**High-resolution models reveal structure and function of a Northeast Pacific ecosystem**

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**Section A: Study area**

The archipelago of Haida Gwaii occupies the northwestern corner of coastal British Columbia (Canada) and the southeastern extremity of the Alaska Current (Gulf of Alaska) Large Marine Ecosystem (Mundy et al. 2010). The southerly Alaska Current typically originates from the westerly North Pacific Current immediately south of Haida Gwaii (Batten and Welch 2004), although occasionally this occurs just north of the archipelago (Batten and Freeland 2007). This location lends the Haida Gwaii marine ecosystem numerous environmental and biological similarities to neighboring southeast Alaska (Guénette 2005), albeit combined with more southern biogeographical traits. These include higher biomass and more frequent incursions of Pacific hake (Berger et al. 2017), as well as lower walleye pollock biomass (Guénette 2005), compared to southeast Alaska. Haida Gwaii boasts a highly diverse and productive marine ecosystem, including kelp forests and eelgrass beds, globally rare glass sponge reefs, estuaries, fjords, rocky reefs and sandy banks, and a steep continental shelf break immediately off the west coast (PNCIMA 2011). This ecological diversity results primarily from complex bathymetry due to Pleistocene glaciation, Holocene sea level rise and isostatic rebound, and ongoing tectonic processes (Barrie et al. 2005). In addition, persistent anticyclonic mesoscale (Haida) eddies arising in winter off the west coast of Haida Gwaii draw nutrients into the open Northeast Pacific, enhancing primary and likely secondary productivity (Whitney and Robert 2002).

The Haida Gwaii marine ecosystem has existed in similar form since at least *circa* 9500 BP, the earliest known date of human exploitation (Fedje et al. 2005a), and likely since *circa* 11500 BP, the close of the Younger Dryas postglacial cold period (Wigen 2005). Zooarchaeological data obtained from the Kilgii Gwaay site in southern Haida Gwaii (*circa* 9500 BP) suggest the early development of a maritime adaptation (i.e., advanced fishing techniques and pronounced reliance on marine protein, including fish, mammals, and birds) among inhabitants of the archipelago (Fedje et al. 2005a). Pacific herring was fished in large quantities by *circa* 8200 BP at the nearby Lyell Bay South site (Fedje et al. 2005b). However, marine vertebrate trophic levels based on stable isotope analysis of skeletal remains from 2000-100 BP (Szpak et al. 2009) indicate that the local marine ecosystem has not undergone massive structural change since 2000 BP, despite heavy exploitation of Pacific dogfish in the 19th century (Chittenden 1884), whales in the 19th and 20th centuries (Webb 1988, Nichol and Heise 1992), and herring in the 20th century (Hourston 1978). The sea otter is now ecologically extinct in the archipelago, with only occasional visits by vagrant individuals (Raum-Suryan et al. 2004). Historically, the explorer Newton H. Chittenden (1884) noted the abundance of herring, halibut, salmon, dogfish, and sablefish off Haida Gwaii in the late 19th century, while approximately a century earlier John Meares (1791) remarked on the bountiful whale populations.

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**Section B: Ecopath with Ecosim (EwE)**

**Ecopath**

EwE is one of the most commonly used ecosystem modelling frameworks (Coll et al. 2015). Its most basic component, Ecopath (Polovina 1984) generates a static snapshot of food web structure based on a set of functional groups linked by biomass flows according to the principle of mass balance. The latter is fundamentally derived from the first law of thermodynamics, and states that the sum of biomass fluxes from a functional group (losses to emigration, fisheries catches, consumption by other groups, and other natural mortality) cannot exceed the total group production (Christensen and Walters 2004). In Ecopath, a functional group is a species or assemblage of species playing a similar role in the food web and sharing basic parameter values. The number of functional groups is set to the minimum needed to explore the ecological consequences of alternative scenarios.

The principle of mass balance is stated mathematically in the first “master equation” of Ecopath (Christensen and Walters 2004):

where:

(*P*/*B*)*i* is the production per biomass (year-1) of prey *i*,

*Fi* is the fishing mortality rate (year-1) of prey *i,*

*M2i* = is the predation mortality (year-1) of prey *i*,

*n* is the number of predator groups *j* consuming prey group *i*,

*Bj* is the biomass density (t⋅km-2) of predator *j*,

(*Q*/*B*)*j* is the consumption per biomass (year-1) of predator *j*,

*DCij* is the proportion of prey *i* in the diet of predator *j*,

*Ei* is the net migration rate, i.e. emigration - immigration (year-1), of prey *i* (assumed = 0),

*BAi* is the biomass accumulation rate (year-1) of prey *i,*

*M2i* = is the non-predation natural mortality (year-1) of prey *i,*

*Bi* is the biomass density (t⋅km-2) of prey *i*,

and *EEi* is the ecotrophic efficiency (dimensionless) of prey *i*.

The biomass accumulation rate *BA* reflects instantaneous biomass change (positive or negative) not caused by other factors considered in the model (i.e. *F*, *M2*, or *M0*). The ecotrophic efficiency *EE* represents the fraction of production of group *i* consumed by other groups or taken by fisheries (in a balanced model, *EE* ≤ 1). *EEi* = 1 implies that all biomass losses suffered by *i* are due to consumption and catch, while a value of 0 implies that group *i* is never consumed or fished and all its biomass losses are due to natural processes unrelated to predation (*M0*). Therefore, the expression (1 - *EEi*) in the *M0* formula refers to the fraction of the production of group *i* lost to natural mortality due to causes other than predation (e.g. senescence, disease, etc.).

Ecopath requires values of any three of *B*, *P*/*B*, *Q*/*B*, *P*/*Q,* and *EE* as input to balance the model and calculate the value of the missing fourth parameter. A diet composition must also be entered for every consumer.

Once mass-balance among groups has been achieved by solving a set of equations such as the first Ecopath “master” (one for each functional group), mass balance within each group is ensured by the second “master equation,” ultimately based on the second law of thermodynamics:

*Consumption = production − respiration − unassimilated food*

where “production” refers to the biomass of new tissues (growth) and individuals (reproduction), “respiration” to the food biomass lost as CO2, and unassimilated food to that lost in urine, feces, and unconsumed food fragments derived from wasteful feeding. Except production, none of these terms may have a value of zero.

**Ecosim**

While Ecopath (Polovina 1984) generates a static snapshot of biomass pools and fluxes within a food web, Ecosim (Walters et al. 1997) provides dynamic simulations of changes in food web structure and function due to bottom-up (oceanographic) and/or top-down (predation and fisheries) effects. The “master equation” of Ecosim is as follows:

where:

*dBi*/*dt* is the biomass growth rate of group *i* over time interval *t*

*Qhi* is the consumption of all groups *h* by group *i*,

*Qij* is the consumption of group *i* by all groups *j*,

*Ii* is the immigration rate of group *i* (independent of model processes),

and *ei* is the emigration rate of group *i*.

Ecosim calculates *Qhi* and *Qij* based on foraging arena theory (Walters and Juanes 1993), which specifies the vulnerability parameter (*vij*) value matrix governing the degree of top-down versus bottom-up control over each trophic interaction between groups *i* and *j*. Each *vij* value represents the instantaneous rate of exchange of prey biomass *Bi* between pools vulnerable and invulnerable to a given predator*.* This vulnerability parameter is theoretically defined as the maximum possible multiplier for the predator consumption rate specified in Ecopath. The value of this multiplier depends on the behavioural ecology of the predator (Walters and Juanes 1993, Ahrens et al. 2012) and on the ratio of Ecopath predator biomass to carrying capacity (Walters and Martell 2005). Models are typically fitted to a set of group biomass and/or catch time series to obtain a robust vulnerability matrix (Heymans et al. 2016). In addition to *vij*, variables affecting *Qij* include prey and predator biomasses *Bi* and *Bj*, feeding times *Ti* and *Tj*, predator handling time *hj*, effective search rate by predator *j* for prey *i* (*aij*), and external forcing factors *Sij* set by the user.

It is noteworthy that unlike in Ecopath, functional group parameter values (including the diet composition matrix) in Ecosim are dynamic and derived from solutions to a system of “master” differential equations like the one above (one equation per functional group).

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Walters, C.J. and Juanes, F. (1993). Recruitment Limitation as a Consequence of Natural Selection for Use of Restricted Feeding Habitats and Predation Risk Taking by Juvenile Fishes. Can J. Fish. Aquat. Sci. 50, 2058-2070. DOI: 10.1139/f93-229**Section C: Ecopath model structure and parameterization**

The basic structure of the current model was previously described in Kumar et al. (2016), while refined versions of all three models first appeared in Surma (2019).

**Fish age structure**

Explicitly including fish age structure and stock-recruitment relationships in ecosystem models is known to improve representation of predator-prey interactions (Hilborn et al. 2017, Walters et al. 2016). In the NBC models, Ainsworth et al. (2008) included two age classes (adult and juvenile) for twelve commercial fish groups: walleye pollock, Pacific herring, Pacific Ocean perch, inshore, piscivorous and planktivorous rockfish; turbot or arrowtooth flounder, Pacific halibut, flatfish (including all local Pleuronectiformes except the two species named above), Pacific cod, sablefish, and lingcod. In the present models, explicit age structure was transferred to EwE 6 for herring and halibut only, with all four local herring stocks (HG, HG 2W, PRD, and CC) forming separate functional groups. Each of these was split into three classes corresponding to ages 0-1 (young of year), 2-3 (juvenile), and 3+ years (adult). While the previous NBC models employed the outdated “split pool” delay difference representation of fish age structure from EwE 5 (Christensen et al. 2005), the models presented in this paper used the fully articulated “multi-stanza” age-structure modelling technique of EwE 6 (Christensen et al. 2008).

Herring catches (*Y*, t⋅km-2) and mortalities (*Z*, year-1) for each age class, as well as adult biomass densities (*B*, t⋅km-2) for each stock, were based on assessment outputs from the Integrated Statistical Catch-at-age Model (*ISCAM*) for the *AM2* (historical) management procedure (DFO 2015, 2016). Absolute biomasses and catches (t) were converted to *B* and *Y* through division by the study area (81,008 km2). *Z* was calculated as the sum of natural mortality *M* and fishing mortality *F* ≈ *Y*/*B*. Adult herring consumption per biomass *Q*/*B* (year-1) was inherited from the NBC models. Ecopath estimated *B* for young-of-year and juvenile herring from adult *B* and *Z*, while *Q*/*B* for non-leading stanzas was calculated from adult *Q*/*B* and the von Bertalanffy growth function (Christensen et al. 2008). Herring parameter values for the latter were based on FishBase (Froese and Pauly 2000). Stanza diet compositions, assumed to be identical across herring stocks, were derived from stomach contents data obtained during field surveys conducted in the study area between March and November (Pakhomov et al. 2017). Herring contributions to predator diets, as well as fleet landings and discards, were allocated to stocks and stanzas in proportion to biomass.

For the remaining ten fish groups, the explicit age structure from the NBC models was removed in this paper for the sake of model simplicity and tractability. This age structure was, however, retained implicitly in diet compositions of the merged functional groups, which were defined as biomass-weighted averages of adult and juvenile diets. Production per biomass (*P*/*B*, year-1) and *Q*/*B* for the aggregated groups was obtained by dividing the total production and consumption, respectively, of adult and juvenile fish classes by their combined biomasses, which also provided *B* for the new groups. Proportions of adults and juveniles in predator diets, as well as in fleet landings and discards, were summed to yield single values for the merged groups.

**Marine mammals**

Goedegebuure et al. (2017) recommended increasing the functional group resolution of predator representations in ecosystem models to accurately reflect trophic interactions. In accordance with this recommendation, the two original groups including all baleen and toothed whales in the NBC models were generally split by species in the present models, except for small odontocetes and orcas (*Orcinus orca*). The former remained as a single group, while the transient and resident orca ecotypes were represented separately due to their dietary specializations and genetic isolation. Likewise, the NBC pinniped functional group was disaggregated into two daughter groups focused on seals and sea lions.

**Gray whales (*Eschrichtius robustus*)**

This species, the only bottom-feeding baleen whale, passes through the model area en route to feeding grounds off Alaska. A small “resident” population apparently does not migrate further north and feeds in British Columbia waters throughout the summer (Heise et al. 2003).

Biomass density for this group is a guesstimate reflecting its moderately common occurrence off Haida Gwaii (Heise et al. 2003). *P/B* and *Q*/*B* were obtained from an EwE model for neighbouring Southeast Alaska (Guénette 2005). Diet composition was derived from the baleen whale group in the NBC models (Ainsworth et al. 2008), whose biomass was dominated by this species, with modifications reflecting the removal of other baleen whales (which feed primarily on zooplankton and fish) from the group.

**Humpback whales (*Megaptera novaeangliae*)**

This species is presently the most locally abundant whale. It is currently undergoing a successful recovery from depletion by 20th-century whaling (Surma and Pitcher 2015).

Biomass density for this group was derived from the Minimum Number Alive (MNA) calculated by Nichol et al. (2009) based on time series of sightings recorded off northern and southern Haida Gwaii. Since the MNA included individuals that only used the model area intermittently (Nichol et al. 2009), half of this value was taken as a likely estimate of the average local abundance. Guénette (2005) used a similar method in an EwE model of Southeast Alaska. The resulting current abundance estimate was converted to biomass using the mean individual mass for this species (Trites and Pauly 1998). *P*/*B* and *Q*/*B* were obtained from a set of Northwest Atlantic EwE models (Araújo and Bundy 2011).

Humpback whale diet composition was largely based on Pauly et al. (1998). Proportions of herring and euphausiids in the modelled diet conform to estimates from recent surveys in Southeast Alaska (Moran et al. 2018, Straley et al. 2018), and closely resemble those in an EwE model of Prince William Sound, Gulf of Alaska (Okey and Pauly 1999). The contributions of fish and euphausiids to humpback whale diets were also modified to agree with trophic levels reported for these whales in the model area (3.5 for NBC and 3.4 for Southeast Alaska, no significant difference between regions) based on stable isotope data (Witteveen et al. 2011). Ecopath estimates group trophic level based on diet composition, so the latter can be adjusted to match an external estimate of the former. Additional aid was provided by a suggestion (Ford et al. 2010) that humpback whale stomach contents records at Coal Harbour whaling station (indicating a diet of ~90% euphausiids) might be biased towards the latter by the fact that most of these catches were made well offshore. The dietary proportion ascribed to “import” (i.e. feeding outside the study area) was estimated from known levels of humpback whale site fidelity to summer feeding grounds (Nichol et al. 2009).

**Minke whales (*Balaenoptera acutorostrata*)**

The smallest of the baleen whales of the Northern Hemisphere, this species is also the only one never to have been hunted in the study area (Nichol and Heise 1992).

Biomass density for this group was derived from an abundance estimate for NBC (Williams and Thomas 2007), converted to biomass using the mean individual mass for minke whales (Trites and Pauly 1998). *P*/*B* and *Q*/*B* for this species were obtained from Araújo and Bundy (2011). In the absence of detailed local data, the diet composition for this group was based on Pauly et al. (1998). The relative importance of herring and other forage fish in the diet is somewhat conjectural and based on qualitative knowledge of minke whale feeding habits in British Columbia waters (Ford 2014).

**Blue whales (*B. musculus*)**

The largest animal in the world, this species now maintains only a small fraction of its historical abundance off British Columbia due to 20th-century industrial whaling (Surma and Pitcher 2015). It is a dietary specialist, feeding almost exclusively on euphausiids.

Biomass density for this group was derived from the number of recent sightings in the model area (Calambokidis et al. 2009), according to which the current local abundance of blue whales was estimated at less than ten individuals. This figure was converted to biomass using the mean individual mass for this species (Trites and Pauly 1998). *P*/*B* and *Q*/*B* were obtained from an EwE model of subtropical Atlantic waters off Northwest Africa (Morissette et al. 2010), as no models of temperate northern ecosystems included blue whales as a distinct functional group. In the absence of detailed local data, the diet composition for this group was based on Pauly et al. (1998). The dietary proportion ascribed to “import” was estimated from the likely membership of locally sighted individuals in the California population (Calambokidis et al. 2009) and the more offshore distribution of this species relative to humpback and fin whales (Gregr and Trites 2001).

**Fin whales (*B. physalus*)**

The second largest animal, this species was once the most locally abundant whale (at least in terms of biomass), but is now only beginning to recover from severe depletion by 20th-century whaling (Surma and Pitcher 2015).

Biomass density for this group was based on an NBC abundance estimate (Williams and Thomas 2007), opportunistic data from the British Columbia Cetacean Sightings Network (COSEWIC 2005) and expert input (Trites 2013, pers. comm.). The estimated local abundance was converted to biomass using the mean individual mass for this species (Trites and Pauly 1998). *P*/*B* and *Q*/*B* were obtained from Araújo and Bundy (2011). Fin whale diet composition was based largely on whaling-era stomach contents records (Flinn et al. 2002). However, based on data from other regions of the North Pacific (Mizroch et al. 2009) and a similar logic to that employed by Ford et al. (2010) for humpback whales, the contribution of fish to the modelled diet was increased slightly relative to that in Flinn et al. (2002) and apportioned among forage fish, Pacific saury and herring. The dietary proportion ascribed to “import” was estimated from seasonality in whaling catch data (Gregr et al. 2000), as well as the more offshore distribution of this species relative to humpback whales (Gregr and Trites 2001).

**Sei whales (*B. borealis*)**

This elusive pelagic species was once quite abundant in the study area (Surma and Pitcher 2015), but is now extremely rare as a result of 20th-century whaling.

Biomass density for this group was based on the number of recent sightings in the study area (DFO 2012), according to which current local abundance of sei whales was estimated as no more than several individuals. This figure was converted to biomass using the mean individual mass for this species (Trites and Pauly 1998). *P*/*B* and *Q*/*B* were obtained from Araújo and Bundy (2011). The diet composition for this species was based on whaling-era stomach contents records (Flinn et al. 2002). The dietary proportion ascribed to “import” was estimated from seasonality in whaling catch data (Gregr et al. 2000), as well as the more offshore distribution of this species relative to humpback and fin whales (Gregr and Trites 2001).

**Sperm whales (*Physeter macrocephalus*)**

The largest toothed whale, this species is now much less abundant locally than it was historically due to 20th-century industrial whaling (Surma and Pitcher 2015). Many of the individuals frequenting the study area are mature males, which are larger and more piscivorous than the females.

Biomass density for this group was based on an abundance estimate by Gregr (2004) and expert input (Trites 2013, Gisborne 2013, pers. comm.). Based on these sources, the current local abundance of sperm whales was estimated to be ~35 individuals, mainly males. This figure was converted to biomass using the sex-specific mean individual masses for this species (Trites and Pauly 1998) and the sex ratio from whaling catch records (Nichol and Heise 1992). *P*/*B* and *Q*/*B* were obtained from Guénette (2005). Sperm whale diet composition was derived primarily from whaling-era stomach contents records (Flinn et al. 2002). The inclusion of large demersal sharks, sablefish, and lingcod in this diet was based on records from California (Kawakami 1980). Minimal (< 0.001) proportions of other demersal fish groups (ratfish, arrowtooth flounder, flatfish, and adult halibut) were added to reflect their possible opportunistic consumption when targeting the species listed above. The dietary proportion ascribed to “import” was estimated from seasonality in whaling catch data (Gregr et al. 2000), as well as the offshore distribution of this species (Gregr and Trites 2001). This proportion also accounted for consumption (Flinn et al. 2002) of species not included in the model (ragfish and Pacific lamprey).

**Resident and transient orcas (*Orcinus orca*)**

Resident orcas feed primarily on Pacific salmon (*Oncorhynchus* spp.) with particular emphasis on Chinook salmon (*O. tshawytscha*), while transient orcas preferentially feed on mammals, especially harbour seals and porpoises (Phocoenidae).

Biomass density for resident orcas originated from an NBC abundance estimate (Williams and Thomas 2007), converted to biomass using the mean individual mass for orcas (Trites and Pauly 1998). In the absence of a local abundance estimate for transient orcas, their *B* was set to 2/3 that of residents to reflect the more wide-ranging movements of the former. *P*/*B* and *Q*/*B* for both ecotypes were obtained from Guénette (2005), while diet compositions were based on field data from British Columbia (Ford et al. 1998) and Southeast Alaska (Matkin et al. 2007). The dietary proportions ascribed to “import” were based on estimated proportions of the habitat of each ecotype lying within the study area.

**Small odontocetes**

This group contains Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), northern right whale dolphin (*Lissodelphis borealis*), Risso’s dolphin (*Grampus griseus*), harbour porpoise (*Phocoena phocoena*) and Dall’s porpoise (*Phocoenoides dalli*). These dolphins and porpoises feed mainly on forage fish and squid, and are hunted by transient orcas.

Biomass density for this group originated from NBC abundance estimates for Pacific white-sided dolphin, harbour porpoise and Dall’s porpoise (Williams and Thomas 2007). These figures were converted to biomass using the mean individual mass for each species (Trites and Pauly 1998) and summed to yield a total biomass. The resulting biomass estimate was then increased to account for unknown abundances of northern right whale dolphin and Risso’s dolphin, as well as white-sided dolphin and porpoise inhabiting the open ocean west of Haida Gwaii. *P*/*B* and *Q*/*B* for this group were obtained from Araújo and Bundy (2011), while the diet composition was derived from Gregr (2004).

**Seals and sea lions**

The single group from the NBC models (Ainsworth et al. 2008) was split into seals (predominantly resident harbour seals *Phoca vitulina*, some migratory northern fur seals *Callorhinus ursinus*) and sea lions (mainly resident Steller sea lions *Eumetopias jubatus*, some migratory California sea lions *Zalophus californianus*) forming two groups of equal biomass, both of which inherited the *P*/*B* and *Q*/*B* values of the parent group. Biomass densities and diet compositions for these groups are based on Gregr (2004).

**Seabirds**

The original NBC seabird group was divided into three daughter groups for piscivorous, teuthivorous, and planktivorous seabirds. Only those species obtaining an approximately known proportion of their annual food consumption from the study area were included. Species biomass densities, derived from data for coastal Alaska (Guénette 2005), were summed to yield a single value per functional group. Diet compositions for all constituent species were based on values for the Gulf of Alaska (Hunt et al. 2000) and proportions of Pacific herring in diets (Bishop et al. 2015). The latter were derived from data collected in Haida Gwaii (Gillespie and Westrheim 1997) and Prince William Sound (Bishop et al. 2015). Dietary proportions of “import” (i.e., feeding outside the study area or on prey not included in the models) were estimated for each species based on visual inspection of the overlap of feeding and breeding ranges with the study area (Peterson 2008). Averages of the proportions of each prey item (including import) across all constituent bird species, weighted by their biomasses, generated functional group diet compositions. Biomass-weighted averaging was also employed to set group *P*/*B* and *Q*/*B* using species-specific values from southeast Alaska (Guénette 2005).

**Piscivorous seabirds**

This group includes the Pelagic and Double-Crested Cormorants (*Phalacrocorax pelagicus* and *P. auritus*), Glaucous-winged Gull (*Larus glaucescens*), Black-legged Kittiwake (*Rissa tridactyla*), Common Murre (*Uria aalge*), Pigeon Guillemot (*Cepphus columba*), Marbled Murrelet (*Brachyramphus marmoratus*), Rhinoceros Auklet (*Cerorhinca monocerata*), and Tufted Puffin (*Fratercula cirrhata*).

**Teuthivorous seabirds**

This group includes the migratory Black-footed and Laysan Albatrosses (*Phoebastria nigripes* and *P. immutabilis*), the resident Northern Fulmar (*Fulmarus glacialis*), the migratory Fork-tailed Storm Petrel (*Oceanodroma furcata*), and the resident Thick-billed Murre (*U. lomvia*).

**Planktivorous seabirds**

This group includes the Ancient Murrelet (*Synthliboramphus antiquus*), Cassin’s Auklet (*Ptychoramphus aleuticus*), Leach’s Storm Petrel (*Oceanodroma leucorhoa*) and Mew Gull (*Larus canus*).

**Elasmobranchs**

The NBC functional group containing all elasmobranchs except Pacific dogfish (*Squalus suckleyi*) was split into four daughter groups: salmon sharks, blue sharks, large demersal sharks, and small demersal elasmobranchs.

**Salmon sharks (*Lamna ditropis*) and blue sharks (*Prionace glauca*)**

Each of these large pelagic predators was allocated its own functional group in the present models. Biomass densities for both species were derived from pelagic shark survey results from the southern portion of the study area (Williams et al. 2010). It was estimated that the pelagic shark assemblage surveyed consists of approximately equal proportions of salmon and blue sharks and that half of these individuals occupy the study area. *P*/*B* and *Q*/*B* for both were derived from Preikshot (2005). Diet compositions for salmon and blue sharks were obtained from Hulbert et al. (2005) and Nakano and Seki (2003), respectively. The proportion of total annual feeding occurring in the model area was estimated from migration data (Weng et al. 2008), with the rest classed as “import.”

**Large demersal sharks**

This group is composed of large ambush predators and scavengers, mainly the bluntnose sixgill shark (*Hexanchus griseus*) and Pacific sleeper shark (*Somniosus pacificus*) but also the broadnose sevengill shark (*Notorynchus cepedianus*). Ecopath parameter values (*B*, *P*/*B*, and *Q*/*B*) for large demersal sharks were obtained from Guénette (2005), with *Q*/*B* adjusted downward to accord better with those for other elasmobranchs. The diet composition for this group was also derived from Guénette (2005).

**Small demersal elasmobranchs**

This group, containing skates (Rajidae) and small demersal sharks, inherited the majority (~90%) of the parent group biomass from the NBC models, reflecting the lower trophic level and higher abundance of skates. Small demersal elasmobranch biomass density was derived from the value for the original group minus the biomass of large sharks (pelagic and demersal). *P*/*B* and *Q*/*B* were directly inherited from the parent group, as was the contribution of this group to sperm whale diet and most of the bycatch in the groundfish trawl fishery (a small proportion of this was allocated to large demersal sharks). The diet composition of small demersal elasmobranchs was also derived from the original group. To account for the removal of the prey items consumed by large sharks, the remaining proportions composing the parent group diet were normalized to a sum of one.

**Teleosts**

**Pacific hake (*Merluccius productus*)**

This species is a semi-pelagic predator of zooplankton and forage fish. While typical of the California Current, its summer migrations extend well into British Columbia waters (Beamish and MacFarlane 1985). This species was excluded from the Hecate Strait and NBC models (Beattie 1999, 2001; Ainsworth et al. 2008) on the assumption that the northern limit of its distribution lie south of the study area. However, most likely because of climate change or decadal shifts in oceanographic conditions, the summer range of Pacific hake has shifted to encompass Haida Gwaii waters, and this species was recently found to spawn off the west coast of Vancouver Island (McFarlane et al. 2000), leading to the decision to restore it to the present models.

Since no hake biomass estimates are available for the study area, the biomass was calculated based on the following assumptions:

• Pacific hake distribution stretches from 55° N to 35.5° N (Stewart and Hamel 2010)

• latitudinal range encompasses 90% of all Pacific hake individuals

• latitudinal distribution of hake *B* approximates a standard normal curve with μ ~ 45° N

Based on the last assumption of a normal latitudinal distribution, the area under the curve (biomass density) was calculated for the study area. Since most Pacific hake reside in British Columbia for only six months, this value was halved to set the biomass density.

Hake *P*/*B*, *P*/*Q*, and diet composition were based on a southern British Columbia shelf Ecopath model (Pitcher 1996) but modified substantially for the sake of mass balance.

**Pacific saury (*Cololabis saira*)**

This species is a large, pelagic forage fish. It feeds on copepods and other zooplankton, and in turn is prey to many fishes, cetaceans and seabirds. *P*/*B*, *Q*/*B*, and *EE* values as well as diet composition for saury were obtained from an Ecopath model of the Alaska Gyre (Livingston 1996). Ecopath estimated biomass density based on the three known parameter values.

**Benthos**

The epifaunal invertebrate functional group from the NBC models was divided into five new groups: sea urchins, other grazers, epifaunal filter-feeders, octopus, and epifaunal carnivores. *P*/*B,* *Q*/*B*, *EE*, and diet compositions for these groups stemmed from a Central Puget Sound EwE model (Harvey et al. 2012) and were occasionally modified to improve agreement with parent group values. Ecopath then estimated *B* for all groups from known parameter values. Contributions of epifaunal invertebrates to consumer diets, as well as to fleet landings and discards, were allocated to daughter groups according to the Central Puget Sound model.

**Sea urchins**

*EE* was raised from 0.8 to 0.9 to accord better with the value for the NBC epifaunal invertebrate group (0.98).

**Other grazers**

This group includes all herbivorous benthic invertebrates other than sea urchins, mainly molluscs (gastropods, chitons) and small crustaceans (isopods, amphipods etc.). *EE* was raised from 0.8 to 0.9 to accord better with the value for the NBC epifaunal invertebrate group (0.98).

**Epifaunal filter-feeders**

This group comprises those sedentary or sessile invertebrates (mainly bivalves, barnacles, and tunicates, but also bryozoans, brachiopods, crinoids, sabellid polychaetes etc.) possessing specialized structures to filter phytoplankton and detritus. *P*/*B*, *Q*/*B* and *EE* values as well as diet composition for this group were obtained from biomass-weighted averages of the mussel, geoduck, barnacle, and tunicate values in the Central Puget Sound EwE model (Harvey et al. 2012).

**Octopus**

This group includes the East Pacific red octopus (*Octopus rubescens*) and the giant Pacific octopus (*Enteroctopus dofleini*).

**Epifaunal carnivores**

This group includes carnivorous benthic invertebrates except octopus and crabs (mainly sea stars and predatory gastropods). *P*/*B*, *Q*/*B*, *EE*, and diet composition for this group were obtained from biomass-weighted averages of values for the sea star and predatory gastropod groups in the Central Puget Sound EwE model (Harvey et al. 2012), with *Q*/*B* raised slightly to account for possibly underestimated sea star *Q*/*B* (Harvey et al. 2010).

**Zooplankton**

Four new groups of this type (i.e., macrozooplankton, amphipods, small gelatinous zooplankton, and microzooplankton) were added to the present models. *P*/*B*, *Q*/*B*, *EE*, and diet compositions for these groups were based on the Central Puget Sound model (Harvey et al. 2012), as were their contributions to consumer diets. Ecopath then estimated *B* for all four groups based on known parameter values.

**Macrozooplankton**

This group includes all large, non-gelatinous zooplankton except euphausiids and amphipods (mainly pelagic shrimp, mysids, and chaetognaths).

**Amphipods**

This group comprises pelagic carnivores and herbivores. The *P*/*B*, *Q*/*B,* *EE*, and diet composition for this group were obtained from the macrozooplankton group in the Central Puget Sound EwE model (Harvey et al. 2012).

**Small gelatinous zooplankton**

This group comprises small zooplankton whose bodies have high water content and often no exoskeleton (pteropods, pelagic tunicates, ctenophores, small hydromedusae, etc.).

**Microzooplankton**

This group includes all heterotrophic protists (e.g. ciliates, foraminiferans, radiolarians, some dinoflagellates, etc.), as well as rotifers and other microscopic animals. All its members feed on phytoplankton and detritus.

**Benthic producers**

The macrophyte functional group from the NBC models was split into three groups: eelgrass, kelps, and benthic macroalgae. *P*/*B* and *EE* for these groups were taken from a Central Puget Sound EwE model (Harvey et al. 2012) and occasionally modified for agreement with parent group values, as were their contributions to consumer diets. Ecopath then estimated *B* for all three groups from known parameter values.

**Kelps**

This group comprises the canopy-forming giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*), ecosystem engineers that define North Pacific kelp forests. *P*/*B* for this group was set to be identical with the value for benthic macroalgae to accord better with the value for the original NBC macrophyte group.

**Benthic macroalgae**

This group includes all macroalgae other than the canopy-forming kelps, including brown, red, and green algae (Phaeophyceae, Rhodophyta and Chlorophyta).

**Benthic microalgae**

*P*/*B* and *EE* for this group (comprising benthic diatoms) were based on the Central Puget Sound model (Harvey et al. 2012), as were its contributions to consumer diets. Ecopath estimated *B* from known parameter values.

**Historical and current model parameterization**

For functional groups inherited from the NBC models, the present historical models retained Ecopath parameter values from their NBC parents. For new groups other than herring, pinnipeds, and whales, historical parameter values were set equal to current ones. Herring *B* and *Z* for 1950 were calculated from stock assessment outputs (DFO 2016). In the absence of such data for 1900 as well as the lack of evidence of stock depletion, such as declining catches in the study area (Hourston 1978), between 1900 and 1950, herring *B* and *Z* for 1900 were assumed equal to 1950 values and modified as required to achieve mass balance. Seal and sea lion *B* for 1900 and 1950 were each set to half the values for the parent NBC pinniped group. The ratios of pinniped *P*/*B* across the three NBC models were applied to the current model values to obtain *P*/*B* for the present 1950 and 1900 models. Historical landings and discards for all groups except whales, along with 1900 and 1950 fleet structures, were inherited from the NBC models. In addition to fleets included in its NBC counterpart, the new current model contains a commercial hake fleet and four Haida fleets (herring spawn-on-kelp, salmon, razor clam, and seaweed).

Historical humpback, blue, fin, sei, and sperm whale *B* was derived from updated surplus production models based on Surma and Pitcher (2015). For these species, *P*/*B* and *Q*/*B* were assumed equal across all models, except for *Q*/*B* in 1900. The latter was set to 0.88 of the 1950 valueto reflect mature, unexploited populations with lower metabolic needs, as in the NBC models (Ainsworth et al. 2008). Gray whale and orca *B* for 1950 was taken from abundance time series listed in section D. Corresponding 1900 biomasses were assumed equal to 1950 and 2010 values for gray whales and orcas, respectively, based on qualitative knowledge of their local population trajectories (Ford 2014).

Input parameter values were modified as required to meet the basic EwE requirement of mass balance (Christensen and Walters 2004). Historical model diet compositions were generated using a plugin that reintroduced lost EwE 5 functionality to a custom version of EwE 6 (Buszowski and Steenbeek 2017). This plugin assumed constant electivity (i.e., consumer preference for a given food) across models and combined this electivity with relative prey biomasses to calculate historical consumer diets. The 1900 and 1950 models were balanced iteratively, with biomasses from preliminary models, balanced for current diets, serving as input for historical diet calculations, outputs of which provided input for final model balancing.

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**Table D1:** Basic parameters of the 1900 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Sea otters | 4.02 | 0.0001 |  | 0.13 | 101.50 | **0.03** | **0.001** |
| Gray whales | 3.14 | 0.0116 |  | 0.05 | 5.30 | **0.27** | **0.009** |
| Humpback whales | 3.99 | 0.3761 |  | 0.06 | 4.05 | **0.00** | **0.015** |
| Minke whales | 3.99 | 0.0315 |  | 0.09 | 6.30 | **0.15** | **0.014** |
| Blue whales | 3.80 | 0.7926 |  | 0.04 | 3.08 | **0.00** | **0.013** |
| Fin whales | 3.97 | 1.8803 |  | 0.05 | 3.61 | **0.00** | **0.014** |
| Sei whales | 3.90 | 0.1067 |  | 0.06 | 4.58 | **0.01** | **0.013** |
| Sperm whales | 5.30 | 0.8216 |  | 0.05 | 4.49 | **0.00** | **0.011** |
| Resident orcas | 5.22 | 0.0036 |  | 0.05 | 7.70 | **0.00** | **0.006** |
| Transient orcas | 5.68 | 0.0024 |  | 0.05 | 7.70 | **0.00** | **0.006** |
| Small odontocetes | 4.85 | 0.1000 |  | 0.15 | 16.00 | **0.17** | **0.009** |
| Seals | 4.82 | 0.0345 |  | 0.28 | 15.10 | **0.37** | **0.019** |
| Sea lions | 4.80 | 0.0345 |  | 0.28 | 15.10 | **0.32** | **0.019** |
| Piscivorous seabirds | 4.48 | 0.0050 |  | 0.38 | 69.28 | **0.00** | **0.005** |
| Teuthivorous seabirds | 4.61 | 0.0050 |  | 0.36 | 75.19 | **0.02** | **0.005** |
| Planktivorous seabirds | 3.56 | 0.0050 |  | 0.40 | 96.05 | **0.03** | **0.004** |
| Transient salmon | 3.94 | 0.8400 |  | 2.48 | 3.72 | **0.11** | **0.667** |
| Coho salmon | 4.66 | 0.1600 |  | 2.76 | **10.22** | **0.08** | 0.270 |
| Chinook salmon | 4.21 | 0.1600 |  | 2.16 | **10.29** | **0.16** | 0.210 |
| Small squid | 3.68 | 3.1400 |  | 9.00 | 34.68 | **0.95** | **0.260** |
| Large squid | 4.34 | 8.0000 |  | 10.00 | 34.68 | **0.96** | **0.288** |
| Octopus | 4.05 | **0.1900** |  | 0.86 | 2.50 | 0.27 | **0.344** |
| Ratfish | 4.05 | 0.1830 |  | 0.20 | 1.40 | **0.13** | **0.142** |
| Pacific dogfish | 4.50 | 0.6000 |  | 0.20 | 3.33 | **0.38** | **0.060** |
| Walleye pollock | 3.87 | 1.4050 |  | 0.20 | 4.46 | **0.84** | **0.046** |
| Forage fish | 3.49 | 30.0000 |  | 2.00 | 6.61 | **0.97** | **0.303** |
| Pacific hake | 4.04 | 0.8200 |  | 0.55 | **2.75** | **0.16** | 0.200 |
| Pacific saury | 3.81 | **32.7520** |  | 2.00 | 6.61 | 0.95 | **0.303** |
| Eulachon | 3.58 | 5.5000 |  | 2.00 | 6.61 | **0.97** | **0.303** |

**Table D1 (continued):** Basic parameters of the 1900 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| HG herring age 0-1 years | 3.62 | 0.0503 | 1.230 |  | 21.43 | **0.25** | **0.057** |
| HG herring age 1-3 years | 3.85 | 0.4935 | 0.995 |  | 9.20 | **0.24** | **0.108** |
| HG herring age 3+ years | 4.03 | 0.3250 | 1.057 |  | 5.84 | **0.27** | **0.181** |
| HG 2W herring age 0- years | 3.62 | 0.0007 | 1.230 |  | 23.67 | **0.25** | **0.052** |
| HG 2W herring age 1-3 years | 3.85 | 0.0118 | 0.452 |  | 9.56 | **0.32** | **0.047** |
| HG 2W herring age 3+ years | 4.03 | 0.0384 | 0.452 |  | 5.84 | **0.32** | **0.077** |
| PRD herring age 0-1 years | 3.62 | 0.0767 | 1.230 |  | 22.24 | **0.19** | **0.055** |
| PRD herring age 1-3 years | 3.85 | 1.1090 | 0.630 |  | 9.16 | **0.22** | **0.069** |
| PRD herring age 3+ years | 4.03 | 1.5740 | 0.758 |  | 5.84 | **0.29** | **0.130** |
| CC herring age 0-1 years | 3.62 | 0.0435 | 1.230 |  | 22.87 | **0.31** | **0.054** |
| CC herring age 1-3 years | 3.85 | 0.7117 | 0.520 |  | 9.30 | **0.25** | **0.056** |
| CC herring age 3+ years | 4.03 | 1.5087 | 0.600 |  | 5.84 | **0.26** | **0.103** |
| Pacific Ocean perch | 3.78 | 1.1640 |  | 0.24 | 4.35 | **0.09** | **0.056** |
| Inshore rockfish | 4.20 | 0.0800 |  | 0.18 | 5.54 | **0.06** | **0.033** |
| Piscivorous rockfish | 4.27 | 0.7500 |  | 0.06 | 1.27 | **0.98** | **0.047** |
| Planktivorous rockfish | 4.03 | 1.4200 |  | 0.10 | 2.25 | **0.18** | **0.044** |
| Arrowtooth flounder | 4.74 | 1.7000 |  | 0.30 | 2.01 | **0.25** | **0.150** |
| Flatfish | 3.43 | 2.6200 |  | 0.33 | 5.50 | **0.70** | **0.061** |
| Juvenile halibut | 4.61 | 0.0898 | 0.550 |  | 4.60 | **0.60** | **0.120** |
| Adult halibut | 4.69 | 0.6080 | 0.220 |  | 1.70 | **0.23** | **0.129** |
| Pacific cod | 4.17 | 1.7500 |  | 0.45 | 2.52 | **0.72** | **0.179** |
| Sablefish | 4.12 | 0.7100 |  | 0.20 | 4.23 | **0.41** | **0.047** |
| Lingcod | 4.71 | 0.1240 |  | 0.30 | 2.85 | **0.79** | **0.107** |

**Table D1 (continued):** Basic parameters of the 1900 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Shallowwater benthic fish | 4.04 | 5.4000 |  | 0.45 | 2.10 | **0.94** | **0.214** |
| Small demersal elasmobranchs | 4.21 | 0.2000 |  | 0.31 | 1.20 | **0.98** | **0.258** |
| Large demersal sharks | 4.98 | 0.0500 |  | 0.13 | 1.24 | **0.60** | **0.105** |
| Salmon sharks | 4.99 | 0.0200 |  | 0.20 | 1.20 | **0.00** | **0.167** |
| Blue sharks | 4.91 | 0.0200 |  | 0.17 | 0.80 | **0.00** | **0.213** |
| Large crabs | 3.44 | 0.3900 |  | 1.50 | 5.00 | **0.28** | **0.300** |
| Small crabs | 3.41 | 1.4600 |  | 3.50 | 14.00 | **0.65** | **0.250** |
| Commercial shrimp | 3.42 | 0.0470 |  | 5.70 | **22.80** | **0.91** | 0.250 |
| Sea urchins | 2.00 | **0.0097** |  | 0.50 | 10.88 | 0.90 | **0.046** |
| Other grazers | 2.00 | **27.5016** |  | 0.75 | 8.86 | 0.90 | **0.085** |
| Epifaunal filter-feeders | 2.95 | **21.1020** |  | 1.00 | 4.50 | 0.90 | **0.222** |
| Epifaunal carnivores | 3.42 | **3.1262** |  | 0.85 | 7.50 | 0.90 | **0.113** |
| Infaunal carnivorous invertebrates | 2.06 | 13.2451 |  | 2.00 | **22.22** | **0.22** | 0.090 |
| Infaunal detritivorous invertebrates | 2.00 | 34.3051 |  | 1.30 | 14.40 | **0.53** | **0.090** |
| Carnivorous jellyfish | 2.68 | 6.0000 |  | 18.00 | 60.00 | **0.71** | **0.300** |
| Macrozooplankton | 3.18 | **4.0768** |  | 7.00 | 35.00 | 0.90 | **0.200** |
| Amphipods | 3.08 | **1.2209** |  | 7.00 | 35.00 | 0.90 | **0.200** |
| Euphausiids | 2.80 | 33.0000 |  | 6.00 | 24.82 | **0.97** | **0.242** |
| Copepods | 2.57 | 24.0000 |  | 27.00 | **100.00** | **0.95** | 0.270 |
| Small gelatinous zooplankton | 3.08 | **15.8389** |  | 9.00 | 30.00 | 0.80 | **0.300** |
| Microzooplankton | 2.33 | **62.1988** |  | 100.00 | 285.71 | 0.99 | **0.350** |
| Corals and sponges | 2.00 | 1.9286 |  | 0.01 | 2.00 | **0.00** | **0.005** |
| Eelgrass | 1.00 | **3.5247** |  | 24.54 | N/A | 0.40 | N/A |
| Kelps | 1.00 | **0.0011** |  | 15.00 | N/A | 0.40 | N/A |
| Benthic macroalgae | 1.00 | **10.3850** |  | 15.00 | N/A | 0.40 | N/A |

**Table D1 (continued):** Basic parameters of the 1900 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Benthic microalgae | 1.00 | **2.5340** |  | 100.00 | N/A | 0.50 | N/A |
| Phytoplankton | 1.00 | 76.0000 |  | 200.00 | N/A | **0.99** | N/A |
| Detritus | 1.00 | **10.0000** |  | N/A | N/A | **0.24** | N/A |

**Table D2:** Basic parameters of the 1950 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Sea otters | 3.50 | 0.0001 |  | 0.13 | 101.50 | **0.00** | **0.001** |
| Gray whales | 3.04 | 0.0116 |  | 0.05 | 5.30 | **0.04** | **0.009** |
| Humpback whales | 3.76 | 0.0301 |  | 0.06 | 4.60 | **0.67** | **0.013** |
| Minke whales | 3.77 | 0.0315 |  | 0.09 | 6.30 | **0.02** | **0.014** |
| Blue whales | 3.43 | 0.0660 |  | 0.04 | 3.50 | **0.38** | **0.011** |
| Fin whales | 3.55 | 0.2402 |  | 0.05 | 4.10 | **0.50** | **0.012** |
| Sei whales | 3.47 | 0.0236 |  | 0.06 | 5.20 | **0.42** | **0.012** |
| Sperm whales | 4.18 | 0.0463 |  | 0.05 | 5.10 | **0.70** | **0.010** |
| Resident orcas | 4.82 | 0.0015 |  | 0.05 | 7.70 | **0.50** | **0.006** |
| Transient orcas | 5.22 | 0.0004 |  | 0.05 | 7.70 | **0.00** | **0.006** |
| Small odontocetes | 4.27 | 0.1000 |  | 0.15 | 16.00 | **0.02** | **0.009** |
| Seals | 4.33 | 0.0650 |  | 0.17 | 15.10 | **0.28** | **0.011** |
| Sea lions | 4.33 | 0.0650 |  | 0.17 | 15.10 | **0.77** | **0.011** |
| Piscivorous seabirds | 4.16 | 0.0019 |  | 0.38 | 69.28 | **0.01** | **0.005** |
| Teuthivorous seabirds | 4.02 | 0.0002 |  | 0.36 | 75.19 | **0.05** | **0.005** |
| Planktivorous seabirds | 3.38 | 0.0002 |  | 0.40 | 96.05 | **0.06** | **0.004** |
| Transient salmon | 3.41 | 0.5000 |  | 2.48 | 8.33 | **0.69** | **0.298** |
| Coho salmon | 3.89 | 0.1000 |  | 2.76 | **13.80** | **0.66** | 0.200 |
| Chinook salmon | 3.83 | 0.0900 |  | 2.16 | **10.80** | **0.52** | 0.200 |
| Small squid | 3.05 | 1.0900 |  | 6.02 | 34.68 | **0.62** | **0.174** |
| Large squid | 3.10 | 0.7650 |  | 6.02 | 34.68 | **0.86** | **0.174** |
| Octopus | 3.72 | **0.0454** |  | 0.86 | 2.50 | 0.90 | **0.344** |
| Ratfish | 3.60 | 0.5170 |  | 0.10 | 1.40 | **0.51** | **0.071** |
| Pacific dogfish | 3.79 | 0.4170 |  | 0.15 | 2.72 | **0.92** | **0.055** |

**Table D2 (continued):** Basic parameters of the 1950 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Walleye pollock | 3.56 | 1.5100 |  | 0.88 | 2.28 | **0.50** | **0.386** |
| Forage fish | 3.09 | 10.0000 |  | 1.74 | 8.40 | **0.89** | **0.207** |
| Pacific hake | 3.75 | 0.8200 |  | 0.55 | **2.75** | **0.35** | 0.200 |
| Pacific saury | 3.44 | **1.1697** |  | 1.60 | 7.90 | 0.95 | **0.203** |
| Eulachon | 3.17 | 1.8930 |  | 1.43 | 8.40 | **0.84** | **0.171** |
| HG herring age 0-1 years | 3.27 | 0.0202 | 1.230 |  | 22.27 | **0.67** | **0.055** |
| HG herring age 1-3 years | 3.49 | 0.1982 | 0.995 |  | 9.56 | **0.66** | **0.104** |
| HG herring age 3+ years | 3.59 | 0.2022 | 0.750 |  | 5.84 | **0.88** | **0.128** |
| HG 2W herring age 0-1 years | 3.27 | 0.0005 | 1.230 |  | 24.40 | **0.72** | **0.050** |
| HG 2W herring age 1-3 years | 3.49 | 0.0084 | 0.452 |  | 9.85 | **0.74** | **0.046** |
| HG 2W herring age 3+ years | 3.59 | 0.0384 | 0.350 |  | 5.84 | **0.90** | **0.060** |
| PRD herring age 0-1 years | 3.27 | 0.0767 | 1.230 |  | 22.24 | **0.49** | **0.055** |
| PRD herring age 1-3 years | 3.49 | 1.1090 | 0.630 |  | 9.16 | **0.89** | **0.069** |
| PRD herring age 3+ years | 3.59 | 1.5740 | 0.758 |  | 5.84 | **0.65** | **0.130** |
| CC herring age 0-1 years | 3.27 | 0.0669 | 1.230 |  | 22.21 | **0.73** | **0.055** |
| CC herring age 1-3 years | 3.49 | 1.0279 | 0.575 |  | 9.09 | **0.92** | **0.063** |
| CC herring age 3+ years | 3.59 | 1.5087 | 0.767 |  | 5.84 | **0.51** | **0.131** |
| Pacific Ocean perch | 3.39 | 1.0550 |  | 0.14 | 2.25 | **0.41** | **0.062** |
| Inshore rockfish | 3.75 | 0.0950 |  | 0.19 | 5.69 | **0.49** | **0.033** |
| Piscivorous rockfish | 3.41 | 0.5490 |  | 0.06 | 1.27 | **0.60** | **0.047** |
| Planktivorous rockfish | 3.55 | 1.4025 |  | 0.10 | 2.25 | **0.62** | **0.044** |
| Arrowtooth flounder | 3.92 | 1.7480 |  | 0.26 | 2.01 | **0.50** | **0.131** |
| Flatfish | 3.23 | 0.9000 |  | 0.63 | 5.19 | **0.97** | **0.121** |
| Juvenile halibut | 3.95 | 0.2075 | 0.500 |  | 2.36 | **0.71** | **0.212** |

**Table D2 (continued):** Basic parameters of the 1950 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Adult halibut | 4.02 | 0.4290 | 0.450 |  | 1.10 | **0.57** | **0.411** |
| Pacific cod | 3.53 | 0.5330 |  | 1.55 | 5.24 | **0.64** | **0.297** |
| Sablefish | 3.67 | 0.8380 |  | 0.38 | 4.73 | **0.63** | **0.079** |
| Lingcod | 4.34 | 0.1820 |  | 1.06 | 3.21 | **0.44** | **0.330** |
| Shallowwater benthic fish | 3.52 | 0.5090 |  | 1.50 | 5.26 | **0.71** | **0.285** |
| Small demersal elasmobranchs | 3.63 | 0.3000 |  | 0.32 | 1.24 | **0.47** | **0.258** |
| Large demersal sharks | 3.94 | 0.0250 |  | 0.13 | 1.24 | **0.14** | **0.105** |
| Salmon sharks | 4.51 | 0.0200 |  | 0.20 | 1.20 | **0.00** | **0.167** |
| Blue sharks | 4.16 | 0.0200 |  | 0.17 | 0.80 | **0.00** | **0.213** |
| Large crabs | 2.94 | 0.5060 |  | 1.50 | 5.00 | **0.52** | **0.300** |
| Small crabs | 3.05 | 0.5990 |  | 3.50 | 8.75 | **0.70** | **0.400** |
| Commercial shrimp | 2.83 | 0.1500 |  | 11.48 | **45.92** | **0.38** | 0.250 |
| Sea urchins | 2.00 | **0.0212** |  | 0.50 | 10.88 | 0.90 | **0.046** |
| Other grazers | 2.00 | **6.7144** |  | 0.75 | 8.86 | 0.90 | **0.085** |
| Epifaunal filter-feeders | 2.32 | **5.8860** |  | 1.00 | 4.50 | 0.80 | **0.222** |
| Epifaunal carnivores | 3.11 | **1.0642** |  | 0.85 | 7.50 | 0.90 | **0.113** |
| Infaunal carnivorous invertebrates | 2.06 | 12.2450 |  | 2.00 | **22.22** | **0.19** | 0.090 |
| Infaunal detritivorous invertebrates | 2.00 | 34.3050 |  | 2.85 | 14.99 | **0.24** | **0.190** |
| Carnivorous jellyfish | 2.21 | 3.0000 |  | 18.00 | 60.00 | **0.69** | **0.300** |
| Macrozooplankton | 2.79 | **3.1515** |  | 7.00 | 35.00 | 0.80 | **0.200** |
| Amphipods | 2.42 | **2.6209** |  | 7.00 | 35.00 | 0.80 | **0.200** |
| Euphausiids | 2.44 | 12.5000 |  | 6.60 | 24.82 | **0.97** | **0.266** |
| Copepods | 2.17 | 8.0000 |  | 27.00 | **90.00** | **0.98** | 0.300 |
| Small gelatinous zooplankton | 2.62 | **4.4849** |  | 9.00 | 30.00 | 0.80 | **0.300** |
| Microzooplankton | 2.09 | **4.0171** |  | 100.00 | 285.71 | 0.80 | **0.350** |
| Corals and sponges | 2.00 | 1.9290 |  | 0.01 | 2.00 | **0.00** | **0.005** |

**Table D2 (continued):** Basic parameters of the 1950 Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Eelgrass | 1.00 | **0.6871** |  | 24.54 | N/A | 0.40 | N/A |
| Kelps | 1.00 | **0.0070** |  | 15.00 | N/A | 0.40 | N/A |
| Benthic macroalgae | 1.00 | **2.0929** |  | 15.00 | N/A | 0.40 | N/A |
| Benthic microalgae | 1.00 | **0.5007** |  | 100.00 | N/A | 0.50 | N/A |
| Phytoplankton | 1.00 | 15.4060 |  | 178.50 | N/A | **0.66** | N/A |
| Detritus | 1.00 | **10.0000** |  | N/A | N/A | **0.60** | N/A |

**Table D3:** Basic parameters of the current Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Sea otters | 3.18 | 0.0001 |  | 0.13 | 101.50 | **0.01** | **0.001** |
| Gray whales | 3.03 | 0.0300 |  | 0.05 | 5.30 | **0.15** | **0.009** |
| Humpback whales | 3.57 | 0.1900 |  | 0.06 | 4.60 | **0.00** | **0.013** |
| Minke whales | 3.57 | 0.0315 |  | 0.09 | 6.30 | **0.08** | **0.014** |
| Blue whales | 3.32 | 0.0043 |  | 0.04 | 3.50 | **0.00** | **0.011** |
| Fin whales | 3.43 | 0.1374 |  | 0.05 | 4.10 | **0.00** | **0.012** |
| Sei whales | 3.37 | 0.0017 |  | 0.06 | 5.20 | **0.00** | **0.012** |
| Sperm whales | 4.08 | 0.0110 |  | 0.05 | 5.10 | **0.00** | **0.010** |
| Resident orcas | 4.70 | 0.0036 |  | 0.05 | 7.70 | **0.00** | **0.006** |
| Transient orcas | 5.09 | 0.0024 |  | 0.05 | 7.70 | **0.00** | **0.006** |
| Small odontocetes | 4.11 | 0.1000 |  | 0.15 | 16.00 | **0.09** | **0.009** |
| Seals | 4.21 | 0.1250 |  | 0.17 | 15.10 | **0.14** | **0.011** |
| Sea lions | 4.19 | 0.1250 |  | 0.17 | 15.10 | **0.09** | **0.011** |
| Piscivorous seabirds | 4.01 | 0.0019 |  | 0.38 | 69.28 | **0.01** | **0.005** |
| Teuthivorous seabirds | 3.90 | 0.0002 |  | 0.36 | 75.19 | **0.10** | **0.005** |
| Planktivorous seabirds | 3.31 | 0.0002 |  | 0.40 | 96.05 | **0.12** | **0.004** |
| Transient salmon | 3.31 | 0.2080 |  | 2.48 | 8.33 | **0.81** | **0.298** |
| Coho salmon | 3.78 | 0.0240 |  | 2.76 | **13.80** | **0.68** | 0.200 |
| Chinook salmon | 3.70 | 0.0340 |  | 2.16 | **10.80** | **0.94** | 0.200 |
| Small squid | 2.93 | 1.0898 |  | 6.02 | 34.68 | **0.70** | **0.174** |

**Table D3 (continued):** Basic parameters of the current Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Large squid | 3.01 | 0.7652 |  | 6.02 | 34.68 | **0.95** | **0.174** |
| Octopus | 3.68 | **0.1899** |  | 0.86 | 2.50 | 0.90 | **0.344** |
| Ratfish | 3.49 | 0.5170 |  | 0.10 | 1.40 | **0.79** | **0.071** |
| Pacific dogfish | 3.68 | 0.9090 |  | 0.10 | 2.72 | **0.74** | **0.036** |
| Walleye pollock | 3.43 | 0.4910 |  | 0.48 | 2.28 | **0.96** | **0.209** |
| Forage fish | 2.95 | 8.4780 |  | 1.60 | 8.40 | **0.99** | **0.191** |
| Pacific hake | 3.64 | 0.8200 |  | 0.55 | **2.75** | **0.97** | 0.200 |
| Pacific saury | 3.30 | **1.2810** |  | 1.60 | 7.90 | 0.95 | **0.203** |
| Eulachon | 3.11 | 1.6600 |  | 1.43 | 8.40 | **0.85** | **0.171** |
| HG herring age 0-1 years | 3.17 | 0.0483 | 1.230 |  | 21.43 | **0.97** | **0.057** |
| HG herring age 1-3 years | 3.36 | 0.4745 | 0.995 |  | 9.20 | **0.96** | **0.108** |
| HG herring age 3+ years | 3.49 | 0.3125 | 1.057 |  | 5.84 | **0.99** | **0.181** |
| HG 2W herring age 0-1 years | 3.17 | 0.0002 | 1.230 |  | 23.67 | **0.98** | **0.052** |
| HG 2W herring age 1-3 years | 3.36 | 0.0028 | 0.452 |  | 9.56 | **0.97** | **0.047** |
| HG 2W herring age 3+ years | 3.49 | 0.0091 | 0.452 |  | 5.84 | **0.95** | **0.077** |
| PRD herring age 0-1 years | 3.17 | 0.0222 | 1.230 |  | 22.31 | **0.93** | **0.055** |
| PRD herring age 1-3 years | 3.36 | 0.3201 | 0.630 |  | 9.18 | **0.82** | **0.069** |
| PRD herring age 3+ years | 3.49 | 0.4688 | 0.740 |  | 5.84 | **0.93** | **0.127** |
| CC herring age 0-1 years | 3.17 | 0.0281 | 1.230 |  | 22.87 | **0.97** | **0.054** |
| CC herring age 1-3 years | 3.36 | 0.4600 | 0.520 |  | 9.30 | **0.88** | **0.056** |
| CC herring age 3+ years | 3.49 | 0.9752 | 0.600 |  | 5.84 | **0.91** | **0.103** |
| Pacific Ocean perch | 3.30 | 0.6230 |  | 0.20 | 2.25 | **0.92** | **0.087** |
| Inshore rockfish | 3.59 | 0.1000 |  | 0.19 | 5.69 | **0.83** | **0.033** |
| Piscivorous rockfish | 3.37 | 0.6600 |  | 0.06 | 1.27 | **0.89** | **0.047** |
| Planktivorous rockfish | 3.45 | 1.3430 |  | 0.10 | 2.25 | **0.98** | **0.044** |

**Table D3 (continued):** Basic parameters of the current Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Arrowtooth flounder | 3.79 | 1.7480 |  | 0.23 | 2.01 | **1.00** | **0.116** |
| Flatfish | 3.20 | 0.4950 |  | 1.46 | 5.19 | **0.70** | **0.282** |
| Juvenile halibut | 3.88 | 0.3563 | 0.500 |  | 2.43 | **0.98** | **0.205** |
| Adult halibut | 3.93 | 0.9000 | 0.400 |  | 1.10 | **0.55** | **0.365** |
| Pacific cod | 3.41 | 0.2520 |  | 1.55 | 5.24 | **0.98** | **0.297** |
| Sablefish | 3.54 | 0.3880 |  | 0.38 | 4.73 | **0.86** | **0.079** |
| Lingcod | 4.24 | 0.0700 |  | 0.98 | 3.30 | **0.87** | **0.296** |
| Shallowwater benthic fish | 3.46 | 0.5090 |  | 1.50 | 5.26 | **0.99** | **0.285** |
| Small demersal elasmobranchs | 3.62 | 0.3000 |  | 0.32 | 1.24 | **0.96** | **0.258** |
| Large demersal sharks | 3.89 | 0.0250 |  | 0.13 | 1.24 | **0.05** | **0.105** |
| Salmon sharks | 4.36 | 0.0200 |  | 0.20 | 1.20 | **0.00** | **0.167** |
| Blue sharks | 3.99 | 0.0200 |  | 0.17 | 0.80 | **0.00** | **0.213** |
| Large crabs | 2.97 | 0.4560 |  | 1.50 | 5.00 | **0.96** | **0.300** |
| Small crabs | 3.05 | 0.6495 |  | 3.50 | 14.00 | **0.77** | **0.250** |
| Commercial shrimp | 2.72 | 0.2000 |  | 11.48 | **45.90** | **0.40** | 0.250 |
| Sea urchins | 2.00 | **0.2188** |  | 0.50 | 10.88 | 0.90 | **0.046** |
| Other grazers | 2.00 | **11.4154** |  | 0.75 | 8.86 | 0.90 | **0.085** |
| Epifaunal filter-feeders | 2.21 | **9.6832** |  | 1.00 | 4.50 | 0.80 | **0.222** |
| Epifaunal carnivores | 3.08 | **1.6534** |  | 0.85 | 7.50 | 0.90 | **0.113** |
| Infaunal carnivorous invertebrates | 2.06 | 13.2451 |  | 2.00 | **22.22** | **0.20** | 0.090 |
| Infaunal detritivorous invertebrates | 2.00 | 34.3051 |  | 1.35 | 14.99 | **0.54** | **0.090** |
| Carnivorous jellyfish | 2.17 | 3.0000 |  | 18.00 | 60.00 | **0.70** | **0.300** |
| Macrozooplankton | 2.64 | **1.6442** |  | 7.00 | 35.00 | 0.80 | **0.200** |
| Amphipods | 2.27 | **1.0447** |  | 7.00 | 35.00 | 0.80 | **0.200** |
| Euphausiids | 2.33 | 10.0000 |  | 6.60 | 24.82 | **0.90** | **0.266** |
| Copepods | 2.11 | 5.2500 |  | 27.00 | **90.00** | **0.93** | 0.300 |

**Table D3 (continued):** Basic parameters of the current Ecopath model. Bold face indicates values estimated by Ecopath.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Functional group** | **TL** | **B**  **(t⋅km-²)** | **Z**  **(yr-1)** | **P/B (yr-1)** | **Q/B (yr-1)** | **EE** | **P/Q (yr-1)** |
| Small gelatinous zooplankton | 2.47 | **1.4661** |  | 9.00 | 30.00 | 0.80 | **0.300** |
| Microzooplankton | 2.05 | **1.5008** |  | 100.00 | 285.71 | 0.80 | **0.350** |
| Corals and sponges | 2.00 | 1.9286 |  | 0.01 | 2.00 | 0.10 | **0.005** |
| Eelgrass | 1.00 | **1.2362** |  | 24.54 | N/A | 0.40 | N/A |
| Kelps | 1.00 | **0.2152** |  | 15.00 | N/A | 0.40 | N/A |
| Benthic macroalgae | 1.00 | **3.9590** |  | 15.00 | N/A | 0.40 | N/A |
| Benthic microalgae | 1.00 | **0.9197** |  | 100.00 | N/A | 0.50 | N/A |
| Phytoplankton | 1.00 | 15.4060 |  | 178.50 | N/A | 0.36 | N/A |
| Detritus | 1.00 | **10.0000** |  | N/A | N/A | 0.45 | N/A |

**Section E: Fitting the 1950 model to time series**

The goal of fitting an Ecosim model to time series is to minimize the Akaike Information Criterion with a second-order correction for small sample size (AICc):

where

*k* is the number of parameters estimated (i.e, vulnerability values plus primary production anomaly spline points), *n* is the number of “observations” (i.e., annual values in reference time series), and *minSS* is the minimum sum of squared residuals from fitting Ecosim outputs (typically functional group catch and biomass) to time series. The AIC from the second equation was employed in the first equation instead of that calculated by Ecosim. The final term -*cn*, where *c* = constant, in the AICc formula (Venables and Ripley 2002) was omitted from the first equation, since AICc was only used to compare scenarios with equal *n*. Scenario comparisons were repeated with *n* replaced by *n*/2 in the first equation to account for the likely non-independence of time series values (“observations) and as an additional precaution against model overfitting. The fitting procedure was also employed to construct a “test” Ecopath model of the current ecosystem state, derived from Ecosim outputs for the final year (2015) of the “most parsimonious fit” scenario, for comparison with the “base” current model and validation of the “most parsimonious fit.”

In order to prevent the fitting procedure from yielding unrealistic biomass changes, e.g., the extirpations observed in a previous Gulf of Alaska EwE model (Gaichas et al. 2011), for functional groups lacking reference time series to reduce AICc, vulnerabilities were only estimated for groups with time series, according to best practice (e.g., a Baltic Sea EwE model; Tomczak et al. 2012). Equal vulnerability values were set across all prey of a given predator. This “fit by predator” approach has been successfully applied to EwE models of the Celtic Sea (Moullec et al. 2017) and three Alaskan Pacific ecosystems (Heymans 2005a,b; Guénette 2005), and performed better in the 1950 NBC model than the alternative “fit by prey” strategy. While the “fit by predator” strategy was marginally outperformed in the NBC model by fitting vulnerabilities for each trophic interaction, this approach has little justification in trophodynamics or behavioral ecology, as it may entail differently controlled interactions with the same predator for otherwise similar prey, e.g., forage fish and herring (Ainsworth 2006). Furthermore, the “fit by prey” component of this approach is likely to yield model overfitting, since the time series values utilized to calculate AIC are not independent.

All vulnerabilities were scaled to consumer trophic level prior to fitting, according to the method of Ainsworth (2004). For consumers without time series, vulnerabilities remained scaled to trophic level. While Ainsworth et al. (2008) observed that in the 1950 NBC model this scaling raised the sum of squared deviations from time series relative to the default vulnerability setting of all *v* = 2, they also noted that low vulnerabilities hamper model response to rapidly changing dynamics (Martell et al. 2002) and only provide good fits to data for “lightly exploited” ecosystems. This result could be expected given the close relationship between vulnerability and the ratio of consumer biomass to carrying capacity (Walters and Martell 2004). Given the notable catches of whales (Nichol and Heise 1992), herring (Hourston 1978), and Pacific dogfish (Chittenden 1884) in the study area before 1950, it is doubtful whether the Haida Gwaii ecosystem remained “lightly exploited” in that year, and hence whether the default of *v* = 2 remains appropriate.

Vulnerabilities were fitted to a set of reference time series for biomass (t⋅km-2, 30 groups) and/or catch (t⋅km-2⋅year-1, 23 groups). Sources and values for these time series are given in supplementary files S1 (section D) and S5, respectively. Since including time series for functional groups other than assessed fish stocks resulted in lower AICc in a North Sea EwE model (Mackinson 2014), such time series were also employed here (e.g. for marine mammals, euphausiids, and phytoplankton). Following best practice (Heymans et al. 2016), where both biomass and catch time series existed (i.e., for 22 groups; 7 marine mammals and 15 fish), fishing mortality (year-1) time series were calculated and utilized as absolute drivers in the fitting process. If catch and biomass time series lengths differed, the shorter series was extended using the first or last value to match the longer series and calculate fishing mortality for the full fitting interval. In the North Sea model (Mackinson 2014), biomass time series were similarly extended using final values. Based on lengths of herring catch and biomass time series (DFO 2016), the fitting interval was set to 1950-2015. Finally, once again according to best practice (Heymans et al. 2016), all catch and biomass time series were further employed to search for a primary production anomaly (PPA), i.e., an annual time series of deviations from the Ecopath phytoplankton biomass, which was used to drive phytoplankton biomass during fitting to further reduce AICc. For phytoplankton, the NBC time series was extended with 2001-2015 values randomly resampled from the original data, yielding a 1950-2015 time series qualitatively matching the North Pacific trend (Boyce et al. 2014).

The *AICc* was employed to quantitatively compare overall fits to reference time series across ten scenarios (Table 1). Scenario 1 (baseline) was a simple Ecosim run with no vulnerability search or fishing mortality drivers and all vulnerabilities scaled to consumer trophic level. Scenario 2 was essentially identical but employed the default vulnerability setting (*v* = 2) across all groups. Scenario 3 added fishing mortality drivers (without a vulnerability search) to the baseline set by scenario 1, while scenario 4 was the reverse of scenario 3. Scenario 5 included both a vulnerability search and fishing mortality drivers. In scenarios 3 and 5, all catches and fishing mortalities were based on stock assessments. In scenario 6, these time series values were multiplied by annual ratios of reconstructed to reported British Columbia yields from the Sea Around Us database (Ainsworth 2018), catches from which were employed to fit a Mediterranean Sea EwE model (Piroddi et al. 2017). The validity of such catch reconstructions, undertaken according to methods outlined in Zeller and Pauly (2016) has recently (Pauly and Zeller 2018) been accepted by the UN Food and Agriculture Organization (FAO). In scenario 7, the Sea Around Us multipliers introduced in scenario 6 were only applied to herring stock time series.

Scenario 8 added a PPA (separately fitted to time series with *σ2* = 1 and 10 spline points) to scenario 7 settings. Mackinson et al. (2009) recommended that PPAs be statistically searched for true trends and correlations with oceanographic drivers. Thus, the fitted PPA was tested for significant relationships with time, as well as basin-scale and local physical oceanographic indices, using Spearman rank correlation. The Pacific Decadal Oscillation (PDO; Mantua et al. 1997) and Northern Oscillation Index (NOI; Schwing et al. 2002) were utilized as basin-scale oceanographic indices due to their significant negative and positive correlations, respectively, with the PPA from the 1950 NBC model (Ainsworth et al. 2008), while sea surface temperature (SST) at Langara Island in northwestern Haida Gwaii served as the local oceanographic index.

Scenario 9 augmented scenario 8 with three manually sketched forcing functions (Figure D1) simulating recent non-predation natural mortality (*M0*) peaks for 1) coho salmon (*O. kisutch*), 2) chinook salmon (*O. tschawytsha*), 3) adult herring (age 3+, all stocks), and 4) Pacific cod, sablefish, and lingcod. These forcing functions were designed to 1) prevent the model from generating recoveries after 2005 inconsistent with observed stock status, and 2) emulate elevated herring natural mortality predicted by assessment models (DFO 2016). Finally, scenario 10 employed whale biomass and catch time series based on a higher precision (kg) of species-specific mean individual masses (Trites and Pauly 1998) than that (t) utilized in previous simulations.

All fitting scenarios employed the same set of values (given in supplementary file S6) for Ecosim parameters other than vulnerabilities. Mackinson et al. (2003) noted that baleen whale functional responses to prey abundance assumed in Ecosim affect predator-prey interaction strength. A Type III (sigmoid or “prey switching”) response was observed for humpback and fin whales in a fjord ecosystem adjacent to the study area (Keen 2017). A shallow sigmoid curve was set in Ecosim using an intermediate value of 0.5 for the Ecosim feeding time adjustment rate parameter (0 ≤ *Pi* ≤1). This value was applied to all marine mammals, as in ecosystem models of southeast Alaska (Guénette 2005) and the Western and Central Aleutians (Heymans 2005a), as well as to seabirds, transient salmon, and adult stanzas of all herring stocks (which are prey to humpback and fin whales). The default *Pi* = 0, approximately representing a Type II response, was retained elsewhere. Other Ecosim parameters likewise maintained their default values.

**Table E1:** Time series used to fit the 1950 Ecopath model.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Functional group** | **Data type** | **Sources** | **Notes on data type** | **Area** |
| Gray whalesa,b | Biomass | Laake et al. (2012)1, Ford (2014)2 | 1Historical NE Pacific abundances  2Current BC abundance | A |
| Blue, fin, sei, humpback,sperm whalesa | Catch | Nichol and Heise (1992) |  | A |
| Bluea, fin a, seia, humpbacka sperma | Biomass | Surplus production models |  | A |
| Resident orcasa,b | Biomass | Ford (2016), pers. comm. | Northern residents | A |
| Transient orcasa,b | Biomass | Ford et al. (2013)3, Ford (2014)4 | 3Current northern BC abundance  4*rc* = 0.03 yr-1 | A |
| Sealsb | Biomass | Gregr (2004)5, Olesiuk (2010)5 | 5Data for Hecate Strait | A |
| Sea lionsb | Biomass | Olesiuk (2016)5 | 5Data for Hecate Strait | A |
| Seals  Sea lions | Catch | Gregr (2004)5 | 5Data for Hecate Strait | A |
| Piscivorous, teuthivorous, planktivorous seabirdsc,d | Biomass | Sea Around Us Project |  | B |
| Transient salmon | Biomass | Ruggerone and Irvine (2018),  Irvine and Ruggerone (2016), Irvine et al. (2012) |  | C |

**Table E1 (continued):** Time series used to fit the 1950 Ecopath model.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Transient salmon | Catch | Irvine et al. (2013),  Tompkins (2015) |  | D |
| Coho salmon  Chinook salmon  Pacific dogfish | Biomass, catch | Ainsworth et al. (2008) |  | E |
| Eulachon | Catch | Moody and Pitcher (2010)5 | 5Nass River | A |
| Adult herring (HG, HG 2W, PRD, CC) | Biomass, catch | Cleary (2016), pers. comm.6,7 | 6Σ (biomass) over ages 3+  7(Individual mass at age) \* (number or catch at age) | A |
| Pacific Ocean perch | Biomass | Ainsworth et al. (2008) |  | E |
| Pacific Ocean perch | Catch | Haigh and Yamanaka (2011)8 | 8Recorded + reconstructed catches | A |
| Flatfish | Biomass, catch | Ainsworth et al. (2008) |  | E |
| Adult halibutb | Biomass | Stewart and Martell (2013)9 | 9Spawning biomass | A |
| Adult halibutb | Catch | Stewart and Monnahan (2015) |  | A |
| Pacific cod | Biomass, catch | Forrest et al. (2015) |  | A |
| Sablefish | Biomass | Ainsworth et al. (2008) |  | E |
| Sablefish | Catch | McFarlane and Beamish (1983),  DFO (2014) |  | C |
| Lingcodb | Biomass, catch | King et al. (2011) |  | A |
| Small demersal elasmobranchs | Biomass | Ainsworth et al. (2008) |  | E |
| Small demersal elasmobranchs | Catch | King et al. (2015)8 | 8Recorded + reconstructed catches | A |
| Euphausiids | Biomass | Ainsworth et al. (2008) |  | E |
| Phytoplankton | Biomass | Ainsworth et al. (2008) |  | E |

**General notes:**

aMammal abundance-to-biomass conversions derived from Trites and Pauly (1998).

bTime series values scaled so that final value equals current Ecopath biomass.

cEach group biomass time series value = sum of constituent species biomasses.

dSeabird abundance-to-biomass conversions derived from Bishop et al. (2015).

**Surface areas employed in biomass and catch density (t⋅km-2) calculations**

1. Haida Gwaii model area (81,008 km2).
2. Gulf of Alaska area (1,406,422 km2) from the Sea Around Us Project.
3. Canadian Pacific EEZ shelf area (87,418 km2) from the Sea Around Us Project.
4. Canadian Pacific EEZ full area (470,238 km2) from the Sea Around Us Project.
5. Northern British Columbia model area (70,000 km2) from Ainsworth et al. (2008).

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**Section F: Ecosim vulnerability parameters**

**Table F1:** Vulnerability parameter (*vij*) values and estimation methods.

|  |  |  |
| --- | --- | --- |
| **Functional group** | ***vij*** | **Estimation method** |
| Sea ottersa | 16.01 | *B0*/*B1950* |
| Gray whales | 1.00 | Fit to time series |
| Humpback whales | 1.0 x 1010 | Fit to time series |
| Minke whales | 3.28 | Scaling to TL |
| Blue whales | 1.0 x 1010 | Fit to time series |
| Fin whalesb | 1.0 x 1010 | Fit to time series (tweaked) |
| Sei whales | 1.0 x 1010 | Fit to time series |
| Sperm whales | 1.0 x 1010 | Fit to time series |
| Resident orcas | 10.00 | Fit to time series (tweaked) |
| Transient orcas | 1.45 | Fit to time series |
| Small odontocetes | 3.88 | Scaling to TL |
| Seals | 1.63 | Fit to time series |
| Sea lions | 1.50 | Fit to time series (tweaked) |
| Piscivorous seabirds | 2.00 | Fit to time series (tweaked) |
| Teuthivorous seabirds | 1.41 | Fit to time series |
| Planktivorous seabirds | 1.00 | Fit to time series |
| Transient salmon | 1.00 | Fit to time series |
| Coho salmon | 5.11 | Fit to time series |
| Chinook salmon | 1.00 | Fit to time series |
| Small squid | 2.44 | Scaling to TL |
| Large squid | 2.50 | Scaling to TL |
| Octopus | 3.22 | Scaling to TL |
| Ratfish | 3.08 | Scaling to TL |
| Pacific dogfish | 1.38 | Fit to time series (tweaked) |
| Walleye pollock | 3.04 | Scaling to TL |
| Forage fish | 2.49 | Scaling to TL |
| Pacific hake | 3.26 | Scaling to TL |
| Pacific saury | 2.89 | Scaling to TL |
| Eulachon | 1.00 | Fit to time series |
| All herring stocks age 0-1 years | 2.70 | Scaling to TL |
| All herring stocks age 1-3 years | 2.96 | Scaling to TL |
| HG, PRD, CC herring age 3+ years | 1.0 x 1010 | Fit to time series |
| HG 2W herring age 3+ yearsb | 1.0 x 1010 | Fit to time series (tweaked) |

**Table F1 (continued):** Vulnerability parameter (*vij*) values and estimation methods.

|  |  |  |
| --- | --- | --- |
| **Functional group** | ***vij*** | **Estimation method** |
| Pacific Ocean perch | 1.16 | Fit to time series |
| Inshore rockfish | 3.26 | Scaling to TL |
| Piscivorous rockfish | 2.86 | Scaling to TL |
| Planktivorous rockfish | 3.03 | Scaling to TL |
| Arrowtooth flounder | 3.47 | Scaling to TL |
| Flatfish | 2.24 | Fit to time series |
| Juvenile halibut | 3.50 | Scaling to TL |
| Adult halibut | 6.12 | Fit to time series |
| Pacific cod | 11.27 | Fit to time series |
| Sablefish | 3.54 | Fit to time series |
| Lingcod | 1.00 | Fit to time series |
| Shallowwater benthic fish | 2.99 | Scaling to TL |
| Small demersal elasmobranchs | 1.00 | Fit to time series |
| Large demersal sharks | 3.48 | Scaling to TL |
| Salmon sharks | 4.16 | Scaling to TL |
| Blue sharks | 3.75 | Scaling to TL |
| Large crabs | 2.31 | Scaling to TL |
| Small crabs | 2.43 | Scaling to TL |
| Commercial shrimp | 2.18 | Scaling to TL |
| Sea urchins | 1.20 | Scaling to TL |
| Other grazers | 1.20 | Scaling to TL |
| Epifaunal filter-feeders | 1.58 | Scaling to TL |
| Epifaunal carnivores | 2.51 | Scaling to TL |
| Infaunal carnivorous invertebrates | 1.27 | Scaling to TL |
| Infaunal detritivorous invertebrates | 1.20 | Scaling to TL |
| Carnivorous jellyfish | 1.45 | Scaling to TL |
| Macrozooplankton | 2.13 | Scaling to TL |
| Amphipods | 1.69 | Scaling to TL |
| Euphausiids | 30.37 | Fit to time series |
| Copepods | 1.40 | Scaling to TL |
| Small gelatinous zooplankton | 1.93 | Scaling to TL |
| Microzooplankton | 1.30 | Scaling to TL |
| Corals and sponges | 1.20 | Scaling to TL |

**Notes:**

a Ratio of biomasses in the 1750 and 1950 NBC models (i.e., before and after depletion by the maritime fur trade, respectively), as recommended by Walters and Martell (2004).

b Formal fitting generated lower *v* for fin whales and adult HG 2W herring than for other baleen whales and herring, respectively. As no ecological justification was apparent for these fitting results, fin whale and HG 2W vulnerabilities were set to match the others.

c Sea lion, piscivorous seabird, and Pacific dogfish fits to biomass time series were visibly improved by manual vulnerability modifications.

The “most parsimonious fit” scenario generated improved fits to time series relative to the 1950 NBC model (Ainsworth et al. 2008) for all hunted whale species (humpback, blue, fin, sei, and sperm). As was the case for baleen whales in an EwE model of the Western and Central Aleutian ecosystem (Heymans 2005a), biomass accumulation (*BA*) rates were required to produce satisfactory fits for these groups, as well as for resident orcas. The 1950 NBC model and an EwE model of the Central Puget Sound ecosystem (Harvey et al. 2012) also employed *BA* rates to improve individual group fits to time series. However, the use of such rates implies the need to force whale biomass with surplus production model outputs in scenarios designed to examine trends in functional group biomasses, as in Surma and Pitcher (2015) and Surma et al. (2018a) as opposed to sets of scenarios evaluated relative to a baseline run, as in Surma et al. (2018b).

The chosen scenario also yielded fits comparable to those in the NBC model for nine groups (seals and sea lions, Pacific dogfish, Pacific Ocean perch, flatfish, Pacific cod, lingcod, sablefish, and small demersal elasmobranchs). Somewhat less accurate fits were obtained for Pacific halibut, lingcod, euphausiids, and phytoplankton. Salmon and herring fits to time series were not comparable across the present and NBC models, as the former did not drive salmon biomasses and catches with data, did not fit a herring recruitment anomaly, and separately represented four herring stocks.

In terms of relative trends, all adult herring groups satisfactorily matched biomass and catch time series in the “most parsimonious fit” scenario. However, underestimation of several early HG stock biomass and catch peaks, together with overestimation of PRD and CC biomasses after 1965, hampered the fits in quantitative terms. These issues represent discrepancies between the single-species herring stock assessment model (DFO 2016) and the multi-stanza age structure embedded in the EwE ecosystem model. Since these models were designed for quite different purposes (tactical single-species versus strategic ecosystem analysis), it would be difficult to justify complete trust in one or the other regarding herring biomass trajectories.

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**Table G1:** Biomass densities (t⋅km-2) of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 60.3, *σ* = 109.9).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Sea otters | 0.0001 | 0.0001 | -26.23 |
| Gray whales | 0.0300 | 0.0130 | -56.79 |
| Humpback whales | 0.1900 | 0.1696 | -10.74 |
| Minke whales | 0.0315 | 0.0239 | -24.04 |
| Blue whales | 0.0043 | 0.0136 | 215.54 |
| Fin whales | 0.1374 | 0.1509 | 9.82 |
| Sei whales | 0.0017 | 0.0060 | 254.33 |
| Sperm whales | 0.0110 | 0.0164 | 49.12 |
| Resident orcas | 0.0036 | 0.0040 | 11.11 |
| Transient orcas | 0.0024 | 0.0006 | -77.06 |
| Small odontocetes | 0.1000 | 0.1274 | 27.39 |
| Seals | 0.1250 | 0.1011 | -19.09 |
| Sea lions | 0.1250 | 0.1851 | 48.05 |
| Piscivorous seabirds | 0.0019 | 0.0034 | 77.17 |
| Teuthivorous seabirds | 0.0002 | 0.0004 | 78.63 |
| Planktivorous seabirds | 0.0002 | 0.0002 | 33.51 |
| Transient salmon | 0.2080 | 0.6636 | 219.03 |
| Coho salmon | 0.0240 | 0.0746 | 210.88 |
| Chinook salmon | 0.0340 | 0.0603 | 77.50 |
| Small squid | 1.0898 | 1.8140 | 66.45 |
| Large squid | 0.7652 | 1.1512 | 50.44 |
| Octopus | 0.1899 | 0.0373 | -80.39 |
| Ratfish | 0.5170 | 0.6778 | 31.11 |
| Pacific dogfish | 0.9090 | 0.8658 | -4.75 |
| Walleye pollock | 0.4910 | 2.6762 | 445.05 |
| Forage fish | 8.4780 | 17.1865 | 102.72 |
| Pacific hake | 0.8200 | 1.4241 | 73.67 |
| Pacific saury | 1.2810 | 0.9134 | -28.70 |
| Eulachon | 1.6600 | 1.8071 | 8.86 |
| HG herring age 0-1 years | 0.0483 | 0.0295 | -38.94 |
| HG herring age 1-3 years | 0.4745 | 0.2604 | -45.12 |
| HG herring age 3+ years | 0.3125 | 0.3051 | -2.37 |
| HG 2W herring age 0- years | 0.0002 | 0.0005 | 204.16 |
| HG 2W herring age 1-3 years | 0.0028 | 0.0058 | 108.31 |
| HG 2W herring age 3+ years | 0.0091 | 0.0327 | 261.32 |

**Table G1 (continued):** Biomass densities (t⋅km-2) of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 60.3, *σ* = 109.9).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| PRD herring age 0-1 years | 0.0222 | 0.1019 | 360.08 |
| PRD herring age 1-3 years | 0.3201 | 1.0746 | 235.66 |
| PRD herring age 3+ years | 0.4688 | 1.3333 | 184.41 |
| CC herring age 0-1 years | 0.0281 | 0.0806 | 186.64 |
| CC herring age 1-3 years | 0.4600 | 0.8900 | 93.47 |
| CC herring age 3+ years | 0.9752 | 1.0981 | 12.61 |
| Pacific Ocean perch | 0.6230 | 1.0258 | 64.66 |
| Inshore rockfish | 0.1000 | 0.0971 | -2.91 |
| Piscivorous rockfish | 0.6600 | 0.6635 | 0.52 |
| Planktivorous rockfish | 1.3430 | 1.5225 | 13.36 |
| Arrowtooth flounder | 1.7480 | 2.5351 | 45.03 |
| Flatfish | 0.4950 | 0.6280 | 26.88 |
| Juvenile halibut | 0.3563 | 0.2741 | -23.08 |
| Adult halibut | 0.9000 | 1.0460 | 16.22 |
| Pacific cod | 0.2520 | 0.4850 | 92.47 |
| Sablefish | 0.3880 | 0.5392 | 38.96 |
| Lingcod | 0.0700 | 0.1330 | 89.95 |
| Shallowwater benthic fish | 0.5090 | 0.8786 | 72.62 |
| Small demersal elasmobranchs | 0.3000 | 0.2985 | -0.50 |
| Large demersal sharks | 0.0250 | 0.0351 | 40.39 |
| Salmon sharks | 0.0200 | 0.0282 | 41.23 |
| Blue sharks | 0.0200 | 0.0214 | 6.89 |
| Large crabs | 0.4560 | 0.5150 | 12.94 |
| Small crabs | 0.6495 | 0.6856 | 5.55 |
| Commercial shrimp | 0.2000 | 0.2511 | 25.54 |
| Sea urchins | 0.2188 | 0.0245 | -88.79 |
| Other grazers | 11.4154 | 6.5854 | -42.31 |
| Epifaunal filter-feeders | 9.6832 | 7.1583 | -26.07 |
| Epifaunal carnivores | 1.6534 | 1.3013 | -21.30 |
| Infaunal carnivorous invertebrates | 13.2451 | 16.0483 | 21.16 |
| Infaunal detritivorous invertebrates | 34.3051 | 44.5150 | 29.76 |
| Carnivorous jellyfish | 3.0000 | 3.3451 | 11.50 |
| Macrozooplankton | 1.6442 | 5.1005 | 210.21 |
| Amphipods | 1.0447 | 5.2184 | 399.53 |
| Euphausiids | 10.0000 | 21.7681 | 117.68 |
| Copepods | 5.2500 | 7.6067 | 44.89 |
| Small gelatinous zooplankton | 1.4661 | 4.9068 | 234.68 |
| Microzooplankton | 1.5008 | 4.8024 | 220.00 |

**Table G1 (continued):** Biomass densities (t⋅km-2) of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 60.3, *σ* = 109.9).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Corals and sponges | 1.9286 | 1.9217 | -0.36 |
| Eelgrass | 1.2362 | 0.6889 | -44.28 |
| Kelps | 0.2152 | 0.0069 | -96.77 |
| Benthic macroalgae | 3.9590 | 2.0979 | -47.01 |
| Benthic microalgae | 0.9197 | 0.5023 | -45.38 |
| Phytoplankton | 15.4060 | 19.8861 | 29.08 |
| Detritus | 10.0000 | 12.6943 | 26.94 |

**Table G2:** P/B or Z (year-1) values of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 1.5, *σ* = 38.1).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Sea otters | 0.13 | 0.11 | -14.50 |
| Gray whales | 0.05 | 0.01 | -78.16 |
| Humpback whales | 0.06 | 0.01 | -77.17 |
| Minke whales | 0.09 | 0.05 | -42.21 |
| Blue whales | 0.04 | 0.02 | -61.88 |
| Fin whales | 0.05 | 0.02 | -66.29 |
| Sei whales | 0.06 | 0.03 | -55.59 |
| Sperm whales | 0.05 | 0.01 | -79.18 |
| Resident orcas | 0.05 | 0.05 | 0.00 |
| Transient orcas | 0.05 | 0.03 | -38.52 |
| Small odontocetes | 0.15 | 0.10 | -35.09 |
| Seals | 0.17 | 0.11 | -37.12 |
| Sea lions | 0.17 | 0.10 | -42.72 |
| Piscivorous seabirds | 0.38 | 0.29 | -22.81 |
| Teuthivorous seabirds | 0.36 | 0.26 | -28.92 |
| Planktivorous seabirds | 0.40 | 0.38 | -4.58 |
| Transient salmon | 2.48 | 2.48 | -0.15 |
| Coho salmon | 2.76 | 3.82 | 38.44 |
| Chinook salmon | 2.16 | 5.08 | 134.99 |
| Small squid | 6.02 | 6.70 | 11.31 |
| Large squid | 6.02 | 6.94 | 15.17 |
| Octopus | 0.86 | 0.93 | 8.65 |
| Ratfish | 0.10 | 0.10 | 0.01 |
| Pacific dogfish | 0.10 | 0.10 | 5.65 |
| Walleye pollock | 0.48 | 0.97 | 102.92 |

**Table G2 (continued):** P/B or Z (year-1) values of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 1.5, *σ* = 38.1).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Forage fish | 1.60 | 1.73 | 8.41 |
| Pacific hake | 0.55 | 0.59 | 6.75 |
| Pacific saury | 1.60 | 1.96 | 22.78 |
| Eulachon | 1.43 | 1.64 | 14.62 |
| HG herring age 0-1 years | 1.23 | 1.37 | -11.66 |
| HG herring age 1-3 years | 1.00 | 1.06 | -6.63 |
| HG herring age 3+ years | 1.06 | 0.64 | 39.35 |
| HG 2W herring age 0- years | 1.23 | 1.20 | 2.44 |
| HG 2W herring age 1-3 years | 0.45 | 0.80 | -76.96 |
| HG 2W herring age 3+ years | 0.45 | 0.23 | 48.21 |
| PRD herring age 0-1 years | 1.23 | 1.32 | -7.36 |
| PRD herring age 1-3 years | 0.63 | 0.90 | -42.86 |
| PRD herring age 3+ years | 0.74 | 0.69 | 6.31 |
| CC herring age 0-1 years | 1.23 | 1.52 | -23.82 |
| CC herring age 1-3 years | 0.52 | 0.80 | -53.85 |
| CC herring age 3+ years | 0.60 | 0.75 | -24.87 |
| Pacific Ocean perch | 0.20 | 0.16 | -19.70 |
| Inshore rockfish | 0.19 | 0.19 | 1.32 |
| Piscivorous rockfish | 0.06 | 0.06 | -7.07 |
| Planktivorous rockfish | 0.10 | 0.10 | -1.14 |
| Arrowtooth flounder | 0.23 | 0.28 | 20.67 |
| Flatfish | 1.46 | 0.87 | -40.75 |
| Juvenile halibut | 0.50 | 0.57 | -13.00 |
| Adult halibut | 0.40 | 0.30 | 25.48 |
| Pacific cod | 1.55 | 2.11 | 35.90 |
| Sablefish | 0.38 | 0.54 | 42.76 |
| Lingcod | 0.98 | 1.63 | 66.64 |
| Shallowwater benthic fish | 1.50 | 1.64 | 9.03 |
| Small demersal elasmobranchs | 0.32 | 0.36 | 11.81 |
| Large demersal sharks | 0.13 | 0.12 | -11.10 |
| Salmon sharks | 0.20 | 0.20 | -0.10 |
| Blue sharks | 0.17 | 0.17 | -0.18 |
| Large crabs | 1.50 | 1.76 | 17.37 |
| Small crabs | 3.50 | 3.95 | 12.77 |
| Commercial shrimp | 11.48 | 11.84 | 3.16 |
| Sea urchins | 0.50 | 0.46 | -7.08 |
| Other grazers | 0.75 | 0.82 | 8.99 |
| Epifaunal filter-feeders | 1.00 | 1.08 | 7.71 |

**Table G2 (continued):** P/B or Z (year-1) values of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 1.5, *σ* = 38.1).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Epifaunal carnivores | 0.85 | 0.91 | 6.48 |
| Infaunal carnivorous invertebrates | 2.00 | 2.02 | 0.99 |
| Infaunal detritivorous invertebrates | 1.35 | 2.88 | 113.13 |
| Carnivorous jellyfish | 18.00 | 20.52 | 13.98 |
| Macrozooplankton | 7.00 | 6.51 | -6.93 |
| Amphipods | 7.00 | 5.52 | -21.11 |
| Euphausiids | 6.60 | 7.64 | 15.78 |
| Copepods | 27.00 | 35.66 | 32.07 |
| Small gelatinous zooplankton | 9.00 | 10.30 | 14.44 |
| Microzooplankton | 100.00 | 111.31 | 11.31 |
| Corals and sponges | 0.01 | 0.01 | -0.02 |
| Eelgrass | 24.54 | 24.51 | -0.13 |
| Kelps | 15.00 | 15.10 | 0.69 |
| Benthic macroalgae | 15.00 | 14.98 | -0.12 |
| Benthic microalgae | 100.00 | 99.84 | -0.16 |
| Phytoplankton | 178.50 | 189.50 | 6.16 |

**Table G3:** Q/B (year-1) values of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 10.4, *σ* = 25.6).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Sea otters | 101.50 | 102.14 | 0.63 |
| Gray whales | 5.30 | 5.80 | 9.38 |
| Humpback whales | 4.60 | 4.69 | 1.91 |
| Minke whales | 6.30 | 6.45 | 2.44 |
| Blue whales | 3.50 | 3.58 | 2.22 |
| Fin whales | 4.10 | 4.17 | 1.75 |
| Sei whales | 5.20 | 5.26 | 1.11 |
| Sperm whales | 5.10 | 5.15 | 0.96 |
| Resident orcas | 7.70 | 7.62 | -1.02 |
| Transient orcas | 7.70 | 7.85 | 1.93 |
| Small odontocetes | 16.00 | 16.20 | 1.24 |
| Seals | 15.10 | 15.01 | -0.58 |
| Sea lions | 15.10 | 11.08 | -26.63 |
| Piscivorous seabirds | 69.28 | 68.78 | -0.72 |
| Teuthivorous seabirds | 75.19 | 73.66 | -2.03 |

**Table G3 (continued):** Q/B (year-1) values of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 10.4, *σ* = 25.6).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Planktivorous seabirds | 96.05 | 95.58 | -0.49 |
| Transient salmon | 8.33 | 8.24 | -1.04 |
| Coho salmon | 13.80 | 22.67 | 64.25 |
| Chinook salmon | 10.80 | 25.51 | 136.23 |
| Small squid | 34.68 | 38.80 | 11.91 |
| Large squid | 34.68 | 39.88 | 15.00 |
| Octopus | 2.50 | 3.08 | 23.28 |
| Ratfish | 1.40 | 1.91 | 36.34 |
| Pacific dogfish | 2.72 | 1.95 | -28.21 |
| Walleye pollock | 2.28 | 2.64 | 15.64 |
| Forage fish | 8.40 | 8.36 | -0.40 |
| Pacific hake | 2.75 | 3.46 | 25.86 |
| Pacific saury | 7.90 | 9.39 | 18.87 |
| Eulachon | 8.40 | 9.55 | 13.79 |
| HG herring age 0-1 years | 21.43 | 20.43 | -4.68 |
| HG herring age 1-3 years | 9.20 | 8.76 | -4.77 |
| HG herring age 3+ years | 5.84 | 5.21 | -10.75 |
| HG 2W herring age 0- years | 23.67 | 23.01 | -2.76 |
| HG 2W herring age 1-3 years | 9.56 | 9.67 | 1.22 |
| HG 2W herring age 3+ years | 5.84 | 5.28 | -9.64 |
| PRD herring age 0-1 years | 22.31 | 18.81 | -15.69 |
| PRD herring age 1-3 years | 9.18 | 7.94 | -13.55 |
| PRD herring age 3+ years | 5.84 | 4.86 | -16.78 |
| CC herring age 0-1 years | 22.87 | 18.50 | -19.11 |
| CC herring age 1-3 years | 9.30 | 7.63 | -18.03 |
| CC herring age 3+ years | 5.84 | 4.76 | -18.41 |
| Pacific Ocean perch | 2.25 | 3.65 | 62.29 |
| Inshore rockfish | 5.69 | 7.43 | 30.65 |
| Piscivorous rockfish | 1.27 | 1.60 | 25.94 |
| Planktivorous rockfish | 2.25 | 3.24 | 43.91 |
| Arrowtooth flounder | 2.01 | 2.70 | 34.66 |
| Flatfish | 5.19 | 7.81 | 50.59 |
| Juvenile halibut | 2.43 | 2.59 | 6.24 |
| Adult halibut | 1.10 | 1.04 | -4.96 |
| Pacific cod | 5.24 | 7.23 | 38.08 |
| Sablefish | 4.73 | 7.97 | 68.29 |
| Lingcod | 3.30 | 4.93 | 49.26 |
| Shallowwater benthic fish | 5.26 | 5.71 | 8.72 |

**Table G3 (continued):** Q/B (year-1) values of the original and Ecosim-generated current model, along with the percentage difference between them (*μ* = 10.4, *σ* = 25.6).

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional group** | **Original** | **Ecosim** | **% Difference** |
| Small demersal elasmobranchs | 1.24 | 1.52 | 22.69 |
| Large demersal sharks | 1.24 | 1.46 | 17.62 |
| Salmon sharks | 1.20 | 1.28 | 6.28 |
| Blue sharks | 0.80 | 0.90 | 12.65 |
| Large crabs | 5.00 | 6.03 | 20.60 |
| Small crabs | 14.00 | 9.91 | -29.19 |
| Commercial shrimp | 45.90 | 47.46 | 3.39 |
| Sea urchins | 10.88 | 9.90 | -8.97 |
| Other grazers | 8.86 | 9.65 | 8.88 |
| Epifaunal filter-feeders | 4.50 | 4.97 | 10.40 |
| Epifaunal carnivores | 7.50 | 8.01 | 6.79 |
| Infaunal carnivorous invertebrates | 22.22 | 22.70 | 2.14 |
| Infaunal detritivorous invertebrates | 14.99 | 15.25 | 1.71 |
| Carnivorous jellyfish | 60.00 | 68.53 | 14.22 |
| Macrozooplankton | 35.00 | 32.46 | -7.26 |
| Amphipods | 35.00 | 27.42 | -21.66 |
| Euphausiids | 24.82 | 28.98 | 16.74 |
| Copepods | 90.00 | 118.82 | 32.02 |
| Small gelatinous zooplankton | 30.00 | 34.46 | 14.88 |
| Microzooplankton | 285.71 | 318.57 | 11.50 |
| Corals and sponges | 2.00 | 2.55 | 27.33 |

**Figures**



**Figure S1.1.** Biomass time series (solid lines) and “best fit” Ecosim outputs (dotted lines) for marine mammal functional groups.



**Figure S1.2.** Biomass time series (solid lines) and “best fit” Ecosim outputs (dotted lines) for commercial fish functional groups.



**Figure S1.3.** Biomass time series (solid lines) and “best fit” Ecosim outputs (dotted lines) for other (seabird and plankton) functional groups.



**Figure S1.4.** Catch time series (solid lines) and “best fit” Ecosim outputs (dotted lines) for marine mammal functional groups.



**Figure S1.5.** Catch time series (solid lines) and “best fit” Ecosim outputs (dotted lines) for commercial fish functional groups.



**Figure S1.6.** Non-predation natural mortality (*M0*) forcing functions for five fish species employed in the model fitting exercise, 1950-2015.