpouts	Grenadiers	Misc. fish deep
Tanner crab		0.01540		0.00628	0.00504	0.05574			0.00068		
Snow crabs	0.00601			0.00001	0.03116	0.02214			0.09334		
Pandalids		0.22241		0.09605	0.00127			0.00145			
Non-pandalid shrimp	0.00006	0.26470	0.54548	0.10020	0.06458	0.11109		0.00522	0.01367	0.50000	0.50000
Sea stars	2.04E-08				0.00063			0.00053			
Brittle stars	0.00169	0.01027		0.05995	0.00006			0.00026	0.18225		
Urchins, dollars, cucumbers	0.01513			0.00020	9.16E-08						
Snails	0.00351			0.00045	0.00034						
Hermit crabs	0.00011			0.00108	0.02163	0.20065		0.00001	0.00251		
Misc. crabs	0.00028				0.00079	0.01715			0.00491		
Misc. crustaceans	0.00175	0.00191		0.00468	0.00003				0.00536		
Benthic amphipods	0.09972	0.08916	0.11797	0.06402	0.00881	0.00529		0.00023	0.32805		
Hydroids	2.00E-10			9.55E-07					0.00172		
Urochordata	0.00048				1.89E-06		0.15000				
Sponges	0.00002				9.07E-06						
Bivalves	0.15501	0.01052	0.00011	0.07007	0.00003				0.05258		
Polychaetes	0.58410	0.28173	0.20453	0.24426	0.00270	0.00341		0.00003	0.23867		
Misc. worms	0.12316	0.05450	0.03307	0.02002	0.00007				0.02366		
Scyphozoid jellies	5.28E-06				0.00002			0.01559			
Fish larvae	2.76E-06										
Euphausiids	0.00113	0.03518	0.09885	0.00116	0.00004	0.00005	0.50000	0.00034	0.00018		
Mysids	0.00002	0.00240		0.19522	0.00050	0.00008			0.00008		
Pelagic amphipods	0.00001	0.01182		0.00506				0.00006	0.00108		
Gelatinous filter feeders	0.00004										
Pteropods	1.35E-07						0.10000				
Copepods	7.81E-06			0.00349			0.15000				
Pelagic microbes	0.00014								0.00065		
Offal	8.56E-06				0.15444	0.00147		0.03919	0.00062		

Appendix Table C7. -- Diet composition of rockfish species.

Prey	Pacific ocean perch	Sharpchin rockfish	Northern rockfish	Dusky rockfish	Shortraker rockfish	Rougheye rockfish	Shortspine thornyhead	Other Sebastes
Misc. fish deep	0.00368							
Other sculpins		0.00130			0.00649			0.00130
Misc. fish shallow		0.00031				0.00139	0.00017	0.00031
Squids	0.00040	0.13134	0.05368		0.00880	0.62013		0.13134
Bathylagids	0.00707							
Myctophids	0.01000	0.00086			0.00279	0.00153		0.00086
Tanner crab		0.00003	0.00008					0.00003
Pandalids		0.16659			0.83019	0.00082	0.00194	0.16659
Non-pandalid shrimp	0.00030	0.06438	0.01810			0.13805	0.15331	0.06438
Hermit crabs		0.00375	0.01103					0.00375
Benthic amphipods	0.00134	0.08452	0.00008	0.04646		0.01426	0.36181	0.08452
Polychaetes	0.00028	0.01673		0.08363				0.01673
Misc. worms	1.7E-08							
Chaetognaths	0.00151	0.01607	0.05833					0.01607
Euphausiids	0.21257	0.18756	0.04049	0.68033	0.01999	0.19385		0.18756
Mysids	0.71154	0.12869	0.00486		0.13174	0.02608	0.48276	0.12869
Pelagic amphipods	2.40E-06	0.00037	0.00145					0.00037
Gelatinous filter feeders	0.00012							
Pteropods	0.00015	0.00085	0.00250					0.00085
Copepods	0.05104	0.19665	0.80941	0.18957		0.00390		0.19665

Appendix Table C8. -- Diet compositions for Atka mackerel, greenlings, sculpins, misc. fish shallow, octopus, and squids.

Prey	Atka mackerel juv.	Atka mackerel adult	Greenlings	Large sculpins	Other sculpins	Misc. fish shallow	Octopus	Squids
Walleye pollock juv.			0.04731	0.09530				
Walleye pollock adult				0.03452				
Pacific cod juv.				4.24E-06	0.04028			
Pacific cod adult				0.00091				
Pacific herring juv.				0.00469				
Pacific herring adult				0.00202				
Arrowtooth flounder adult				0.00008				
Kamchatka flounder adult				0.00027				
Pacific halibut juv.				1.69E-06				
Yellowfin sole juv.				0.02155	0.00972			
Yellowfin sole adult				0.00452				
Flathead sole juv.				0.00018		0.00739		
Flathead sole adult				0.00182				
Northern rock sole juv.				0.00735				
Northern rock sole adult				0.00227				
Alaska plaice				0.00118				
Misc. flatfish			0.02966	0.00099				
Eelpouts				0.03331				
Atka mackerel adult				5.16E-06				
Large sculpins			0.17790	0.00184				
Other sculpins			0.15015	0.02105				
Misc. fish shallow				0.01899	0.04986			
Octopus				0.01436				
Squids				0.00007				
Myctophids								0.02500
Capelin				0.01230				0.02500
Sand lance				0.00937				0.02500
Eulachon				9.97E-06				0.02500
Other managed forage fish				0.05756				0.02500
Other pelagic smelt				0.00034				0.02500
Tanner crab		0.00633		0.00548	0.03537		0.05000	
King crabs				0.01754				
Snow crabs				0.03866			0.05000	
Pandalids				0.00746	0.04199	0.01871		
Non-pandalid shrimp			0.42960	0.18982	0.50136	0.20668		
Sea stars				0.00005				
Brittle stars				0.00010	0.00018			
Urchins, dollars, cucumbers				0.00002				
Snails			0.00004	0.00137			0.40000	
Hermit crabs				0.01918		0.00053	0.10000	
Misc. crabs			0.00442	0.01946	0.01917			
Misc. crustaceans			0.00063	0.00079	0.01442	0.00004		
Benthic amphipods			0.03249	0.05960	0.19473	0.09179		
Hydroids			0.00115	6.78E-06	0.03702			
Bivalves			0.01185	0.00039			0.40000	
Polychaetes			0.07079	0.10978	0.02550	1.19E-05		
Misc. worms				0.01925				
Scyphozoid jellies				7.51E-06		0.06430		
Chaetognaths								0.02500
Euphausiids	0.90000	0.98365		0.00960		0.01161		0.42000
Mysids			0.04327	0.07602	0.00309	0.03460		0.02500
Pelagic amphipods			0.00072	0.04567	0.00829	0.01400		0.14000
Gelatinous filter feeders		0.00369		0.02480		0.55001		0.04000
Pteropods				0.00004				
Copepods	0.10000	0.00633		0.00003	0.01866	0.00032		0.20000
Pelagic microbes					0.00036			
Offal				0.00802				

Appendix Table C9. -- Diet compositions of salmonids, bathylagids, myctophids, capelin, sand lance, eulachon, other managed forage fish, and other pelagic smelt.

Prey	Salmon returning	Salmon smolts	Bathylagids	Myctophids	Capelin	Sand lance	Eulachon	Other managed forage fish	Other pelagic smelt
Squids	0.2								
Chaetognaths	0.2								
Euphausiids	0.2	0.25	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Pelagic amphipods		0.25							
Pteropods	0.2								
Copepods	0.2	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Appendix Table C10. --Diet compositions of commercial crabs, shrimps, sea stars, brittle stars, urchins-dollars-cucumbers, snails, hermit crabs, and misc. crabs.

Prey	Tanner crab	King crabs	Snow crabs	Pandalids	Non-pandalid shrimp	Sea stars	Brittle stars	Urchins, dollars, cucumbers	Snails	Hermit crabs	Misc. crabs
Tanner crab						0.005					
Snow crabs						0.005					
Pandalids						0.005					
Non-pandalid shrimp						0.005					
Sea stars		0.00628	0.00060								
Brittle stars	0.08268	0.02741	0.07162			0.03					
Urchins, dollars, cucumbers	0.01472	0.16641	0.00742			0.1					
Snails	0.03757	0.19770	0.04830			0.005					
Hermit crabs	0.01371	0.01625	0.03007			0.005					
Misc. crabs	0.01371	0.01625	0.03007								
Misc. crustaceans	0.00481	0.01513	0.01721				0.05				
Benthic amphipods	0.03807	0.00938	0.04782	0.3	0.3		0.05				
Anemones			0.00185								
Hydroids	0.01153	0.04575	0.00629								
Urochordata		0.00938				0.005					
Sponges	0.00186		0.00260								
Bivalves	0.30756	0.18405	0.25248	0.1	0.1	0.8	0.05		0.2	0.25	0.25
Polychaetes	0.38361	0.18866	0.28473			0.025	0.05		0.2	0.25	0.25
Misc. worms		0.02596	0.02392			0.01			0.2	0.25	0.25
Euphausiids			0.00060	0.2	0.2		0.05				
Mysids			0.00413				0.05				
Copepods							0.05				
Macroalgae		0.02493	0.00445					0.2	0.2		
Large phytoplankton							0.05	0.2			
Discards	0.00625	0.00314	0.00590								
Offal	0.00625	0.00314	0.00590								
Benthic detritus	0.07767	0.06017	0.15403	0.4	0.4		0.6	0.6	0.2	0.25	0.25

Appendix Table C11. --Diet compositions of misc. crustaceans, benthic amphipods, anemones, corals, hydroids, urochordata, sea pens, sponges, bivalves, polychaetes, and misc. worms.

Prey	Misc. crustaceans	Benthic amphipods	Anemones	Corals	Hydroids	Urochordata	Sea pens	Sponges	Bivalves	Polychaetes	Misc. worms
Misc. crustaceans			0.16667		0.07692					0.025	
Benthic amphipods			0.16667		0.07692					0.025	
Bivalves			0.16667		0.07692					0.1	
Polychaetes		0.1	0.16667		0.07692					0.05	0.1
Misc. worms					0.07692						0.1
Fish larvae					0.07692						
Chaetognaths					0.07692						
Mysids					0.07692						
Gelatinous filter feeders					0.07692						
Copepods		0.1		0.01667	0.07692						
Benthic microbes	0.45	0.1	0.16667	0.2	0.07692	0.45		0.25	0.2	0.1	0.28
Large phytoplankton	0.05	0.1		0.01667	0.07692	0.025	0.2	0.05	0.2	0.05	0.01
Small phytoplankton				0.01667		0.025	0.2	0.2		0.05	0.01
Benthic detritus	0.5	0.6	0.16667	0.75	0.07692	0.5	0.6	0.5	0.6	0.6	0.5

Appendix Table C12. -- Diet compositions of pelagic invertebrate groups and microbial groups.

Prey	Scyphozoid jellies	Fish larvae	Chaetognaths	Euphausiids	Mysids	Pelagic amphipods	Gelatinous filter feeders	Pteropods	Copepods	Pelagic microbes	Benthic microbes
Walleye pollock juv.	0.001										
Pacific herring juv.	0.001										
Squids	0.001										
Bathylagids	0.001										
Myctophids	0.001										
Capelin	0.001										
Sand lance	0.001										
Eulachon	0.001										
Other managed forage fish	0.001										
Other pelagic smelt	0.001										
Fish larvae	0.05										
Euphausiids	0.64		0.05								
Mysids			0.05								
Pelagic amphipods			0.05								
Gelatinous filter feeders	0.05		0.05								
Pteropods			0.05								
Copepods	0.15	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
Pelagic microbes	0.05	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.5		
Large phytoplankton	0.05	0.5	0.25	0.5	0.5	0.5	0.5	0.5	0.25		
Small phytoplankton		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.7	
Pelagic detritus										0.3	
Benthic detritus											1

APPENDIX D: Data Pedigree

Appendix D: Data pedigree (i.e., data quality ratings) for model parameters. See Table 1 in the Methods section for a detailed explanation of the pedigree.

Appendix Table D1. --Data pedigree (i.e., data quality ratings) for model parameters. See Table 1 in the Methods section for a detailed explanation of the pedigree.

Group	Biomass	PB	QB	Diet	Fed	Halibut	State	Subsistence
Transient killer whales	5	3	2	5	1			2
Sperm whales	6	3	2	5	1			2
Resident killer whales	4	3	2	5	1			2
Porpoises	5	6	2	6	1			2
Belugas	4	6	2	6	1			2
Gray whales	2	6	2	5	1			2
Humpback whales	4	2	2	5	1			2
Fin whales	4	6	2	6	1			2
Sei whales	7	6	2	6	1			2
Right whales	2	6	2	6	1			2
Minke whales	4	6	2	6	1			2
Bowhead whales	5	1	2	6	1			2
Sea otters	4	6	2	6	1			2
Pacific walrus/bearded seals	5	6	2	5	1			2
Northern fur seal juv.	2	4	2	4	1			2
Northern fur seal adult	2	4	2	4	1			2
Steller sea lion juv.	2	4	2	4	1			2
Steller sea lion adult	2	4	2	4	1			2
Resident seals	5	6	2	5	1			2
Wintering seals	5	6	2	5	1			2
Shearwaters	6	6	6	6	4			2
Murres	4	6	6	6	4			2
Kittiwakes	4	6	6	6	4			2
Auklets	4	6	6	6	4			2
Puffins	4	6	6	6	4			2
Fulmars	4	6	6	6	4			2
Storm petrels	4	6	6	6	4			2
Cormorants	4	6	6	6	4			2
Gulls	4	6	6	6	4			2
Albatross/jaegers	6	6	6	6	4			2
Sleeper shark	5	7	7	6	3	7		2
Walleye pollock juv.	8	4	4	1	1			2
Walleye pollock adult	1	3	3	1	1			2
Pacific cod juv.	8	4	4	1	1			2
Pacific cod adult	2	3	3	1	1	5		2
Pacific herring juv.	8	4	4	5	1			2
Pacific herring adult	3	3	3	4	1		1	2
Arrowtooth flounder juv.	8	5	5	1	1			2
Arrowtooth flounder adult	2	4	4	1	1	5		2
Kamchatka flounder juv.	8	6	6	2	1			2
Kamchatka flounder adult	3	5	5	2	2			2
Greenland turbot juv.	8	6	6	2	1			2
Greenland turbot adult	2	5	5	1	1			2

Appendix Table D1. Continued. -- Data pedigree (i.e., data quality ratings) for model parameters.

Group	Biomass	PB	QB	Diet	Fed	Halibut	State	Subsistence
Pacific halibut juv.	8	6	6	1	1			2
Pacific halibut adult	2	5	5	1	2	1		2
Yellowfin sole juv.	8	4	4	1	1			2
Yellowfin sole adult	2	3	3	1	1			2
Flathead sole juv.	8	5	5	1	2			2
Flathead sole adult	2	4	4	1	2			2
Northern rock sole juv.	8	4	4	1	1			2
Northern rock sole adult	2	3	3	1	1			2
Alaska plaice	2	6	6	1	1			2
Dover sole	2	6	6	6	1			2
Rex sole	2	6	6	2	1			2
Misc. flatfish	8	6	6	2	2			2
Alaska skate	2	7	7	1	4	7		2
Other skates	3	7	7	5	4	7		2
Sablefish juv.	8	6	6	6	1	5		2
Sablefish adult	2	5	5	1	1	5		2
Eelpouts	8	7	7	6	7			2
Grenadiers	3	7	7	5	4			2
Misc. fish deep	8	7	7	7	4			2
Pacific ocean perch	3	6	6	1	1	6		2
Sharpchin rockfish	8	6	6	5	2	6		2
Northern rockfish	8	6	6	2	2	6		2
Dusky rockfish	3	6	6	2	1	6		2
Shortraker rockfish	3	6	6	2	2	6		2
Rougheye rockfish	3	6	6	2	2	6		2
Shortspine thornyhead	3	6	6	2	1	6		2
Other Sebastes	8	6	6	6	2	6		2
Atka mackerel juv.	8	6	6	7	1			2
Atka mackerel adult	4	5	5	2	1			2
Greenlings	2	7	7	2	7			2
Large sculpins	2	7	7	2	4	6		2
Other sculpins	8	7	7	2	4	6		2
Misc. fish shallow	8	7	7	5	7			2
Octopus	8	7	7	7	3			2
Squids	8	7	7	7	3			2
Salmon returning	6	5	5	5	2		1	2
Salmon smolts	8	6	6	6	2			2
Bathylagids	8	7	7	7	4			2
Myctophids	8	7	7	7	4			2
Capelin	8	7	7	7	4			2
Sand lance	8	7	7	7	4			2
Eulachon	8	7	7	7	4			2
Other managed forage fish	8	7	7	7	4			2
Other pelagic smelt	8	7	7	7	4			2

Appendix Table D1. Continued. -- Data pedigree (i.e., data quality ratings) for model parameters.

Group	Biomass	PB	QB	Diet	Fed	Halibut	State	Subsistence
Tanner crab	2	6	5	5	2		1	2
King crabs	2	6	5	5	2		1	2
Snow crabs	2	6	5	5	2		1	2
Pandalids	8	5	5	7	4			2
Non-pandalid shrimp	8	6	6	7	4			2
Sea stars	3	6	7	6	4	6		2
Brittle stars	8	6	7	7	4			2
Urchins, dollars, cucumbers	8	6	7	7	4			2
Snails	3	6	7	7	4			2
Hermit crabs	8	6	7	7	4			2
Misc. crabs	8	6	7	7	4			2
Misc. crustaceans	8	6	7	7	4			2
Benthic amphipods	8	6	7	7	4			2
Anemones	3	6	7	7	4			2
Corals	3	6	7	7	4			2
Hydroids	8	6	7	7	4			2
Urochordata	3	6	7	7	4			2
Sea pens	3	6	7	7	4			2
Sponges	3	6	7	7	4			2
Bivalves	7	6	7	6	4			2
Polychaetes	7	6	7	7	4			2
Misc. worms	8	6	7	7	4			2
Scyphozoid jellies	4	6	6	7	4			2
Fish larvae	8	7	7	7	1			2
Chaetognaths	8	7	7	7	1			2
Euphausiids	8	5	5	7	1			2
Mysids	8	7	7	7	1			2
Pelagic amphipods	8	6	6	7	1			2
Gelatinous filter feeders	8	7	7	7	1			2
Pteropods	8	7	7	7	1			2
Copepods	8	7	5	7	1			2
Pelagic microbes	7	7	7	7	1			2
Benthic microbes	8	7	7	1	1			2
Macroalgae	8	7			1			2
Large phytoplankton	8	5			1			2
Small phytoplankton	8	5			1			2
Discards	8				1			2
Offal	8				1			2
Pelagic detritus	8				1			2
Benthic detritus	8				1			2

U.S. Secretary of Commerce
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June 2025

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