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# **Design and Parameterization of a Spatially Explicit Ecosystem Model of the Central California Current**

January 2010

**U.S. DEPARTMENT OF COMMERCE**  
**National Oceanic and Atmospheric Administration**  
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# Design and Parameterization of a Spatially Explicit Ecosystem Model of the Central California Current

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# Executive Summary

Widespread declines in the status of species and habitats in marine ecosystems have led to calls for ecosystem-scale management as a strategy to restore our oceans. Implementing ecosystem-based management requires an understanding of the complex dynamics of marine ecosystems as well as an understanding of how humans fit into the system. The Atlantis modeling framework integrates physical, chemical, ecological, and anthropogenic processes in a three-dimensional, spatially explicit domain. As such, Atlantis can be a powerful tool for guiding ecosystem-based management.

We present here the basic formulations and parameterization for the biology and physics of the Central California Atlantis Model (CCAM). For this work, we have built on the framework developed in NOAA Technical Memorandum NMFS-NWFSC-84, A Spatially Explicit Ecosystem Model of the California Current Food Web and Oceanography, adding spatial resolution and additional biological data that focus the model on central California. Our goal is to produce a robust simulation of the California Current ecosystem that will allow us to explore potential effects of natural and human-induced perturbations over a range of spatial and temporal scales.

CCAM is bounded by the U.S.-Canada border in the north, Point Conception in the south, the U.S. shoreline to the east, and the 2,400 isobath to the west. The model extent is divided into 82 three-dimensional boxes, each containing up to 7 vertical water column layers. We link CCAM to the Regional Ocean Modeling System to force temperature and water fluxes, and we simulate food web dynamics using 62 biological functional groups: 5 bacteria/detritus, 8 plankton/algae, 14 invertebrate, and 35 vertebrate.

We utilized historical biomass data to guide the calibration of CCAM, and throughout the calibration process we evaluated the model's ability to represent historical biomass trends under historical fishing pressure from 1950 to present. After calibrating and testing CCAM under a variety of conditions, we believe the model produces an adequate representation of ecosystem dynamics. Thus we are confident that CCAM will be a powerful management tool, providing a platform for addressing important hypotheses relating to the effects of perturbations (e.g., harvest), characterizing the potential trade-offs of alternate management actions, and testing the utility of ecosystem indicators for long-term monitoring programs.



# Acknowledgments

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# Introduction

Widespread declines in the status of species and habitats in marine ecosystems have led to calls for ecosystem-scale management as a strategy to restore our oceans (Pew 2003, US COP 2004). An ecosystem approach to management requires that we identify the primary natural and human-induced threats experienced by ecosystems, and develop management strategies that ensure long-term sustainability of these systems. Such an approach must be based on an understanding of the factors that drive human behavior as well as the impacts of human behavior on the ecosystem. Consequently, implementing ecosystem-based management (EBM) requires an understanding of the complex dynamics of marine ecosystems as well as an understanding of how humans fit into the system.

In addition to understanding ecological and socioeconomic systems, EBM requires that stakeholders, resource managers, and scientists define shared goals based on a common currency. Goals can be expressed as clean beaches, healthy and abundant wildlife populations, stable fisheries, healthy coastal economies, and a variety of other goods and activities that benefit humans. To measure progress toward such goals, we can translate general statements such as those above into ecosystem services that can be quantified and tracked (National Research Council 2004, Hassan et al. 2005). We can evaluate potential management strategies on the basis of the resulting socioeconomic value of ecosystem services, as well as on assessments of ecosystem status and function. The power of the EBM approach lies in its ability to assist resource managers in forecasting changes in ecosystem services across different scenarios, often revealing trade-offs among particular services (Hassan et al. 2005).

The current array of tools for supporting EBM includes models for prioritizing sites for conservation (e.g., MARXAN in Ball 2000, Possingham et al. 2000), simulating food webs (e.g., Ecopath with Ecosim in Walters et al. 2000, Christensen et al. 2000), and statistically estimating population dynamics within the context of species interactions or changes in climate-driven demographic rates (Taylor and Stefansson 2004, Jurado-Molina and Livingston 2006, Schirripa and Colbert 2006). While each of these approaches has been successfully utilized to inform aspects of EBM, none of them completely integrates physical, chemical, and biological processes with human activity, nor do they adequately capture the spatiotemporal heterogeneity of natural systems.

Atlantis is a recently developed simulation modeling approach that successfully integrates physical, chemical, ecological, and anthropogenic processes in a three-dimensional, spatially explicit domain (Fulton et al. 2003, Fulton 2004, Fulton et al. 2004). In Atlantis, ecosystem dynamics are represented by spatially explicit submodels that simulate hydrographic processes (light-driven and temperature-driven fluxes of water and nutrients), biogeochemical factors driving primary production, and food web relations among flora and fauna. The model represents key exploited species at the level of detail necessary to evaluate direct effects of

fishing, and it also represents other anthropogenic and climate impacts on the ecosystem as a whole.

In this document, we present the basic formulations and parameterization for the biology and physics of the Central California Atlantis Model (CCAM). For this work, we have built on the framework developed in NOAA Technical Memorandum NMFS-NWFSC-84, A Spatially Explicit Ecosystem Model of the California Current Food Web and Oceanography (Brand et al. 2007), adding spatial resolution and additional biological data that focus the model on central California. Our goal is to develop a robust simulation of the California Current ecosystem that will allow us to explore potential effects of natural and human-induced perturbations over a range of spatial and temporal scales. We intend to apply the model to explore ecological and socioeconomic trade-offs of alternative management strategies, understand how management scenarios impact the system's response to variations in climate, and identify indicator metrics that are most effective for measuring ecosystem attributes and informing management decisions.



## Model Extent

The CCAM extends along the U.S. West Coast; it is bounded by the U.S.-Canada border in the north, Point Conception in the south, the U.S. shoreline to the east, and the 2,400 isobath to the west (Figure 1 and Figure 2). The model area is divided into 12 regions from north to south based on biogeography and management boundaries, and each of these regions is subdivided into depth zones from east to west defined by bathymetric contours. The spatial resolution varies throughout the model extent, with the regions of Northern California, Oregon, and Washington containing three depth zones, and those in Central California each containing six or seven depth zones. These 64 dynamic boxes are flanked by 18 nondynamic boundary boxes on the north, south, and west edges. Boundary boxes allow for the exchange of water nutrients to and from the dynamic model domain, but other processes are not explicitly modeled for these areas.

All model boxes are further divided into water column depth layers, ranging from one layer for nearshore boxes to seven for offshore boxes. Depth layers are defined in Figure 2. Each box also contains one sediment layer.

# Physical Model

The CCAM employs a physical oceanographic model that drives bottom-up forcing of the system. Ocean currents across each box face advect nutrients and have direct impacts on nutrient availability (ammonia [NH<sub>3</sub>] and nitrate [NO<sub>3</sub>]) to primary producers; the velocity and direction of ocean currents also influence the spatial distribution of planktonic groups. Temperature fields from the physical model influence biological processes such as respiration and spawning. Although salinity is included in the physical model, it is not currently linked to biological processes in the CCAM.

To model circulation, salinity, and temperature fluxes in each box and depth layer, we linked CCAM to the Regional Ocean Modeling System (ROMS). ROMS is a state-of-the-art, free surface, hydrostatic, primitive equation ocean circulation model developed at Rutgers University and the University of California Los Angeles. ROMS is a terrain-following, finite difference (Arakawa C-grid) model. It features a unified treatment of surface and bottom boundary layers, based on the Large et al. (1994) and Styles and Glenn (2000) algorithms, and an integrated set of procedures for data assimilation. Numerical details can be found in Haidvogel et al. (2000), Moore et al. (2004), and Shchepetkin and McWilliams (2005), as well as the ROMS Web site (<http://www.myroms.org>).

For CCAM, we used an existing suite of basin-scale and regional-scale circulation models based on ROMS, linked via one-way coupling. The nested model domains are a basin-scale model encompassing the North Pacific Basin (NPac) at 20–40 km resolution (Curchitser et al. 2005), and a regional-scale model at approximately 10 km resolution spanning the Northeast Pacific (NEP) (Hermann et al. 2009). The NEP domain covers the area from the Baja Peninsula to the Bering Sea, and from the coast out to 2,000 km offshore. One-way nesting of the models has been implemented using a hybrid of nudging and radiation approaches, as described in Marchesiello et al. (2001).

In our implementation, the NEP model receives its initial and lateral boundary conditions from prestored NPac model output. The NPac model was forced with coarse-scale Comprehensive Ocean-Atmosphere Data Set winds and heat fluxes; the NEP model was forced with winds and heat fluxes from a regional atmospheric model (MM5), implemented at 15–45 km resolution. The NEP model was also forced with freshwater runoff time series at the coast, as described in Hermann et al. (2009). Surface fluxes of heat and momentum are calculated from the National Center for Environmental Prediction using bulk formulae, which include the instantaneous model SST. No tides are included in these simulations.

NEP hindcasts were generated for the period 1958–2004. The results were stored as weekly averages and interpolated onto the Atlantis model geometry using the latitude-longitude coordinates of each box (polygon). Velocities normal to each vertical face of the box, along with the mean salinity and temperature along each face, were then calculated from the stored NEP

hindcast and interpolated in time to create 12-hour time steps (all fluxes in Atlantis are calculated at 12-hour intervals).

# Biological Model

CCAM utilizes 62 functional groups to model biological processes: 5 bacteria/detritus, 8 plankton/algae, 14 invertebrate, and 35 vertebrate. Primary producers and invertebrates are modeled as biomass pools ( $\text{mgN/m}^3$ ), while vertebrate groups are divided into 10 age classes, each tracked by abundance and weight at age. Weights are measured through both structural and reserve nitrogen (measured in  $\text{mgN}$ ), with structural nitrogen ( $N_s$ ) representing bones and other hard parts and reserve nitrogen ( $N_r$ ) representing muscle, fat, reproductive parts, and other soft tissue. The separation of age classes for vertebrates allows for ontogenetic shifts in the parameterization.

## Nutrients

CCAM uses nitrogen as the currency for nutrient exchange. Dissolved inorganic nitrogen is composed of both ammonia (NH) and nitrate (NO). Concentrations of these two nitrogen pools are governed by uptake by autotrophs, excretion by consumers, nitrification, and denitrification.

Rates of change for NH and NO in the water column are:

$$\frac{d(NH_w)}{dt} = - \sum_{i=PX_w} A_{NH_w,i} - A_{NH_w,MB_w} - A_{NH_w,MA} - A_{NH_w,PFB} + \sum_{i=CX_w, BF} E_i + \sum_{i=FX} E_i + \sum_{i=pe\text{lagic bacteria}} E_i - S_{NIT,PAB} + R_{NET} \quad (1)$$

$$\frac{d(NO_w)}{dt} = - \sum_{i=PX_w} A_{NO_w,i} - A_{NO_w,MB_w} - A_{NO_w,MA} + S_{NIT,PAB} \quad (2)$$

where  $A_{N,XX}$  is uptake of NH or NO by autotrophs;  $E_i$  is production of NH by invertebrate consumers ( $i = CX$ ), fish ( $i = FX$ ), and pelagic bacteria;  $S_{NIT,PAB}$  is amount of NH converted to NO by bacteria; and  $R_{NET}$  is amount of NH produced by denitrification.

Full descriptions of the dynamics of bacteria, detritus, and sediment chemistry, as well as specific parameterizations for dinoflagellates and macrophytes, are in Fulton (2004).

## Primary Production

CCAM contains four primary producer groups: seagrass, kelp, and large and small phytoplankton. Estimates of initial abundance and distribution were taken from Brand et al. (2007). Growth is driven by Michaelis-Menten dynamics and varies with nutrient, light, and space availability. Biomass is lost to predation, lysis, and both linear and quadratic mortality. The rate of change for primary producers is:

$$dA / dt = G_A - M_{A,lys} - M_{A,lin} - M_{A,quad} - \sum_{j=1}^n M_{A,Pred_j} \quad (3)$$

where  $G_A$  is growth of autotroph ( $A$ ),  $M_{A,lys}$  is loss of  $A$  due to lysis,  $M_{A,lin}$  is linear mortality of  $A$ ,  $M_{A,quad}$  is quadratic mortality of  $A$ ,  $M_{A,Pred_j}$  is mortality of  $A$  due to predator  $j$ , and  $n$  is number of predators of  $A$ , and where:

$$G_A = \mu_A \times \delta_{irr} \times \delta_N \times \delta_{space} \times AX \quad (4)$$

where  $\mu_A$  is maximum growth rate of autotroph,  $\delta_{irr}$  is light limitation which is  $\min[IRR / k_{IRR}, 1]$ ,  $\delta_N$  is nutrient limitation which is  $N / (k_N + N)$ ,  $\delta_{space}$  is space limitation which is  $1 - (A / \theta_{A,max})$ , and  $A$  is abundance of autotroph.

We adapted values for the half saturation constants ( $k_{IRR}$  and  $k_N$ ) and maximum autotroph biomass ( $\theta_{A,max}$ ) from Fulton (2004).

## Invertebrates

CCAM includes 17 invertebrate groups (Table 1) that are each modeled as biomass pools ( $\text{mgN/m}^3$ ). Densities for invertebrates in coastal boxes were derived from Partnership for Interdisciplinary Studies of Coastal Oceans swath survey data.<sup>1</sup> For all other areas, invertebrate densities were based on Brand et al. (2007).

Changes in invertebrate biomass are affected by growth, predation, and multiple sources of mortality. The rate of change for invertebrate biomass is given by:

$$dI / dt = G_I - \sum_{j=1}^n M_{I,Pred_j} - M_{I,lin} - M_{I,quad} - M_{I,F} \quad (5)$$

where  $G_I$  is growth of invertebrate consumer ( $I$ ),  $M_{I,Pred_j}$  is mortality of  $I$  due to predator  $j$ ,  $n$  is number of predators of  $I$ ,  $M_{I,lin}$  is linear mortality of  $I$ ,  $M_{I,quad}$  is quadratic mortality of  $I$ , and  $M_{I,F}$  is fishing mortality on  $I$ , and where:

$$G_I = \left( \sum_{i=1}^n P_{i,I} \times \varepsilon_{I,i} + \sum_{j=DL,DR} P_{j,I} \times \varepsilon_{I,j} \right) \times \delta_{O_2} \times \delta_{space} \quad (6)$$

where  $P_{i,I}$  is predation on living prey  $i$  by  $I$ ,  $\varepsilon_{I,i}$  is assimilation efficiency of  $I$  feeding on living prey ( $i$ ),  $P_{j,I}$  is predation on detrital prey  $j$  by  $I$ ,  $\varepsilon_{I,j}$  is assimilation efficiency of  $I$  feeding on detrital prey  $j$ ,  $\delta_{O_2}$  is oxygen limitation, and  $\delta_{space}$  is space limitation.

<sup>1</sup> J. Caselle, Marine Science Institute, University of California Santa Barbara. Pers. commun., October 2007.

Oxygen and space limitation apply only to benthic invertebrates living on or in the sediment layer. Oxygen limitation is governed by a Michaelis-Menten relationship in which limitation increases with depth. We adopted half saturation constants and the depth of oxygen horizon for this relationship from Fulton et al. (2004). Similarly, space limitation is driven by Michaelis-Menten dynamics. As the density of an invertebrate group increases beyond a lower threshold, the growth of that group is increasingly inhibited until it reaches a maximum allowed density. Lower thresholds, maximum densities, and half saturation constants for invertebrate space limitation were also adapted from Fulton et al. (2004).

## Vertebrates

CCAM represents vertebrate biomass in 35 functional groups: 26 fish, 3 bird, and 6 mammal (Table 2). Each vertebrate group is divided into 10 age classes, with each class representing one-tenth of the overall life span of the group. For fish groups, we estimated initial abundance at age using instantaneous mortality rates, total abundance, and life span estimates from the literature (Appendix A). We applied von Bertalanffy age-weight relationships to generate initial weights.

Abundance at age is a function of individual movement, predation, fishing mortality, and both linear and quadric mortality terms:

$$dV_{i,a} / dt = T_{Imm,Vi} - T_{Emm,Vi} - \sum_{j=1}^n M_{Vi,Pred_j} - M_{Vi,F} - M_{Vi,lin} - M_{Vi,quad} \quad (7)$$

where  $T_{Imm,Vi}$  is movement of individuals into a cell,  $T_{Emm,Vi}$  is movement of individuals out a cell,  $M_{Vi,Pred_j}$  is mortality due to predator j,  $M_{Vi,F}$  is mortality due to fishing,  $M_{Vi,lin}$  is linear mortality, and  $M_{Vi,Quad}$  is quadratic mortality.

Vertebrate growth follows the same form as for invertebrates (equation 6), but includes an extra term to allocate growth between structural and reserve nitrogen pools:

$$dV_{i,sn} / dt = \Lambda \times G_{Vi} \quad (8)$$

$$dV_{i,rn} / dt = (1 - \Lambda) \times G_{Vi} \quad (9)$$

where  $\Lambda$  describes the relationship between structural and reserve nitrogen for each functional group (Fulton 2004) such that:

$$\Lambda = \frac{(1 / X_{RS}) + X_{pR,V} \times (-V_{i,r} / (X_{RS} \times V_{i,x}))}{(1 / X_{RS}) + (V_{i,r} / (X_{RS} \times V_{i,x}))} \quad (10)$$

if greater than 0 and G is greater than zero; otherwise,  $\Lambda$  equals zero.

Spawning and recruitment also affect vertebrate fluxes, and these processes in CCAM are described below.

## Predation

In their study of alternative grazing formulations in Atlantis, Fulton et al. (2003) determined that the Holling Type II functional response generated similar dynamics to other, more complicated forms of predation. They concluded that the differences in results produced by alternative predation routines did not warrant the additional parameterization required by more sophisticated formulations. Thus we implement the modified version of the Type II response designed by Fulton et al. (2003) to model predation ( $P$ ) by consumers in CCAM:

$$P_{ij} = \frac{B_i \times a_{ij} \times B_j \times C_j}{1 + \frac{C_j}{g_j} \left( \sum_{i=1}^n B_i \times a_{i,j} \times E_{ij} \right)} \quad (11)$$

where  $P_{ij}$  is ingestion of prey  $i$  by predator  $j$  (mgN),  $B_i$  is biomass of prey  $i$  (mgN/m<sup>3</sup>),  $a_{ij}$  is availability of prey  $i$  to predator  $j$  (unitless),  $B_j$  is biomass of predator  $j$  (mgN/m<sup>3</sup>),  $C_j$  is clearance rate of predator  $j$  (m<sup>3</sup>/mgN/day),  $g_j$  is growth rate of predator  $j$  (/day), and  $E_{ij}$  is growth efficiency of predator  $j$  eating prey  $i$  (unitless).

The availability term “ $a$ ” in Equation 11 is a combined measure of prey preference (i.e., contribution of prey in a predator’s diet) and the relative availability of the prey to the predator. It is designed to reflect the notion that not all prey are available to predators at all times. To derive availability parameters, we began by constructing a diet matrix to define the relative contribution of each functional group to each predator’s diet (Table 3); the terms for each predator group in this matrix sum to one. Using these diet data, estimates for initial biomass, clearance, growth, and efficiency, we used the functional response to solve for “ $a$ ” (Table 4), using algorithms developed by Gamble and Link.<sup>2</sup>

The availability parameter “ $a$ ” is inversely related to the half saturation point of the functional response; the result for model dynamics is that predation is linearly related to prey availability when prey is scarce or availability is low. Higher values of availabilities or higher prey abundance lead to higher consumption rates, but with a nonlinear (asymptotic) relationship between prey abundance and consumption rates per predator.

The maximum growth rate “ $g$ ” in Equation 11 represents the upper bound for predator growth when food is abundant (Table 5). This term is related to the maximum ingestion rate ( $G_{max}$ ), which is the asymptote of the Holling Type II functional response (i.e., the maximum ingestion rate per predator when prey is unlimited). Maximum growth rate  $g$  is  $G_{max}$  times  $E$ , where  $E$  represents an average growth efficiency over all food prey types.

For fish groups, we derived the maximum growth rate by utilizing the weight-consumption relationship from fish bioenergetics (Hanson et al. 1997):

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<sup>2</sup> R. Gamble, Northeast Fisheries Science Center, Woods Hole, MA. Pers. commun., 10 October 2007.

$$G_{\max} = CA \times \text{Weight}^{CB} \quad (12)$$

We used weight estimates from von Bertalanffy curves to obtain maximum consumption for an average individual, and we generalized the constants across functional groups, setting  $CA$  equal to 0.3 and  $CB$  equal to 0.7. We considered growth efficiency to be 10% (Pauly and Christensen 1995).

For bird and mammal groups, we derived consumption using mass, daily energy requirements, prey energy densities, and assimilation efficiencies documented in Hunt et al. (2000). Using this approach:

$$G_{\max} = \frac{\text{DailyEnergyRequirement}}{\text{PreyEnergyDensity} \times \text{AssimilationEfficiency}} \quad (13)$$

We considered the consumption rates from this equation to represent daily averages, and we assumed that individuals generally operate at about 30% of their potential maximum. Thus we multiplied the resulting  $G_{\max}$  by three to obtain theoretical maxima. As with fish groups, we assumed a growth efficiency of 10% for calculating the maximum growth rate “ $g$ .”

Clearance is a measure of feeding efficiency when prey is scarce (Table 6). While “ $g$ ” defines the asymptotic growth at high prey abundance, clearance determines the slope of the response curve, that is, the rate at which growth increases with increased food abundance. We based clearance rates on those used by Brand et al. (2007).

## **Spawning and Recruitment**

Reproduction is modeled in two distinct phases in CCAM. First, spawning occurs over a time window specified for each functional group, and the materials (nitrogen) required for reproduction are removed from reserve nitrogen pools, which includes both gonadal and somatic tissue, such that parental weight-at-age declines. After spawning, each age class is incremented by one year, and the oldest class leaves the model domain. Recruitment into the population follows at a specified time after spawning, and new recruits are then assigned to the first age class. The lag time between spawning and recruitment represents larval settlement time for fish, incubation period for birds, and gestation period for mammals.

We modeled recruitment for fish groups using Beverton-Holt dynamics, with alpha and beta parameters taken from stock assessments (Table 2) (Meyers and Barrowman 1996). We estimated bird and mammal recruitment using a fixed number of offspring produced per adult. For birds, recruit per adult is the product of hatch success, broods per year, and clutch size; for mammals, it is the product of number of calves per female, pregnancy rate, proportion of females in population, and pregnancy interval.

## **Habitat Associations**

Habitat types in Atlantis include both physical and biogenic habitats. We defined physical habitats based on two bottom types (soft and hard) and two geographic features



(canyons and seamounts). The area of canyon and seamount habitat per box was determined from bathymetric data, and the area of soft and hard bottom per box was determined from an Essential Fish Habitat study (EFH, NMFS 2004). The proportion of soft versus hard bottom in each box sums to one, with canyon and seamount bottom types being independent.

Biogenic habitat types are kelp, seagrass, and types of benthic filter feeders. Kelp and seagrass percent cover were calculated from EFH habitat data (NMFS 2004).

Vertebrate habitat associations were determined for those species in the Pacific Coast Groundfish Fishery Management Plan from text descriptions provided in Appendix B of the EFH document. Distributions for adults and juveniles were recorded separately whenever data existed at that level of precision. Species level data were then compiled to the level of the functional group.

Invertebrate habitat associations were determined from the California Department of Fish and Game Web site ([http://www.dfg.ca.gov/marine/table\\_inv\\_id.asp](http://www.dfg.ca.gov/marine/table_inv_id.asp)). Habitat use was specified on a species-by-species basis and then compiled at the functional group level. For species or groups (invertebrate or vertebrate) that were not included in either of these data sources, we assumed they used all habitat types and were not dependent on benthic habitat.

## **Movement**

Atlantis simulates movement of individuals at two scales. Within the model domain, movement can be either density dependent or independent. Fulton et al. (2004), however, found that differences in model results at the scale of the Atlantis polygons were slight using the alternative movement algorithms. In CCAM, we employ the simpler density-independent algorithm for individual movement. Five groups are also forced with seasonal migrations such as onshore/offshore movements during spawning seasons; we parameterized this type of within-model movement for small planktivorous fish, hake, midwater rockfish, small flatfish, and miscellaneous nearshore fish. In addition to movement within the model domain, CCAM simulates larger migratory events for nine vertebrate groups: small planktivorous fish, large pelagic predators, salmon, hake, migrating seabirds, piscivorous seabirds, pinnipeds, baleen whales, and toothed whales (Table 7).

# Model Calibration

Atlantis is a simulation model that projects differential equations forward in time, based on a set of ecological parameters and initial conditions (biomasses, weights at age, and numbers at age). Unlike statistical models such as stock assessments, Atlantis does not use automated optimization algorithms to estimate parameters within the model; instead, parameters are derived outside the model prior to beginning a simulation. However, we use an iterative process to tune or calibrate the model, adjusting parameters to reproduce more ecologically reasonable dynamics and to fit historical observations. This feedback approach typically involves adjusting the most uncertain parameters (e.g., predator-prey interaction rates) to try to re-create observed patterns (e.g., weight at age from field data). This type of qualitative parameter adjustment is labor intensive, but gives the modeler a strong understanding of the key parameters and sensitivities in the model. Below we describe the steps used to calibrate or tune CCAM.

We calibrated the dynamic behavior of CCAM in three phases. In the first phase, we initialized the model with 2008 estimates of biomass and ran the model forward without fishing. Our initial goals in these runs were to keep functional groups from going extinct and achieve vertebrate weights at age ( $R_n$  and  $S_n$ ) within 0.5 and 1.5 times their initial values. Weight at age has fluctuated by similar amounts in the California Current for species such as English sole (*Parophrys vetulus*) and Pacific hake (*Merluccius productus*) (Stewart 2005, Helser et al. 2008). This range is also consistent with twofold variability in weight at age seen for species such as Atlantic cod (*Gadus morhua*) (Sherwood et al. 2007). In the absence of fishing, we assumed that the system should return to a condition similar to its state prior to major commercial exploitation, and thus we used estimates of unfished biomass ( $B_0$ ) as calibration targets. We derived these target biomass levels for 14 functional groups using historical estimates from stock assessments. We generally used 1950 biomass levels as proxies for unfished condition. For groups that did not have unfished biomass estimates from stock assessments or other sources, our goal was merely to produce reasonable, steady biomass through time.

Extinctions during calibration typically pointed to excessively high levels of predation or extremely low productivity of the stock. The primary parameters involved with resolving these problems included maximum growth rates ( $g$ ), clearance rates ( $C$ ), and predation pressure dictated by the availability parameter ( $a$ ). Additionally, recruit weights (referred to in Atlantis parameter files as KWRR and KWSR for reserve and structural weight, respectively) and assimilation efficiencies ( $E$ ) were important for tuning vertebrate weights at age. Once weights at age were stable, vertebrate biomass could be adjusted by manipulating Beverton-Holt recruitment parameters for fish groups ( $\alpha$  and  $\beta$ ), constant recruitment parameters for birds and mammals (KDENR), and linear and quadratic mortality.

Quadratic mortality, a density-dependent control, can be used when explicit predation in the model is not sufficient to cap growth or generate reasonable age structures. We found this to be a useful parameter for top predators and other groups with small levels of predation. Linear mortality is density independent and represents death from disease, senescence, or other

mortality sources not explicitly modeled; we used it to fine-tune the projections of un-fished abundance. While we tried to explicitly model as much mortality as possible and minimize our use of the linear mortality term, we found that some level of forced linear mortality was required to generate stable dynamics. Overall, our iterative approach in this first phase of calibration was first to adjust weights at age and abundances to prevent extinctions, then to fine-tune weights at age, and finally to further calibrate biomass, matching  $B_0$  where appropriate by adjusting recruitment and mortality parameters. One of the advantages of Atlantis, particularly for vertebrates, is that it allows this sort of explicit tracking and checking of numbers at age and weights at age.

In the second phase of calibration, we exercised the model with varying degrees of fishing pressure to evaluate responses of functional groups when perturbed. For these scenarios, we did not attempt to simulate fleet dynamics, but rather applied constant fishing mortality (denoted in Atlantis parameter files as  $m_{FC}$ ) on all fish groups, market squid (*Loligo opalescens*), shrimp, and large megazoobenthos (crabs) throughout the duration of the simulation. We expected biomass to decrease in response to fishing without going extinct at reasonable levels of fishing pressure. Generally, we expected highly productive stocks such as small planktivores to be able to withstand moderate amounts of fishing mortality, and unproductive, long-lived groups like rockfish (*Sebastes* spp.) to decline under similar fishing rates. More specifically, at fishing levels equal to the natural mortality rate ( $M$ ), we expected functional group biomass to decline by 50% compared to a no-fishing scenario (roughly assuming that the level of fishing mortality that results in the maximum sustainable yield [ $F_{MSY}$ ] =  $M$  and biomass at maximum sustained yield [ $B_{MSY}$ ] = 50%  $B_0$ , Gulland 1970). Cases where biomass was too sensitive or robust to additional fishing pressure usually pointed to problems with recruitment, and thus adjusting productivity via recruitment was generally the best solution.

In the final phase of calibration, we evaluated the model's ability to replicate historical biomass trends under historical fishing pressures (Table 8 and Table 9). During these runs, we initialized the model with 2008 biomasses and let it equilibrate for 50 years to achieve a pseudo-unfished condition. We then applied fishing using historical time-series catch data from 1950 to 2008 and compared biomass output to historical biomass data from the same time period. We did not attempt to parameterize multiple fleets for these simulations, but rather used the time-series data to force catch for a single "umbrella" fleet. We compiled historical fishing data (catch or landings) for 19 functional groups. Of this subset, we had biomass time series for all but market squid. For groups that did not have historical biomass data to guide tuning, we relied on phase two of the calibration process to ensure that these groups responded reasonably to fishing pressure.

# Model Performance

## Initial Calibration: No Fishing

Our goal for vertebrates in the initial tuning phase was to produce a steady unfished condition in the absence of fishing (Figure 3a through Figure 3j). We obtained 1950 biomass estimates from stock assessments or other literature sources for 21 functional groups, and we were able to closely match the literature and model values of 1950 biomass for all but three groups in the first phase of calibration. We did not attempt to quantify the model fit in these simulations, but rather qualitatively compared model estimates and historical data. Groups that did not perform well in this phase of calibration included yelloweye rockfish (*Sebastes ruberrimus*) and cowcod (*S. levis*), toothed whales, and baleen whales. None of these groups reached a steady state during the 85-year run, and thus it was difficult to determine how well their parameterizations would replicate historical estimates. The long-lived nature of these groups made them particularly difficult to tune, as effects of calibration were slow to arise in any given run. But despite their relatively poor performance in the initial calibration, we were able to address these problems in subsequent tuning efforts.

For groups that lacked historical biomass estimates, we aimed to keep groups from going extinct and to achieve stable biomass through time. Generally this expectation is similar to assumption of the existence of a stable, unfished biomass ( $B_0$ ) in stock assessments (e.g., Methot 2009), a carrying capacity in classic ecological models (e.g., Gause 1934), or mass balance in other ecosystem models (e.g., Polovina 1984). However, unlike these other model types, Atlantis does not strictly impose stability, and all groups continue to show some dynamics even after long simulations. In general, stability in Atlantis is an emergent property due to resource limitation, though it is also influenced by the stock recruitment parameterization (for fish only). True equilibrium behavior is prevented by stochastic shocks from the oceanographic and fishery catch forcing, and is delayed by the long age span of many vertebrates.

Most vertebrate groups performed well in these simulations, reaching a steady state by the end of the run. Some groups such as deep miscellaneous fish, nearshore fish, and small demersal sharks were exceptions, but we were able to address related problems in the following calibration stages.

Our goal with vertebrate densities (Figure 4a through Figure 4f) during the initial calibration phase was to maintain a reasonable age structure that roughly followed an exponential decline in abundance with age, as might be expected based on natural mortality rates. Cases in which equilibrium abundance did not decline with age suggested a lack of mortality, and we increased the predation availability parameter ( $a$ ) and linear and quadratic mortality to resolve these issues. We were successful in most cases, but some groups such as large pelagic predators (albacore tuna [*Thunnus alalunga*]), yelloweye rockfish and cowcod, and sablefish (*Anoplopoma fimbria*) continue to show questionable age structure. However, the majority of functional groups demonstrated reasonable age structure at the unfished equilibrium.

We considered the optimal range for weights at age after the initial phase of calibration to be between 0.8 and 1.2 times initial values, although a broader range between 0.5 and 1.5 was deemed acceptable (Figure 5a through Figure 5f and Figure 6a through Figure 6f). The majority of groups at least fell within the broader range, and some groups remained close to initial values (e.g., sea otter [*Enhydra lutris*], migratory birds, demersal sharks). The primary parameters that we adjusted to calibrate weight at age included maximum growth rates ( $g$ ), clearance rates ( $C$ ), and weight of recruits (KWSR and KWRR). We did not force or expect weight at age to be constant, since Atlantis allows differential growth based on time-varying consumption rates; instead, modeled weight at age varied within the ranges mentioned above.

Primary producers and invertebrates were difficult to tune due to a lack of good calibration targets and their sensitivity to changes in parameterization of seemingly unrelated groups. Our primary goal was to keep these groups from extinction, but we were unsuccessful in several cases. Macroalgae, benthic filter feeders, and benthic grazers were particularly sensitive, and each went extinct within a few years of the model start. Attempts to resolve these problems resulted in extinction of alternate groups. The remaining primary producers and invertebrates did not go extinct in these simulations; some groups such as large phytoplankton, microzooplankton, large carnivorous zooplankton, and shrimp showed large but bounded fluctuations, while others such as shallow benthic filter feeders and large megazoobenthos continued to increase indefinitely. These difficulties in calibrating primary producer and invertebrate biomass necessitate further tuning efforts in the future, but also reflect the relative lack of data for these groups compared to the fish, mammal, and bird species that are the focus of the model.

## Secondary Calibration: Constant Fishing Pressure

In the second phase of calibration, we applied a range of fishing mortalities to evaluate biomass responses to varying levels of harvest (Figure 7a through Figure 7m). We had expected that fishing mortality rates equal to the natural mortality rate (Table 2) would be sustainable, leading to equilibrium biomasses of approximately one-half the unfished biomass. Our results show that only large pelagic predators (albacore tuna) appeared able to sustain fishing mortality rates ( $F = 0.5 \text{ year}^{-1}$ ) substantially higher than natural mortality ( $M = 0.3$ ); however, this group migrates outside the model domain for most of the year and therefore experiences only a fraction of the imposed fishing rates.

All other species were heavily depleted when fishing rates exceeded natural mortality rates (Figure 6a through Figure 6f). In fact, 16 of 24 harvested species appeared to have maximum sustainable fishing mortality rates ( $F_{\text{MSY}}$ ) of one-third or less of natural mortality. In particular, most rockfish (*Sebastes* spp.) and thornyhead (*Sebastolobus* spp.) functional groups appeared to have  $F_{\text{MSY}}$  greater than 0.01 but less than 0.05, flatfish groups'  $F_{\text{MSY}}$  is approximately 0.1, and large planktivores'  $F_{\text{MSY}}$  is approximately 0.1. Patterson (1992), Patterson et al. (2001), and Walters and Martell (2002, 2004) have suggested that a useful rule of thumb is that sustainable fishing mortality rates rarely exceed 0.5–0.8 times natural mortality. Though a full analysis of this issue would require testing a finer range of fishing mortality rates as well as a comprehensive comparison to  $F_{\text{MSY}}$  estimated in single species assessments, it is clear that our Atlantis model achieves a satisfactory representation of the true productivity of California Current stocks.

## Final Calibration: Historical Fishing Pressure

In the final calibration, we first ran the simulation without fishing to attain an unfished condition that resembled 1950 biomass levels. After this initial “spin up,” we applied historical catches in order to replicate biomass time series from 1950 to 2007 (Figure 8a through Figure 8j). In the initial calibration phase, most groups had reached near-equilibrium unfished biomass conditions by year 50; thus we allowed 50 years for spin up before applying fishing mortalities.

Of the 18 groups for which we had historical time series data, all but four groups qualitatively matched historical responses, and we characterized successful tuning efforts in three tiers: 1) both magnitude and behavior of biomass were similar to historical time series for entire length of run (deep large rockfish, Dover sole [*Microstomus pacificus*], sablefish, canary rockfish [*Sebastes pinniger*]); 2) biomass response to fishing mortality replicated historical response over the entire run, but the magnitude was inconsistent (deep small rockfish, midwater rockfish, large flatfish, yelloweye rockfish and cowcod); and 3) biomass matched either the magnitude or the trend given by historical data for some part of the time series, but not for the entire duration of the run (shallow large rockfish, shallow small rockfish, skates and rays, small flatfish, large pelagic predators [albacore tuna], shortbelly rockfish [*S. jordani*]). CCAM was unable to replicate either biomass abundance or behavior of small planktivorous fish, large planktivorous fish, hake, and large demersal predators.

The responses in age structure to historical fishing depended on the magnitude of the difference between total mortality under the unfished scenario (from predation) and total mortality under the historical scenario (from predation and fishing) (Figure 9a through Figure 9f). In the initial tuning phase (without fishing), we attempted to produce equilibrium age structures that roughly followed an exponential decline in abundance with age, and in many cases these patterns persisted after we applied fishing mortality (e.g., shallow small rockfish, deep small rockfish, small flatfish, Dover sole, hake, shortbelly rockfish). For groups with little predation mortality in the unfished model (e.g., large pelagic predators [albacore tuna], yelloweye rockfish and cowcod), the addition of fishing mortality created more truncated age structures with fewer older individuals. For some species, high historical fishing mortality led to severely truncated age structures and a scarcity of older individuals (e.g., midwater rockfish, canary rockfish, sablefish, deep large rockfish). CCAM projections of biomass under historical catch forcing tended to closely agree with stock assessment and monitoring trends for these heavily fished groups with highly truncated age structure.

Weights at age, as represented by structural and reserve nitrogen (Figure 10a through Figure 10f and Figure 11a through Figure 11f), were generally robust to the addition of fishing mortality. While some groups began to fall outside of preferred size ranges, most groups continued to follow trends that were established prior to fishing. Large fluctuations in weight at age are evident where fishing caused extinction, but these crashes in size merely reflect the extinction event, that is, individuals have no size simply because none remain in the model.

## Discussion

Our work with CCAM is driven by a need for more sophisticated modeling approaches to help characterize the efficacy of management actions within the California Current ecosystem. CCAM brings together physical, chemical, and biological processes in a three-dimensional framework that allows for exploration and testing at a variety of spatiotemporal scales. While no such model will ever perfectly replicate ecosystem processes in nature, we have calibrated and tested CCAM under a wide variety of conditions, and we believe the model produces an adequate representation of ecosystem dynamics. Thus we believe CCAM to be a powerful management tool, providing a platform for addressing important hypotheses relating to the effects of perturbations (e.g., harvest), characterizing the potential trade-offs of alternate management actions, and testing the utility of ecosystem indicators for long-term monitoring programs.

In our tests against historical data, CCAM successfully replicated biomass behavior for 14 of the 18 groups for which we had historical time series. While some groups closely matched magnitudes of historical biomass, we focused primarily on simulating general patterns rather than absolute abundance. In most cases, CCAM required increased biomass relative to single species estimates to sustain historical fishing pressures. Historical estimates are derived from single species models, which lack the spatial complexity and trophic interactions (e.g., predation mortality) embedded in Atlantis and present in the real ecosystem. As such, deviations in Atlantis output with respect to single species simulation tools are expected, and this behavior is consistent with that found in the southeast Australia Atlantis model (Fulton and Smith 2007). As a strategic tool, the power of CCAM lies in its ability to reveal patterns rather than replicate absolute biomass estimates produced by more tactical approaches.

Fishing tended to be the primary driver for groundfish biomass in the historical CCAM scenario, but forage fish tended to be less responsive to the addition of historical harvests. These relative influences of fishing have been documented across multiple Atlantis models (Fulton et al. in prep.), and they contributed to our ability to model some groups more effectively (e.g., fishery targets like rockfish) than others (e.g., planktivores). Large and small planktivorous fish were particularly difficult to model, as their historical fluctuations likely reflect responses to large-scale climactic variation rather than fishing or direct trophic effects (Chavez et al. 2003).

Recruitment responses to climate drivers are difficult to model in Atlantis with the recruitment routines currently in use. Future simulations using the suite of spawning and recruitment options already implemented for Australian Atlantis models could allow us to tie recruitment to climate and model these groups more effectively. Other groups for which stock assessments suggest strong repeated fluctuations in abundance (e.g., large pelagic predators [albacore tuna], shortbelly rockfish, small flatfish, hake) may also benefit from alternate recruitment routines. Variation at short (annual) time scales may reflect variable recruitment that is not captured by our use of the Beverton-Holt stock recruitment relationship.

Other groups that responded poorly to historical fishing pressure were hake and large demersal predators. The difficulties with hake most likely stem from the large amount of time they spend outside of the model domain, as we can only crudely calibrate growth and mortality rates for stocks that are outside the model domain. Furthermore, single species stock assessments (Helser and Martell 2007) suggest that this species has strong fluctuations in juvenile production, with only six strong recruitment years since 1966. As mentioned above, CCAM's use of smooth Beverton-Holt recruitment dynamics may be replaced in future simulations.

For large demersal predators, the very strong declines projected in the historical Atlantis model may be tied to slight underestimates of the productivity of this stock. Our tests with constant fishing mortality rates suggest that the simulated functional group can sustain fishing rates of 0.1 but is heavily depleted at  $F = 0.2$ , while the single species assessment for lingcod (*Ophiodon elongatus*) (Jagiello and Wallace 2005) suggest that fishing mortality rates averaging 0.12 and 0.2 through the 1980s and 1990s (in the north and south, respectively) caused only moderate declines. Thus productivity of our large demersal predator stock may be slightly less than real-world potential yields. Further calibration of both hake and large demersal predators can resolve these issues.

CCAM is one of 13 Atlantis models developed for marine ecosystems, and 7 more models are under development (Fulton et al. in prep.). For more than a decade, Atlantis has been used to understand the dynamics of exploited marine systems, identify major processes such as fishing and oceanographic effects, highlight major gaps in knowledge, and provide a "flight simulator" to test management strategies before implementing them in reality. Atlantis is an ideal tool for this sort of management strategy evaluation; it tests scenarios for management, assessment, and monitoring against simulations that represent a real ecosystem and its complexities (Sainsbury et al. 2000, Fulton and Smith 2007). CCAM should prove to be useful in identifying which policies and methods have the most potential to inform ecosystem-based management on the U.S. West Coast.



## **Figures 1a–11f and Tables 1–9**

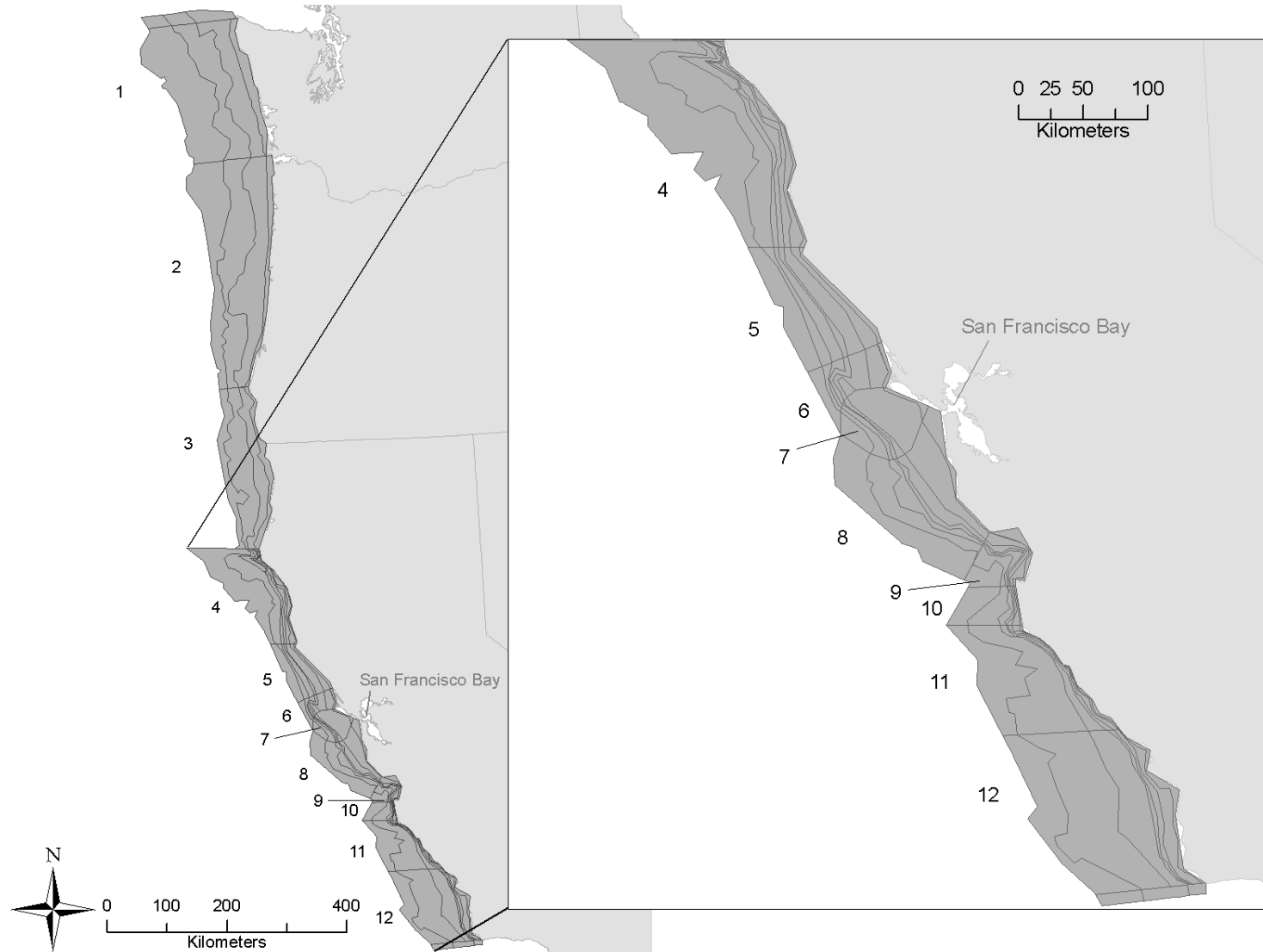


Figure 1. Spatial extent of the CCAM. The model consists of 12 longitudinal divisions determined by geographical features and management boundaries. Spatial resolution is coarse in the northern boxes and finer in the southern regions. The inset shows finer resolution in the southern extent of the model.

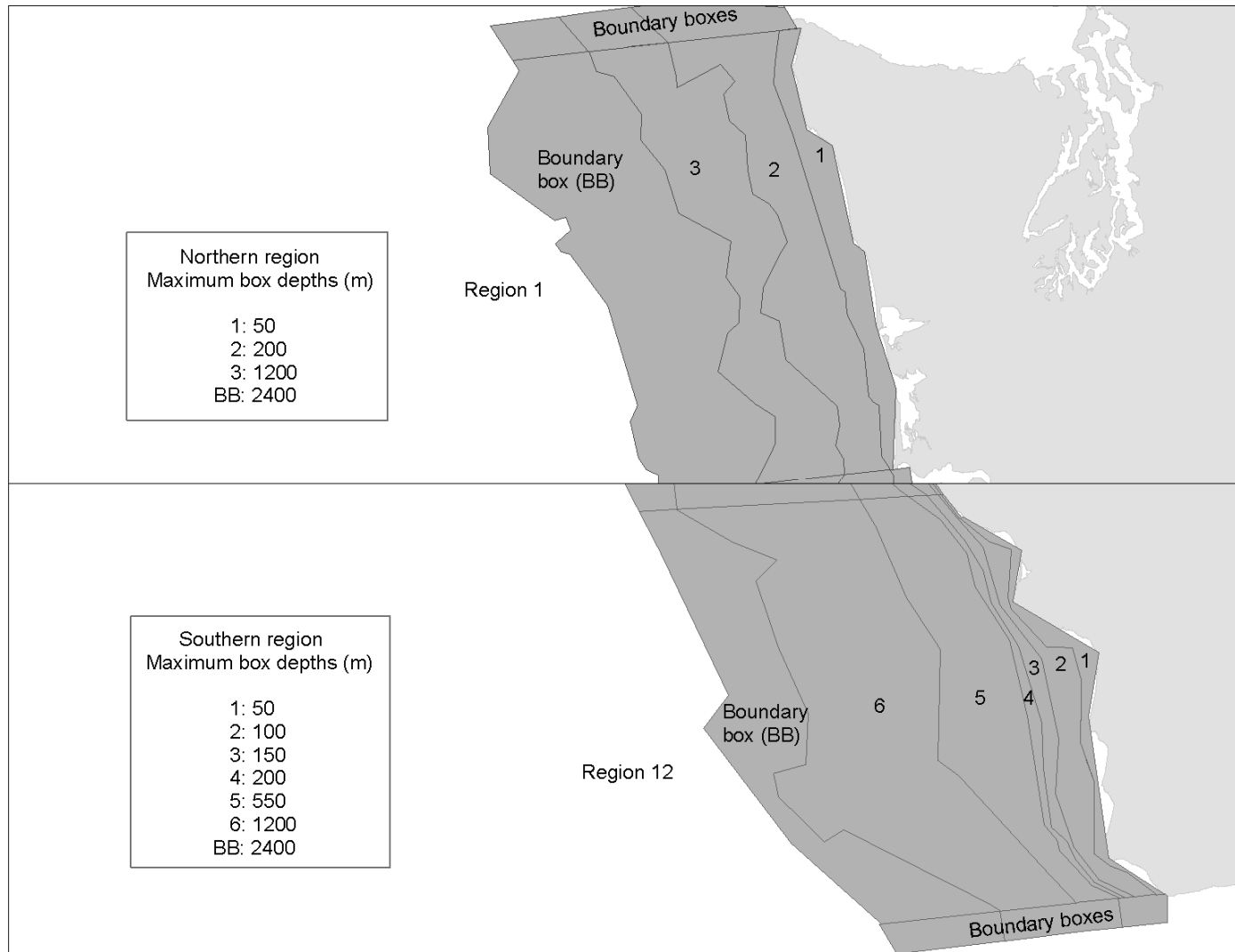


Figure 2. Spatial resolution of CCAM. Resolution varies throughout the model extent. Top panel demonstrates northern region breaks with four boxes from east to west; bottom panel demonstrates southern region breaks with seven boxes east to west. Each box contains up to seven water column layers defined by the following isobaths: 0–50 m, 51–100 m, 101–150 m, 151–200 m, 201–550 m, 551–1,200 m, and 1,201–2,400 m. The number of vertical layers per box increases from east to west. Each box also contains a single sediment layer.

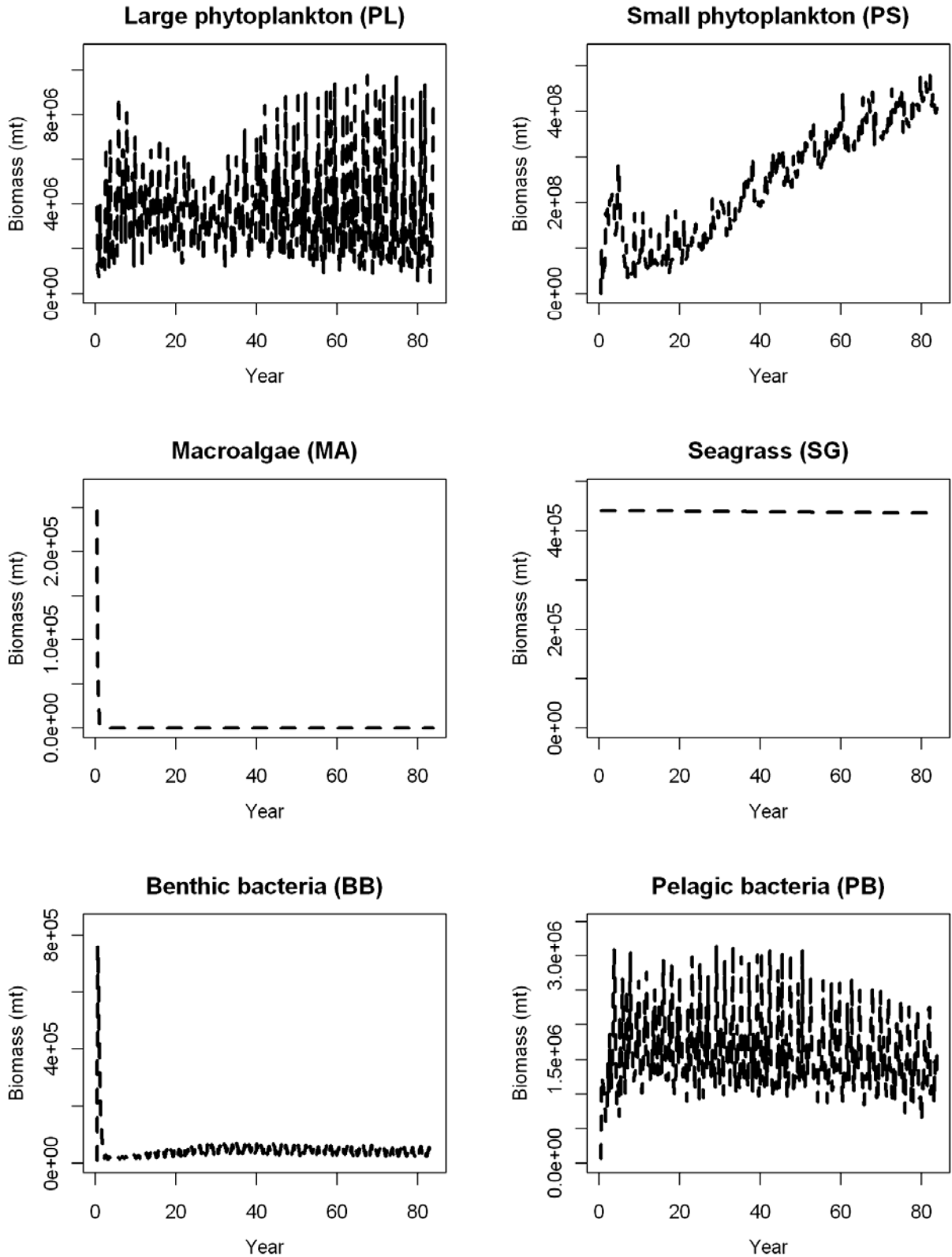


Figure 3a. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. X-axis shows years from start of simulation.

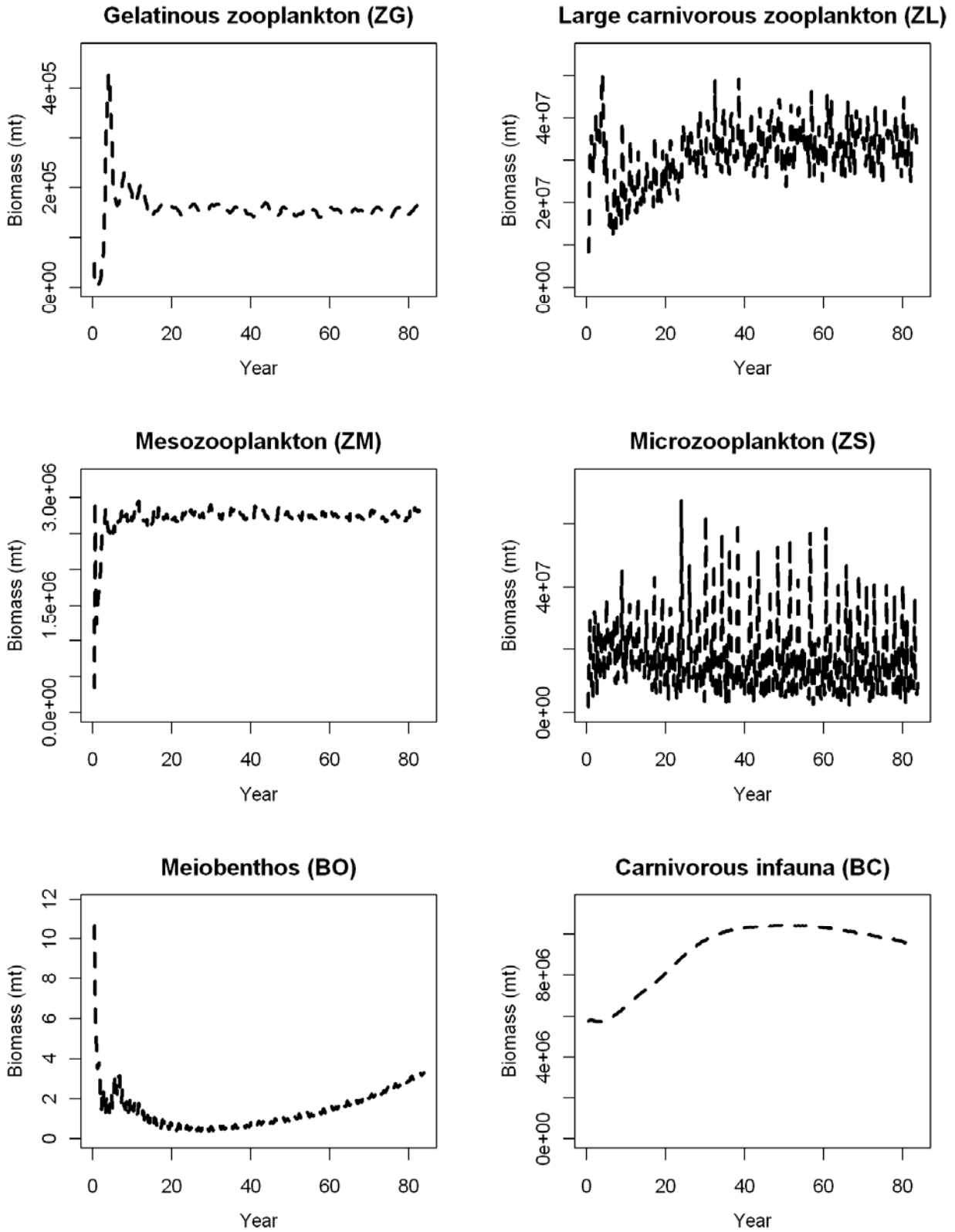


Figure 3b. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. X-axis shows years from start of simulation.

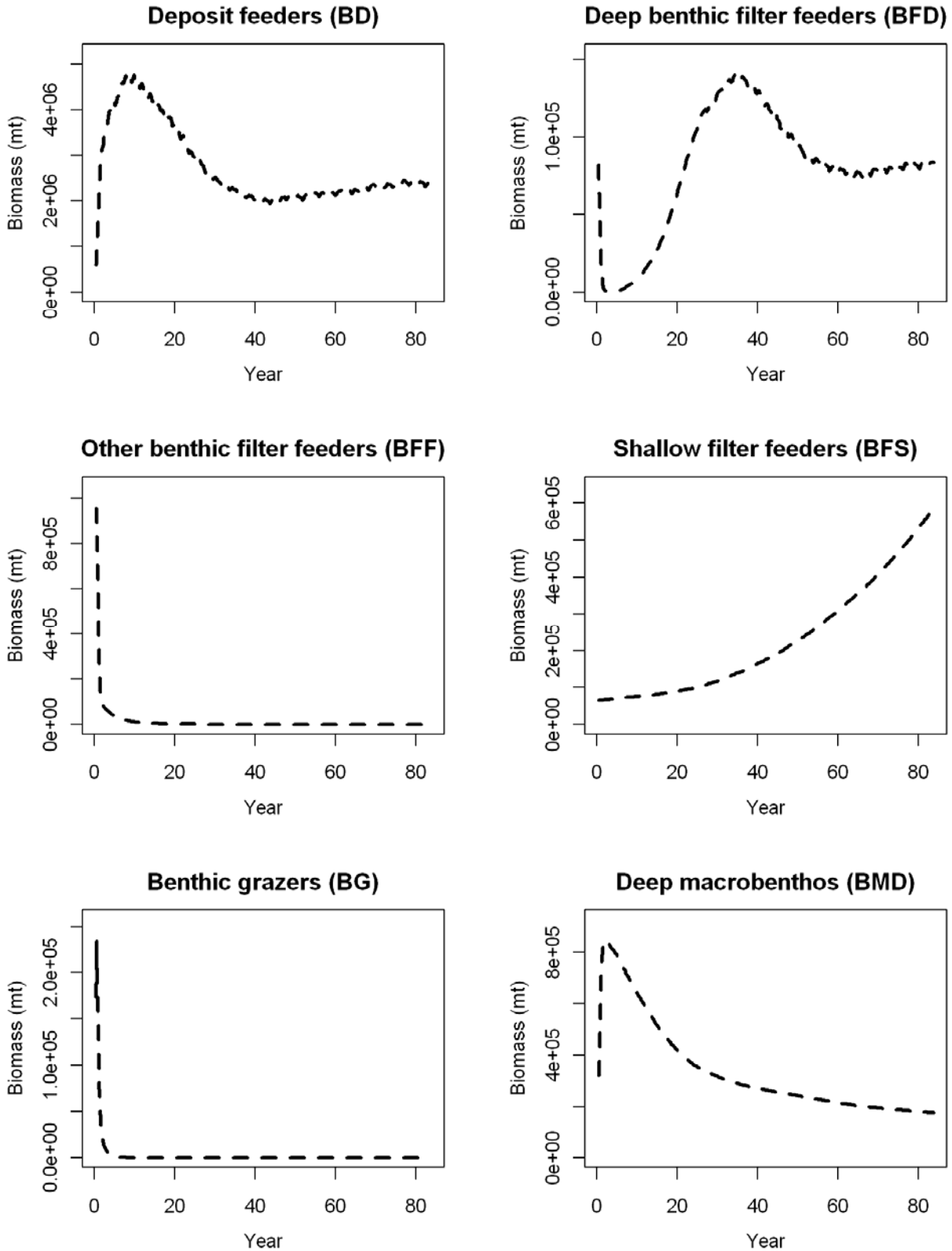


Figure 3c. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. X-axis shows years from start of simulation.

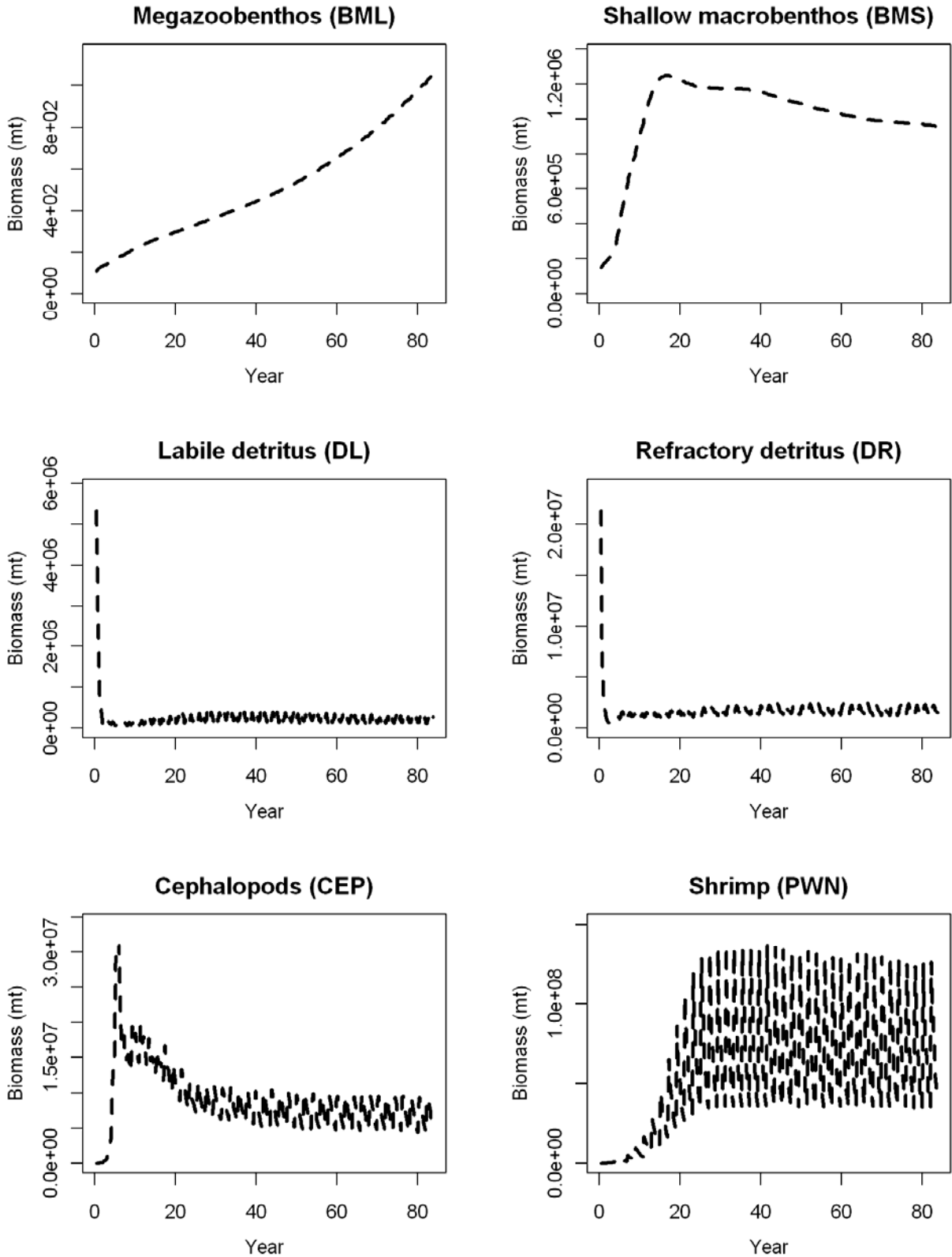


Figure 3d. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. X-axis shows years from start of simulation.

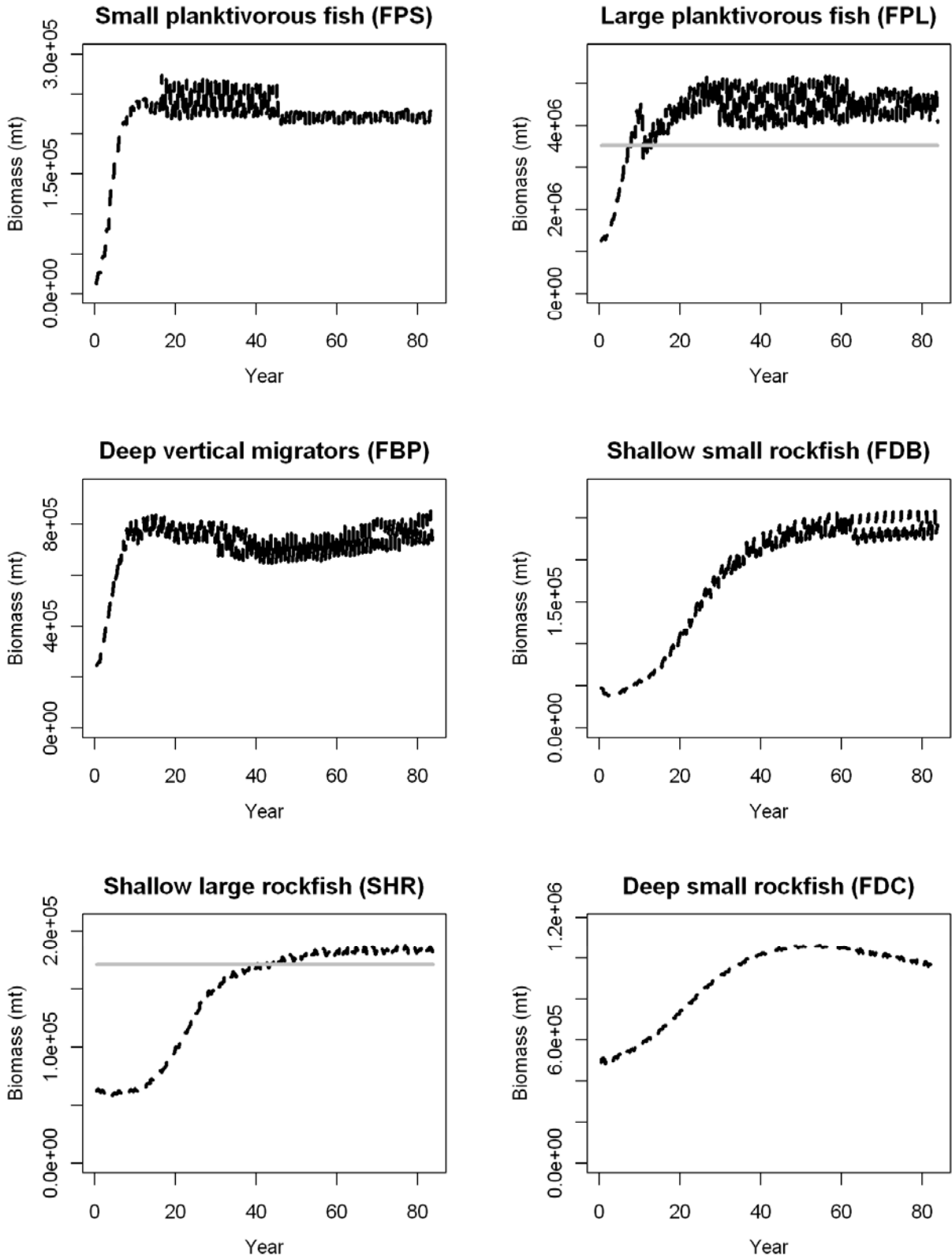


Figure 3e. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. Solid gray lines indicate 1950 biomass estimates where available (22 groups). X-axis shows years from start of simulation.



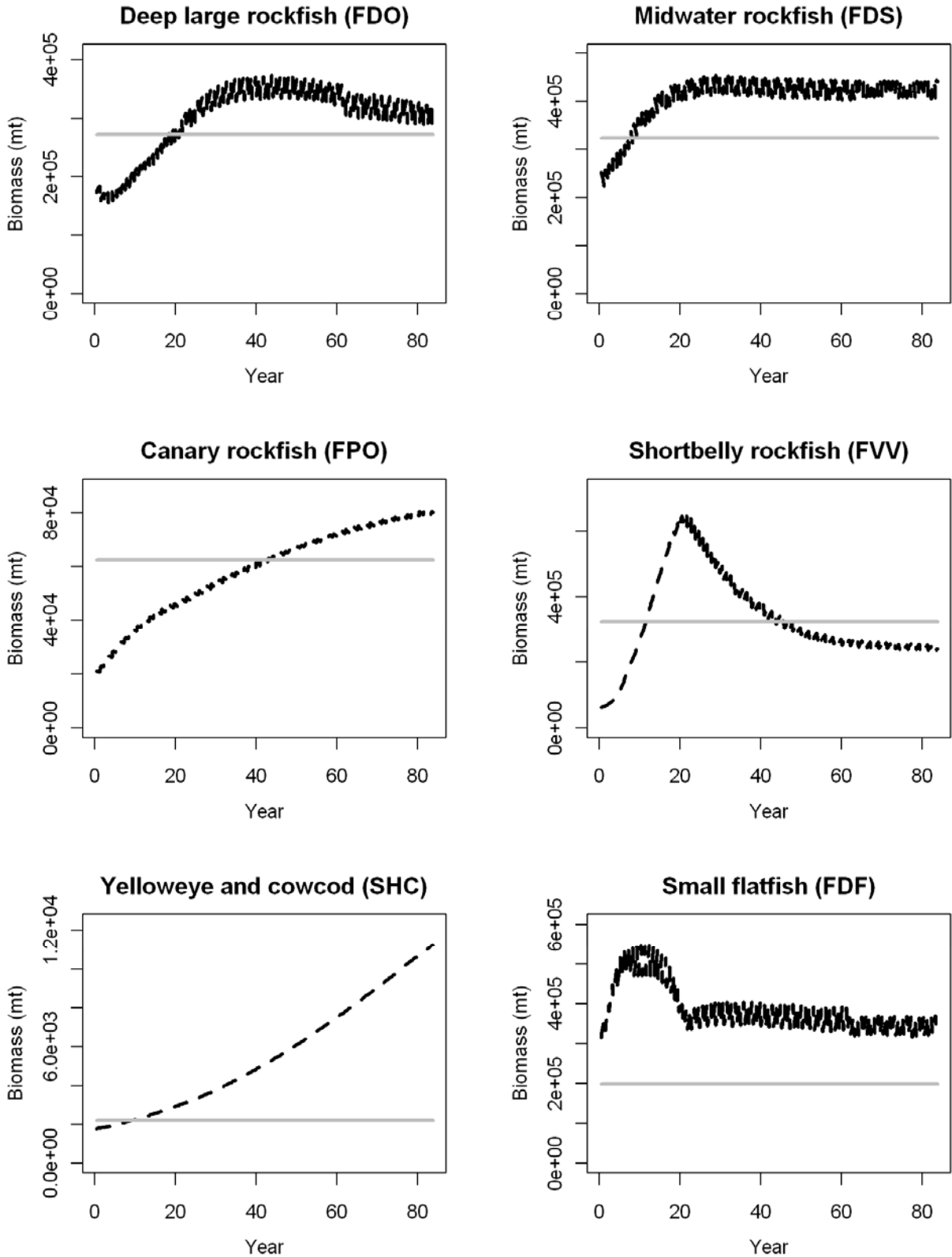


Figure 3f. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. Solid gray lines indicate 1950 biomass estimates where available (22 groups). X-axis shows years from start of simulation.

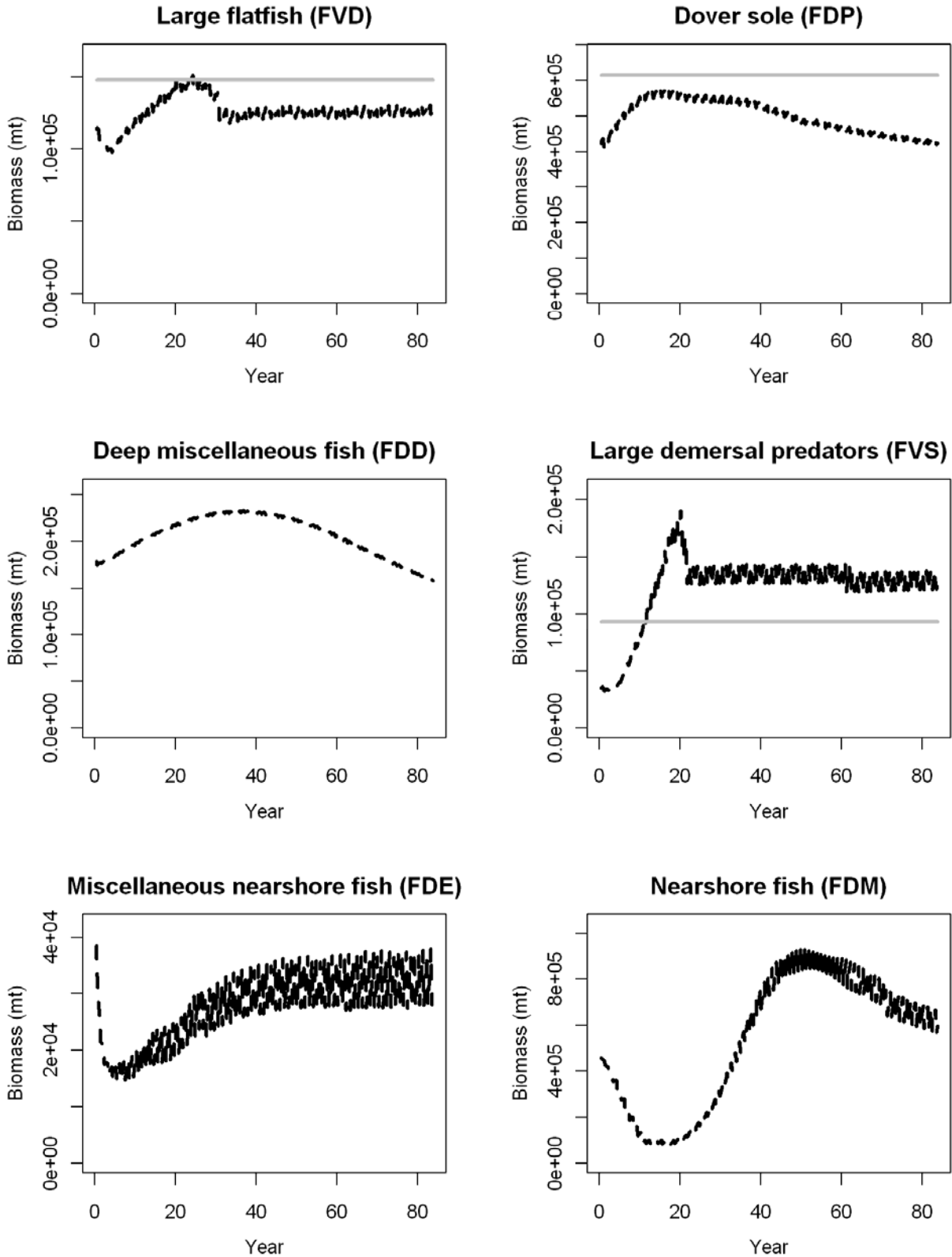


Figure 3g. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. Solid gray lines indicate 1950 biomass estimates where available (22 groups). X-axis shows years from start of simulation.

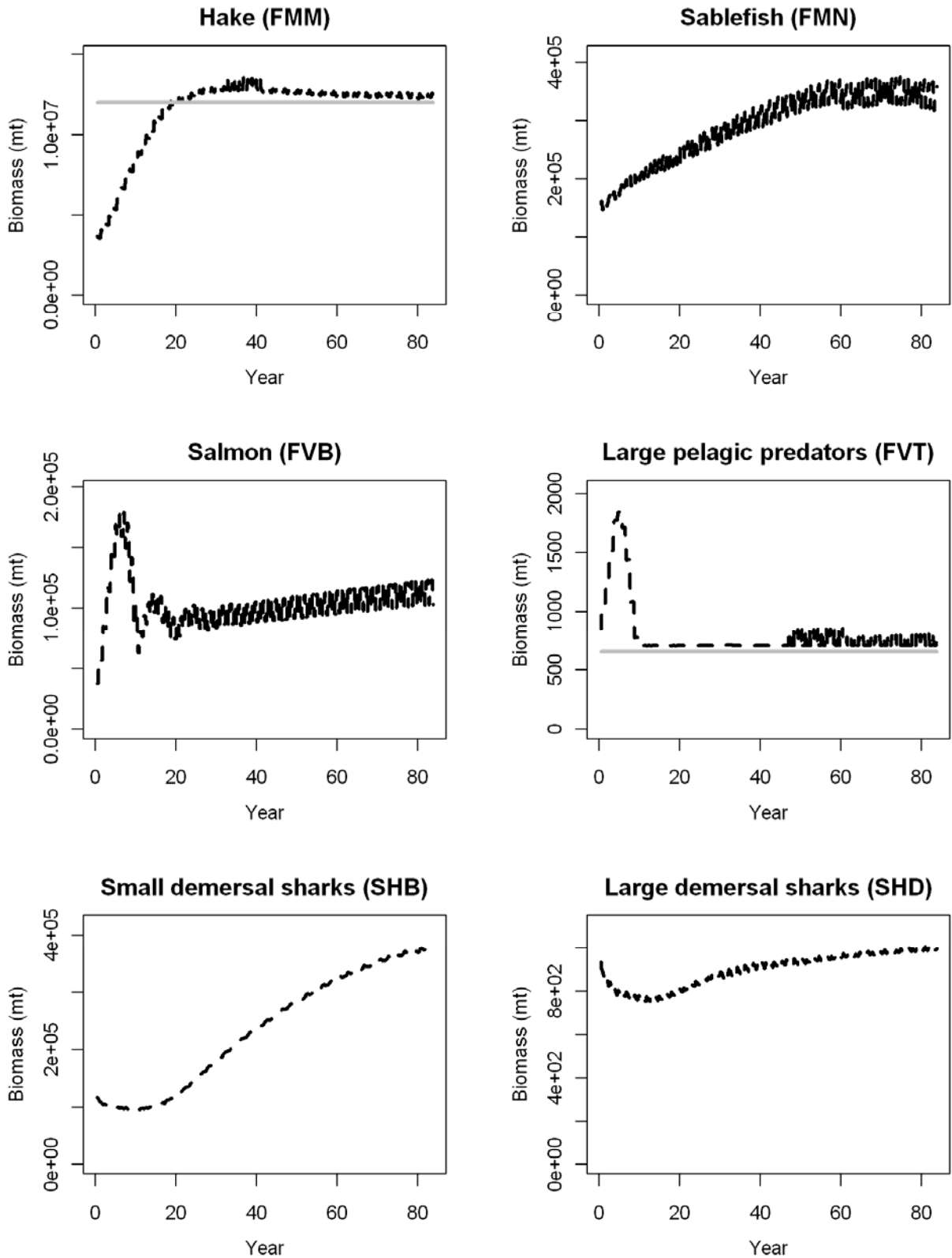


Figure 3h. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. Solid gray lines indicate 1950 biomass estimates where available (22 groups). X-axis shows years from start of simulation.

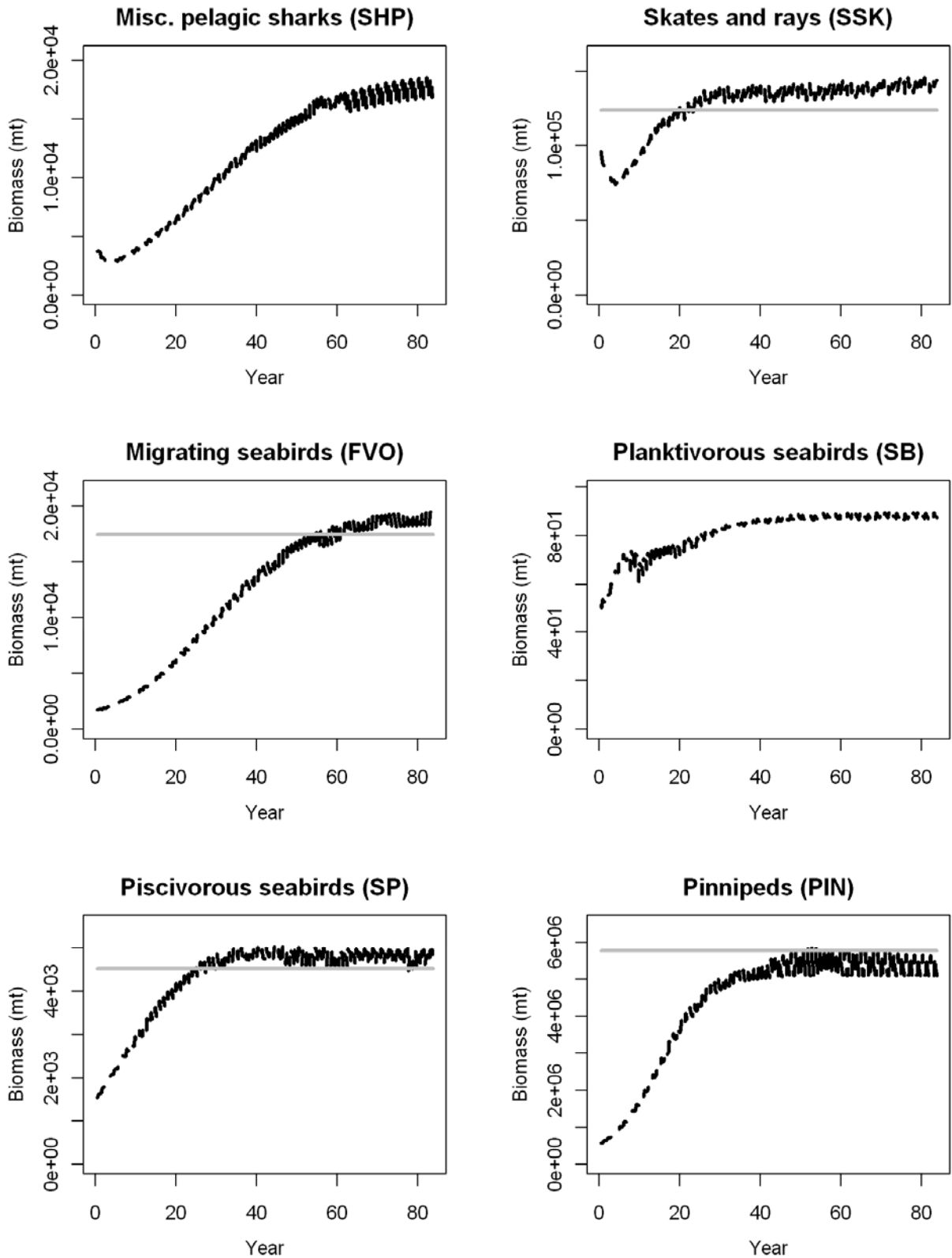


Figure 3i. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. Solid gray lines indicate 1950 biomass estimates where available (22 groups). X-axis shows years from start of simulation.

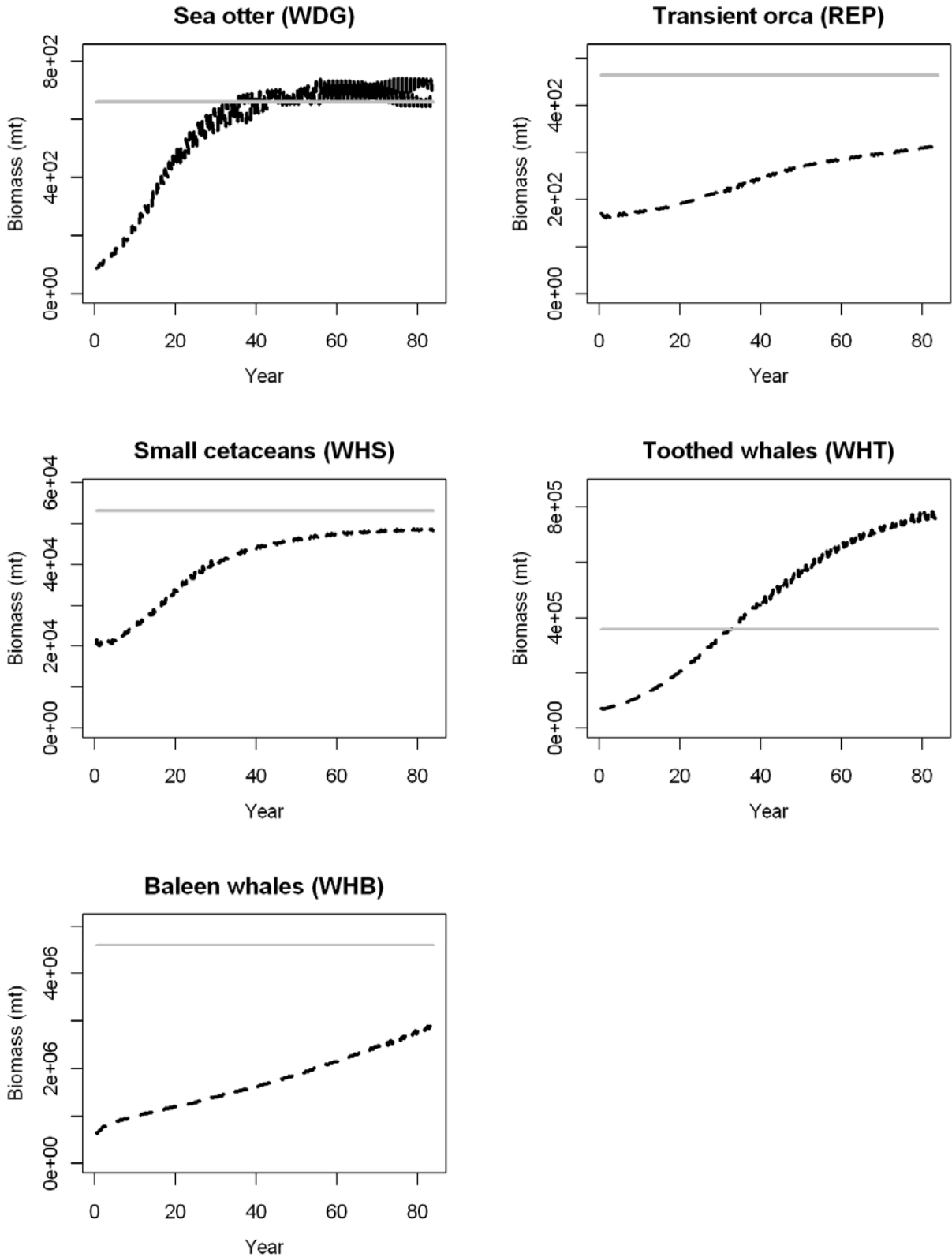


Figure 3j. Biomass results for each functional group after initial tuning phase. Biomass is represented in metric tons summed over the entire model extent. Solid gray lines indicate 1950 biomass estimates where available (22 groups). X-axis shows years from start of simulation.

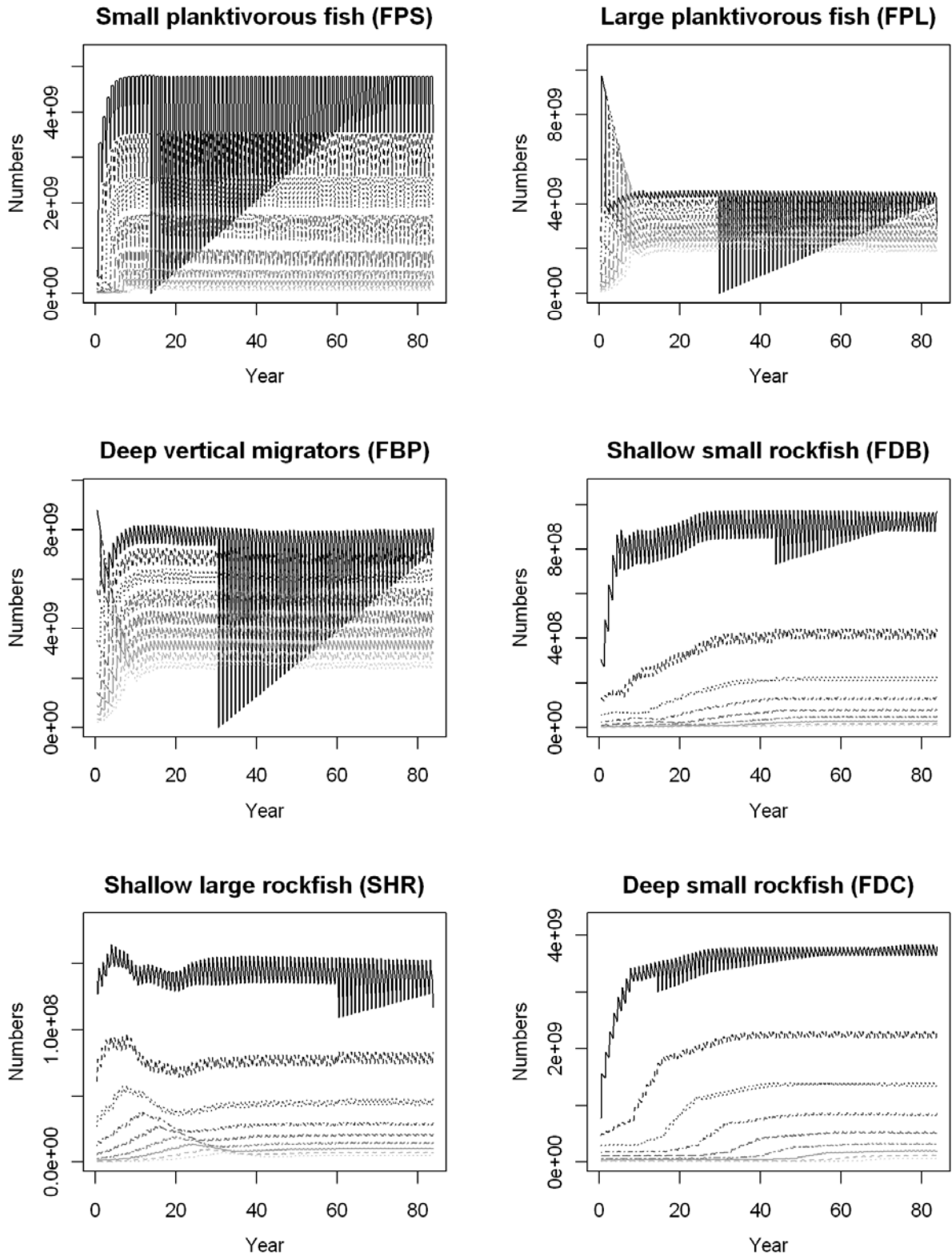


Figure 4a. Total numbers for each age class per vertebrate functional group after initial tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

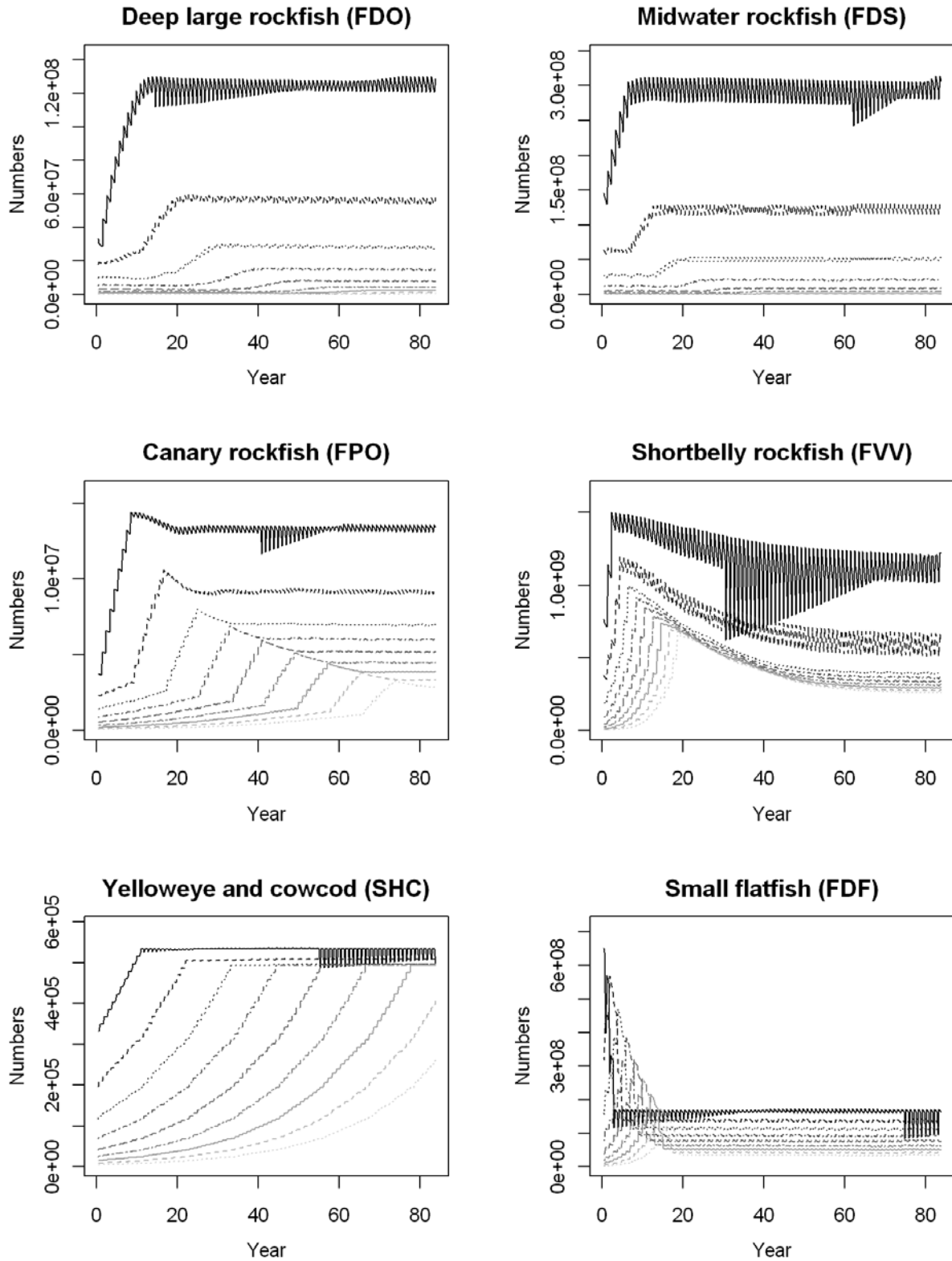


Figure 4b. Total numbers for each age class per vertebrate functional group after initial tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

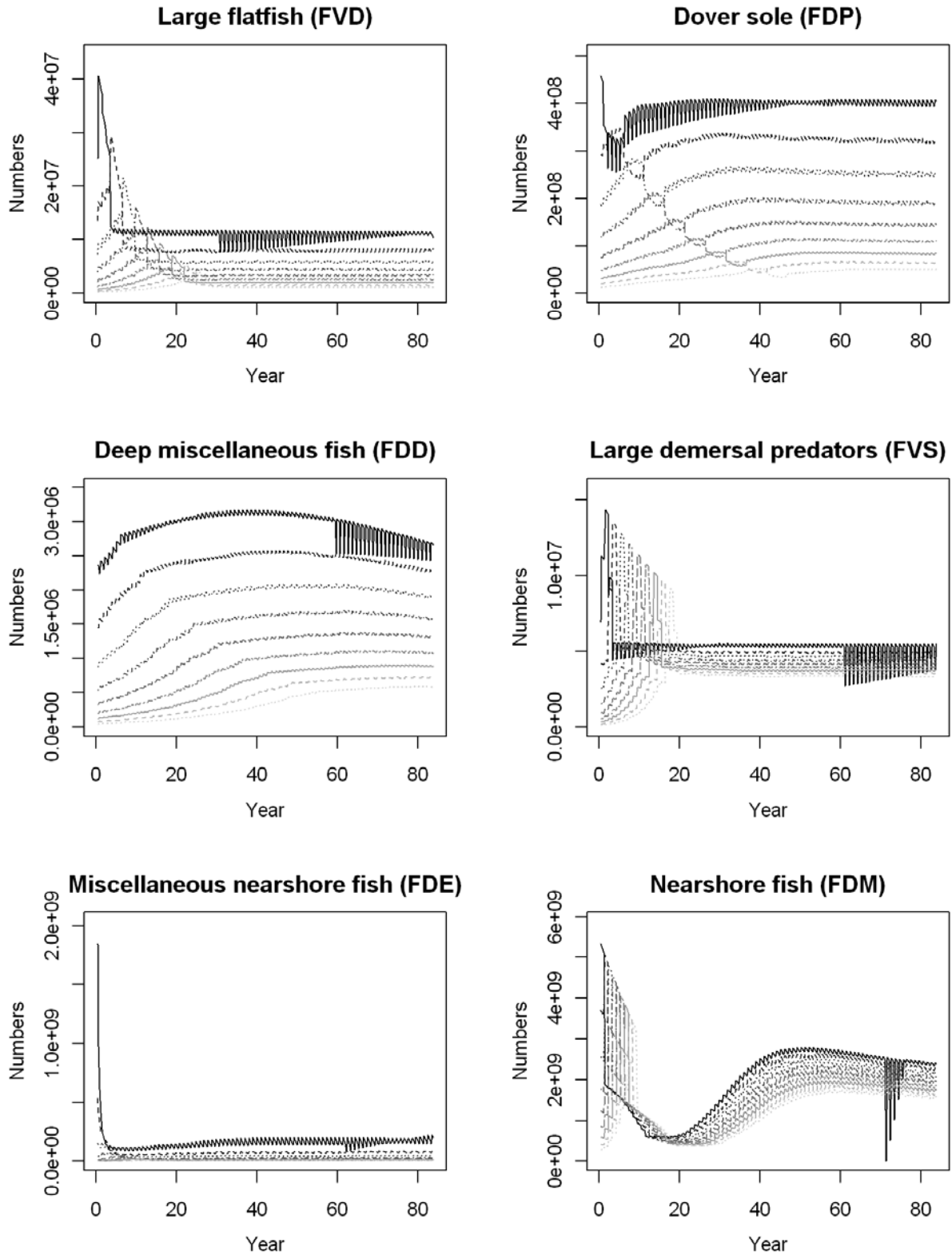


Figure 4c. Total numbers for each age class per vertebrate functional group after initial tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.



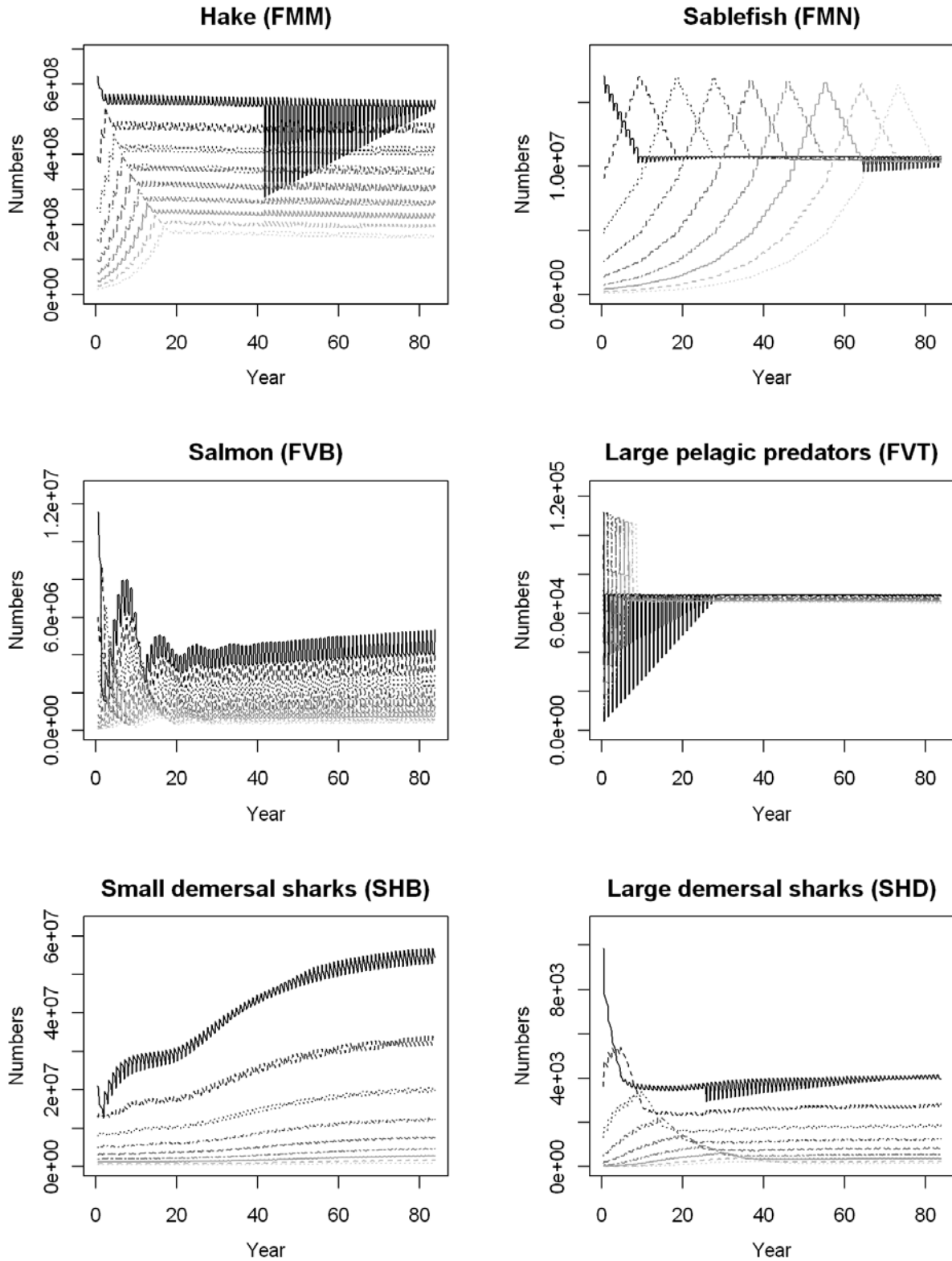


Figure 4d. Total numbers for each age class per vertebrate functional group after initial tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

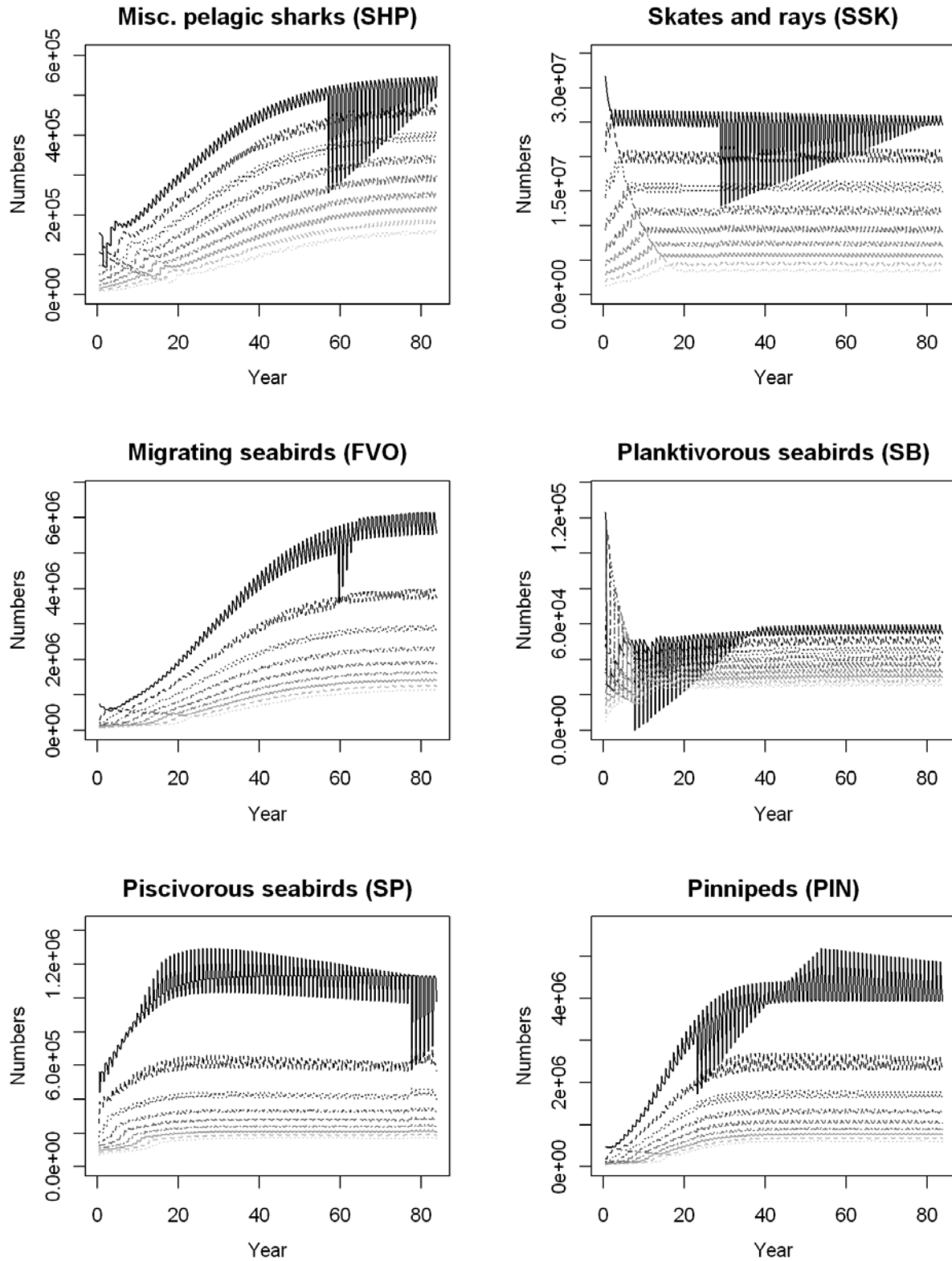


Figure 4e. Total numbers for each age class per vertebrate functional group after initial tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

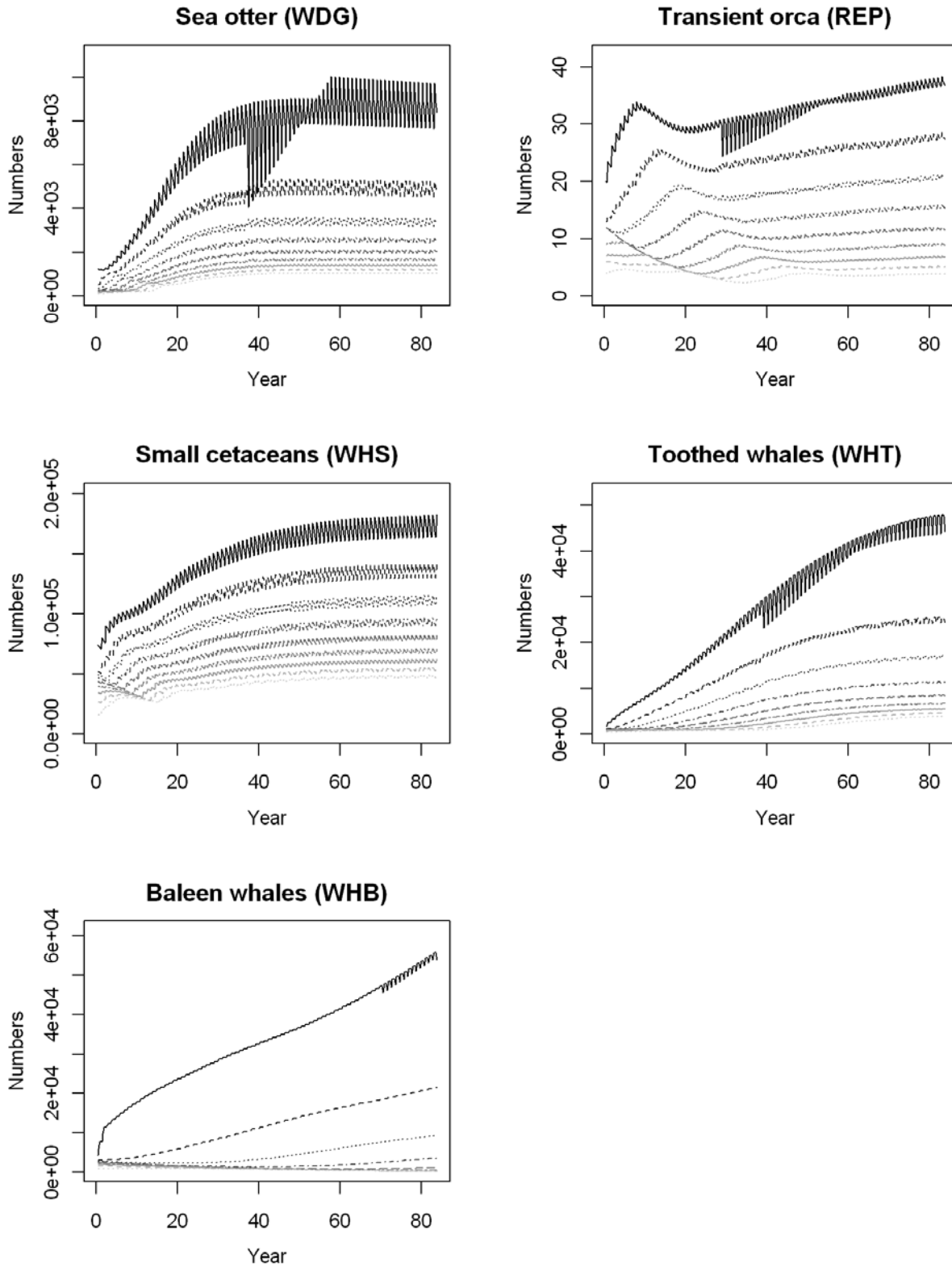


Figure 4f. Total numbers for each age class per vertebrate functional group after initial tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

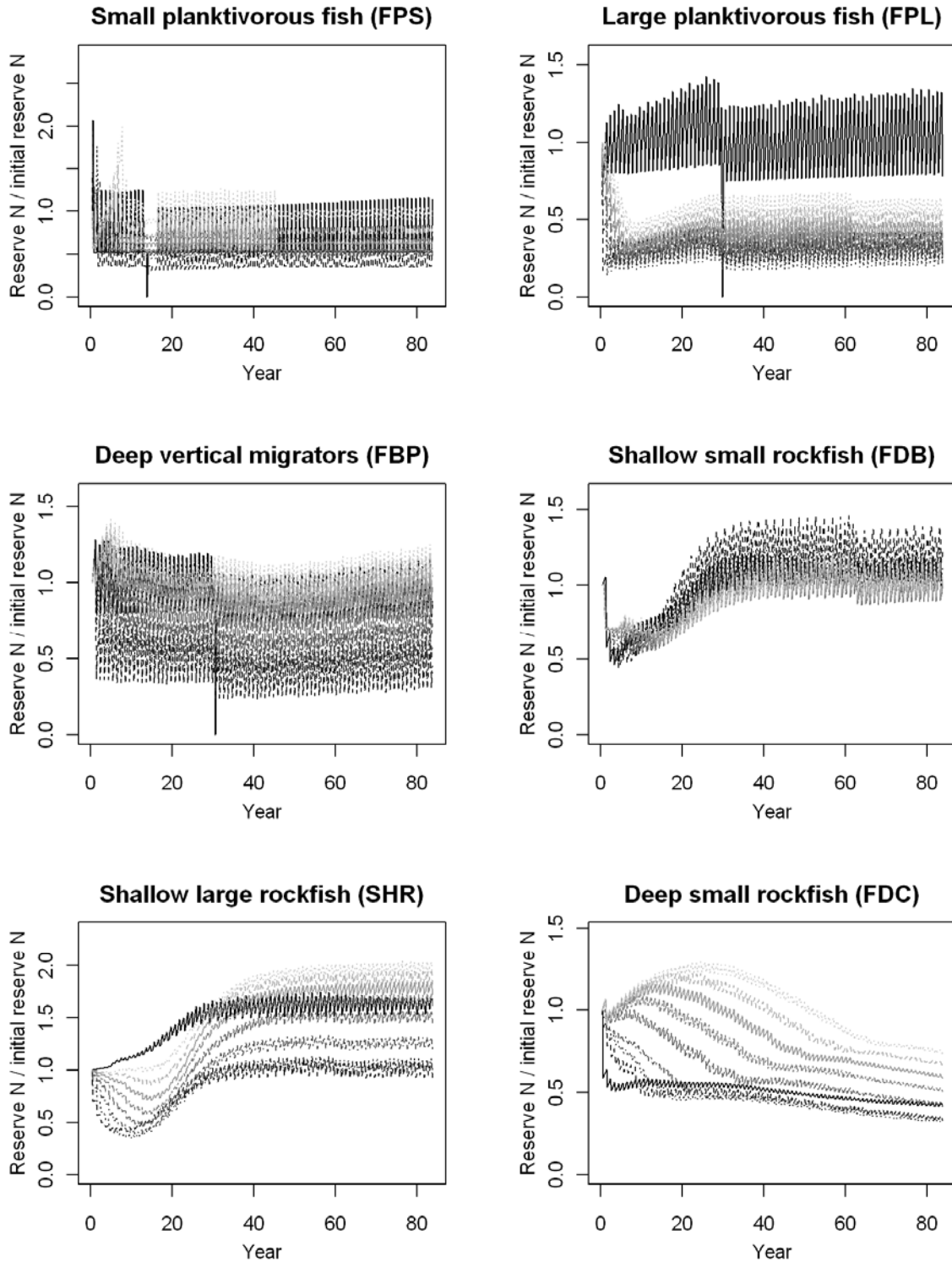


Figure 5a. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Reserve nitrogen represents weight at age that is related to muscle, fat, reproductive parts, and other soft tissue. As the ratio increases above one, individuals become fat; as the ratio declines below one, individuals begin to starve. X-axis shows years from start of simulation.

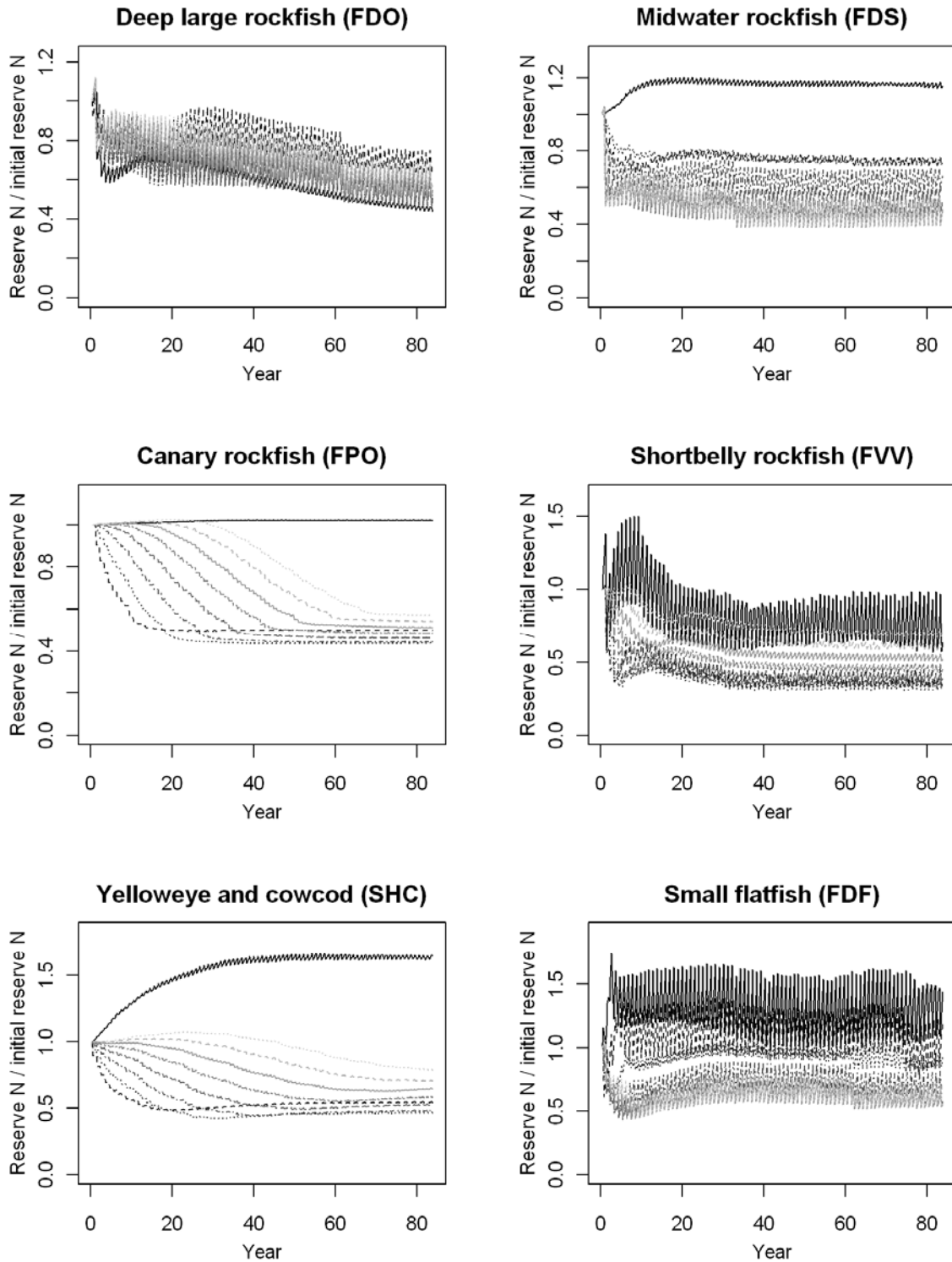


Figure 5b. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Reserve nitrogen represents weight at age that is related to muscle, fat, reproductive parts, and other soft tissue. As the ratio increases above one, individuals become fat; as the ratio declines below one, individuals begin to starve. X-axis shows years from start of simulation.

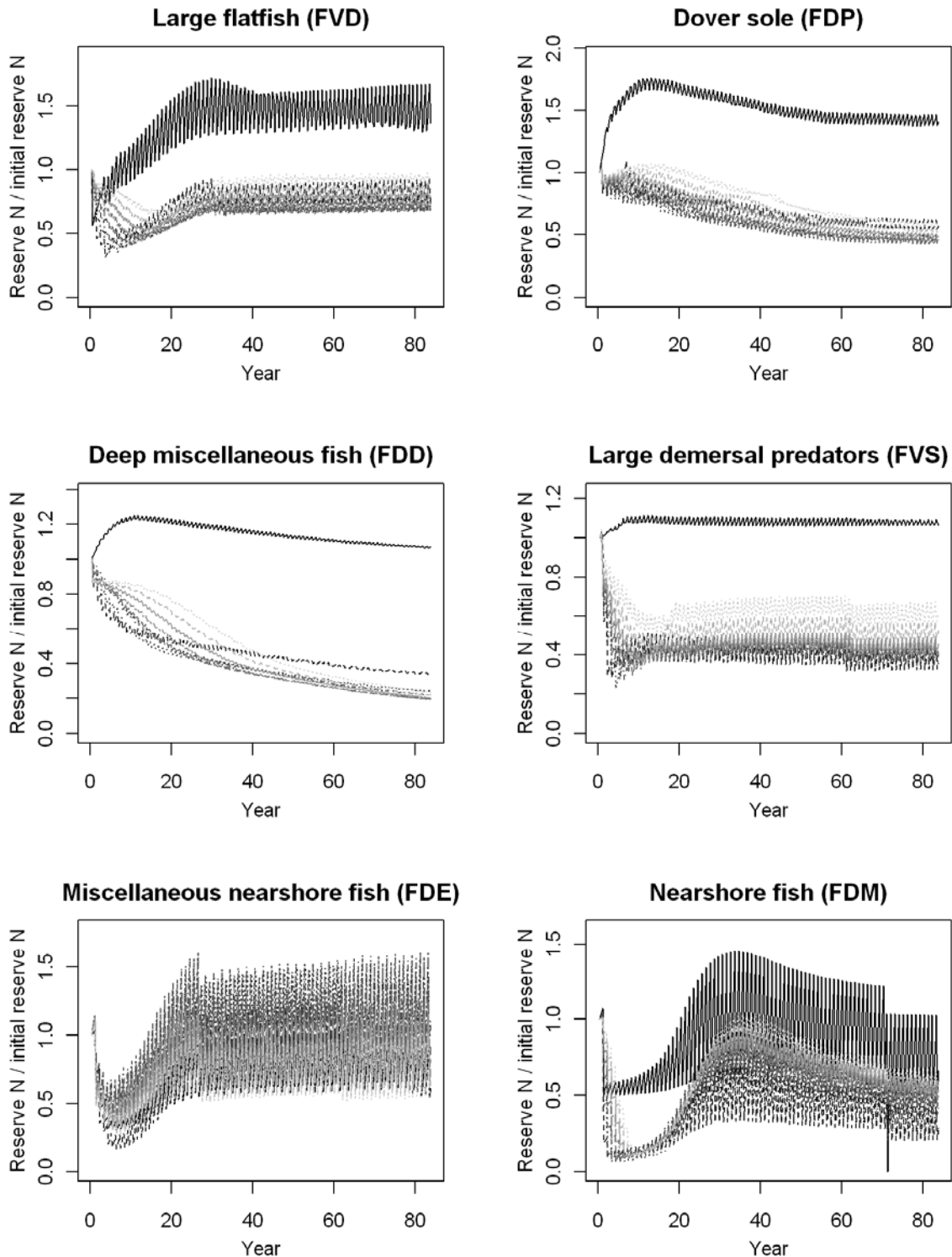


Figure 5c. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Reserve nitrogen represents weight at age that is related to muscle, fat, reproductive parts, and other soft tissue. As the ratio increases above one, individuals become fat; as the ratio declines below one, individuals begin to starve. X-axis shows years from start of simulation.

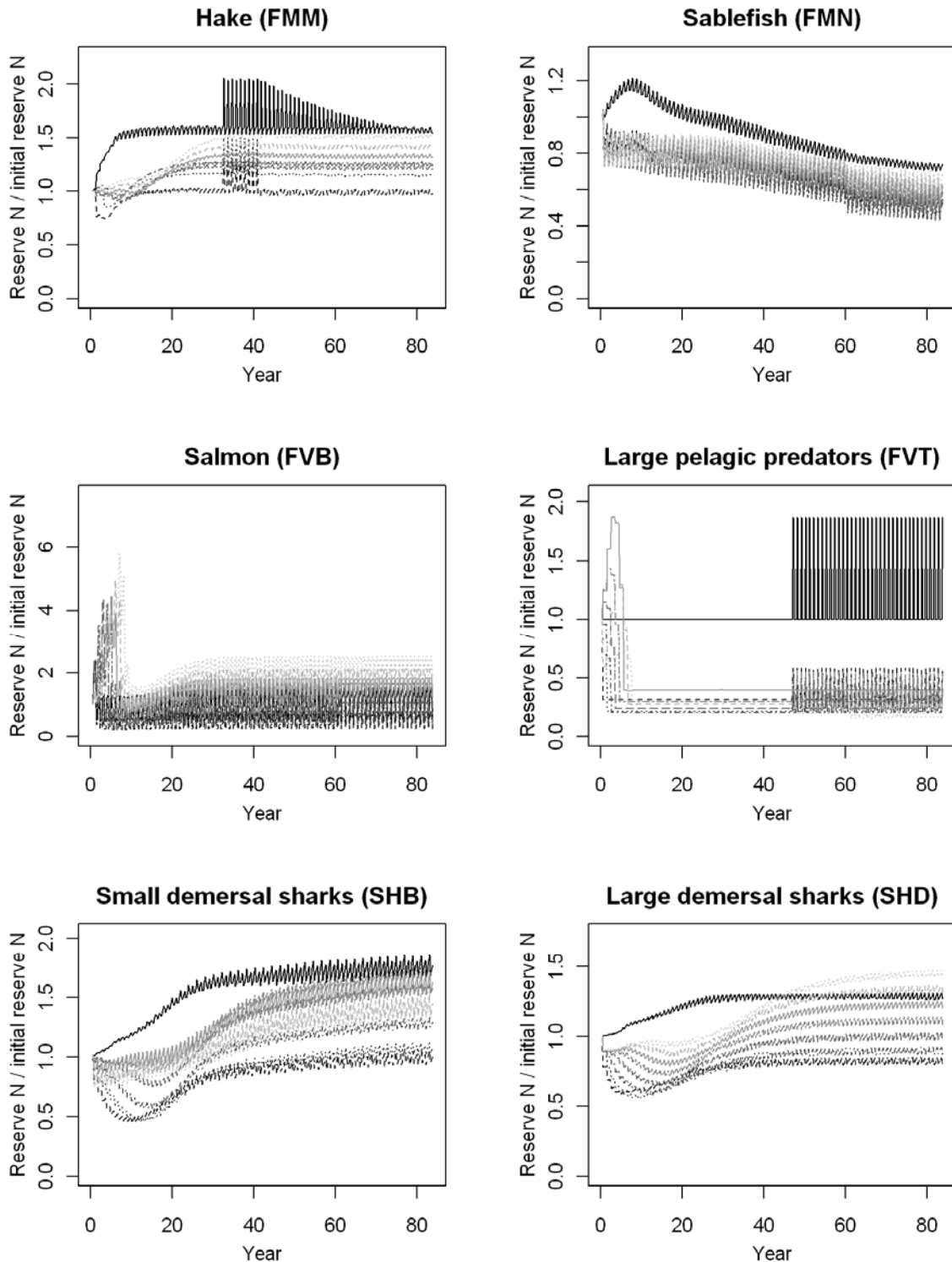


Figure 5d. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Reserve nitrogen represents weight at age that is related to muscle, fat, reproductive parts, and other soft tissue. As the ratio increases above one, individuals become fat; as the ratio declines below one, individuals begin to starve. X-axis shows years from start of simulation.

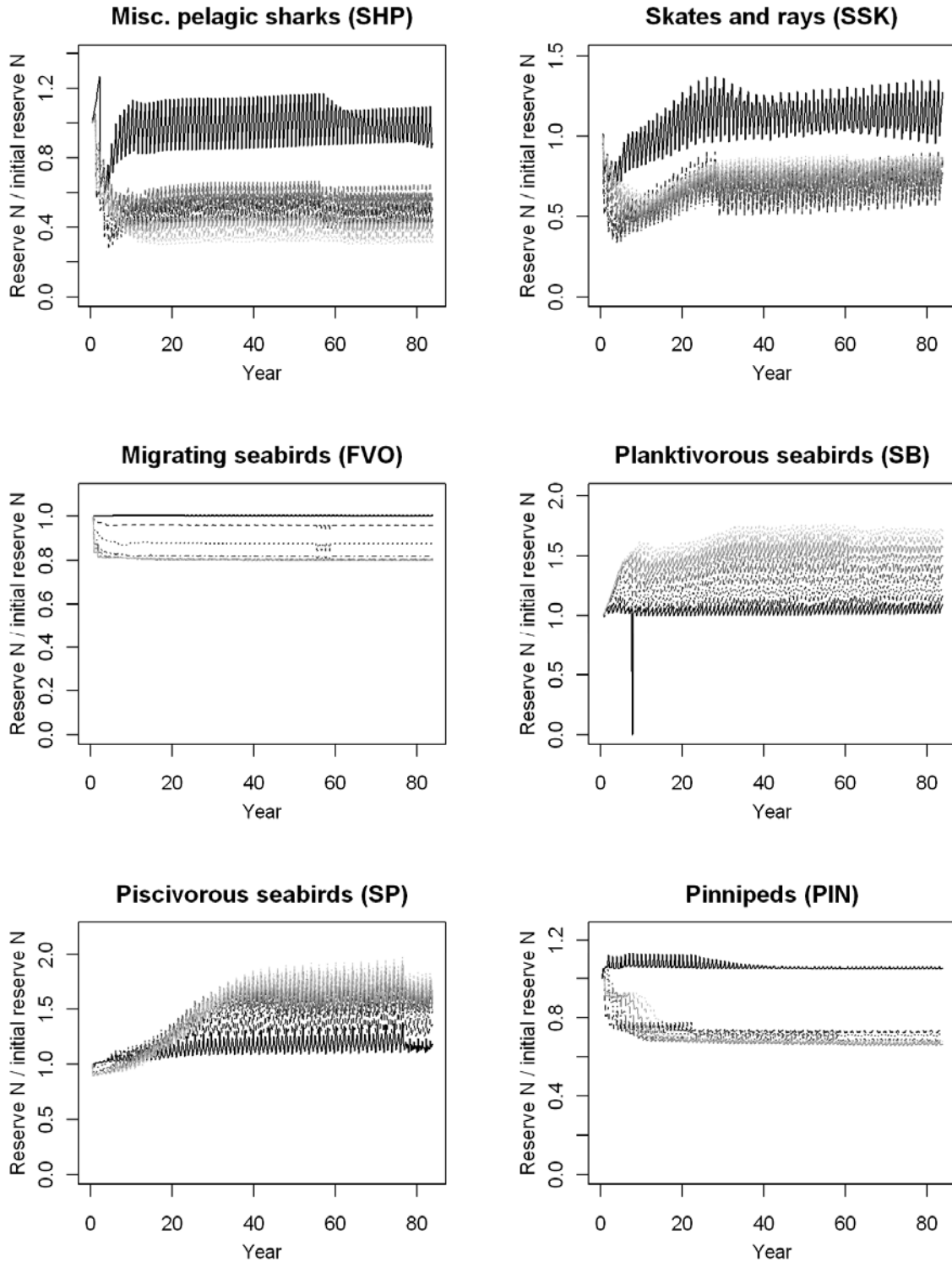


Figure 5e. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Reserve nitrogen represents weight at age that is related to muscle, fat, reproductive parts, and other soft tissue. As the ratio increases above one, individuals become fat; as the ratio declines below one, individuals begin to starve. X-axis shows years from start of simulation.



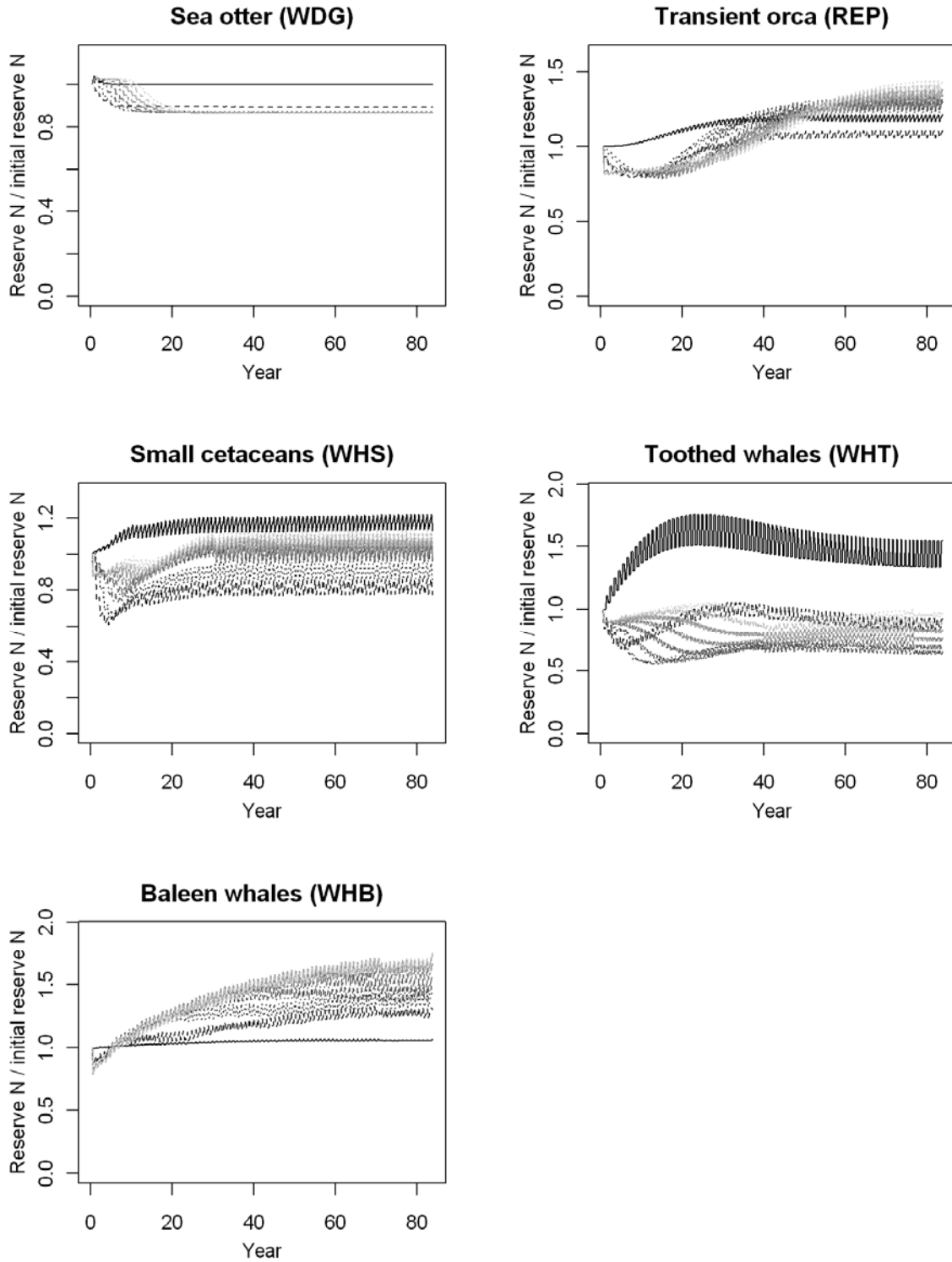


Figure 5f. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Reserve nitrogen represents weight at age that is related to muscle, fat, reproductive parts, and other soft tissue. As the ratio increases above one, individuals become fat; as the ratio declines below one, individuals begin to starve. X-axis shows years from start of simulation.

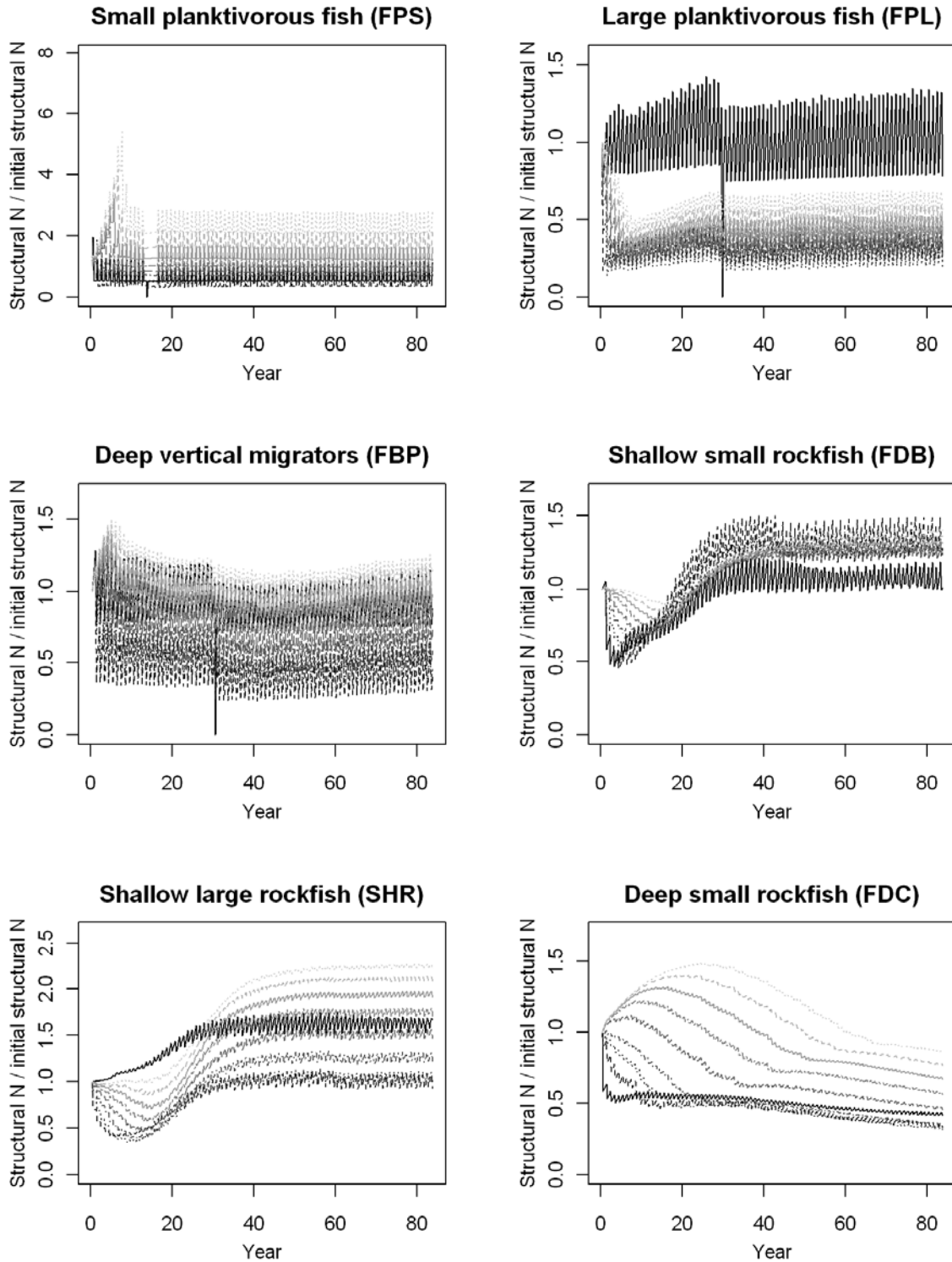


Figure 6a. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Structural nitrogen represents weight at age that is related to bones and other hard parts. X-axis shows years from start of simulation.

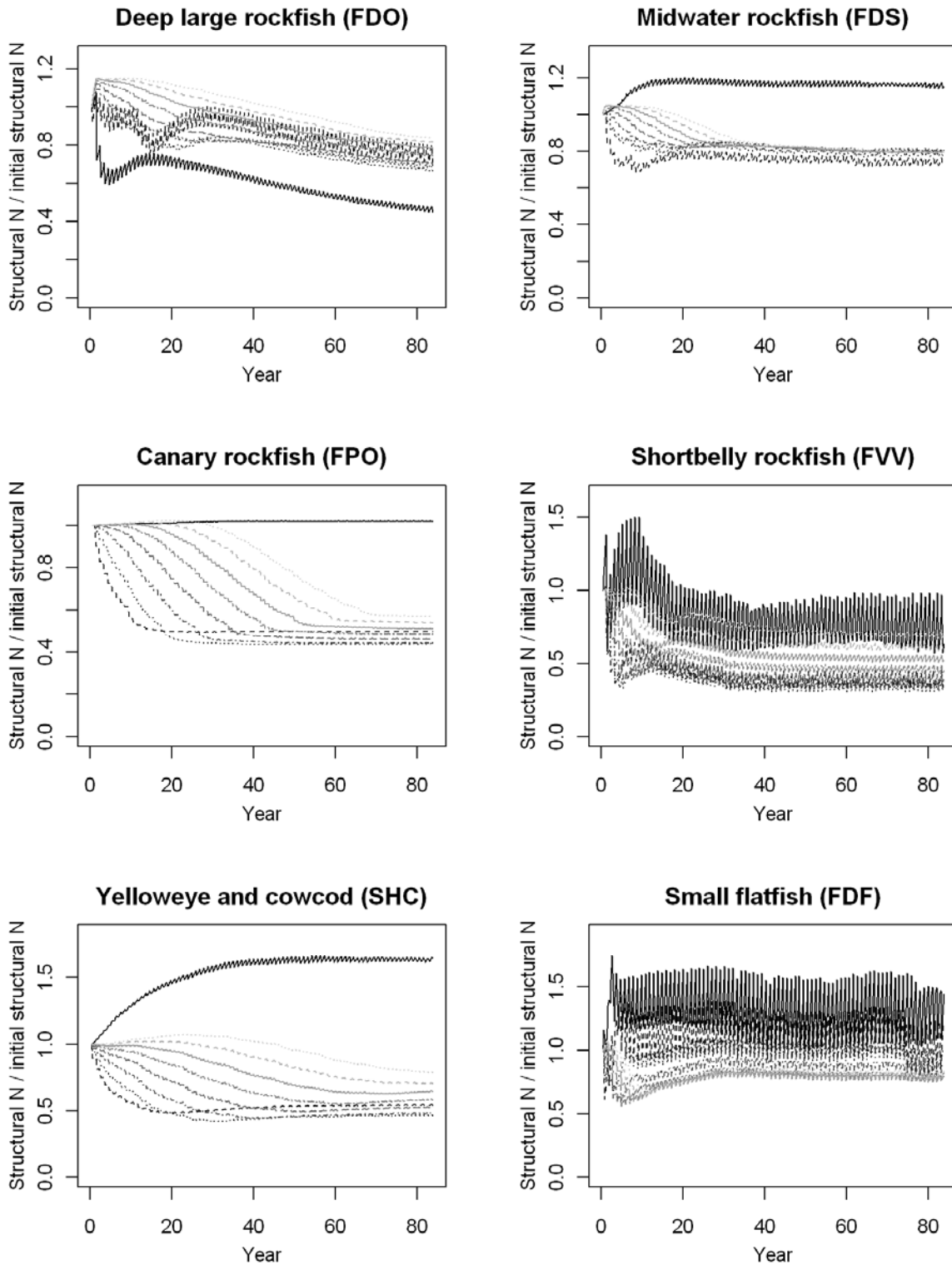


Figure 6b. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Structural nitrogen represents weight at age that is related to bones and other hard parts. X-axis shows years from start of simulation.

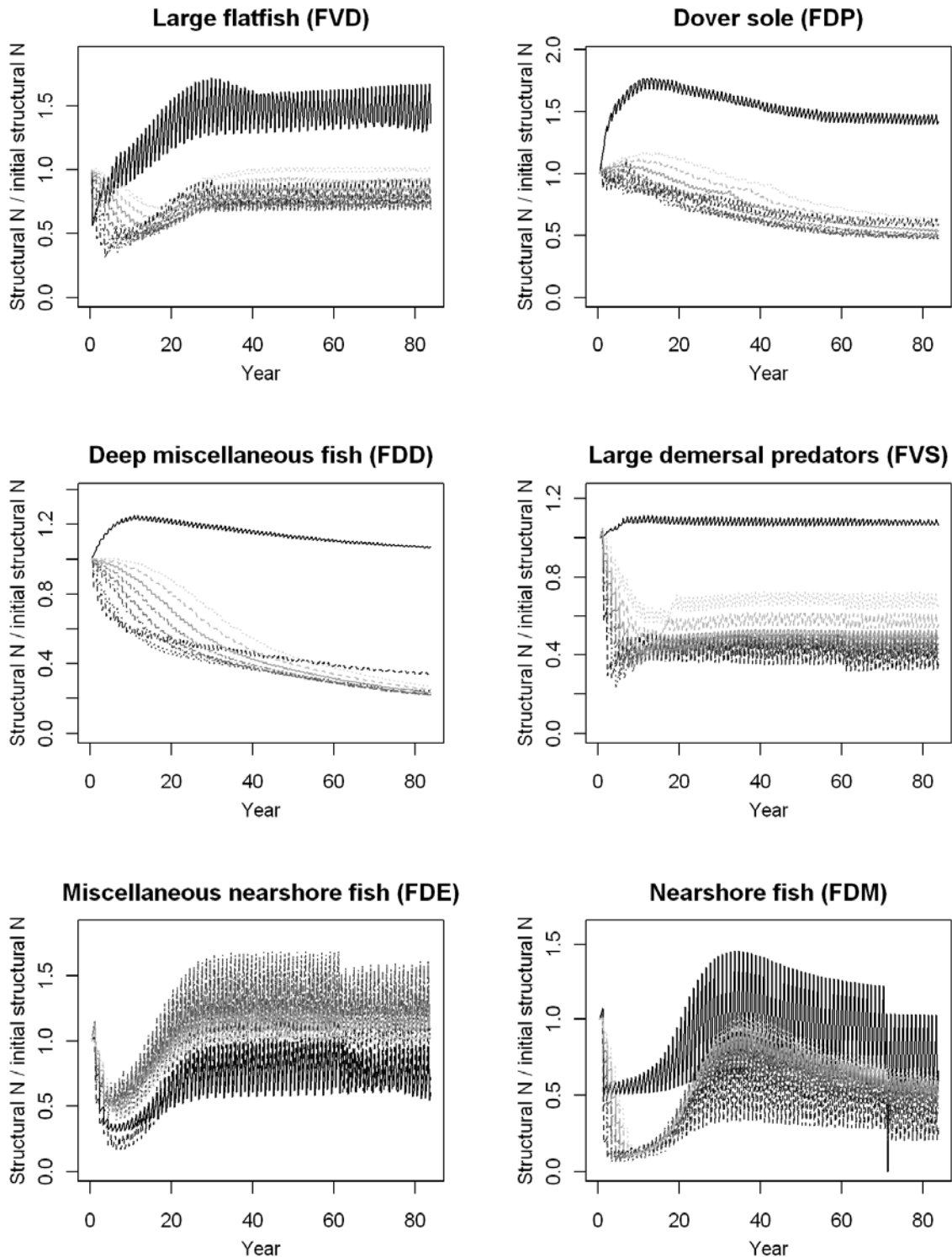


Figure 6c. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Structural nitrogen represents weight at age that is related to bones and other hard parts. X-axis shows years from start of simulation.

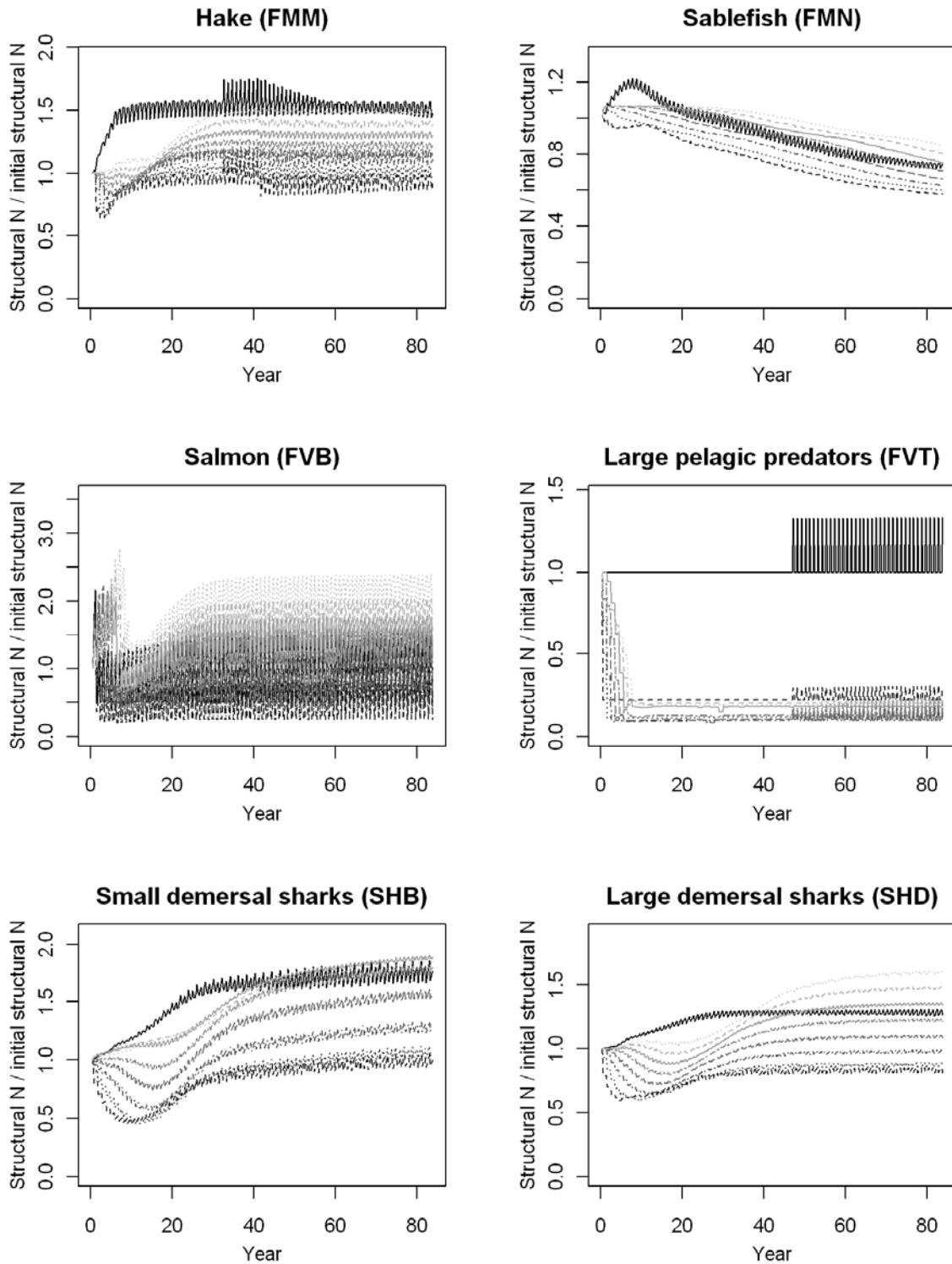


Figure 6d. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Structural nitrogen represents weight at age that is related to bones and other hard parts. X-axis shows years from start of simulation.

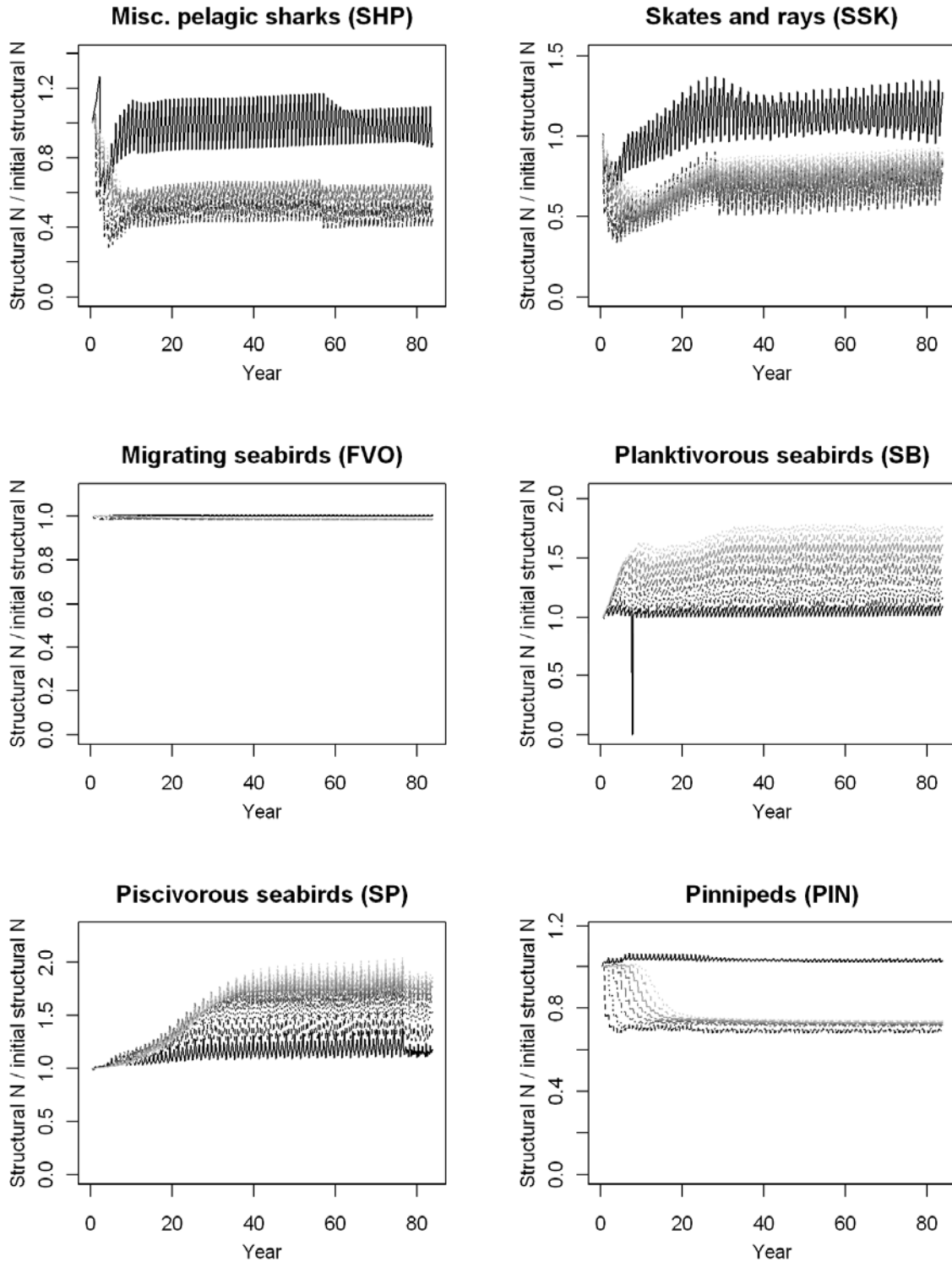


Figure 6e. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Structural nitrogen represents weight at age that is related to bones and other hard parts. X-axis shows years from start of simulation.

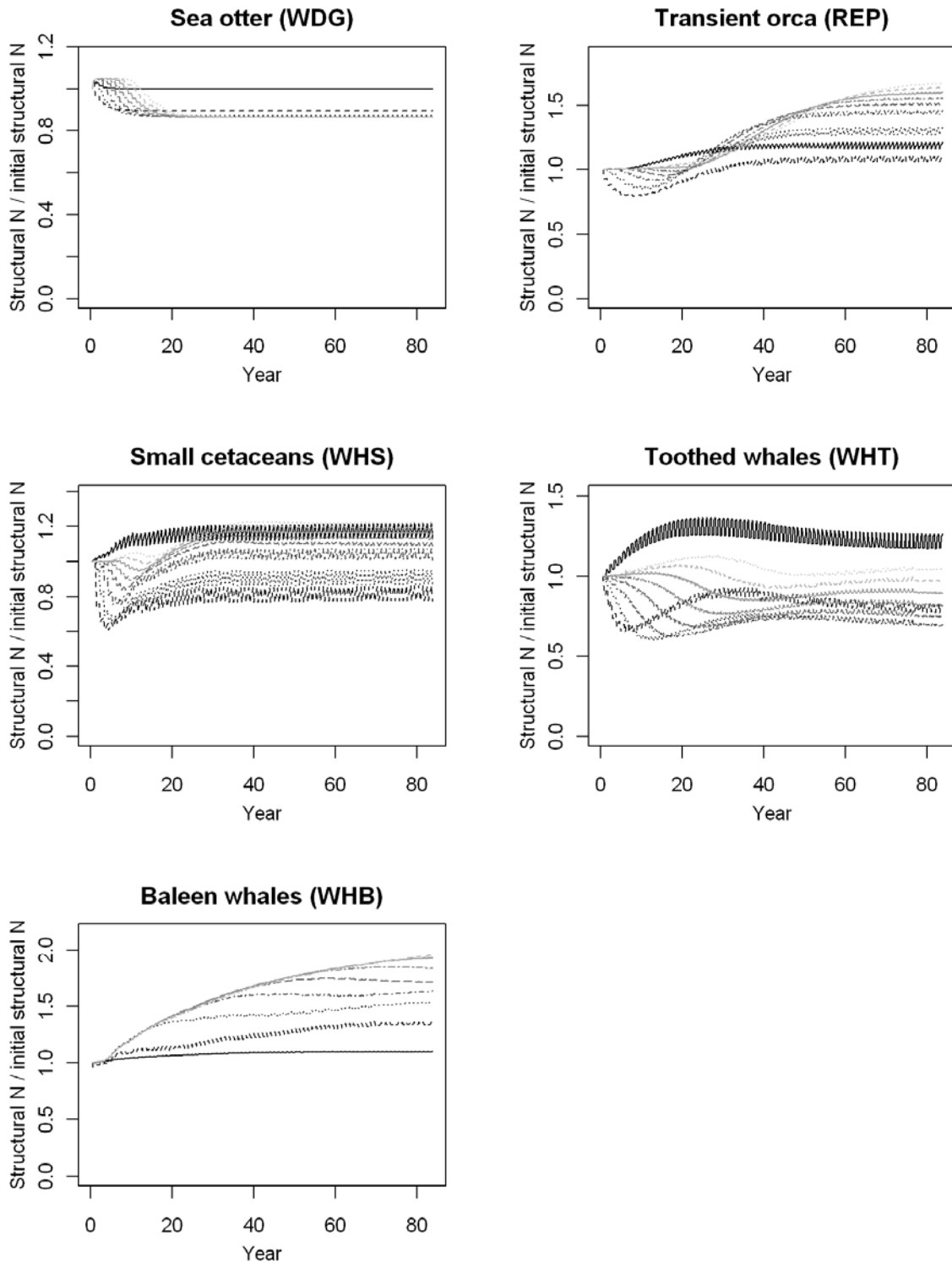


Figure 6f. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after initial tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. Structural nitrogen represents weight at age that is related to bones and other hard parts. X-axis shows years from start of simulation.

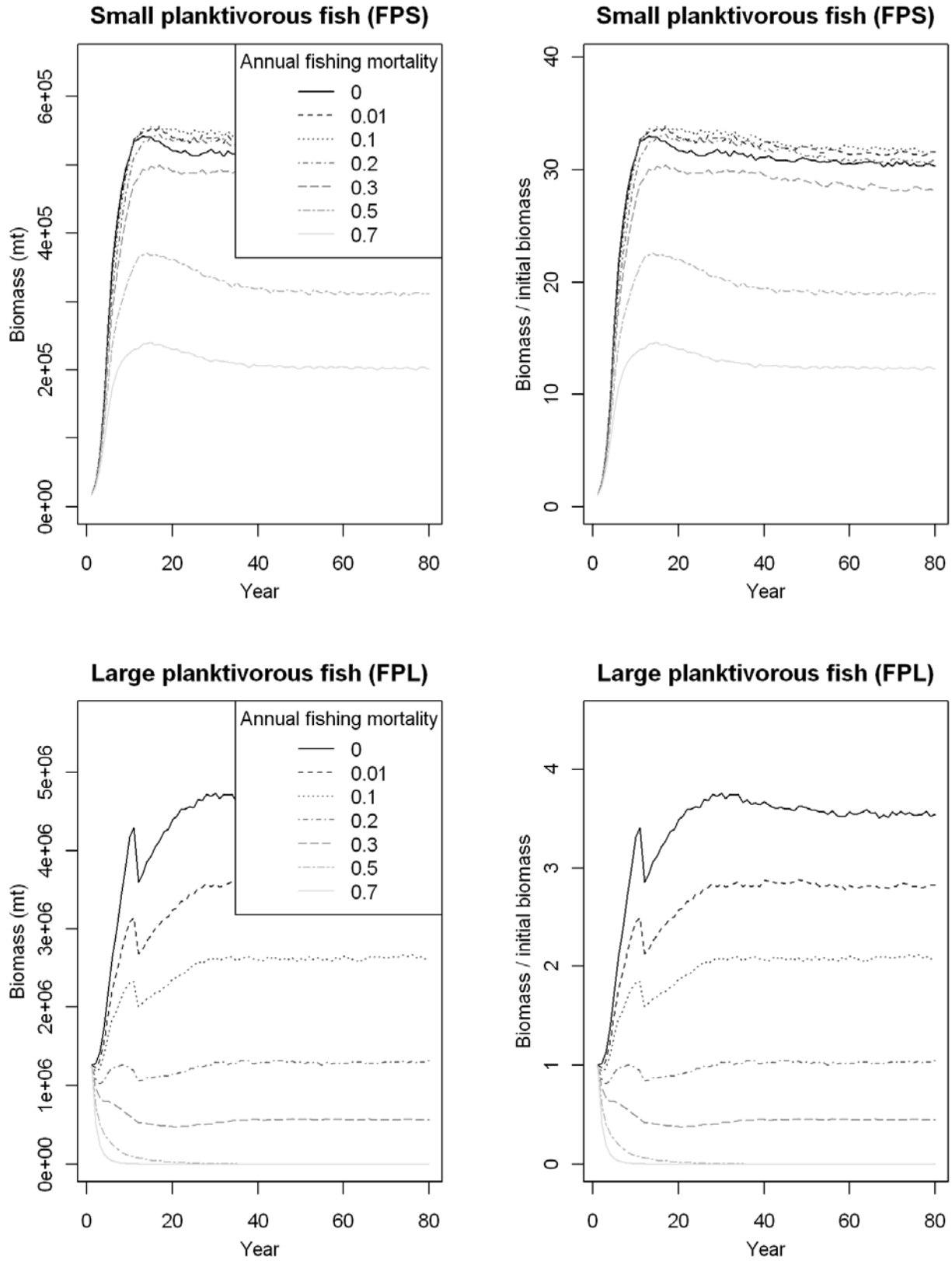


Figure 7a. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.



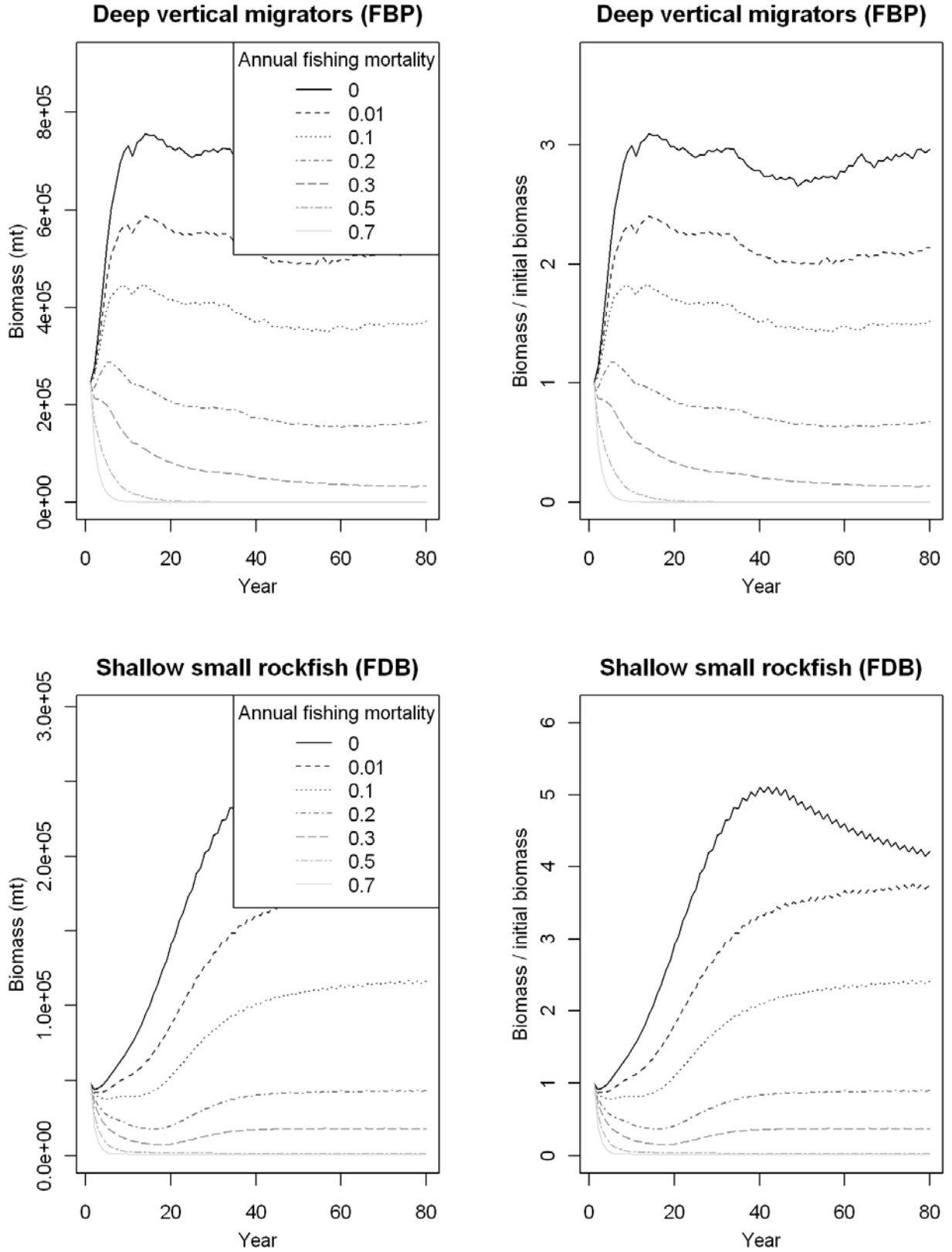


Figure 7b. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

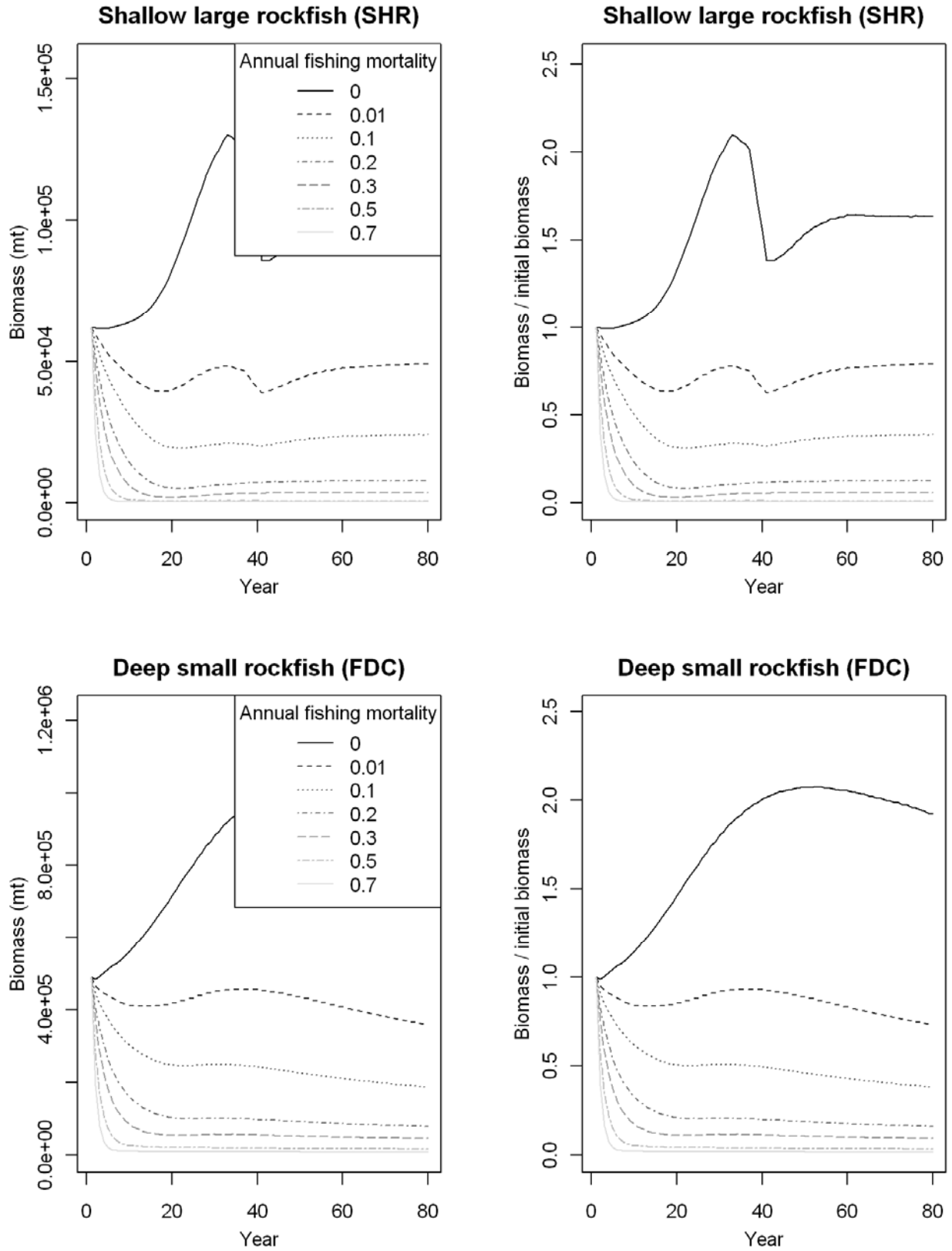


Figure 7c. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

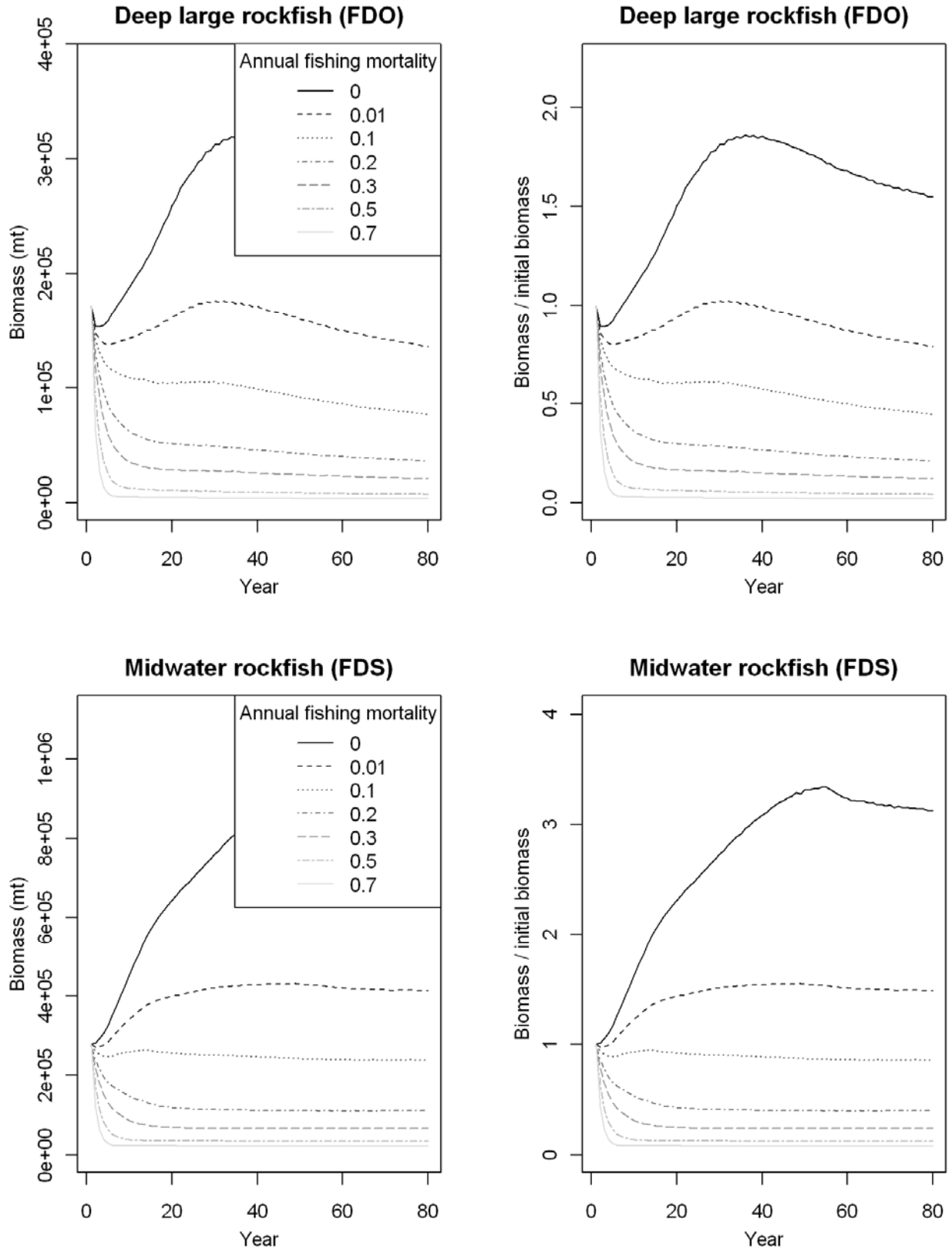


Figure 7d. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

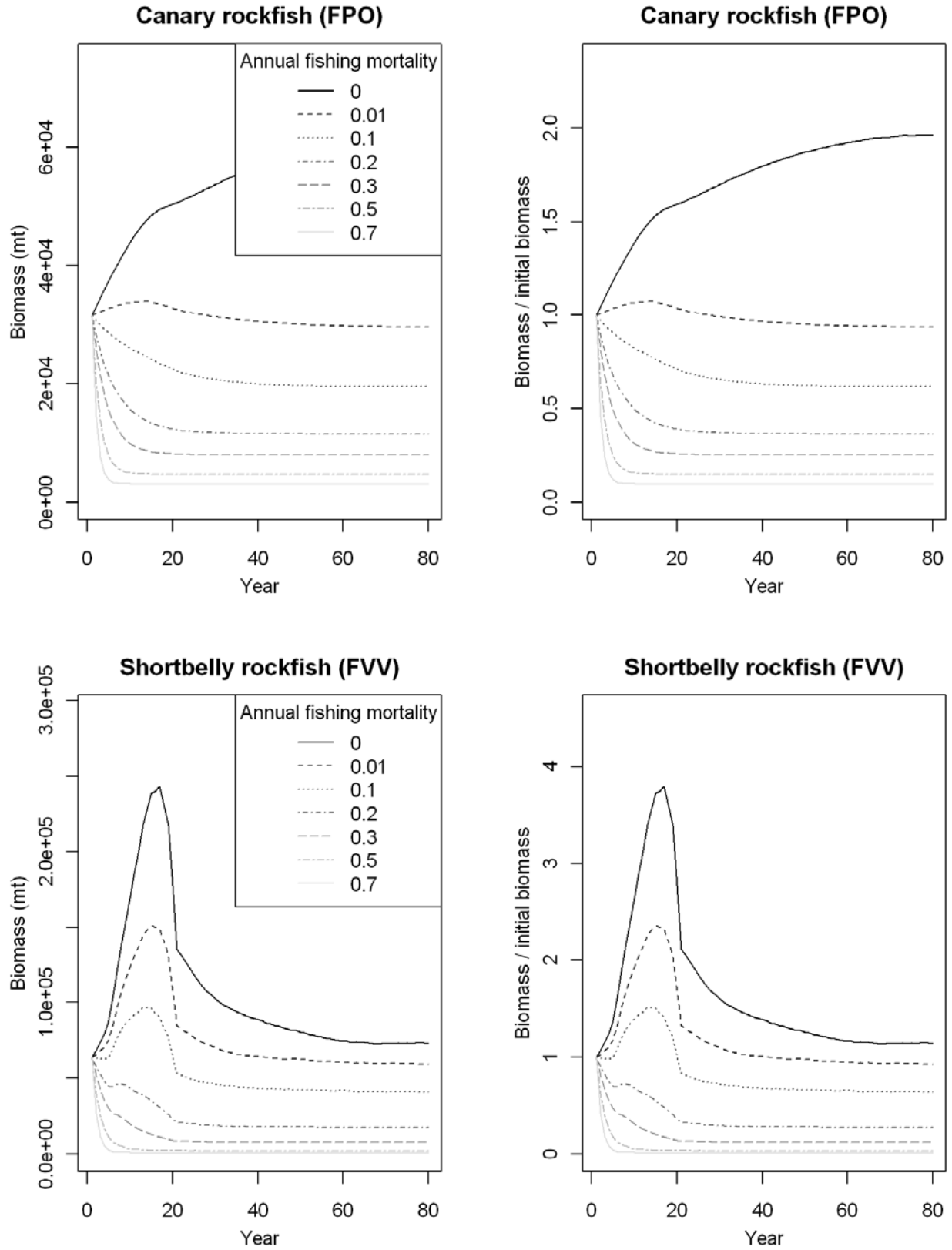


Figure 7e. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

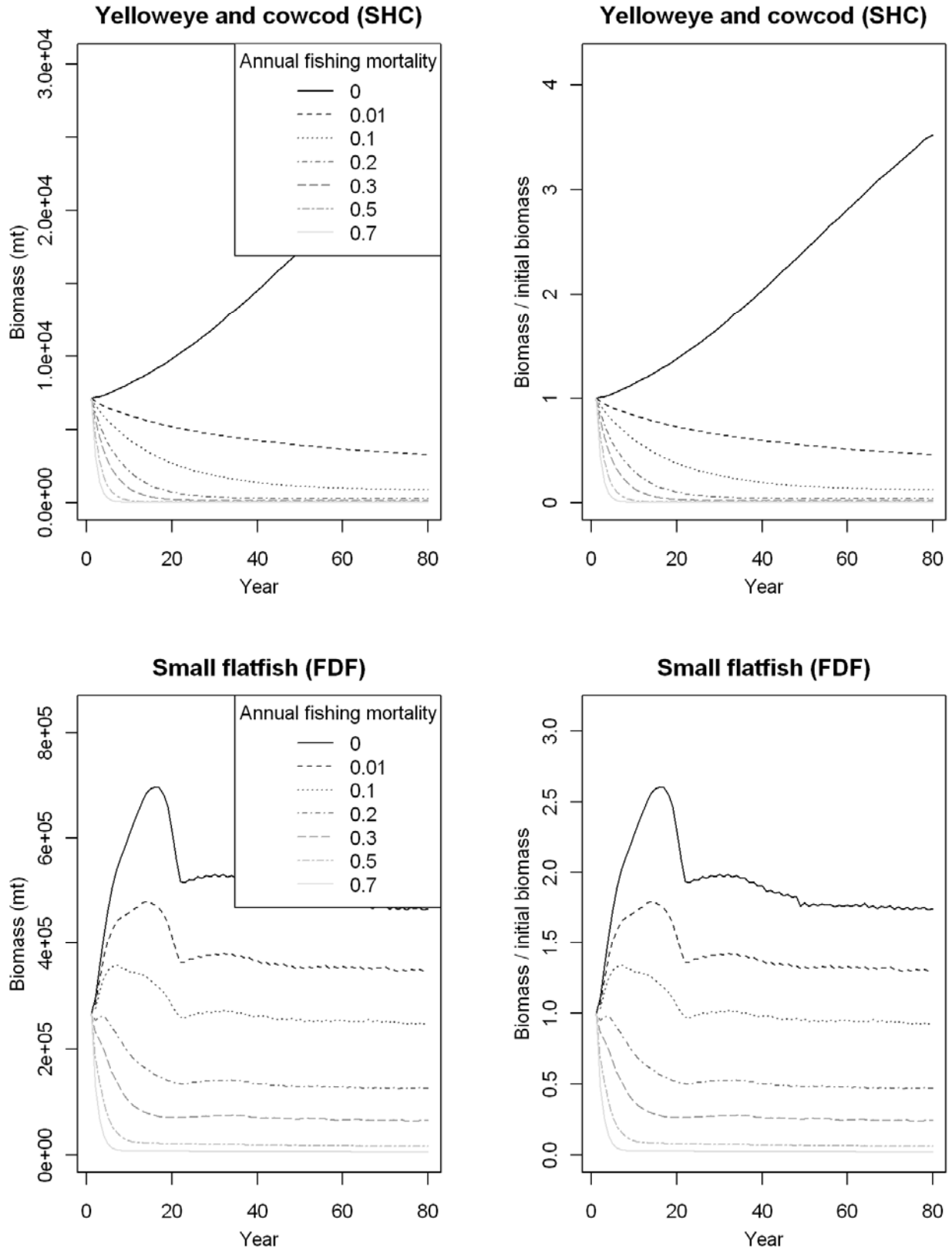


Figure 7f. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

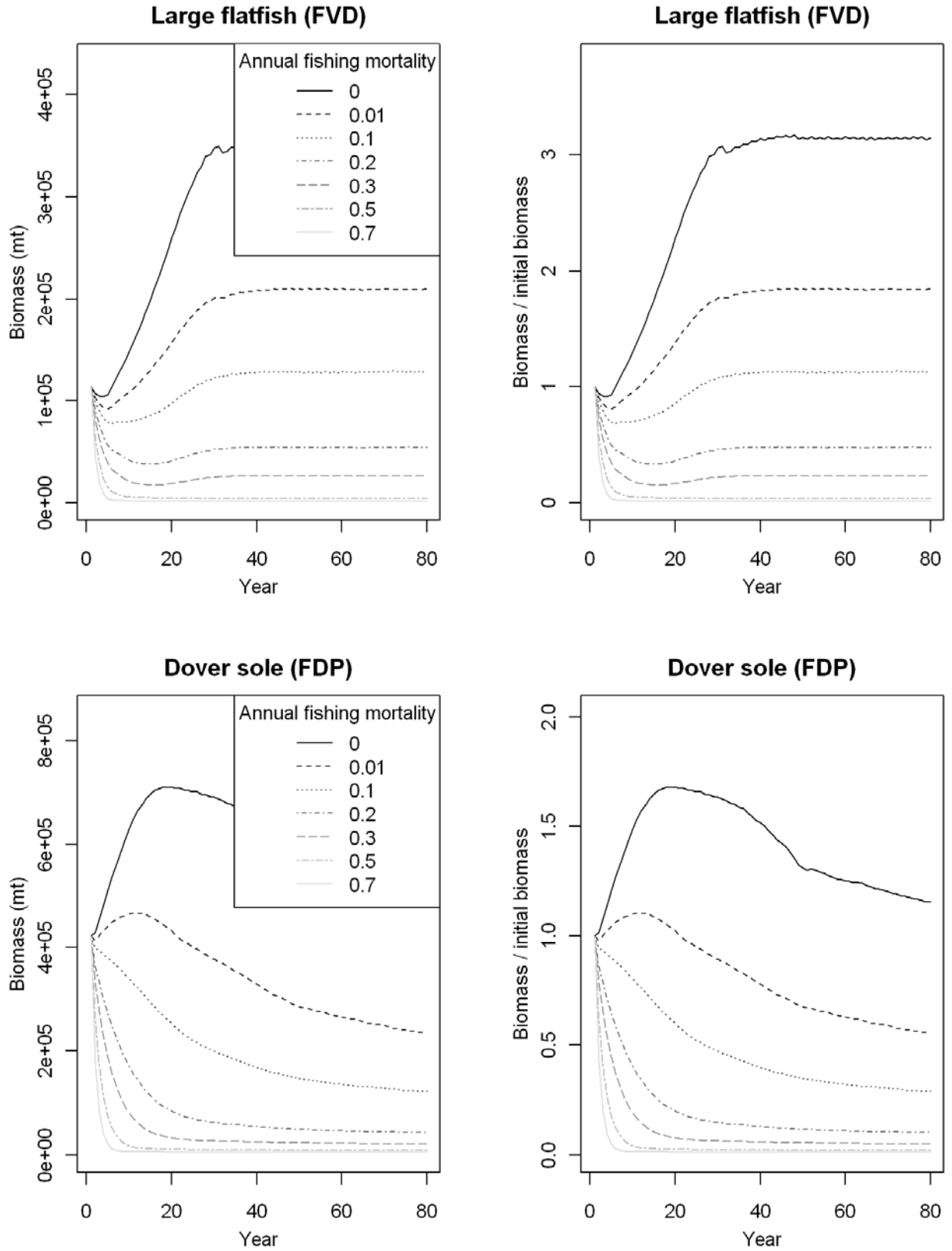


Figure 7g. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

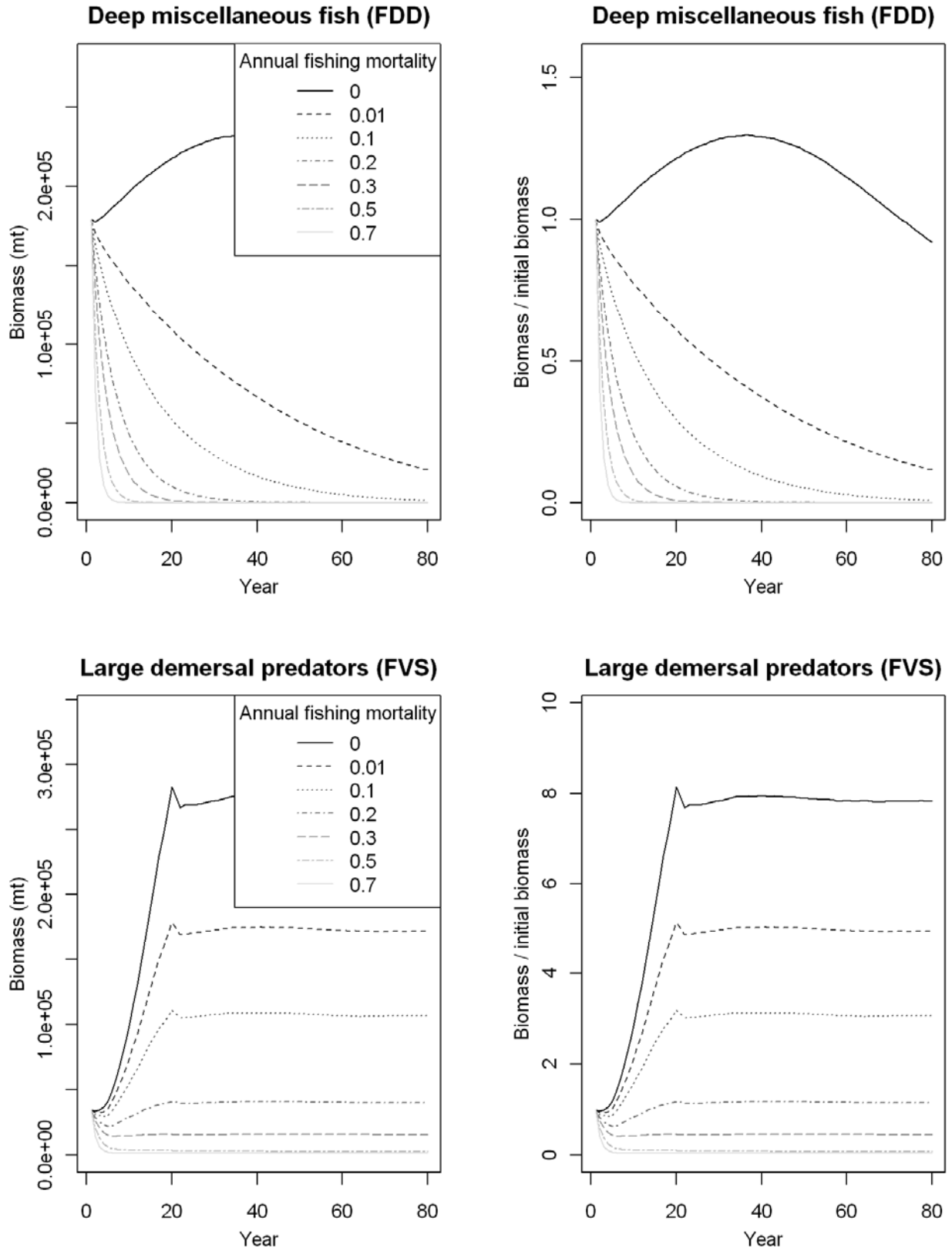


Figure 7h. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

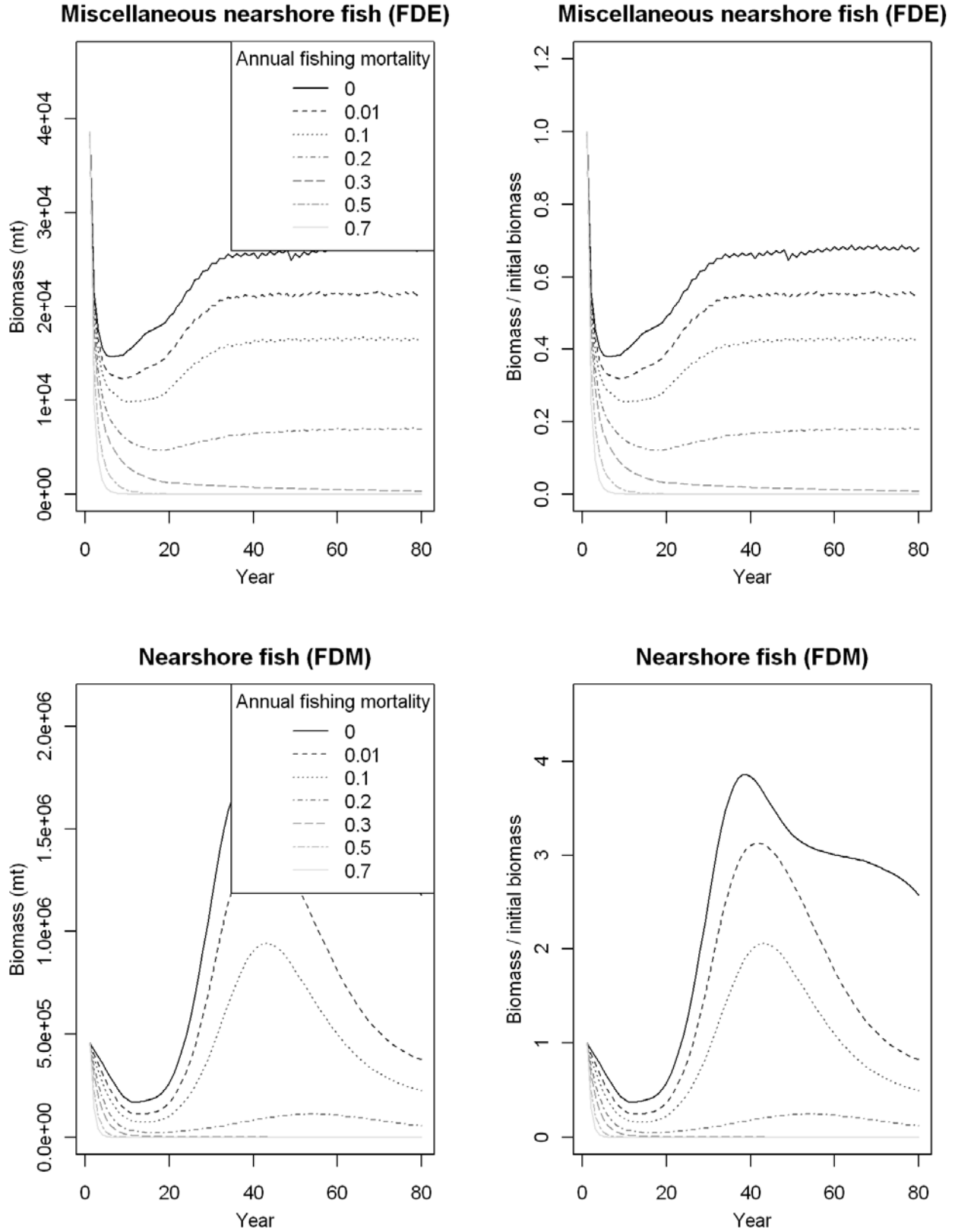


Figure 7i. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.



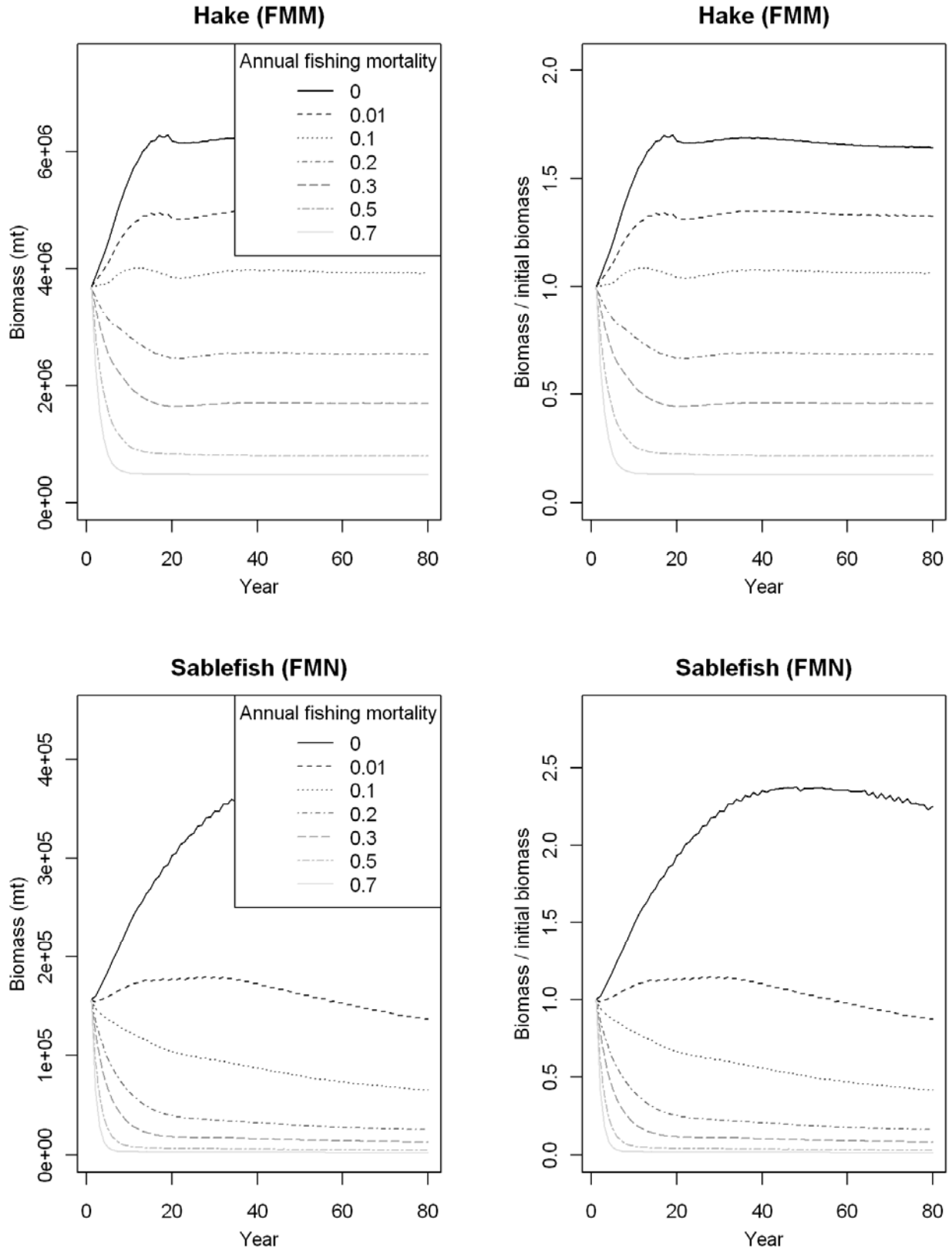


Figure 7j. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

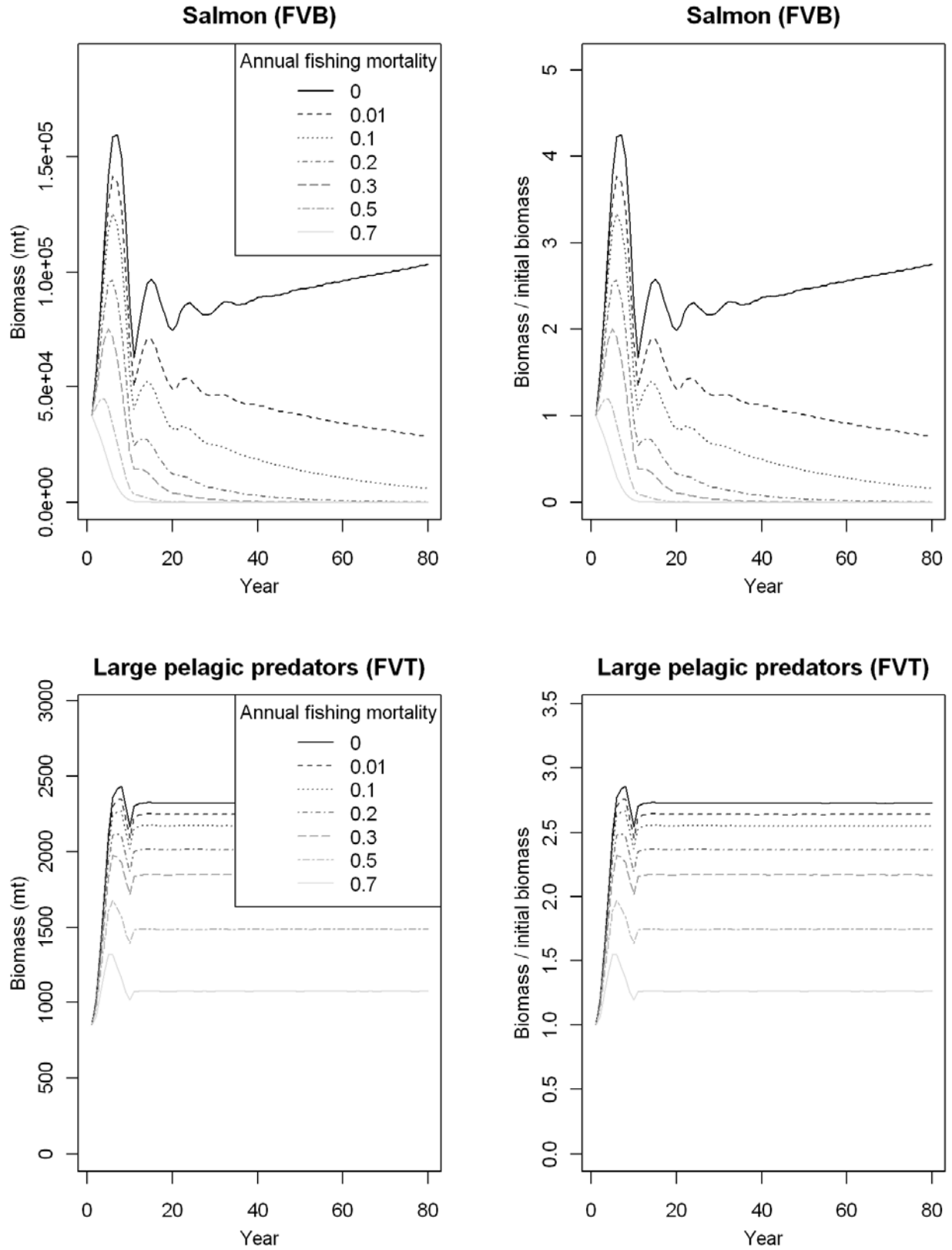


Figure 7k. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

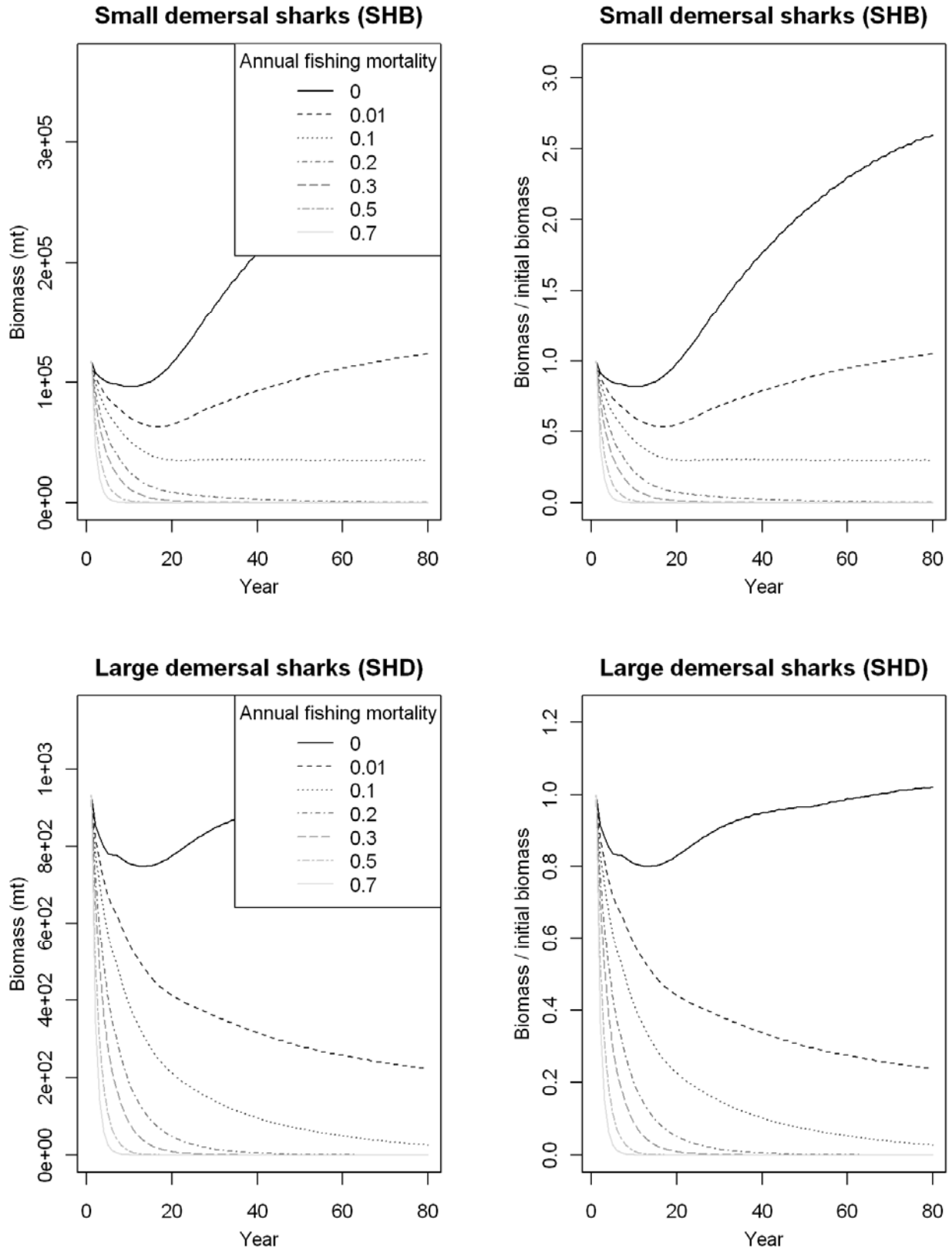


Figure 7I. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

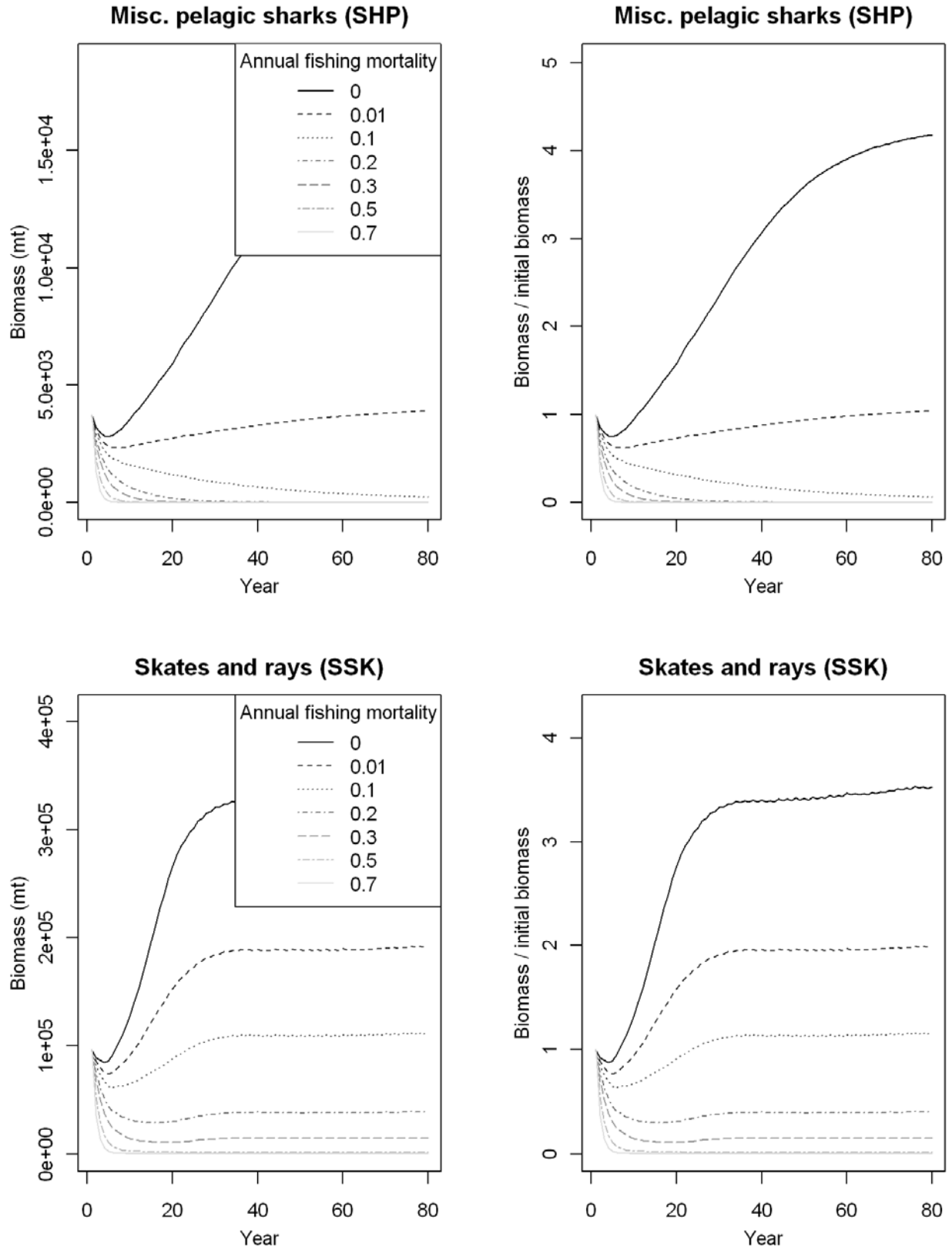


Figure 7m. Biomass responses to varying levels of harvest. Left plots show biomass in metric tons and right plots show the ratio of biomass to initial biomass.

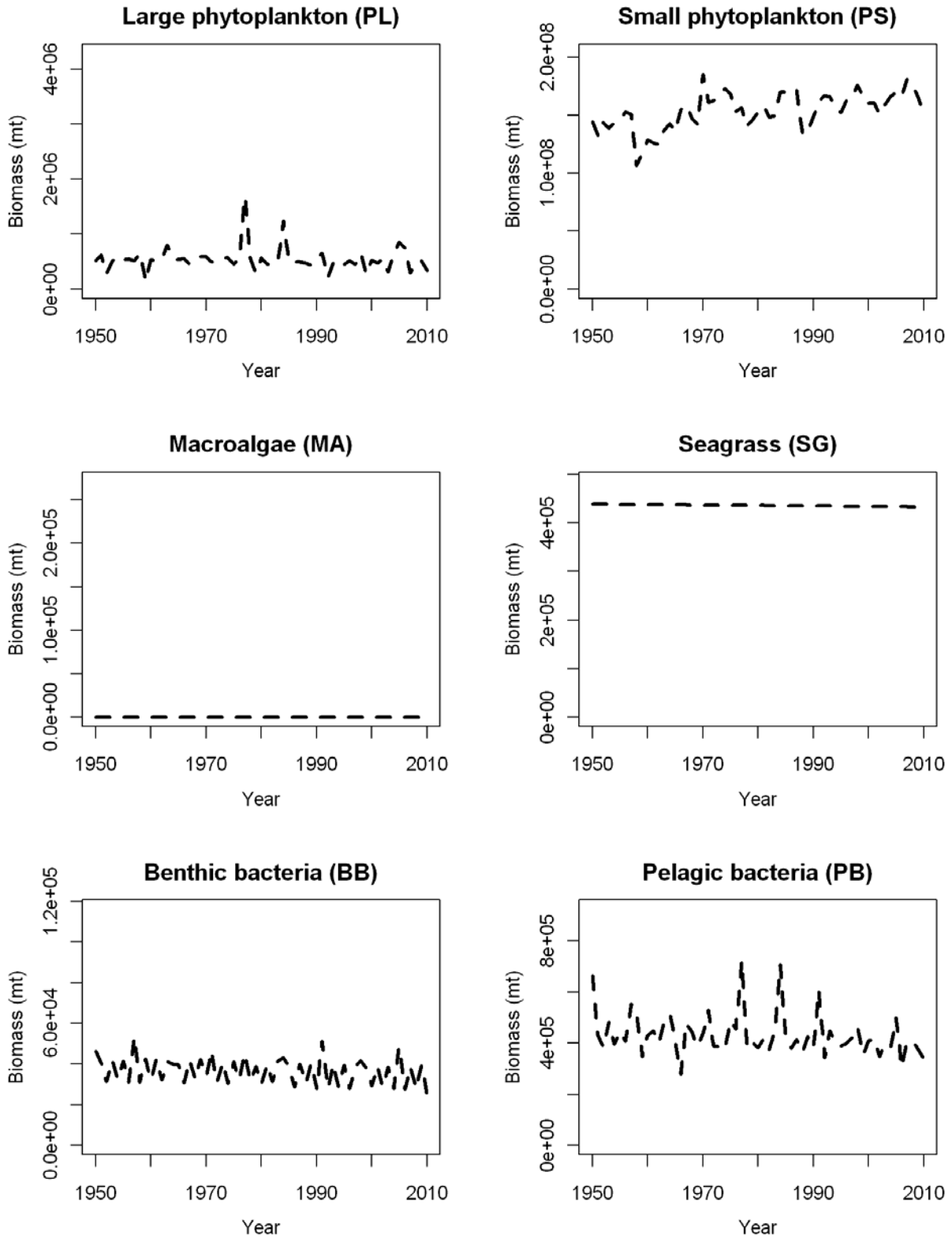


Figure 8a. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown).

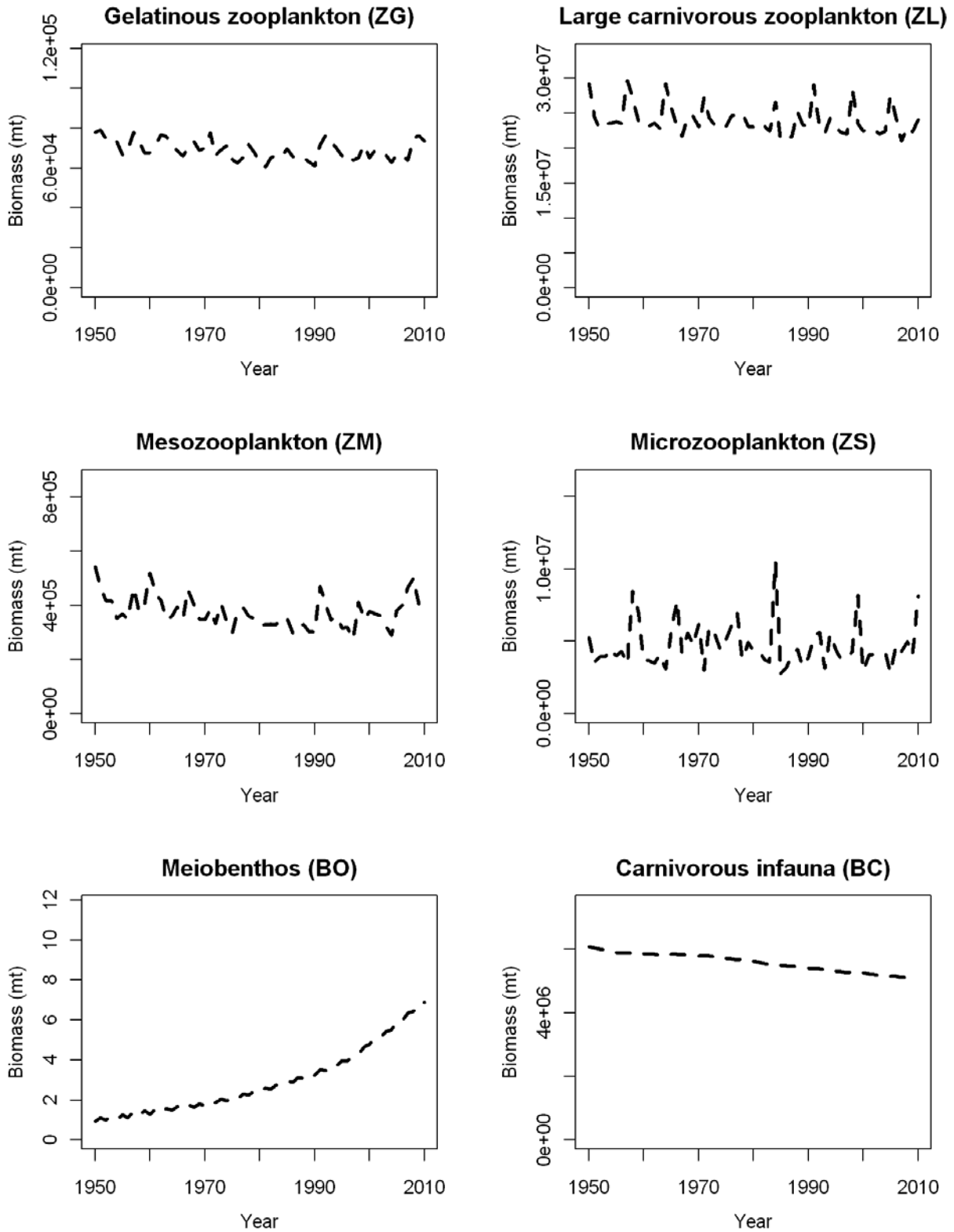


Figure 8b. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown).

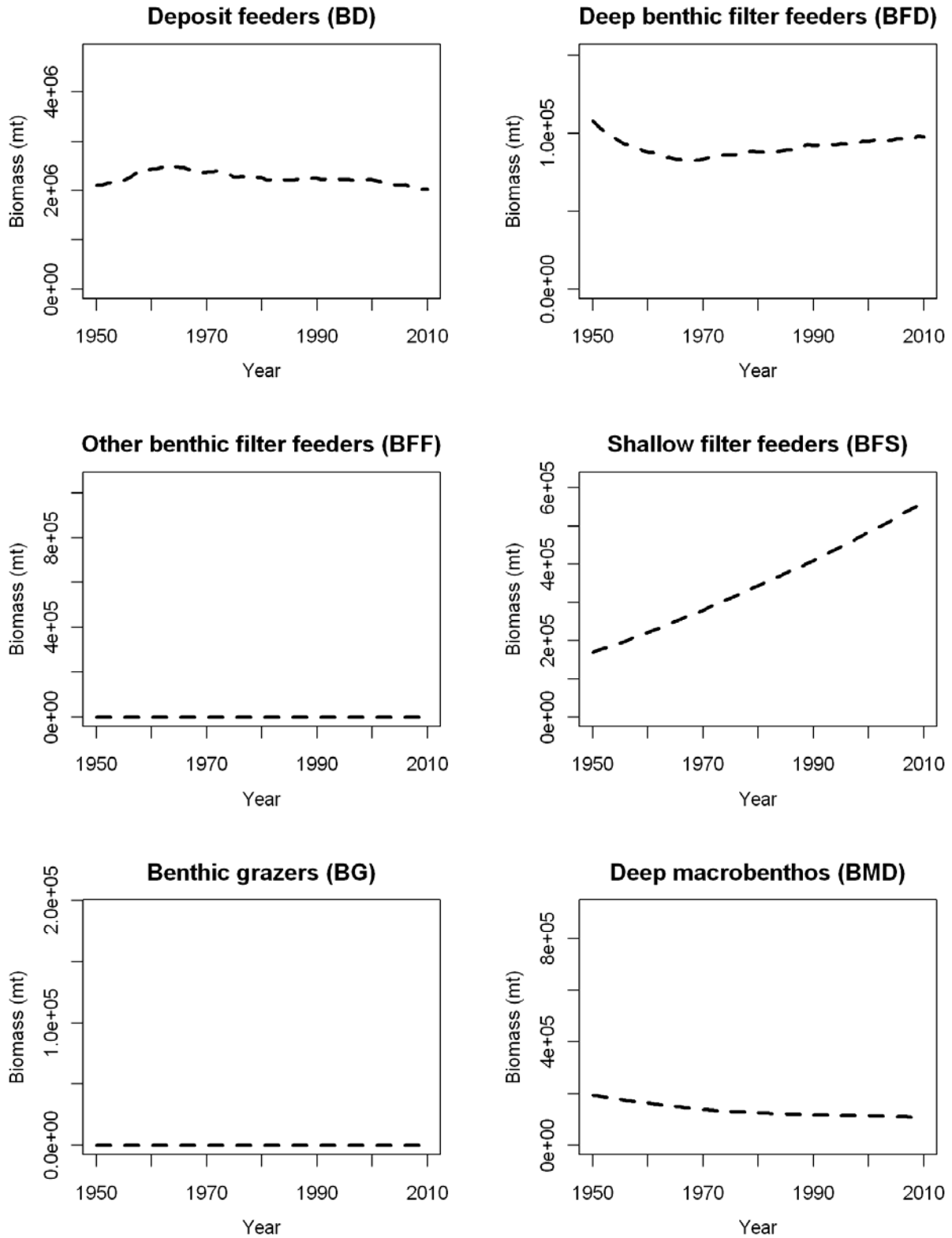


Figure 8c. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown).

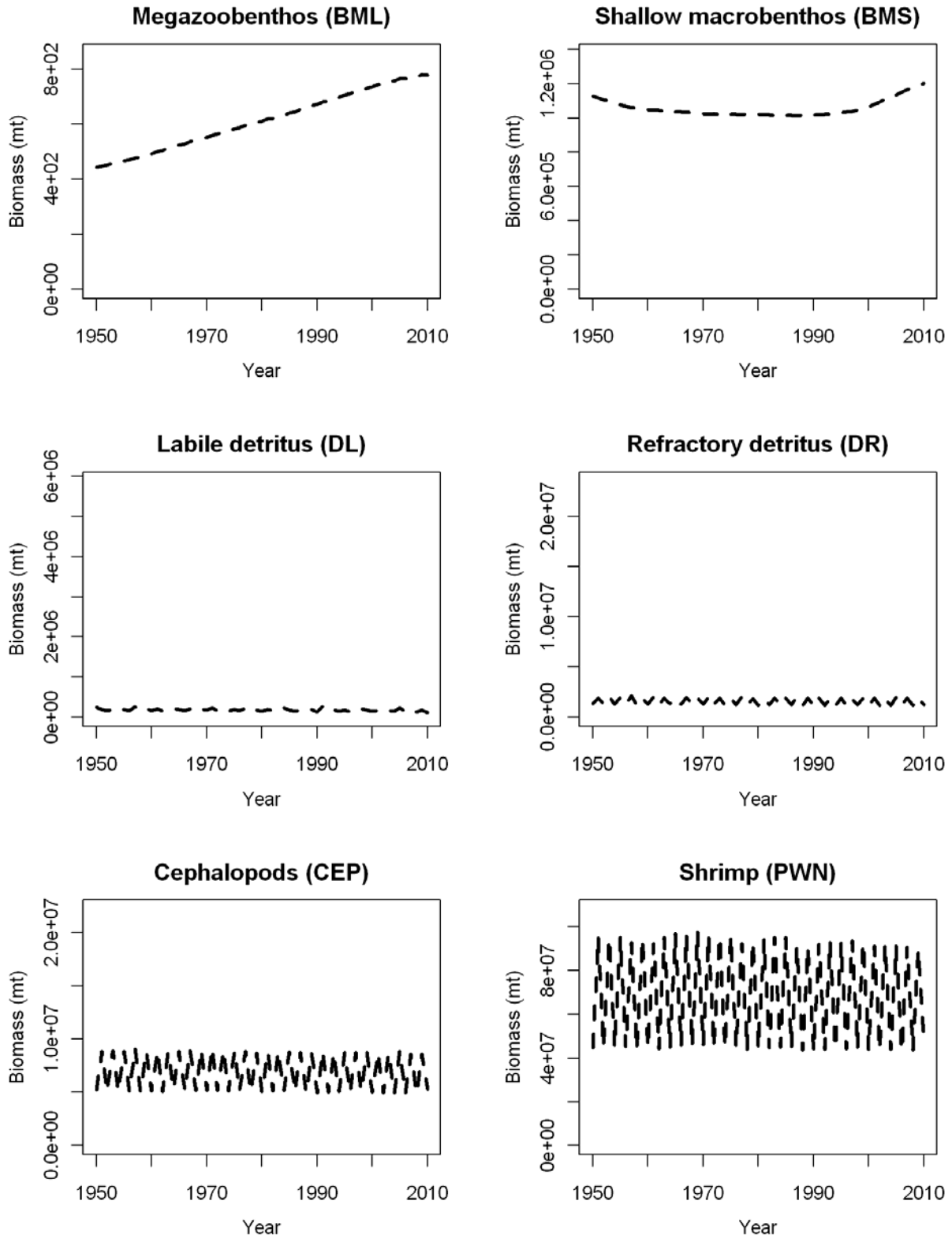


Figure 8d. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown).



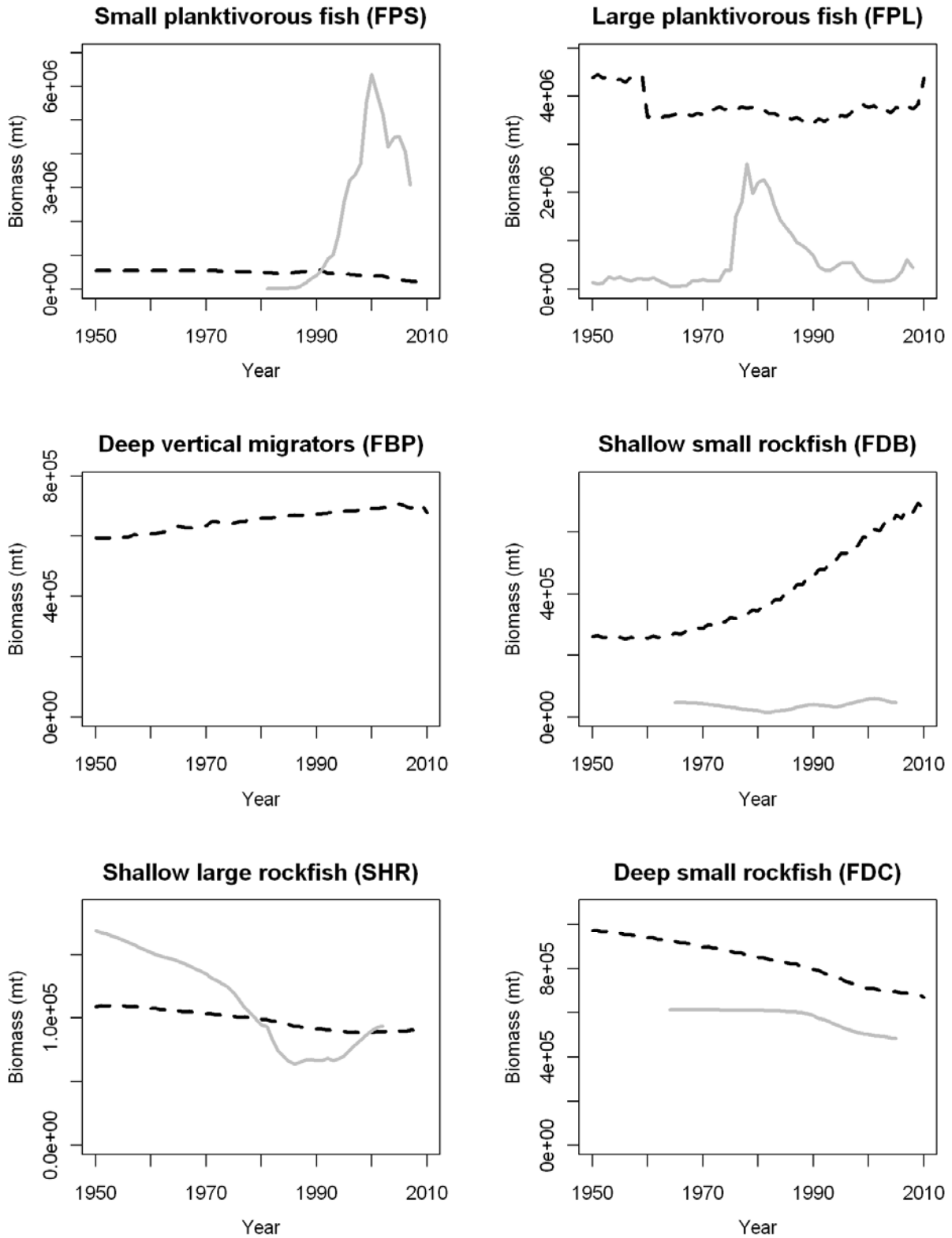


Figure 8e. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown). Solid gray lines represent historical biomass derived from stock assessments where available (18 groups).

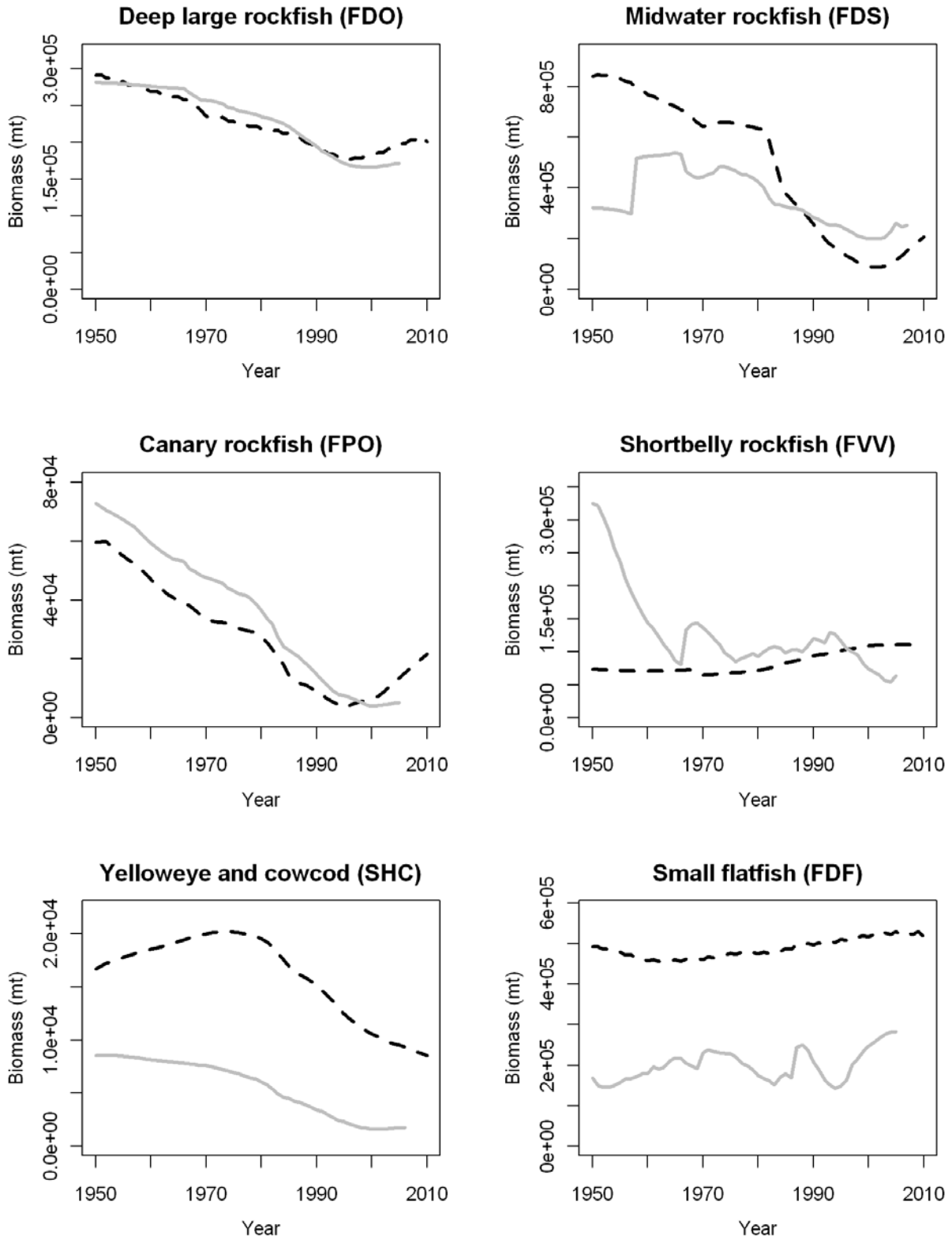


Figure 8f. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown). Solid gray lines represent historical biomass derived from stock assessments where available (18 groups).

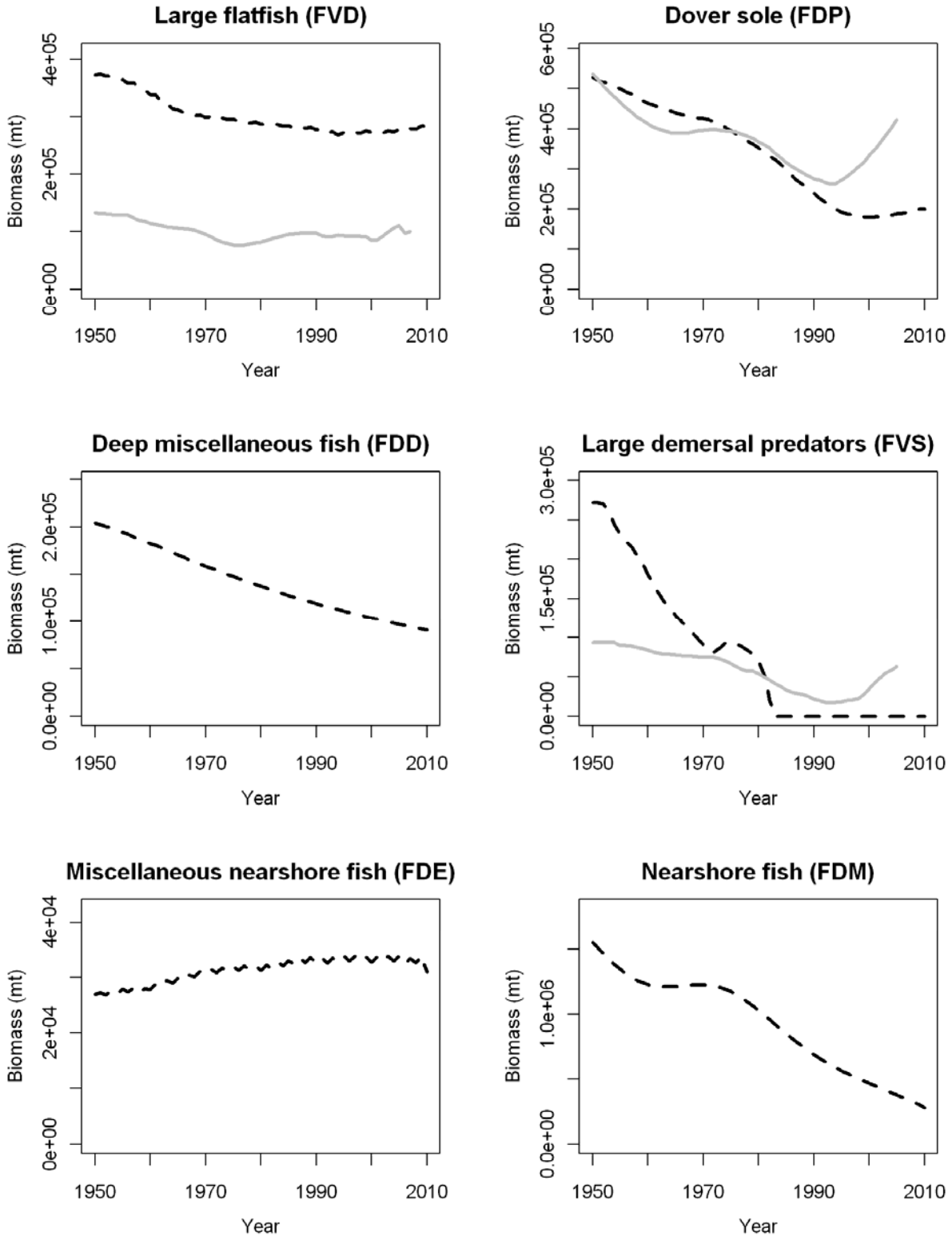


Figure 8g. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown). Solid gray lines represent historical biomass derived from stock assessments where available (18 groups).

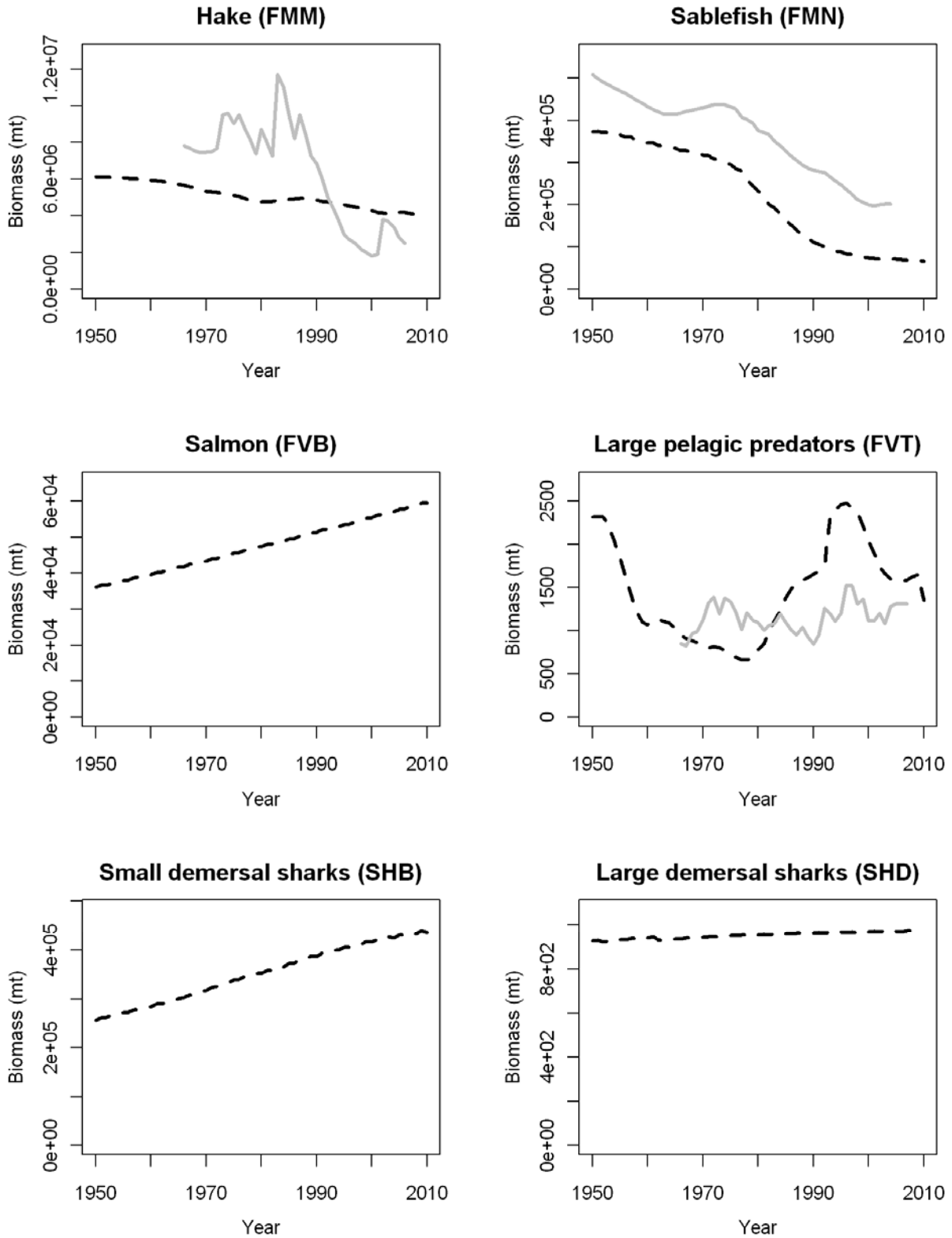


Figure 8h. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown). Solid gray lines represent historical biomass derived from stock assessments where available (18 groups).

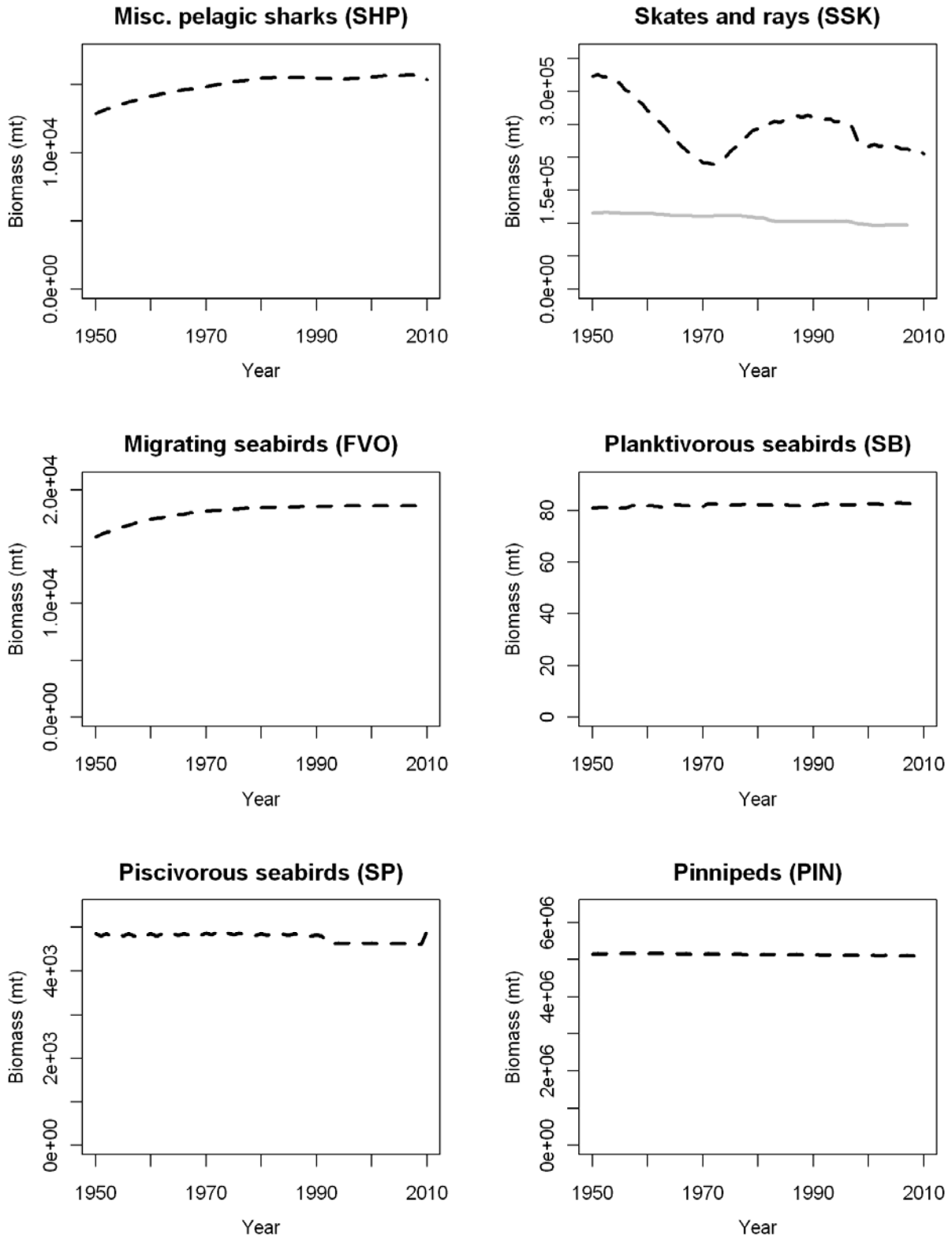


Figure 8i. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown). Solid gray line represents historical biomass derived from stock assessments where available (18 groups).

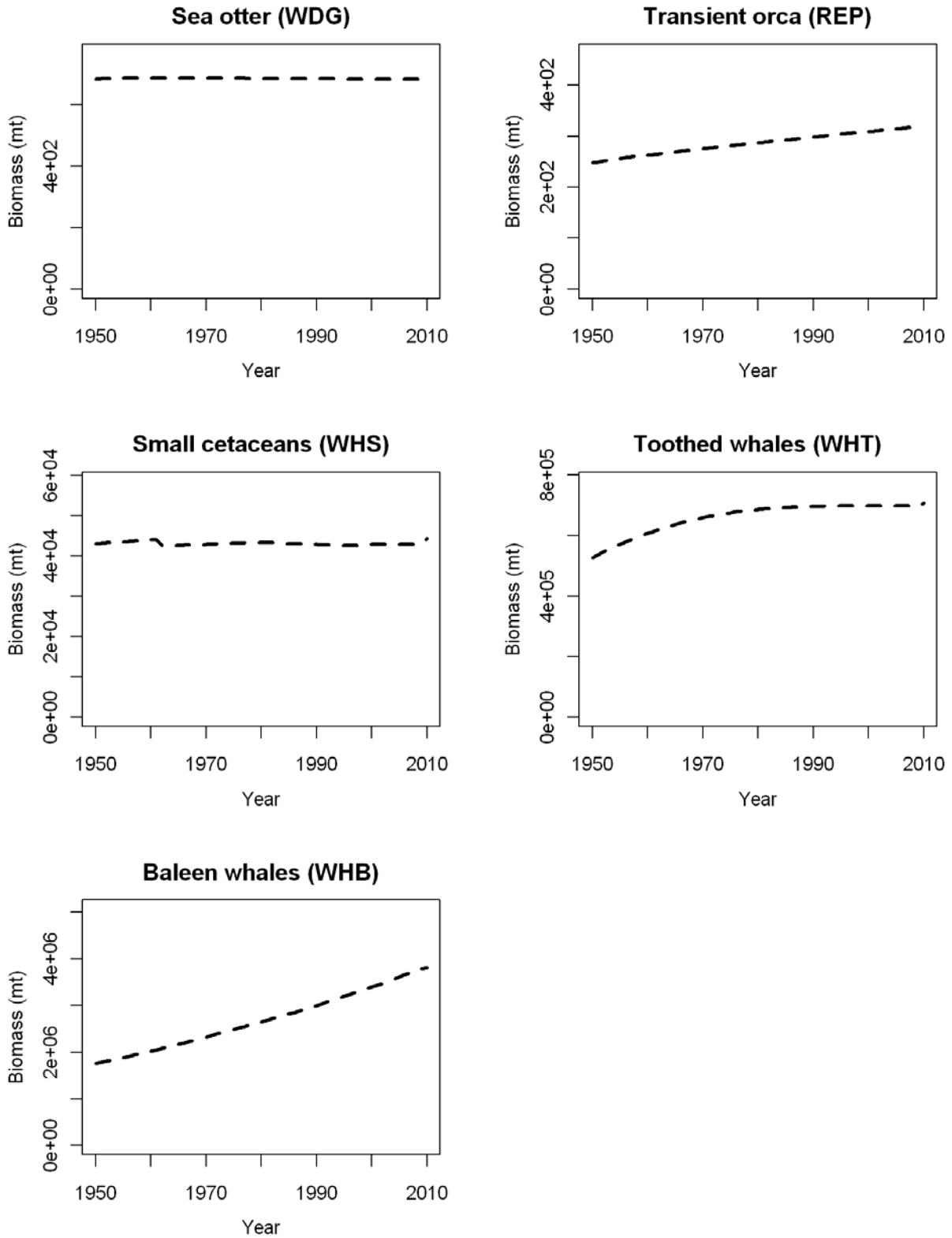


Figure 8j. Biomass results in metric tons for each functional group after final tuning phase. Historical fishing mortalities (1950 to 2007) were applied after an initial 50-year spin up (spin up not shown).

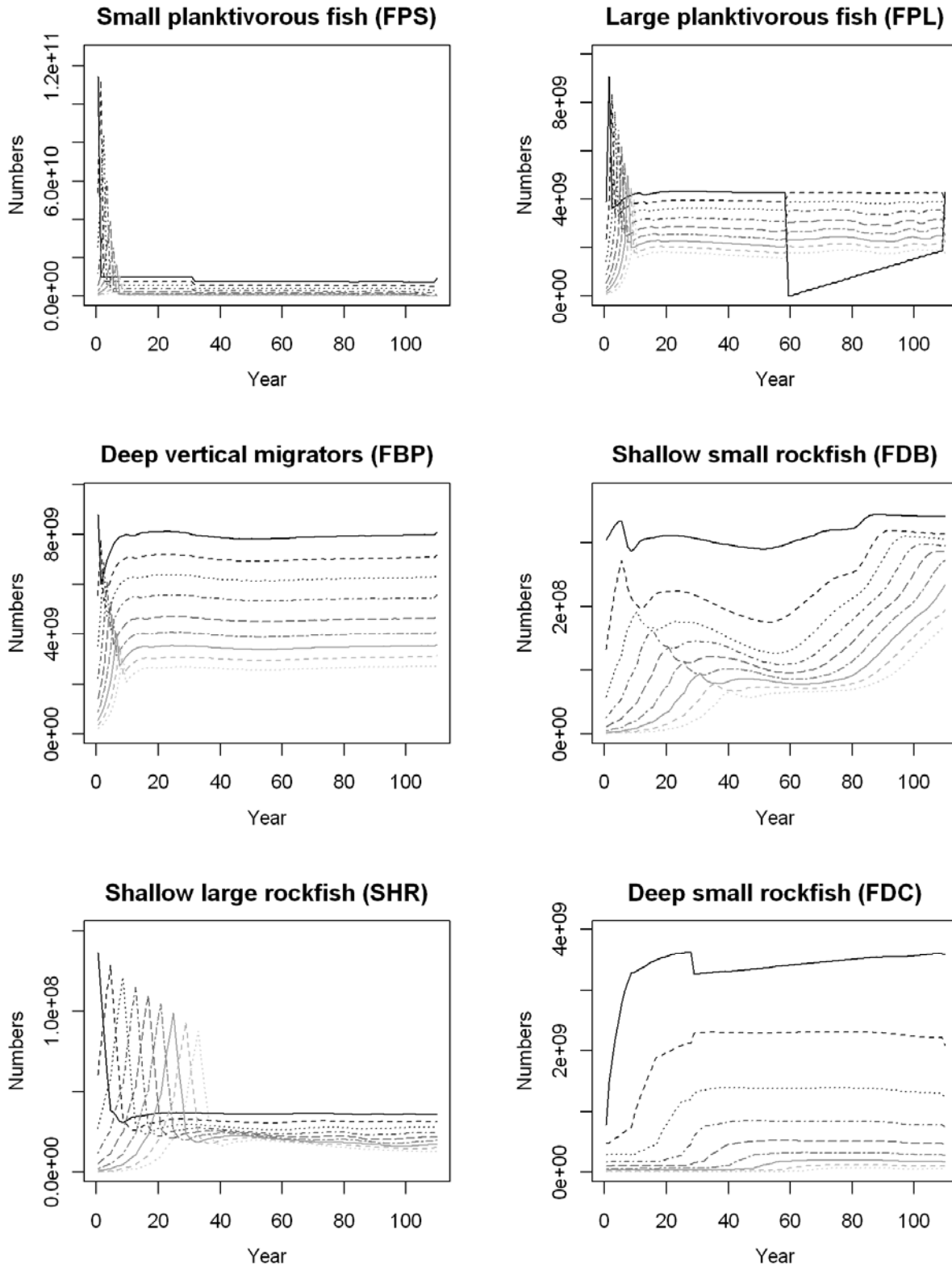


Figure 9a. Total numbers for each age class per vertebrate functional group after final tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation (years 0 to 50 show model “spin up”).

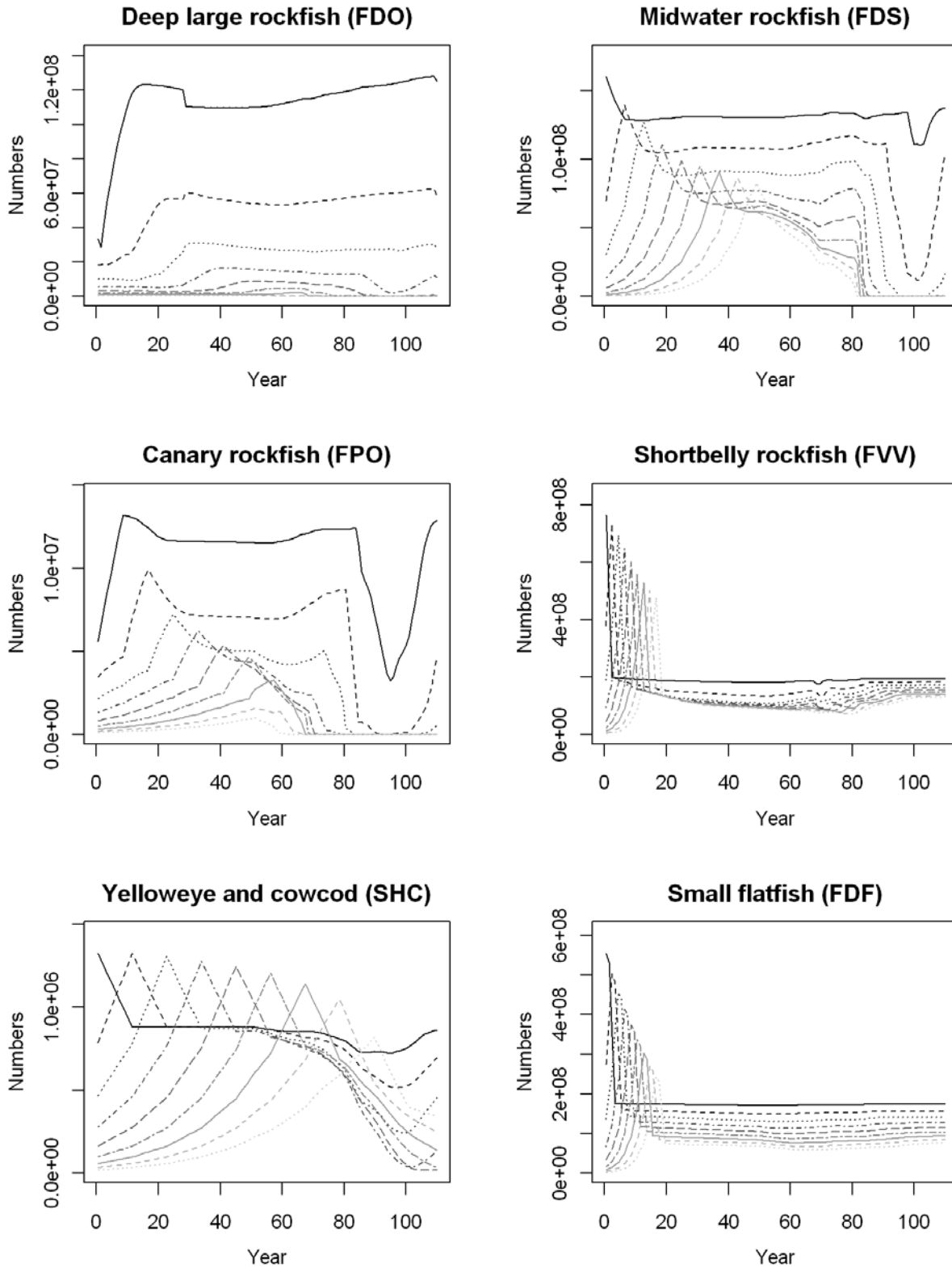


Figure 9b. Total numbers for each age class per vertebrate functional group after final tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation (years 0 to 50 show model “spin up”).



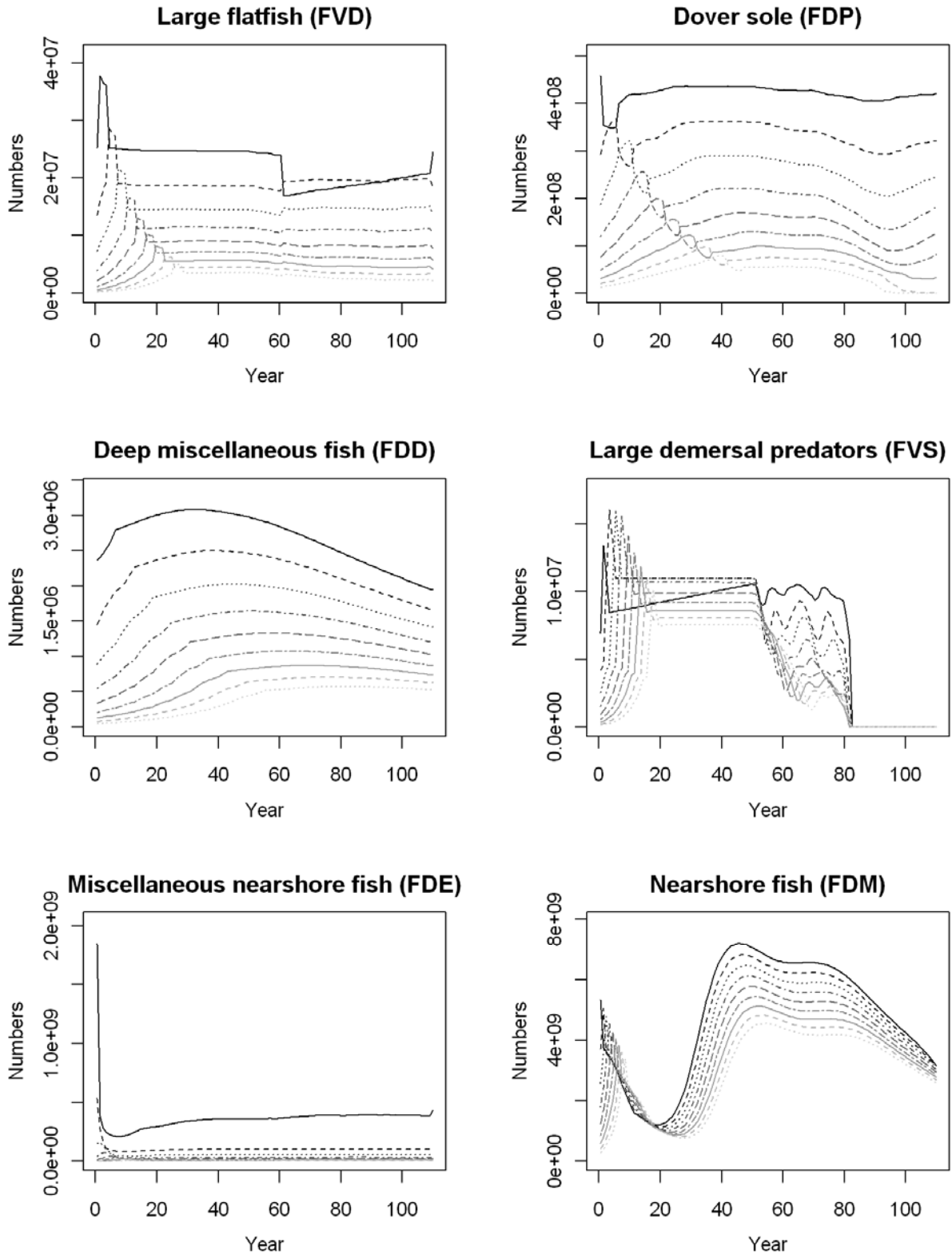


Figure 9c. Total numbers for each age class per vertebrate functional group after final tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation (years 0 to 50 show model “spin up”).

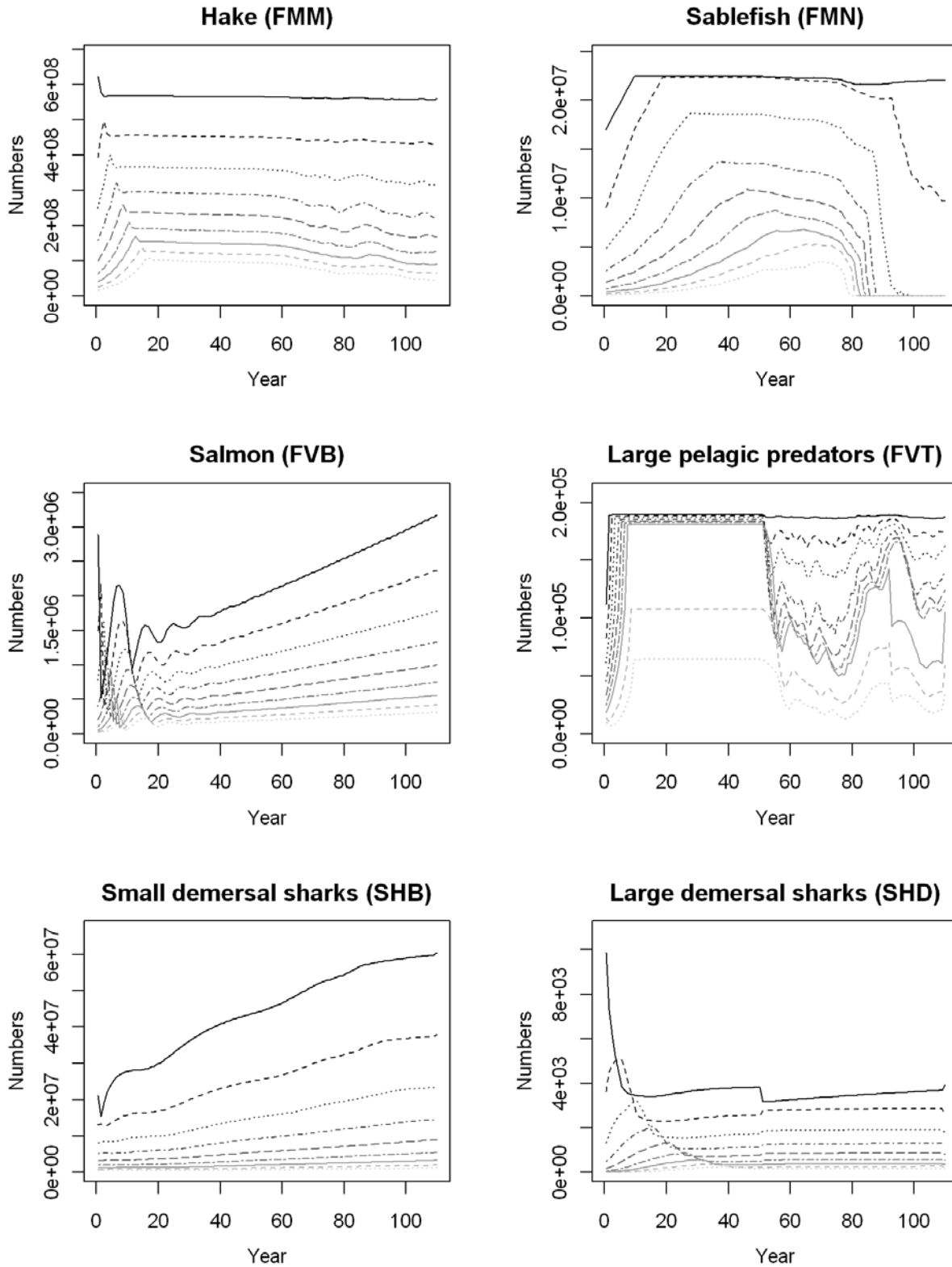


Figure 9d. Total numbers for each age class per vertebrate functional group after final tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation (years 0 to 50 show model “spin up”).

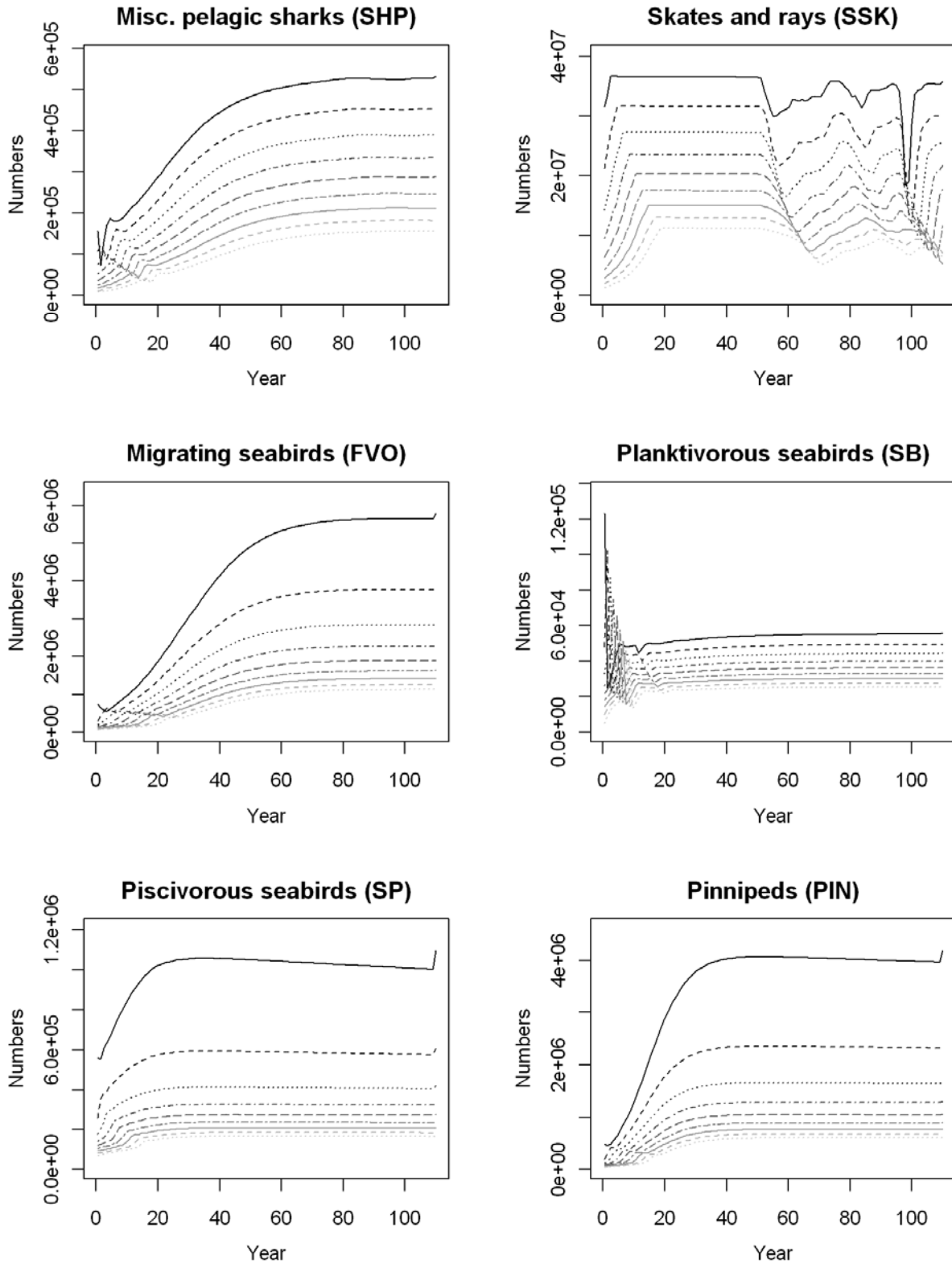


Figure 9e. Total numbers for each age class per vertebrate functional group after final tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation (years 0 to 50 show model “spin up”).

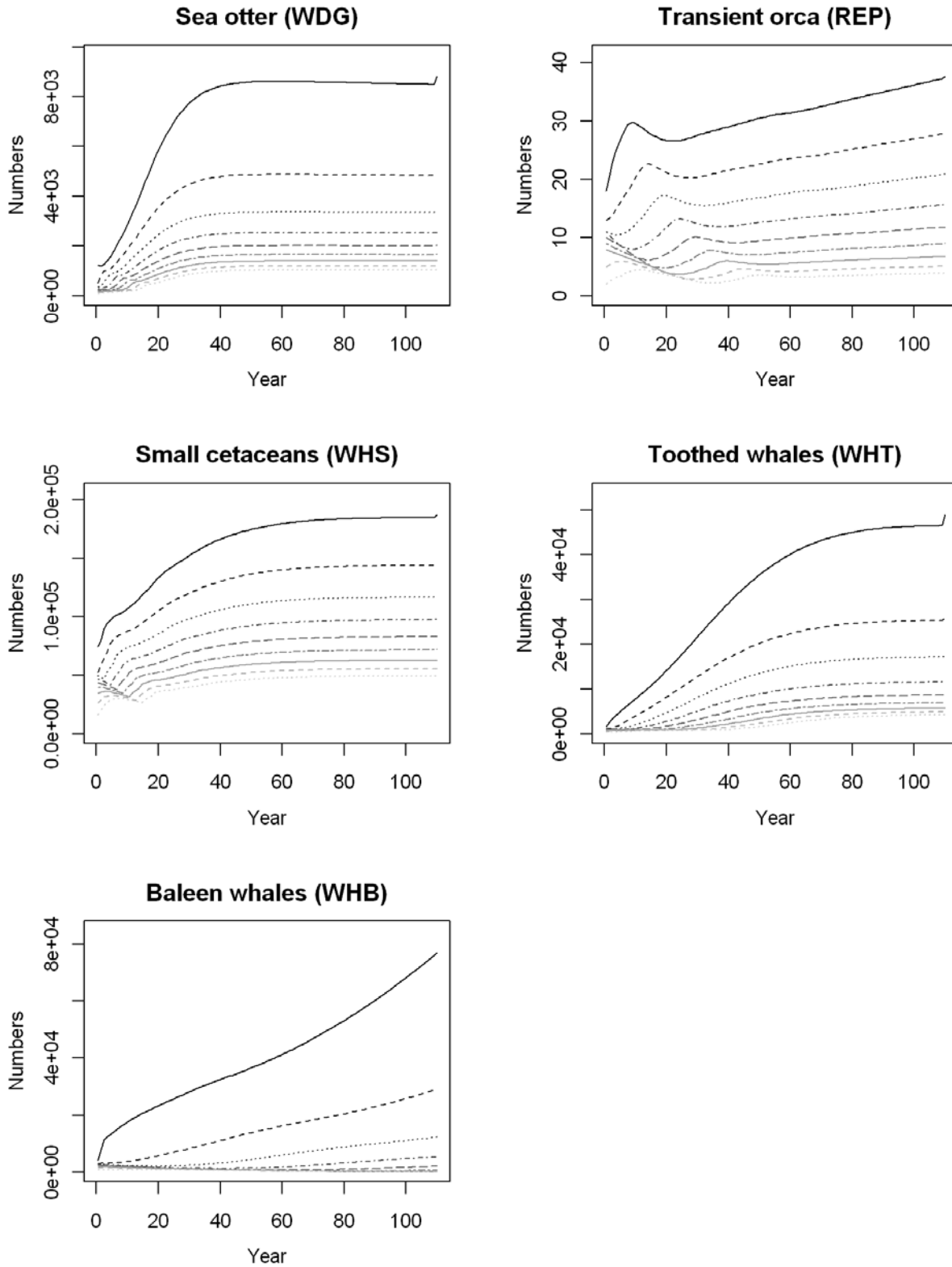


Figure 9f. Total numbers for each age class per vertebrate functional group after final tuning phase. Numbers are summed over the entire model extent. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation (years 0 to 50 show model “spin up”).

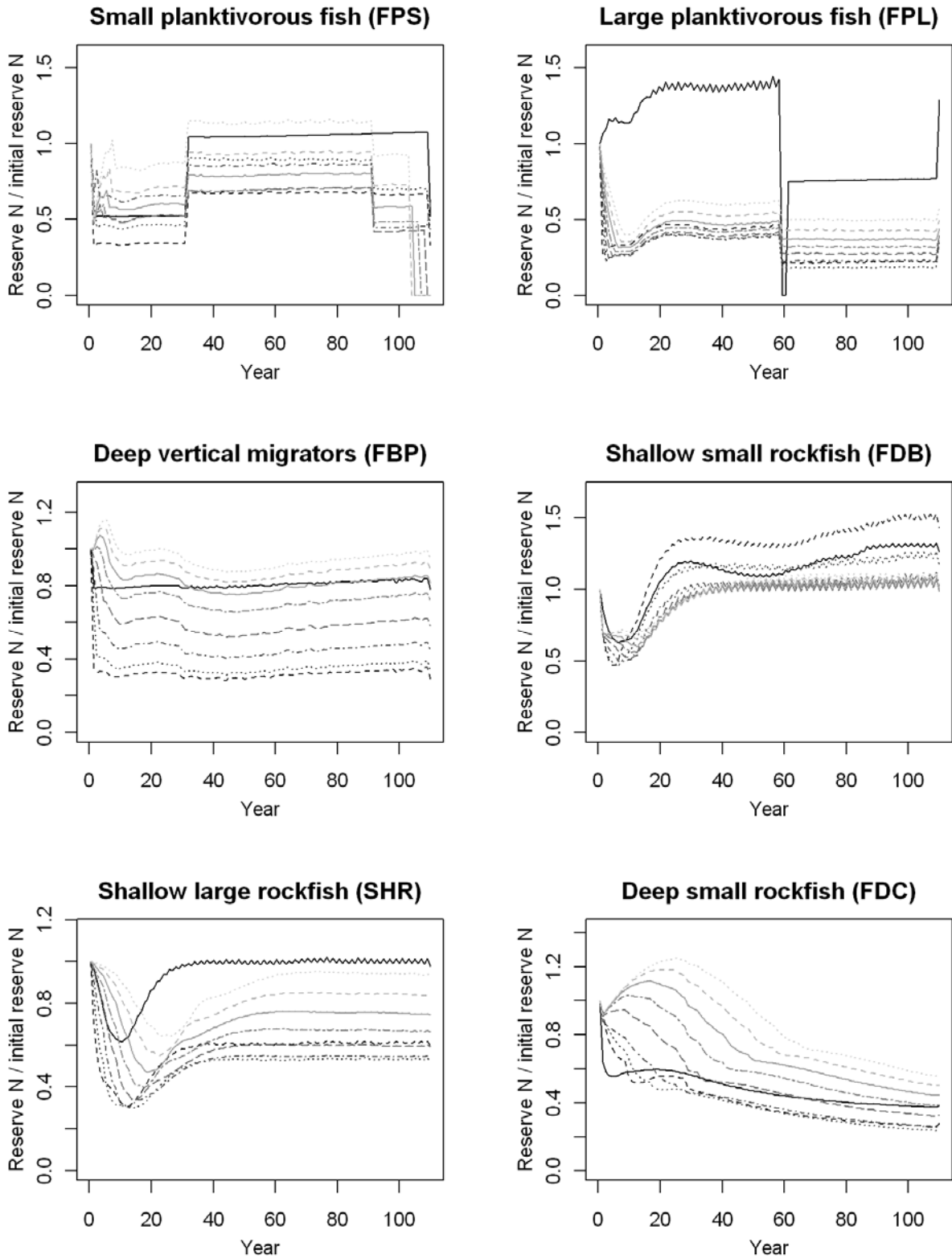


Figure 10a. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

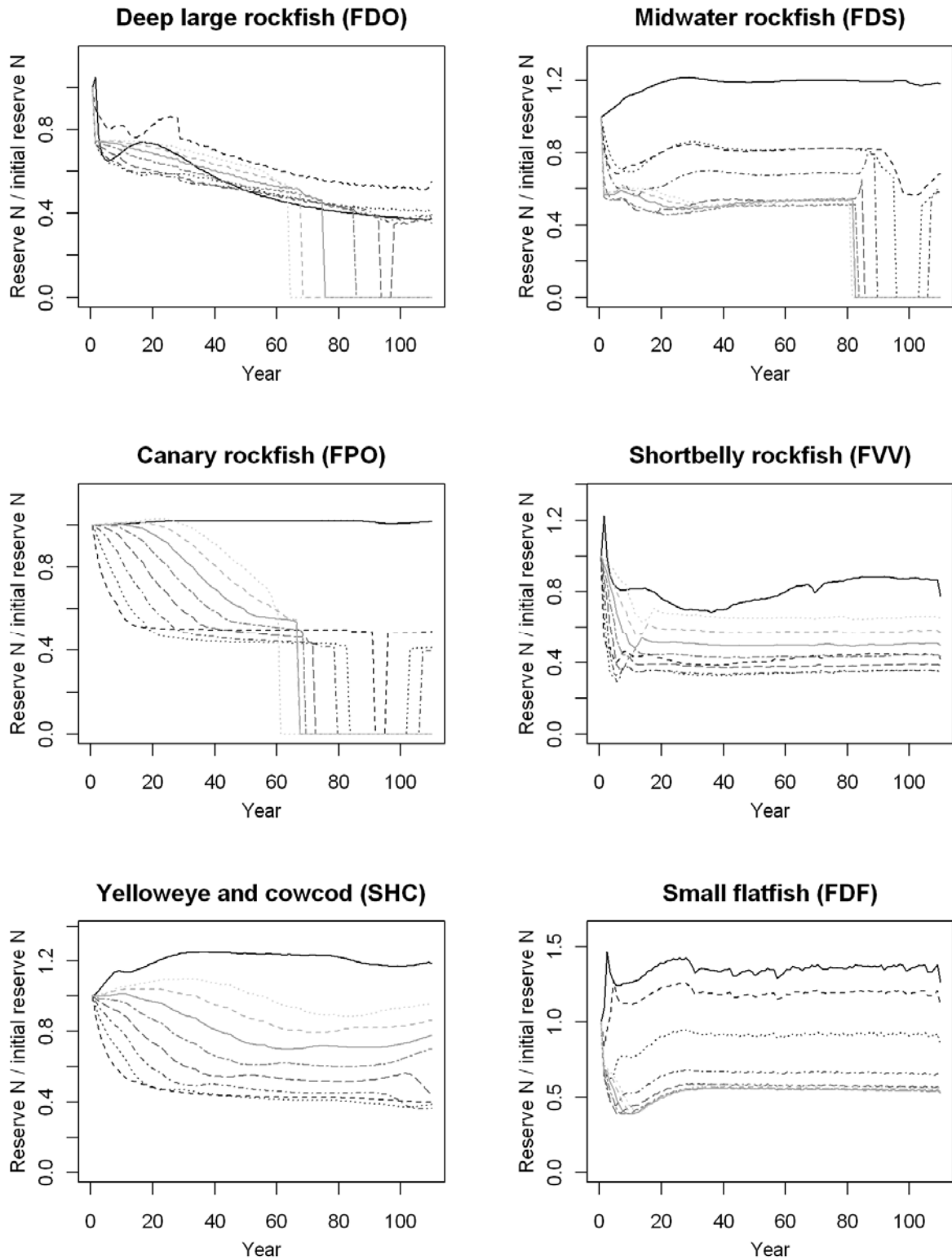


Figure 10b. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

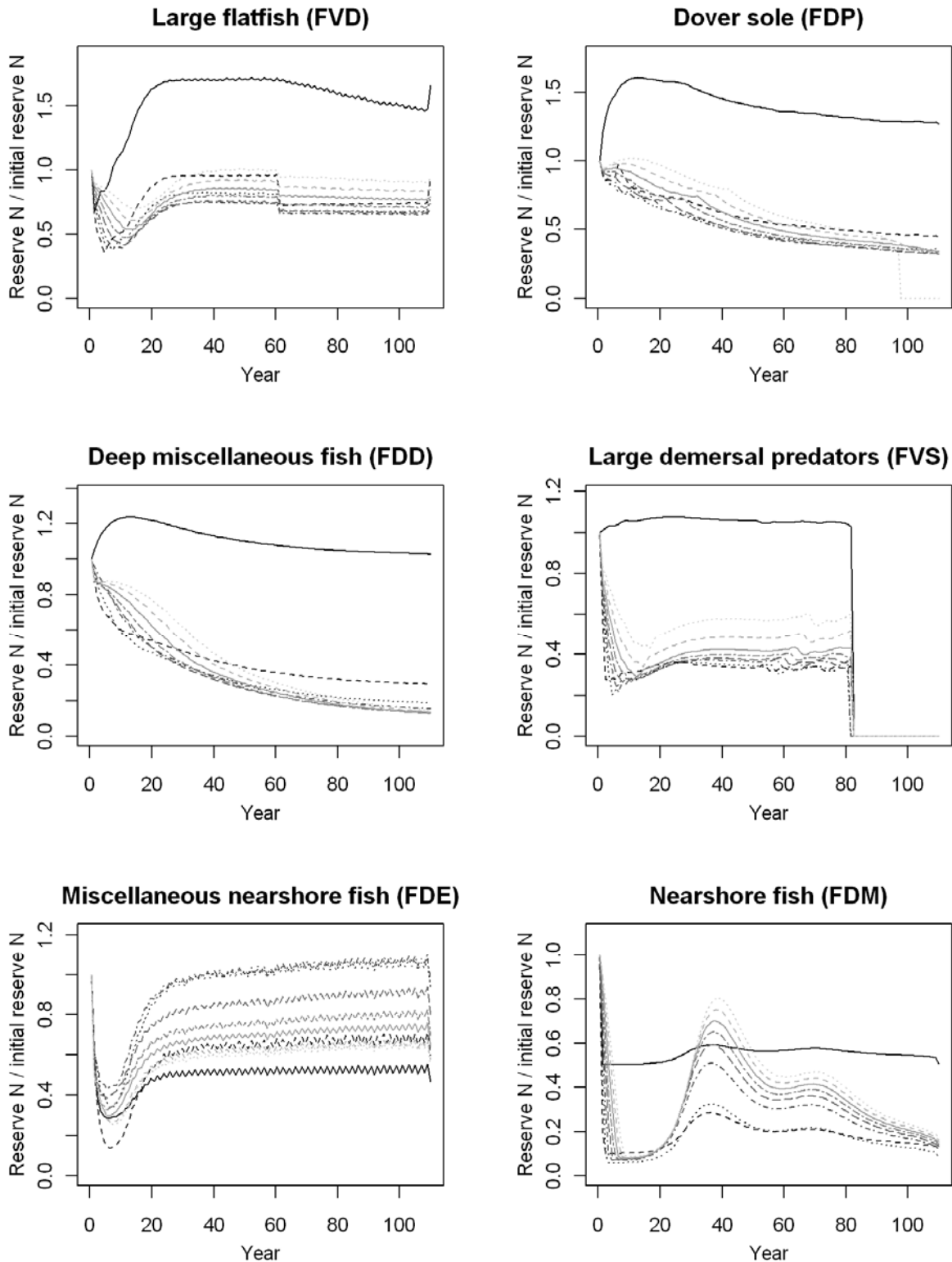


Figure 10c. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

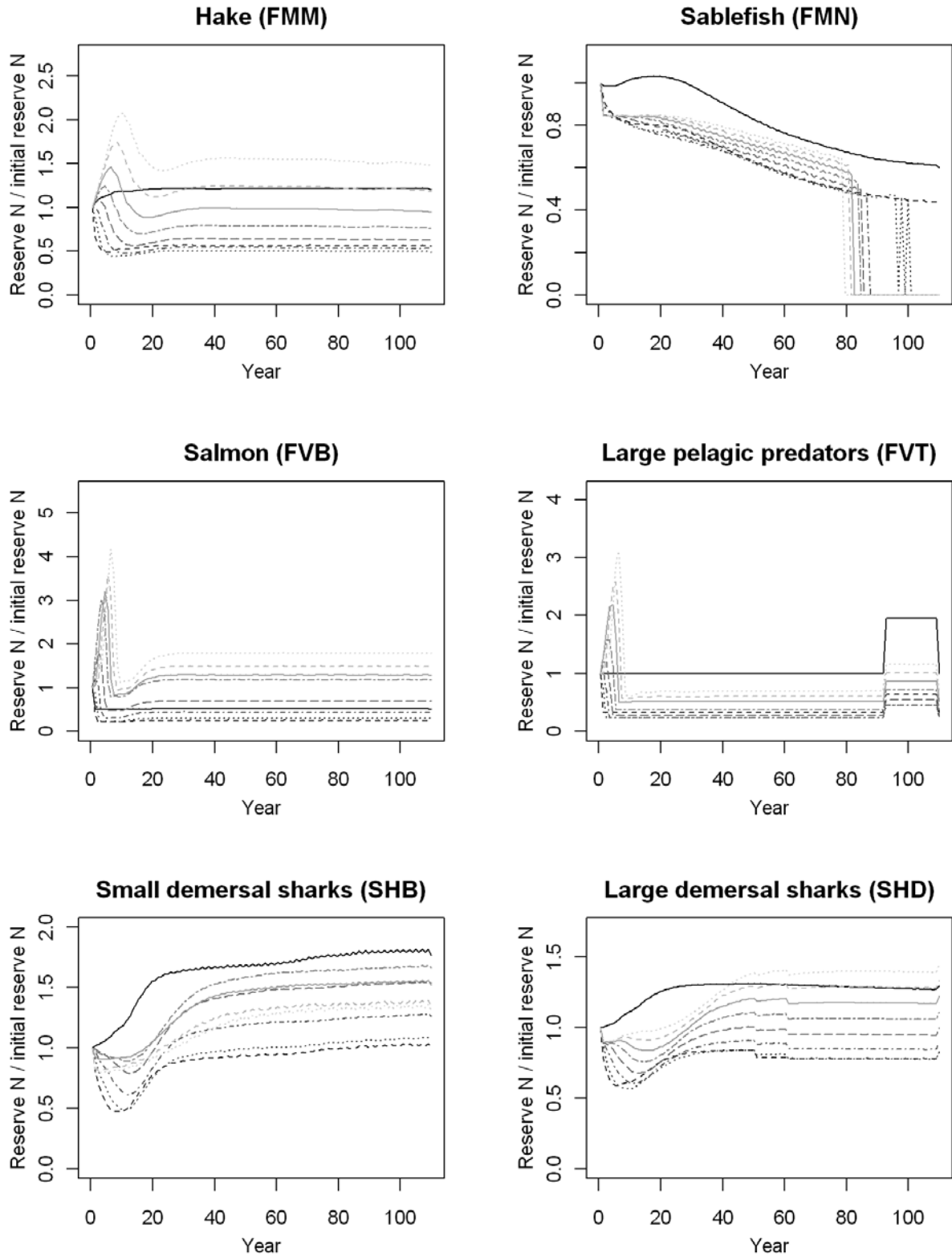


Figure 10d. Ratio of reserve nitrogen to initial reserve nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.



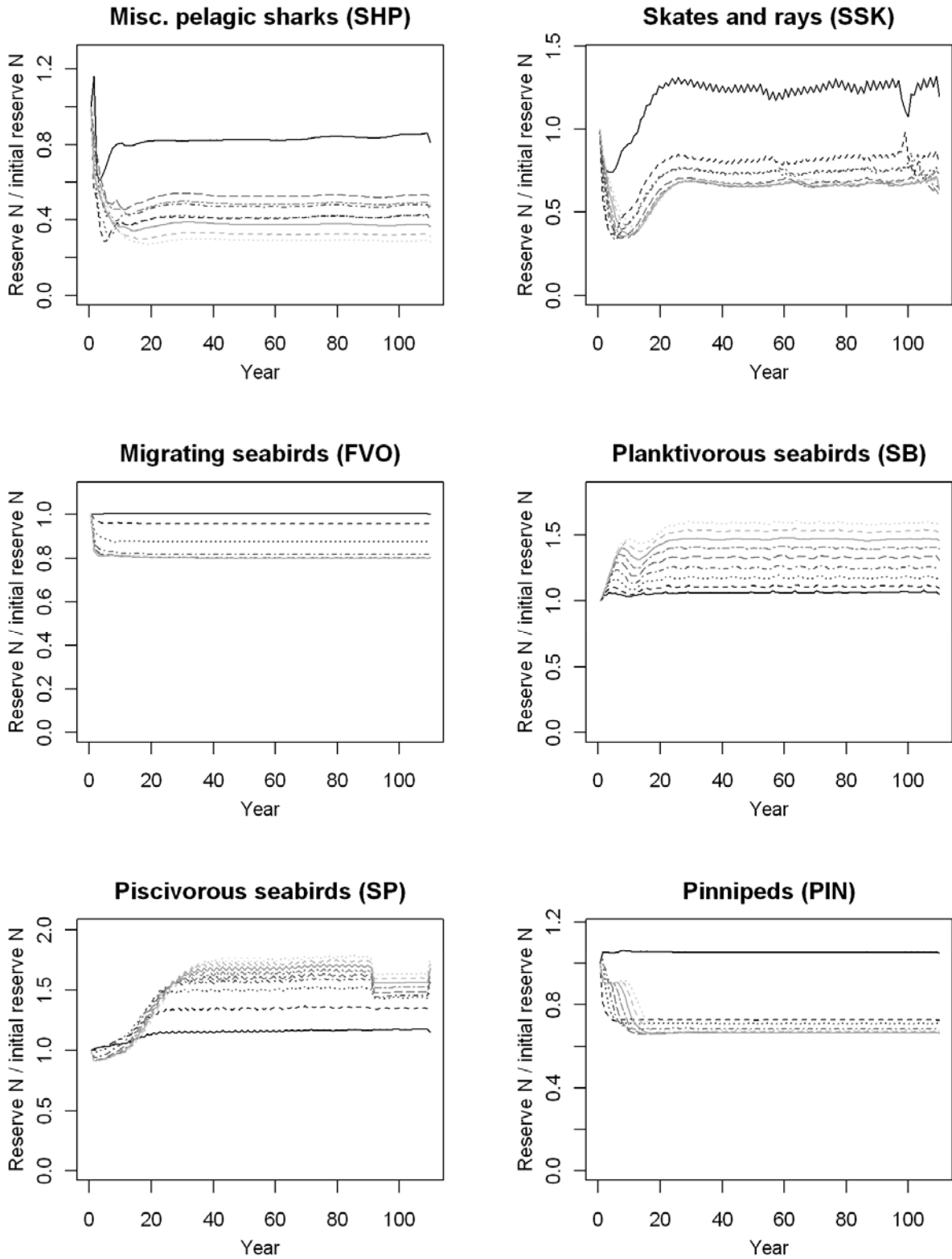


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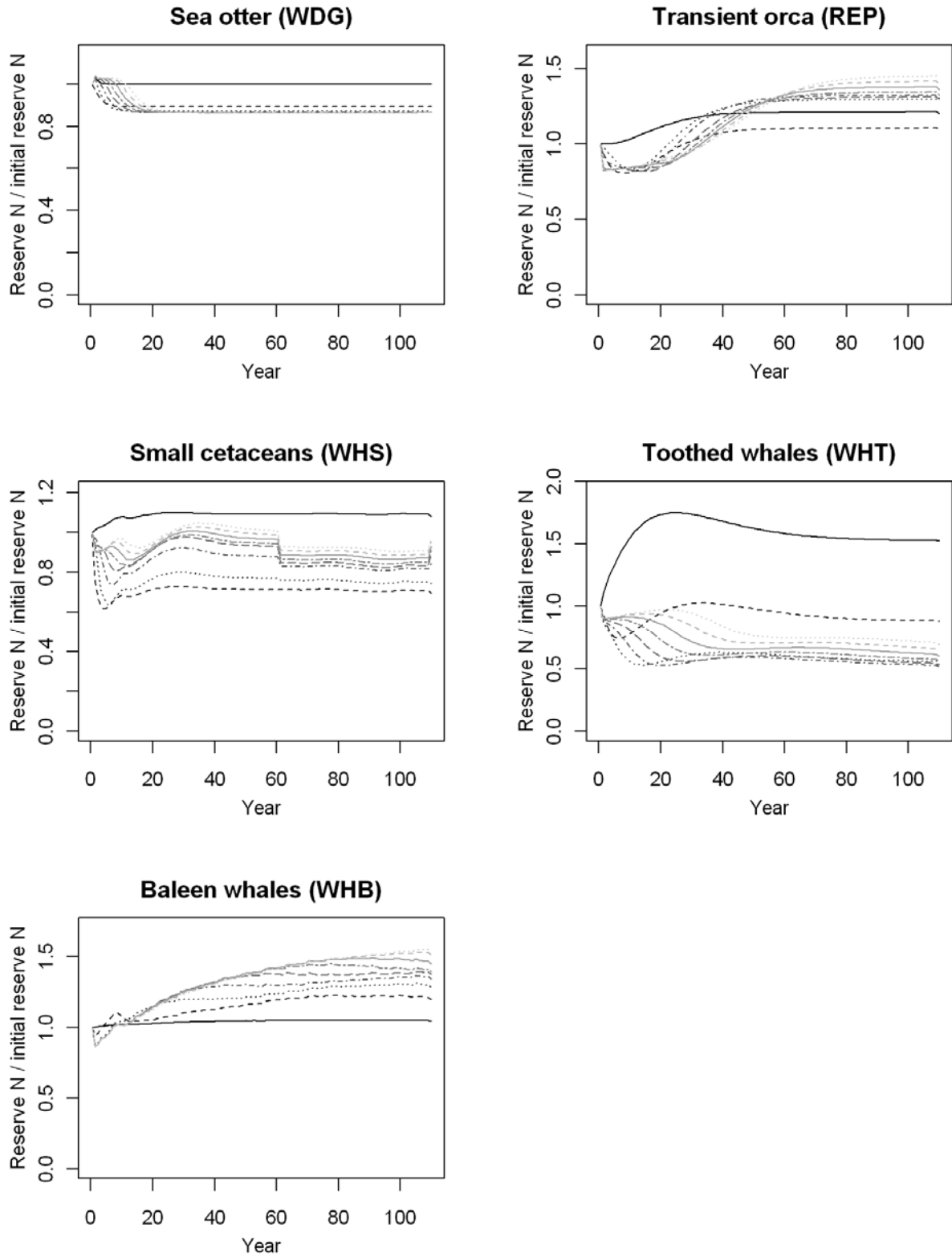


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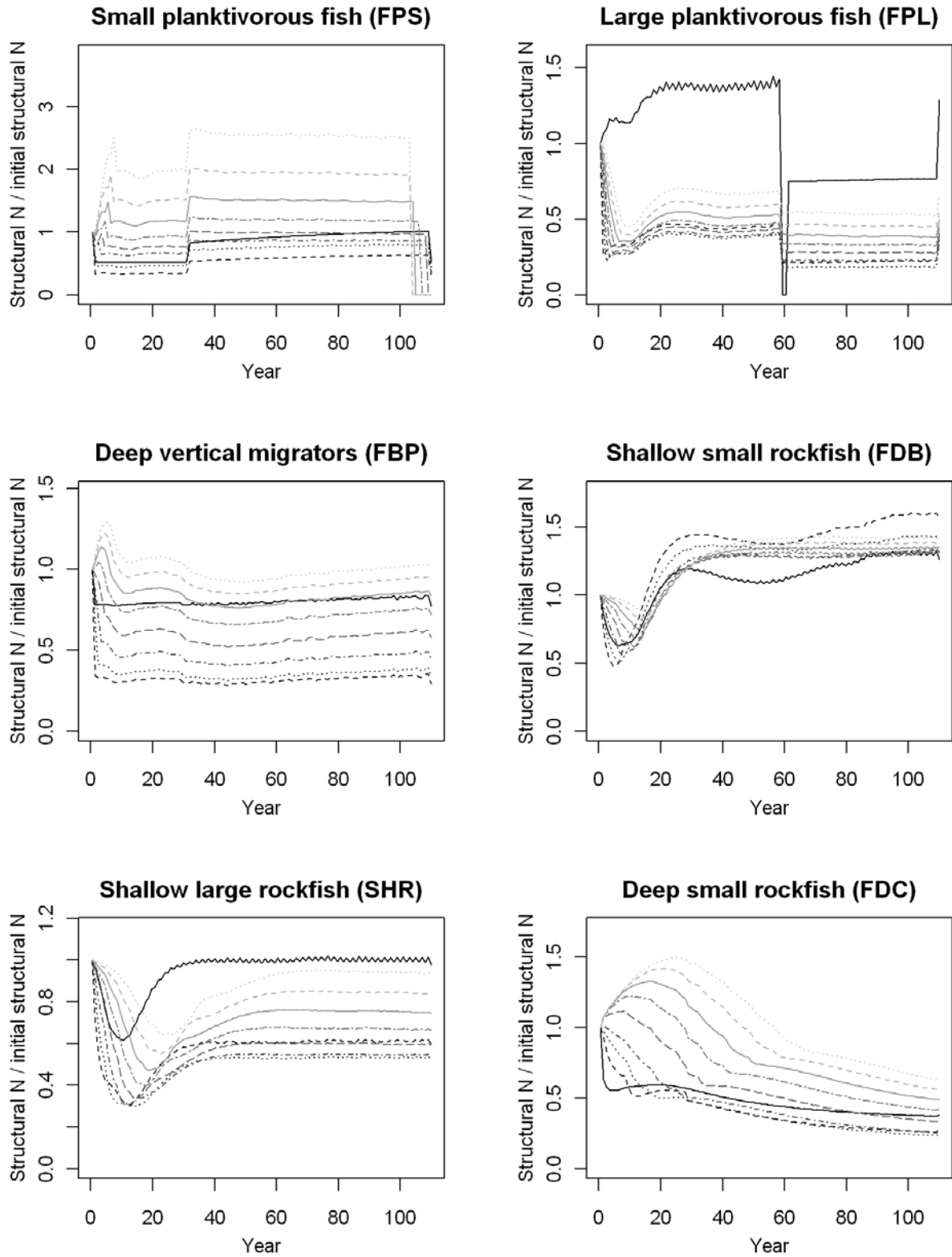


Figure 11a. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

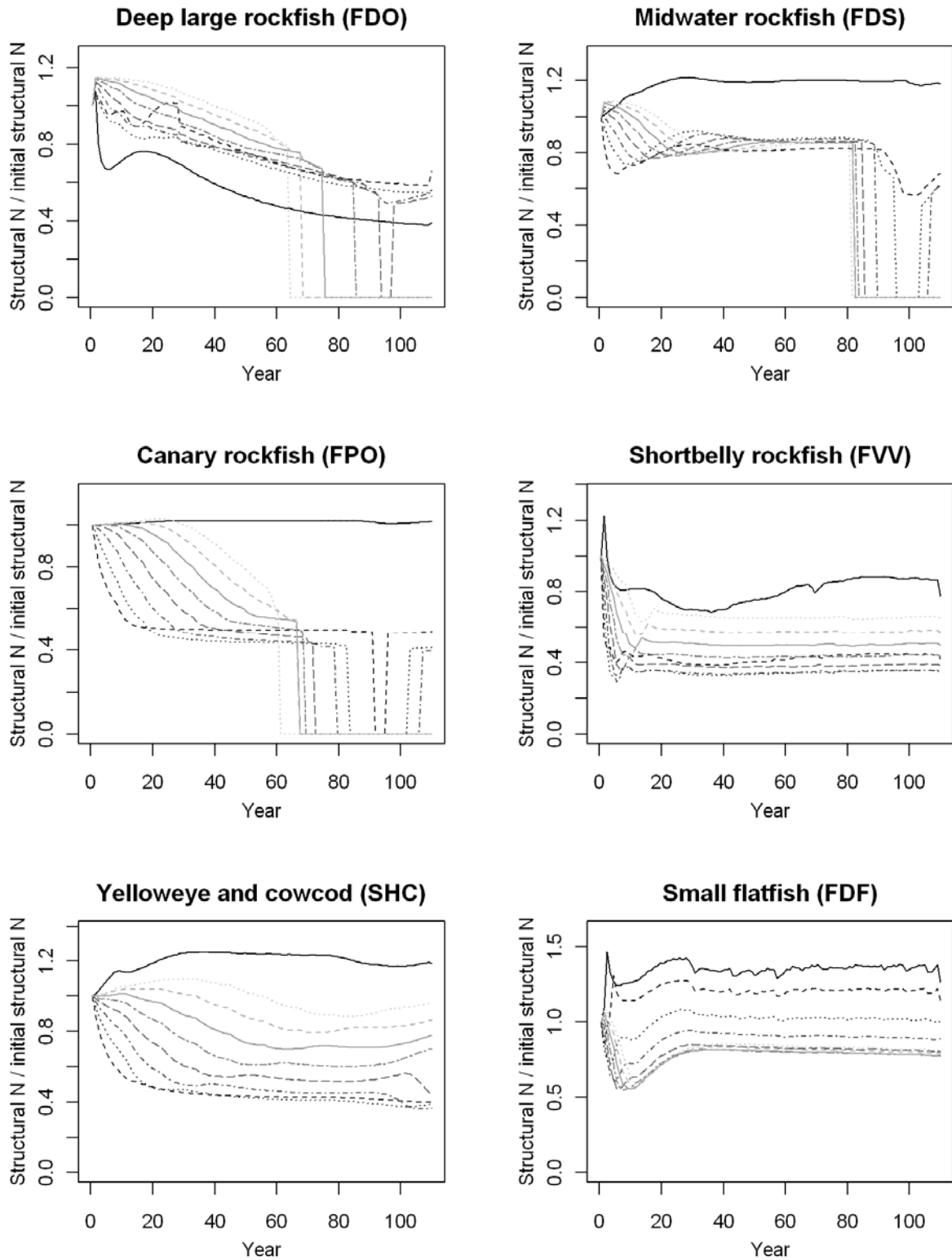


Figure 11b. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

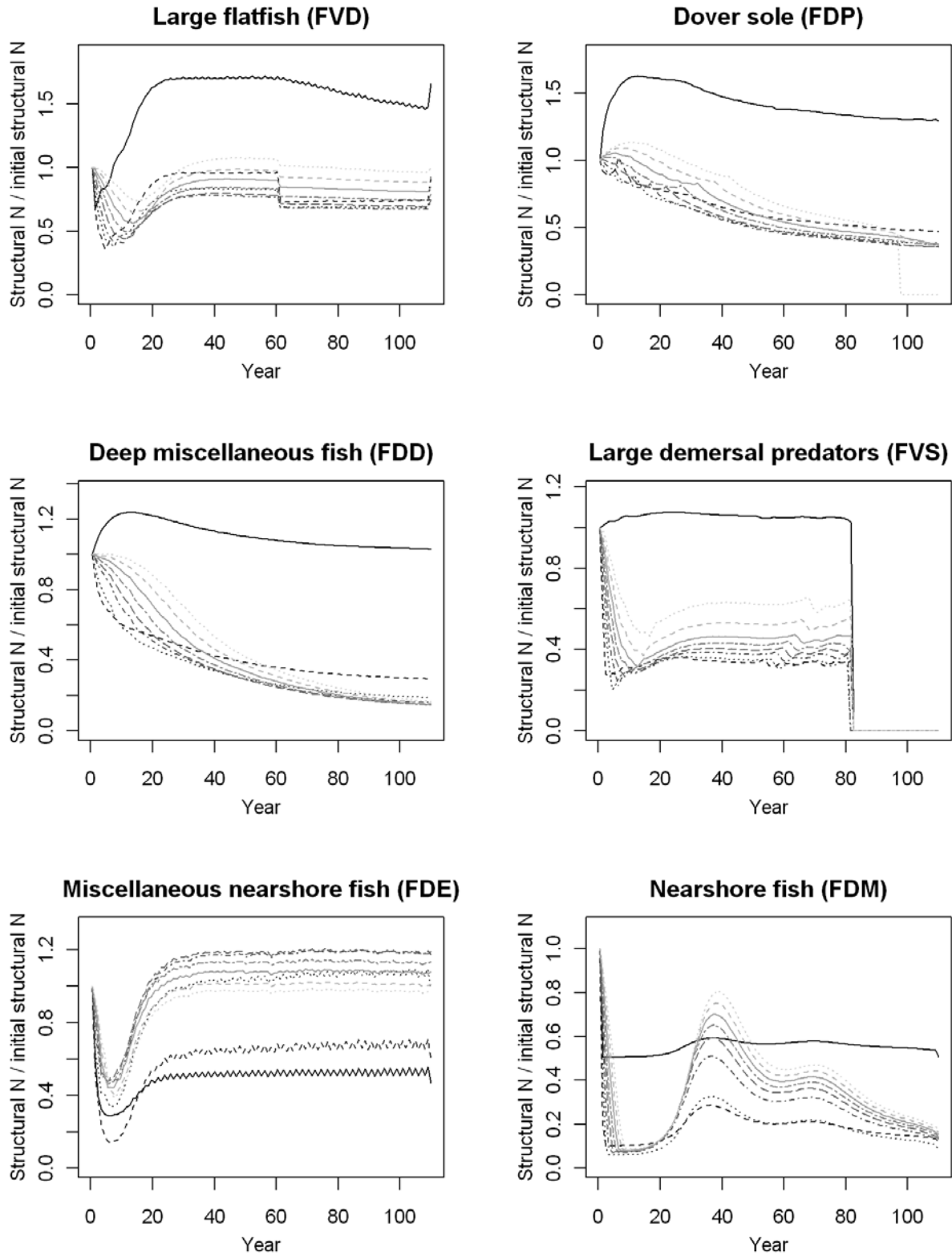


Figure 11c. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

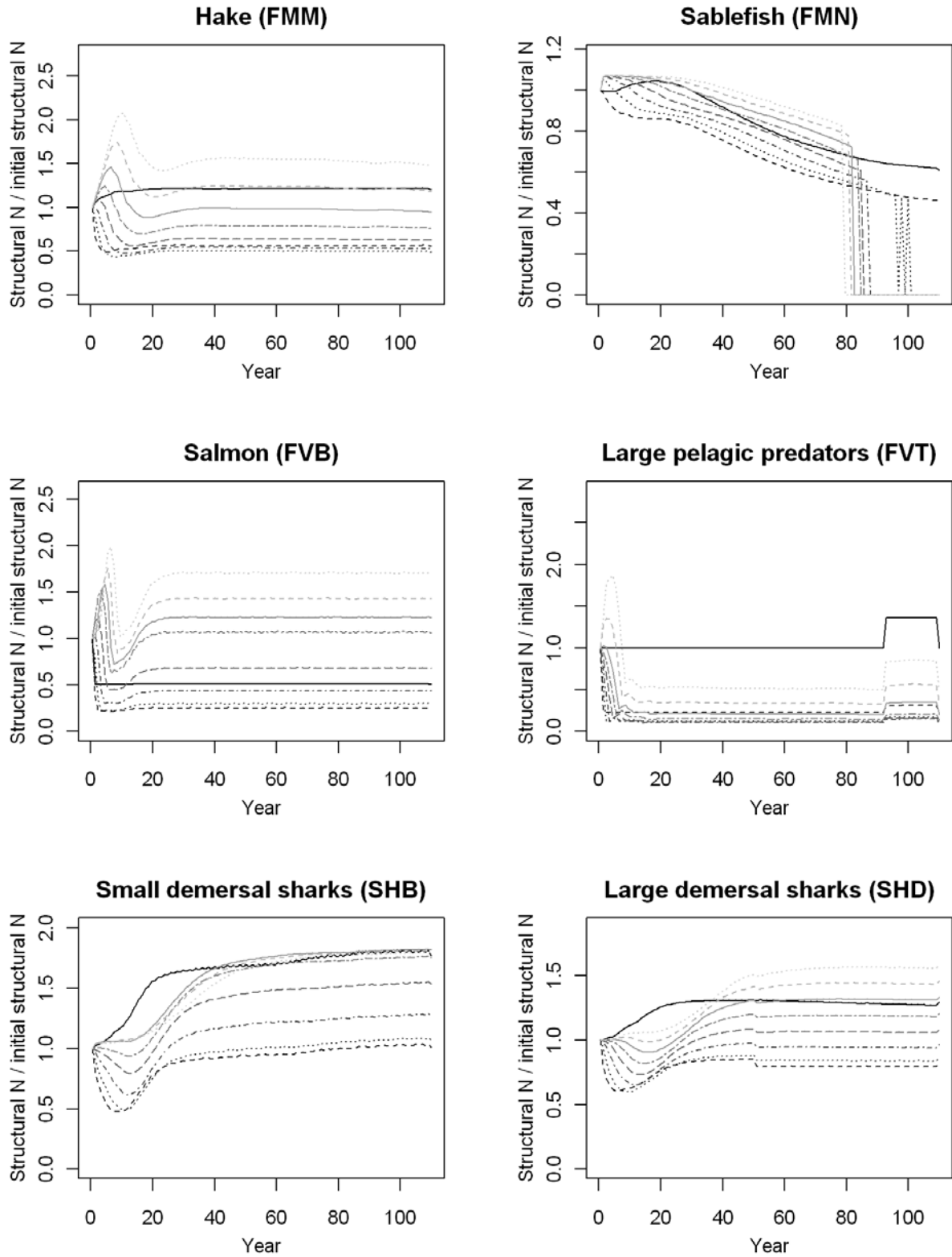


Figure 11d. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.

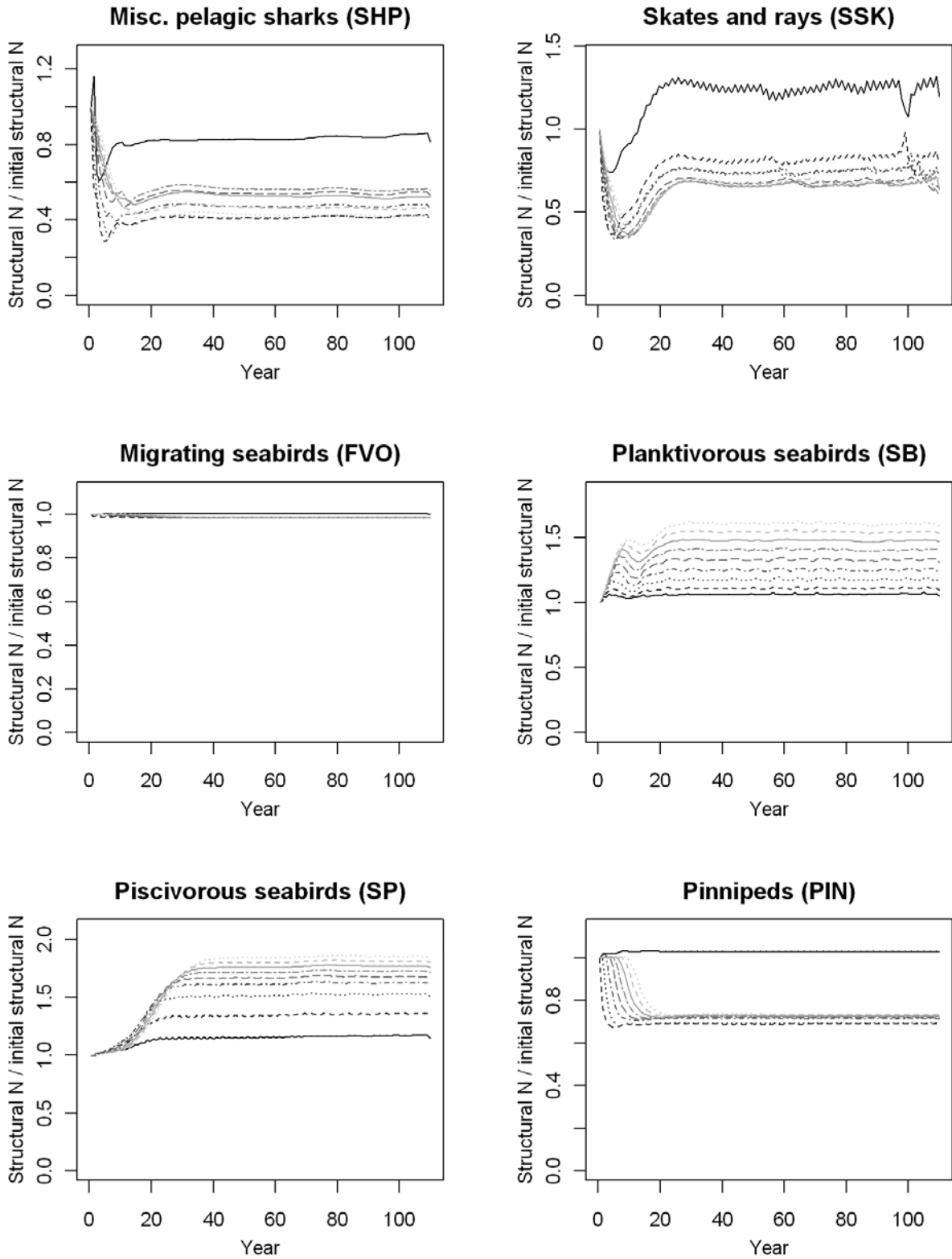


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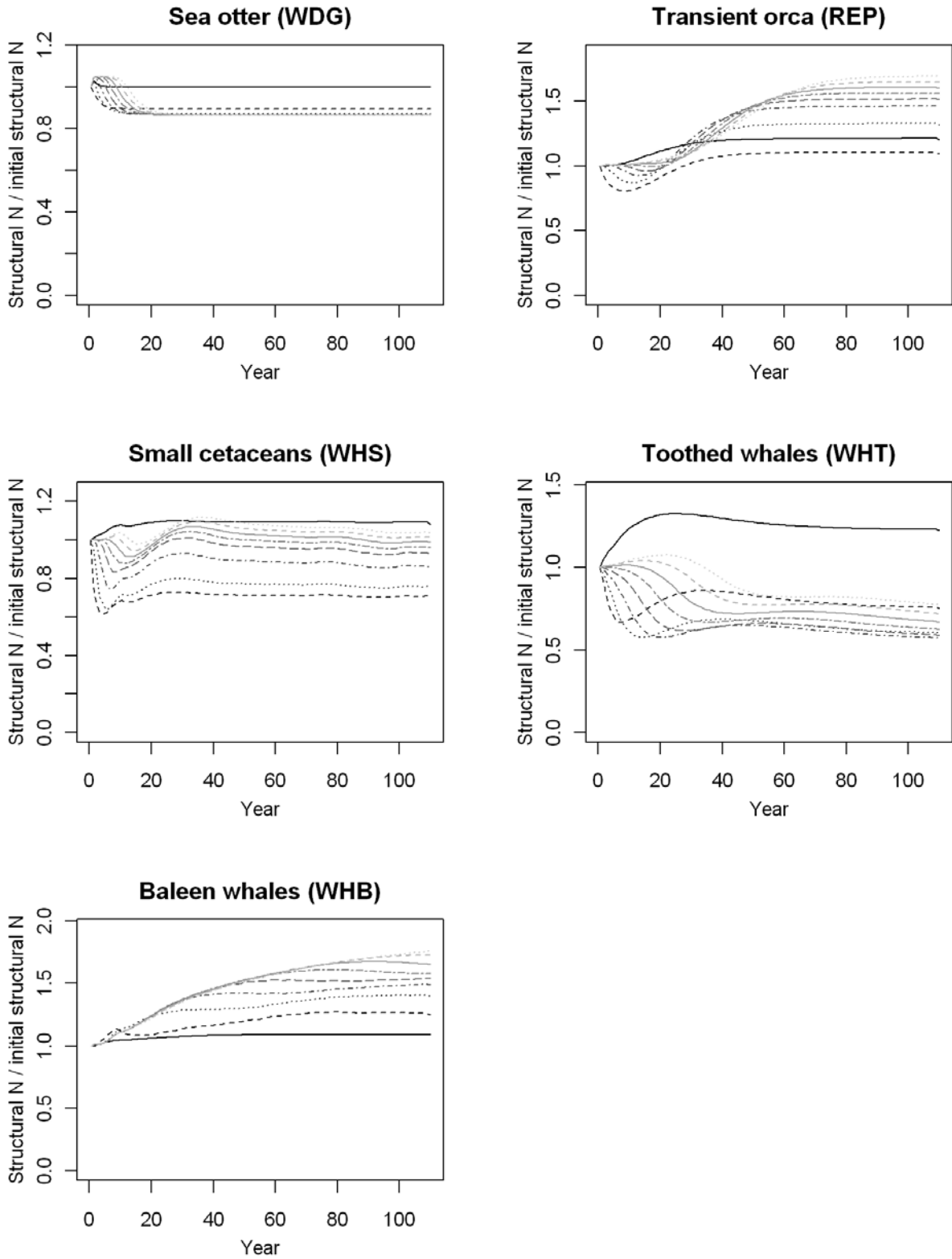


Figure 11f. Ratio of structural nitrogen to initial structural nitrogen for each age class per vertebrate functional group after final tuning phase. Age classes are plotted using a gray scale, with black representing the youngest class and the lightest gray representing the oldest class. X-axis shows years from start of simulation.



Table 1. Invertebrate functional groups and basic life history parameterization. Growth, clearance, and mortality rates are postcalibration values. Initial life history parameters were based on Brand et al. (2007).

Code	Group	Species	Initial concentration (max)	Maximum growth rate (mgN/day)	Clearance (mg <sup>3</sup> /mgN/day)	Linear mortality (/day)	Quadratic mortality (/day)
BC	Benthic carnivores	Polychaetes, nematodes, burrowing crustacea, peanut worms, flatworms	786.91	0.07	0.09312	0.0001	0
BD	Deposit feeders	Amphipods, isopods, small crustacea, snails, ghost shrimps, sea cucumbers, worms, sea mouse, sea slugs, barnacles, solenogasters, hermit crabs	103.66	0.6	0.0744	0	0
BFD	Deep benthic filter feeders	Anemones, deep corals, lampshells, reticulate sea anemone ( <i>Actinauge verrillii</i> ), rough purple sea anemone ( <i>Paractinostola faeculenta</i> ), swimming sea anemone ( <i>Stomphia coccinea</i> ), gigantic sea anemone ( <i>Metridium farcimen</i> ), corals, sponges	108.71	0.0012	0.001485	0	0
BFF	Other benthic filter feeders	Geoduck ( <i>Panopea abrupta</i> ), barnacles, razor clam ( <i>Siliqua patula</i> ), little neck clam ( <i>Venerupis philippinarum</i> ), Manila clam ( <i>Ruditapes philippinarum</i> ), miscellaneous bivalves, Vancouver scallop ( <i>Delectopecten vancouverensis</i> ), glass scallop ( <i>Cyclopecten davidsoni</i> ), green urchin ( <i>Strongylocentrotus droebachiensis</i> ), red urchin ( <i>S. franciscanus</i> )	929.18	1.1	0.23814	0	0
BFS	Shallow benthic filter feeders	Barnacles, sea fans, soft corals, gorgonian corals, black corals, green colonial tunicate ( <i>Didemnum molle</i> ), sea pens, sea whips, sea potatoes, vase sponges, mussels, scallops	112.61	0.24	0.0222	0	0
BG	Benthic grazers	Snails, abalone, nudibranchs, sand dollars, solerelles, Dorid nudibranchs, limpets, heart sea urchin ( <i>Echinocardium cordatum</i> ), spot prawn ( <i>Pandalus platyceros</i> ), pandalid shrimp	840.14	0.03	0.036	0	0
BMD	Deep megazoobenthos	Sea stars, moon snail, whelks, leather sea star ( <i>Dermasterias imbricata</i> ), bat star ( <i>Asterina miniata</i> ), sunflower sea star ( <i>Pycnopodia helianthoides</i> ), common mud star ( <i>Ctenodiscus crispatus</i> ), crinoids, brittle sea stars, basketstar ( <i>Gorgonocephalus eucnemis</i> )	59.99	0.0326	0.03	0.0001	0

Table 1 continued. Invertebrate functional groups and basic life history parameterization. Growth, clearance, and mortality rates are postcalibration values. Initial life history parameters were based on Brand et al. (2007).

Code	Group	Species	Initial concentration (max)	Maximum growth rate (mgN/day)	Clearance (mg <sup>3</sup> /mgN/day)	Linear mortality (/day)	Quadratic mortality (/day)
BML	Large megazoobenthos	Dungeness crab ( <i>Cancer magister</i> ), tanner crab ( <i>Chionoecetes bairdi</i> ), spiny lobster ( <i>Panulirus interruptus</i> ), pinchbug crabs, red rock crab ( <i>Cancer productus</i> ), graceful rock crab ( <i>C. gracilis</i> ), spider crabs, grooved tanner crab ( <i>Chionoecetes tanneri</i> ), scarlet king crab ( <i>Lithodes couesi</i> ), California king crab ( <i>Paralithodes californiensis</i> )	0.1	0.175	0.01713	0.0001	1.00E-06
BMS	Small megazoobenthos	Giant ( <i>Enteroctopus dofleini</i> ), bigeye ( <i>Loligo ocula</i> ), yellowring ( <i>Japetella heathi</i> ), smoothskin octopus ( <i>Octopus leioderma</i> ), flapjack devil fish ( <i>Opisthoteuthis californiana</i> )	34.04	0.1	0.201	0.0001	0
BO	Meiobenthos	Flagellates, ciliates, nematodes	95.81144	0.00688	0.00237		0
CEP	Jumbo squid	Jumbo squid ( <i>Dosidicus gigas</i> )	0.1	0.02	0.006	0.001	0
jCEP	Market squid	Market squid	0.04827	0.15	0.0003	0.001	0
jPWN	Juvenile shrimp	Crangon and mysid shrimp	0.036204	0.388	0.13032	0.001	1.00E-13
PWN	Adult shrimp	Crangon and mysid shrimp	0.01206	0.5068	0.054096	0.001	1.00E-13
ZG	Gelatinous zooplankton	Salps, jellyfish, ctenophores, comb jellies	0.04449	0.03	0.045	0	1.00E-06
ZL	Large carnivorous zooplankton	Euphausiids, chaetognaths, pelagic shrimp, pelagic polychaetes, crimson pasiphaed ( <i>Pasiphae tarda</i> )	8.563443	0.45	0.2301	0	1.00E-06
ZM	Mesozooplankton	Copepods, cladocera	0.309387	1.8	0.18	0	1.00E-06
ZS	Microzooplankton	Ciliates, dinoflagellates, nanoflagellates, gymnodiods, protozoa	3.02	0.5	0.6249	0	1.00E-06

Table 2. Vertebrate functional groups and basic life history parameterization. Life history parameters represent values for each species in the group, weighted by relative abundance. Linf and k are constants in the von Bertalanffy length-age relationship; a and b are constants of the length-weight relationship ( $W=aL^b$ ). Beverton-Holt recruitment parameters and mortality rates are postcalibration values. See Appendix A for life history and biomass references.

Code	Group	Initial biomass (mt)	Natural mortality /year	k	Linf	Max age (yrs)	a	b	Age at maturity (yrs)	Age at recruitment (days)
FDP	Dover sole	423,049	0.0900	0.08	50	53	0.0041	3.2495	5.0	360
FPO	Canary rockfish	21,088	0.0600	0.16	56	75	0.0155	3.0300	8.0	90
FVV	Shortbelly rockfish	64,000	0.3500	0.20	28	17	0.0095	3.0650	2.0	30
SHC	Yelloweye and cowcod rockfish	595	0.0473	0.05	69	110	0.0193	2.9852	16.1	53
FBP	Deep vertical migrators	244,363	0.4582	0.35	25	8	0.0030	2.9980	2.2	30
FDD	Deep miscellaneous fish	179,207	0.0819	0.10	97	65	0.0640	3.0692	25.1	90
FDC	Deep small rockfish	489,619	0.0628	0.11	31	77	0.0075	3.2383	12.7	45
FDO	Deep large rockfish	172,271	0.0675	0.09	61	90	0.0092	3.2310	12.8	45
FDF	Small flatfish	314,932	0.3507	0.23	47	19	0.0066	3.1410	3.8	195
FDE	Miscellaneous nearshore fish	60,181	0.6221	0.06	56	18	0.0105	3.0267	3.2	35
FDM	Nearshore fish	685,808	0.3200	0.24	35	13	0.0030	3.0739	2.2	30
FDS	Midwater rockfish	252,991	0.1384	0.19	50	59	0.0195	2.9276	18.6	141
FDB	Shallow small rockfish	48,221	0.1659	0.13	28	45	0.0108	3.1108	4.6	73
SHR	Shallow large rockfish	62,044	0.2018	0.14	47	41	0.0245	2.7311	6.3	58
FMM	Hake	3,698,000	0.2300	0.33	91	23	0.0204	2.7376	3.5	70
FMN	Sablefish	156,676	0.0700	0.23	78	85	0.0024	3.3469	5.0	360
FVD	Large flatfish	113,779	0.2068	0.14	92	29	0.0044	3.2478	7.0	180
FVS	Large demersal predators	34,744	0.2505	0.14	108	20	0.0031	3.3021	3.9	90
FVT	Large pelagic predators	1,310	0.3000	0.10	140	10	0.0453	2.7900	5.0	30
FPL	Large planktivorous fish	1,259,290	0.5000	0.29	41	14	0.0035	3.3657	1.5	60
FPS	Small planktivorous fish	3,736,609	0.7546	0.52	20	9	0.0086	2.9982	1.7	60
FVB	Salmon ( <i>Oncorhynchus</i> spp.)	37,534	0.2700	0.15	153	7	0.0133	3.0000	4.0	350
SHD	Large demersal sharks	936	0.2000	0.25	202	49	0.0135	3.0000	10.0	360
SHB	Small demersal sharks	117,835	0.1512	0.13	98	49	0.0045	3.0276	31.2	360
SHP	Miscellaneous pelagic sharks	3,742	0.1850	0.13	200	15	0.0068	2.9400	9.0	360
SSK	Skates and rays	96,239	0.2000	0.05	194	20	0.0044	3.0547	7.5	60
PIN	Pinnipeds	34,587	NA	0.95	350	17	0.0015	3.3745	4.5	330
REP	Transient orca ( <i>Orcinus orca</i> )	194	NA	0.40	915	50	0.1430	2.4070	13.0	480
WHB	Baleen whales	49,789	NA	0.22	2,007	86	0.5980	2.3380	7.7	375
WHT	Toothed whales	3,493	NA	0.11	1,343	67	0.4775	2.3561	9.8	448
WHS	Small cetaceans	5,199	NA	0.59	225	20	0.1430	2.4070	5.8	329
WDG	Sea otter	101	NA	0.71	133	15	1.0000	2.1000	4.0	150
FVO	Migrating seabirds	1,534	NA	NA	45	34	12.4650	1.1228	6.2	53
SB	Planktivorous seabirds	41	NA	NA	23	6	7.5982	1.0000	3.0	39
SP	Piscivorous seabirds	1,072	NA	NA	67	22	11.8728	1.0380	4.5	32

Table 2 continued horizontally. Vertebrate functional groups and basic life history parameterization. Life history parameters represent values for each species in the group, weighted by relative abundance. Linf and k are constants in the von Bertalanffy length-age relationship; a and b are constants of the length-weight relationship ( $W=aL^b$ ). Beverton-Holt recruitment parameters and mortality rates are postcalibration values. See Appendix A for life history and biomass references. NA = not applicable.

Code	Group (column list repeated from previous page)	Beverton-Holt alpha	Beverton-Holt beta	Fixed recruitment (recruits/adult)	Adult linear mortality	Juvenile linear mortality	Adult quadratic mortality	Juvenile quadratic mortality
FDP	Dover sole	9.50E+07	1.35E+09	NA	0.000030	0.000009	0	0
FPO	Canary rockfish	1.80E+06	4.85E+08	NA	0.000035	0.000035	1.00E-17	1.00E-16
FVV	Shortbelly rockfish	1.00E+08	4.38E+08	NA	0	0	1.00E-12	0
SHC	Yelloweye and cowcod rockfish	8.00E+04	1.54E+08	NA	0	0	3.00E-11	7.00E-18
FBP	Deep vertical migrators	1.00E+10	1.07E+13	NA	0.000289	0.000289	0	0
FDD	Deep miscellaneous fish	1.00E+06	8.05E+12	NA	0.000100	0.000100	0	0
FDC	Deep small rockfish	6.00E+08	1.17E+09	NA	0.000150	0.000150	0	0
FDO	Deep large rockfish	2.09E+07	1.84E+09	NA	0.000180	0.000200	0	0
FDF	Small flatfish	9.25E+07	9.88E+08	NA	0.000100	0.000100	0	0
FDE	Miscellaneous nearshore fish	3.91E+11	2.42E+15	NA	0.000200	0.000200	8.00E-11	8.00E-11
FDM	Nearshore fish	1.00E+10	4.85E+13	NA	0.000100	0.000100	1.00E-19	1.00E-19
FDS	Midwater rockfish	2.37E+07	3.83E+09	NA	0	0.000020	0	0
FDB	Shallow small rockfish	7.25E+07	1.82E+10	NA	0.000001	0.000001	1.00E-12	0
SHR	Shallow large rockfish	1.00E+07	2.63E+08	NA	0.000015	0.000015	0	0
FMM	Hake	3.00E+08	2.11E+10	NA	0.000001	0.000001	0	0
FMN	Sablefish	2.50E+06	9.42E+09	NA	0.000001	0.000001	1.00E-10	1.00E-14
FVD	Large flatfish	1.00E+07	2.82E+08	NA	0.000175	0.000175	0	0
FVS	Large demersal predators	5.50E+06	1.17E+08	NA	0.000001	0.000001	1.00E-10	1.00E-12
FVT	Large pelagic predators	1.90E+05	1.98E+08	NA	0.000150	0.000150	1.00E-10	1.00E-10
FPL	Large planktivorous fish	5.00E+09	2.20E+13	NA	0.000200	0.000170	0	0
FPS	Small planktivorous fish	1.00E+10	5.90E+11	NA	0.000100	0.000100	0	0
FVB	Salmon ( <i>Oncorhynchus</i> spp.)	7.50E+07	1.23E+13	NA	0.000160	0.000160	1.00E-10	1.00E-10
SHD	Large demersal sharks	2.00E+03	6.51E+10	NA	0.000180	0.000180	1.00E-14	1.00E-14
SHB	Small demersal sharks	2.10E+07	5.04E+12	NA	0.000200	0.000200	1.00E-14	1.00E-14
SHP	Miscellaneous pelagic sharks	5.00E+05	4.77E+11	NA	0.000150	0.000150	1.00E-18	1.00E-18
SSK	Skates and rays	2.00E+07	4.69E+08	NA	0.000170	0.000170	0	0
PIN	Pinnipeds	NA	NA	0.5700	0.000001	0.000001	7.00E-09	7.00E-09
REP	Transient orca ( <i>Orcinus orca</i> )	NA	NA	0.1750	0.000100	0.000100	5.00E-06	7.00E-06
WHB	Baleen whales	NA	NA	0.2375	0	0	5.00E-20	5.00E-19
WHT	Toothed whales	NA	NA	0.1750	0.000002	0.000002	1.00E-06	1.00E-06
WHS	Small cetaceans	NA	NA	0.2375	0.000050	0.000050	3.00E-08	3.00E-08
WDG	Sea otter	NA	NA	0.4750	0.000100	0.000100	6.50E-07	6.50E-07
FVO	Migrating seabirds	NA	NA	0.2622	0.000005	0.000005	9.00E-10	9.00E-10
SB	Planktivorous seabirds	NA	NA	0.3125	0.000100	0.000100	3.00E-08	3.00E-08
SP	Piscivorous seabirds	NA	NA	0.4750	0.000010	0.000010	2.00E-08	2.50E-08

Table 3. Precalibration diet matrix derived from the literature. Predator groups are listed along the left side of the matrix while prey groups are listed along the top. Values represent the proportion of a predator's diet filled by each prey item. For a given predator group, the diet contributions from juvenile and adult prey groups sum to one. This diet matrix was used as the foundation for deriving the availability parameter ( $a$ ) of the functional response.

*[Editor's note: Table 3, too large to be incorporated into this report, is in a Microsoft Excel file, online at <http://www.nwfsc.noaa.gov/publications/displayinclude.cfm?incfile=technicalmemorandum2010.inc>.]*

Table 4. Postcalibration availability values used in the functional response. Predator groups are listed along the left side of the matrix while prey groups are listed along the top. As availability increases, a predator's impact on prey abundance increases, given spatial overlap of predator and prey. Zero values indicate cases where predators do not eat the prey.

*[Editor's note: Table 4, too large to be incorporated into this report, is in a Microsoft Excel file, online at <http://www.nwfsc.noaa.gov/publications/displayinclude.cfm?incfile=technicalmemorandum2010.inc>.]*

Table 5. Precalibration and postcalibration growth rates used in the functional response for each vertebrate functional group and age class (mgN/day).

CCAM group	Age class									
	1		2		3		4		5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
FPS	0.4	0.4	1.1	1.1	1.7	1.7	2.1	2.1	2.4	2.4
FPL	0.6	0.6	2.4	2.4	4.6	4.6	6.8	6.8	8.8	8.8
FPO	19.3	9.3	32.3	16.3	36.5	18.5	37.7	18.7	38.0	19.0
FVS	4.3	4.3	16.1	16.1	31.0	31.0	46.3	46.3	60.3	60.3
FVD	8.0	8.0	25.1	25.1	42.3	42.3	56.4	56.4	66.8	66.8
FVV	0.6	0.6	1.8	1.8	3.0	3.0	4.0	4.0	4.7	4.7
FVT	2.5	2.5	8.7	8.7	17.5	17.5	28.0	28.0	39.5	39.5
FVB	4.1	4.1	15.2	15.2	30.8	30.8	48.7	48.7	67.7	67.7
FMM	12.7	12.7	28.2	28.2	38.5	28.5	44.4	30.4	47.6	30.6
FMN	40.4	40.5	53.2	53.2	54.9	54.9	55.1	55.1	55.1	55.1
FBP	0.2	0.2	0.5	0.5	0.8	0.8	1.1	1.1	1.3	1.3
FDS	12.0	12.0	21.0	21.0	24.3	24.3	25.4	25.4	25.8	25.8
FDD	62.8	62.8	163.7	163.7	243.2	243.2	295.2	295.2	326.8	326.8
FDB	1.5	1.5	3.8	3.8	5.5	5.5	6.6	6.6	7.2	7.2
FDC	2.9	2.9	6.6	6.6	8.8	8.8	9.8	9.8	10.2	10.2
FDO	14.9	14.9	34.2	34.2	45.6	45.6	51.2	51.2	53.8	53.8
FDE	0.3	0.3	1.2	1.2	2.5	2.5	4.1	4.1	5.9	5.9
FDf	2.2	2.2	6.4	6.4	10.3	10.3	13.3	13.3	15.4	15.4
FDM	0.2	0.2	0.6	0.6	1.2	1.2	1.8	1.8	2.3	2.3
FDP	1.7	1.7	5.5	5.5	9.4	9.4	12.7	12.7	15.3	15.3
SHD	230.1	230.1	390.5	309.5	444.7	444.7	460.9	460.9	465.6	465.6
SHC	10.9	10.9	27.7	27.7	40.5	40.5	48.8	48.8	53.8	53.8
SHP	11.5	11.5	37.1	37.1	66.9	66.9	95.7	95.7	121.4	121.4
SHB	11.4	11.4	27.3	27.3	38.2	38.2	44.5	44.5	47.9	47.9
SHR	3.3	3.3	7.7	7.7	11.0	6.0	13.1	7.1	14.3	7.3
SSK	1.4	1.4	5.5	5.5	11.9	11.9	20.1	20.1	29.5	29.5
SB	334.1	334.1	345.1	345.1	349.2	349.2	350.8	350.8	351.3	351.3
SP	924.8	924.8	940.1	940.1	942.1	942.1	942.4	942.4	942.5	942.5
FVO	970.1	97.1	990.7	99.7	992.9	99.9	993.1	99.1	993.1	99.1
PIN	51,293.2	51,293.2	82,323.7	82,323.7	87,922.1	87,922.1	88,787.2	88,787.2	88,917.9	88,917.9
WHB	1,272,965.2	1,272,965.2	1,711,989.2	1,711,989.2	1,777,058.7	1,777,058.7	1,785,957.3	1,785,957.3	1,787,161.6	1,787,161.6
WHT	311,964.5	311,964.5	768,249.6	768,249.6	1,063,718.0	1,063,718.0	1,220,549.9	1,220,549.9	1,297,894.6	1,297,894.6
WHS	12,506.5	12,506.5	23,843.1	23,843.1	28,205.0	28,205.0	29,632.7	29,632.7	30,080.0	30,080.0
REP	50,648.5	50,648.5	68,746.4	68,746.4	71,446.2	71,446.2	71,816.3	71,816.3	71,866.5	71,866.5
WDG	21,909.5	21,909.5	24,504.5	24,504.5	25,154.7	24,154.7	25,313.1	25,313.1	25,351.5	25,351.5

Table 5 continued horizontally. Precalibration and postcalibration growth rates used in the functional response for each vertebrate functional group and age class (mgN/day).

CCAM group (list repeated from previous page)	Age class									
	6		7		8		9		10	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
FPS	2.5	2.5	2.6	2.6	2.7	2.7	2.7	2.7	2.7	2.7
FPL	10.5	10.5	11.8	11.8	12.9	12.9	13.7	13.7	14.4	14.4
FPO	38.1	19.1	38.2	19.2	38.2	19.2	38.2	19.2	38.2	19.2
FVS	72.4	72.4	82.5	82.5	90.7	90.7	97.3	97.3	102.4	102.4
FVD	74.1	74.1	79.2	79.2	82.6	82.6	84.8	84.8	86.3	86.3
FVV	5.3	5.3	5.7	5.7	5.9	5.9	6.1	6.1	6.2	6.2
FVT	51.6	51.6	63.9	63.9	76.2	76.2	88.2	88.2	99.7	99.7
FVB	86.6	86.6	104.9	104.9	122.1	122.1	138.0	138.0	152.5	152.5
FMM	49.2	30.2	50.1	30.1	50.6	30.6	50.8	30.8	50.9	30.9
FMN	55.5	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2
FBP	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9
FDS	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
FDD	345.3	345.3	355.9	355.9	362.0	362.0	365.4	365.4	367.4	367.4
FDB	7.5	7.5	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.8
FDC	10.4	10.4	10.5	10.5	10.6	10.6	10.6	10.6	10.6	10.6
FDO	55.0	55.0	55.5	55.5	55.8	55.8	55.9	55.9	55.9	55.9
FDE	7.7	7.7	9.5	9.5	11.2	11.2	12.9	12.9	14.4	14.4
FDI	16.8	16.8	17.8	17.8	18.4	18.4	18.8	18.8	19.0	19.0
FDM	2.8	2.8	3.2	3.2	3.6	3.6	3.8	3.8	4.1	4.1
FDP	17.1	17.1	18.4	18.4	19.4	19.4	20.0	20.0	20.4	20.4
SHD	466.9	466.9	467.3	467.3	467.4	467.4	467.5	467.5	467.5	467.5
SHC	56.7	56.7	58.4	58.4	59.3	59.3	59.9	59.9	60.2	60.2
SHP	143.2	143.2	161.0	161.0	175.5	175.5	186.9	186.9	195.9	195.9
SHB	49.7	49.7	50.6	50.6	51.1	51.1	51.3	51.3	51.4	51.4
SHR	15.0	8.0	15.5	8.5	15.7	8.7	15.8	8.8	15.9	8.9
SSK	39.7	39.7	50.4	50.4	61.4	61.4	72.4	72.4	83.2	83.2
SB	351.5	351.5	351.6	351.6	351.6	351.6	351.7	351.7	351.7	351.7
SP	942.5	942.5	942.5	942.5	942.5	942.5	942.5	942.5	942.5	942.5
FVO	993.1	99.1	993.1	99.1	993.1	99.1	993.1	99.1	993.1	99.1
PIN	88,937.6	88,937.6	88,940.6	88,940.6	88,941.0	88,941.0	88,941.1	88,941.1	88,941.1	88,941.1
WHB	1,787,324.4	1,787,324.4	1,787,346.4	1,787,346.4	1,787,349.4	1,787,349.4	1,787,349.8	1,787,349.8	1,787,349.8	1,787,349.8
WHT	1,334,871.4	1,334,871.4	1,352,305.7	1,352,305.7	1,360,474.0	1,360,474.0	1,364,289.8	1,364,289.8	1,366,069.9	1,366,069.9
WHS	30,218.3	30,218.3	30,260.9	30,260.9	30,274.0	30,274.0	30,278.0	30,278.0	30,279.2	30,279.2
REP	71,873.3	71,873.3	71,874.2	71,874.2	71,874.3	71,874.3	71,874.3	71,874.3	71,874.3	71,874.3
WDG	25,360.8	25,360.8	25,363.1	25,363.1	25,363.6	25,363.6	25,363.7	25,363.7	25,363.8	25,363.8

Table 6. Precalibration and postcalibration clearance rates used in the functional response for each vertebrate functional group and age class (mg<sup>3</sup>/mgN/day).

CCAM group	Age class									
	1		2		3		4		5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
FPS	13.6	1.4	23.4	2.3	55.5	5.6	68.9	5.9	77.6	5.9
FPL	32.6	1.7	47.5	2.5	133.2	6.6	225.3	11.2	290.5	14.6
FPO	179.3	17.9	187.8	18.8	315.2	31.5	754.1	45.4	3,608.8	45.4
FVS	106.2	10.2	246.4	246.4	407.3	407.3	575.3	575.3	733.4	733.4
FVD	445.3	350.3	476.0	351.0	1,108.3	350.3	1,481.8	350.8	1,745.8	425.8
FVV	5.9	1.0	16.0	50.0	101.0	50.5	512.1	65.2	2,249.8	76.0
FVT	113.6	11.6	287.1	143.1	746.3	190.3	1,227.9	200.9	1,447.5	250.5
FVB	255.6	255.6	798.4	798.4	1,598.8	1,598.8	2,081.2	2,081.2	2,480.4	2,480.4
FMM	1,368.5	136.5	2,159.2	215.2	1,636.6	163.6	1,405.4	140.4	1,569.2	156.2
FMN	1,334.9	65.9	1,755.2	85.2	4,293.3	215.3	4,310.1	215.1	4,312.2	215.2
FBP	2.9	1.0	20.3	5.3	39.3	10.3	59.4	15.4	82.5	20.5
FDS	54.2	54.2	174.7	174.7	240.6	240.6	284.6	284.6	1,048.5	284.6
FDD	1,370.6	100.1	3,781.8	400.2	3,900.7	400.1	4,458.7	475.9	4,814.1	500.4
FDB	49.8	5.0	126.1	54.2	182.3	54.2	295.0	54.2	506.4	54.2
FDC	45.2	8.5	219.1	31.9	289.0	10.5	487.7	12.4	844.6	32.3
FDO	302.9	15.1	716.7	971.8	971.8	971.8	1,464.5	1,464.5	1,225.8	1,225.8
FDE	1.1	0.6	25.2	7.2	63.9	40.3	136.3	80.5	193.6	125.9
FDf	30.7	15.7	75.1	75.1	213.1	213.1	275.8	275.8	340.9	340.9
FDM	21.7	1.0	313.5	2.5	268.9	9.9	575.2	9.9	575.2	9.9
FDP	8.4	4.4	40.5	20.5	71.7	35.7	78.3	39.3	78.3	39.3
SHD	7,540.3	1,459.3	12,860.7	2,488.7	18,974.4	2,867.5	34,133.1	3,020.9	66,880.4	3,036.4
SHC	68.9	68.9	273.8	70.8	735.8	158.8	735.8	158.8	3,493.6	158.8
SHP	380.3	85.3	836.3	165.3	1,626.0	361.0	2,327.6	500.6	2,951.8	675.8
SHB	375.7	250.7	899.4	450.4	1,259.2	625.2	1,467.2	700.2	1,579.8	750.8
SHR	108.2	5.2	254.4	10.4	362.4	10.4	431.2	10.2	472.5	10.5
SSK	45.7	11.7	182.2	91.2	393.7	185.7	662.4	331.4	972.2	261.2
SB	3.3	3.3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
SP	92.5	92.5	94.0	94.0	94.2	94.2	94.2	94.2	94.2	94.2
FVO	97.0	4.0	99.1	5.1	99.3	5.3	99.3	5.3	99.3	5.3
PIN	512,931.7	51,293.2	823,237.2	82,323.7	879,220.6	87,922.1	887,872.0	88,787.2	889,179.2	88,917.9
WHB	12,729,652.3	129,652.3	17,119,891.9	2,119,891.9	17,770,587.3	2,770,587.3	17,859,573.4	2,859,573.4	17,871,616.3	2,871,616.3
WHT	3,119,644.5	15,196.4	7,682,495.7	76,825.0	10,637,179.8	106,371.8	12,205,498.7	122,055.0	12,978,945.8	129,789.5
WHS	18,825.6	900.6	35,890.1	1,700.0	42,456.0	2,100.6	44,605.1	2,200.5	45,278.3	2,250.8
REP	664,832.1	664,832.1	890,405.9	890,405.9	1,481,667.3	1,481,667.3	1,489,341.6	1,489,341.6	1,490,382.0	1,490,382.0
WDG	218,529.2	219.1	243,848.7	245.0	250,318.1	251.1	251,895.2	253.1	252,277.2	253.5



Table 6 continued horizontally. Precalibration and postcalibration clearance rates used in the functional response for each vertebrate functional group and age class (mg<sup>3</sup>/mgN/day).

CCAM group (list repeated from previous page)	Age class									
	6		7		8		9		10	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
FPS	95.5	5.9	117.4	5.9	147.3	5.9	190.9	5.9	255.2	5.9
FPL	365.7	18.1	467.6	23.4	609.2	30.0	800.7	40.1	1,042.2	54.2
FPO	3,616.4	45.4	36,193.9	45.4	36,200.7	45.4	36,202.5	45.4	36,203.0	45.4
FVS	885.9	885.9	1,006.4	1,006.4	2,031.5	2,031.5	2,943.3	2,943.3	3,369.9	3,369.9
FVD	1,898.8	475.8	2,048.0	501.0	2,193.0	526.0	2,360.0	600.0	2,543.5	625.5
FVV	2,508.2	85.9	2,690.2	90.5	2,816.3	95.2	2,902.7	100.2	2,961.6	100.3
FVT	2,371.9	300.9	2,957.2	350.2	3,523.6	450.6	4,077.7	500.7	4,613.0	601.0
FVB	2,859.0	2,859.0	3,462.1	3,462.1	4,029.8	4,029.8	4,554.7	4,554.7	5,033.5	5,033.5
FMM	1,624.8	162.8	1,653.9	165.9	1,669.0	167.0	1,676.8	167.8	1,680.8	168.8
FMN	4,312.4	215.4	4,312.5	215.5	4,312.5	215.5	4,312.5	215.5	4,312.5	215.5
FBP	88.2	22.2	88.2	22.2	115.2	22.2	165.2	22.2	239.2	22.2
FDS	3,704.9	370.5	12,726.7	600.1	42,826.5	600.1	141,869.3	600.0	464,170.1	600.0
FDD	5,086.8	625.7	5,243.5	625.4	5,332.7	625.3	5,383.1	625.3	5,411.6	625.2
FDB	529.6	54.2	542.2	54.2	549.0	55.0	552.6	54.6	554.5	54.5
FDC	861.2	33.0	868.4	33.4	871.5	33.6	872.9	33.6	873.5	33.5
FDO	1,478.7	1,478.7	1,492.8	1,492.8	1,499.0	1,499.0	1,501.8	1,501.8	1,503.0	1,503.0
FDE	252.9	160.3	312.0	190.1	369.6	155.9	424.5	260.6	476.3	285.3
FDG	354.9	354.9	374.5	374.5	387.1	387.1	395.2	395.2	400.4	400.4
FDM	575.2	9.9	575.2	9.9	575.2	9.9	575.2	9.9	575.2	9.9
FDP	78.3	39.3	78.3	39.3	78.3	39.3	78.3	39.3	78.3	39.3
SHD	136,293.8	3,040.9	136,406.8	3,042.2	136,439.2	3,042.5	136,448.5	3,042.6	136,451.2	3,042.7
SHC	3,493.6	158.8	3,493.6	158.8	3,493.6	158.8	3,493.6	158.8	3,493.6	158.8
SHP	3,480.8	765.8	3,915.8	855.8	4,266.2	945.2	4,544.8	512.8	4,763.9	1,050.9
SHB	1,638.8	750.8	1,669.4	750.4	1,685.1	750.1	1,693.1	750.1	1,697.2	750.2
SHR	496.6	10.6	510.4	10.4	518.3	10.3	522.7	10.7	525.3	10.3
SSK	1,309.7	350.7	1,663.7	430.7	2,025.5	512.5	2,387.9	550.9	2,745.5	650.5
SB	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
SP	94.2	94.2	94.2	94.2	94.2	94.2	94.2	94.2	94.2	94.2
FVO	99.3	5.3	99.3	5.3	99.3	5.3	99.3	5.3	99.3	5.3
PIN	889,376.1	88,937.6	889,405.7	88,940.6	889,410.2	88,941.0	889,410.8	88,941.1	889,410.9	88,941.1
WHB	17,873,243.9	2,873,243.9	17,873,463.8	2,873,463.8	17,873,493.5	2,873,493.5	17,873,497.6	2,873,497.6	17,873,498.1	2,873,498.1
WHT	13,348,713.5	133,487.1	13,523,056.8	135,230.6	13,604,739.6	136,047.4	13,642,897.5	136,429.0	13,660,698.8	136,607.0
WHS	45,486.5	2,250.6	45,550.6	2,250.1	45,570.3	2,250.0	45,576.4	2,250.6	45,578.2	2,250.8
REP	1,490,522.9	1,490,522.9	1,490,541.9	1,490,541.9	1,490,544.5	1,490,544.5	1,490,544.9	1,490,544.9	1,490,544.9	1,490,544.9
WDG	252,369.5	253.6	252,391.9	253.6	252,397.3	253.6	252,398.6	253.6	252,398.9	253.6

Table 7. Timing for leaving and returning to the model domain for migrating groups.

<b>Code</b>	<b>Group</b>	<b>Leave</b>	<b>Return</b>	<b>Proportion migrating</b>
FPS	Small planktivorous fish	15 October	15 June	1.00
FVT	Large pelagic predators	1 September	15 August	1.00
FVB	Salmon	2 June	30 October	1.00
FMM	Hake	2 November	2 April	1.00
FVO	Migrating seabirds	12 November	15 February	1.00
SP	Piscivorous seabirds	15 November	15 May	0.30
PIN1	Pinnipeds 1	1 March	30 June	0.64
PIN2	Pinnipeds 2	30 July	1 December	0.64
WHB1	Baleen whales 1	15 May	1 December	0.65
WHB2	Baleen whales 2	15 December	15 February	0.65
WHT	Toothed whales	2 November	15 May	0.30

Table 8. Historical catches (metric tons) used in final model calibration. Values represent the sum of catches for all species in a functional group with historical catch data. *Italic values denote cases where catch and landing values were modeled due to missing data in early years; we assumed exponential increases for these cases.* Catch and landings data for individual species are shown in Table 9.

Year	FDf	FMN	FVV	FDS	FVS	FVD	FDO	FDP	FDC	SHR	FPO	FDB	SHC	FMM	FVT	SSK	FPS	FPL	CEP
1950	6,250	<i>1,592</i>	127	<i>6,395</i>	<i>11,016</i>	4,011	580	2,569	9	229	1,959	<i>10</i>	75	8,442	141	2,891	823	23,001	499
1951	4,936	<i>1,842</i>	125	<i>7,800</i>	<i>12,161</i>	2,794	763	3,000	10	267	1,936	<i>10</i>	81	10,115	172	3,571	941	15,743	565
1952	5,010	<i>2,133</i>	137	<i>8,900</i>	<i>17,239</i>	2,740	620	3,503	10	212	1,902	<i>11</i>	87	12,119	172	4,592	1,075	14,944	640
1953	3,997	<i>2,469</i>	143	<i>9,962</i>	<i>7,614</i>	3,479	648	4,090	10	217	1,753	<i>11</i>	93	14,521	108	6,888	1,229	9,636	725
1954	3,562	<i>2,858</i>	161	<i>10,641</i>	<i>4,534</i>	2,798	671	4,775	11	253	1,949	<i>12</i>	101	17,399	84	6,207	1,405	4,552	821
1955	3,883	<i>3,308</i>	172	<i>11,910</i>	5,104	3,157	663	5,576	11	259	1,961	<i>12</i>	108	20,848	94	5,442	1,606	13,027	929
1956	4,432	3,829	174	13,571	7,890	7,447	793	6,510	12	197	1,998	<i>13</i>	123	24,980	131	5,442	1,836	13,125	1,052
1957	5,366	3,143	154	14,524	8,860	6,828	878	6,206	12	225	2,576	<i>13</i>	121	29,931	146	4,762	2,098	26,570	1,191
1958	6,460	1,911	150	14,994	11,960	5,991	868	5,850	13	304	2,619	<i>14</i>	138	35,863	101	5,272	2,399	26,266	1,349
1959	6,019	2,832	122	15,161	8,229	5,927	810	6,566	13	288	2,452	<i>15</i>	123	42,971	143	3,741	2,742	12,429	1,528
1960	4,882	3,700	119	15,924	5,421	5,768	811	8,120	14	281	2,479	<i>15</i>	115	51,488	140	2,551	3,135	19,901	1,730
1961	4,803	2,690	140	17,509	6,137	7,024	638	6,586	14	209	2,160	<i>16</i>	102	61,693	110	5,017	3,584	19,651	1,959
1962	5,065	3,240	96	19,936	3,962	6,477	1,025	7,497	15	224	2,207	<i>17</i>	101	73,920	153	2,891	4,098	21,576	2,218
1963	5,237	2,269	120	21,785	3,572	6,057	1,223	8,233	15	277	2,071	<i>18</i>	116	88,571	195	3,827	4,686	22,666	2,511
1964	5,373	2,716	166	21,309	4,978	5,890	799	7,647	16	211	1,485	<i>18</i>	102	106,125	154	4,167	5,357	17,764	2,843
1965	5,629	2,686	261	25,194	6,409	5,342	1,517	7,330	37	394	1,756	19	116	127,159	120	2,891	6,125	13,756	3,220
1966	6,152	1,792	1,690	39,637	9,250	5,528	10,142	7,145	26	452	3,616	19	125	137,000	119	3,316	7,004	6,344	3,646
1967	6,623	4,778	8,491	37,144	9,273	5,197	8,006	5,442	12	531	1,954	19	127	177,662	154	2,721	8,008	5,211	4,128
1968	6,941	3,145	1,805	22,135	12,632	4,827	7,339	6,733	12	427	2,327	19	130	60,819	179	3,827	9,157	4,342	4,674
1969	4,440	6,047	247	9,428	14,546	5,148	1,304	9,731	36	661	1,559	31	191	86,280	151	2,466	10,470	5,677	5,292
1970	3,684	4,176	119	11,838	7,237	5,193	1,516	10,837	52	794	1,524	17	203	159,575	179	1,616	11,972	5,352	5,993
1971	3,397	4,490	95	11,331	4,993	5,447	2,083	10,513	55	521	1,400	9	200	127,913	162	510	13,689	5,311	6,786
1972	4,475	7,758	201	15,750	6,297	6,155	3,389	14,412	102	616	1,461	19	273	74,133	190	680	15,653	5,993	7,683
1973	5,066	6,153	1,228	21,054	7,056	6,346	5,499	13,820	115	555	2,316	20	330	147,513	122	680	17,899	6,763	8,700
1974	4,863	9,259	369	21,928	12,345	7,015	3,524	12,685	95	716	1,692	28	322	194,109	170	680	20,467	7,631	9,851
1975	5,933	11,475	973	20,038	9,284	6,910	4,132	14,138	123	735	1,696	59	333	205,656	155	680	23,403	8,611	11,155
1976	6,443	25,989	927	22,651	14,148	6,138	2,833	15,502	67	1,059	1,280	63	386	231,549	131	1,616	26,762	9,717	12,631
1977	4,316	9,805	142	22,138	9,764	5,433	2,688	14,577	126	781	1,895	39	409	127,502	82	1,871	30,602	13,546	14,302
1978	5,999	14,434	102	19,135	17,090	7,279	2,769	15,600	233	940	3,074	78	408	98,372	125	2,976	34,993	19,900	16,194

Table 8 continued. Historical catches (metric tons) used in final model calibration. Values represent the sum of catches for all species in a functional group with historical catch data. Bold values indicate instances where catch had not been reported in later years for at least one species in a group and we repeated the latest known catch. Catch and landings data for individual species are shown in Table 9.

Year	FDF	FMN	FVV	FDS	FVS	FVD	FDO	FDP	FDC	SHR	FPO	FDB	SHC	FMM	FVT	SSK	FPS	FPL	CEP
1979	6,331	25,835	222	28,594	29,300	7,845	4,978	19,911	326	1,543	3,461	61	561	124,680	49	3,741	40,015	32,672	18,337
1980	5,519	9,695	287	87,268	36,060	6,257	3,400	15,635	443	1,180	4,125	114	713	72,352	55	1,956	45,757	43,282	20,763
1981	4,976	12,254	178	101,898	36,606	5,990	4,875	18,279	138	1,882	3,532	94	768	114,760	92	6,122	52,324	53,166	23,510
1982	4,685	19,779	204	97,535	36,688	8,336	5,780	23,220	511	1,962	5,544	70	869	75,577	50	4,082	42,157	55,682	16,308
1983	3,739	15,581	161	50,682	18,276	7,457	5,530	22,192	367	2,034	4,918	38	733	73,150	68	3,146	4,431	51,308	1,824
1984	2,975	14,922	215	48,022	15,622	7,177	6,374	21,317	459	1,900	2,383	51	495	96,332	105	1,616	2,900	53,240	564
1985	3,952	15,194	114	45,634	19,322	7,786	8,197	22,796	904	1,859	2,726	48	564	85,439	62	2,381	1,644	44,648	10,276
1986	3,616	14,087	93	46,943	11,845	6,840	6,816	19,264	909	1,439	2,303	53	412	154,964	36	1,871	1,945	52,866	21,278
1987	4,438	12,707	89	52,579	9,513	8,174	8,685	20,436	1,487	1,307	3,183	51	519	160,448	21	2,126	1,906	54,745	19,984
1988	3,977	11,559	77	47,633	11,725	6,908	7,704	20,110	3,422	1,334	3,074	83	541	160,698	35	1,701	2,706	55,932	37,316
1989	4,502	10,640	98	55,644	18,527	8,714	8,632	20,805	3,946	1,485	3,333	69	678	210,996	16	1,701	3,348	58,458	40,974
1990	3,356	9,519	122	47,058	17,702	10,207	8,729	17,382	7,362	1,448	2,791	159	478	183,800	21	1,276	4,923	43,346	28,447
1991	4,210	10,085	96	34,746	13,900	9,627	6,822	20,200	3,694	1,455	3,203	184	688	217,505	15	765	11,655	33,779	37,389
1992	2,775	9,928	57	32,515	21,280	7,651	5,915	17,745	6,816	1,846	2,866	207	709	208,576	34	1,105	19,222	20,571	13,112
1993	2,721	8,636	63	38,207	24,228	6,592	7,150	15,868	6,664	1,351	2,235	209	590	141,222	46	1,446	17,350	14,079	42,830
1994	1,929	8,034	46	30,461	45,593	6,534	5,963	10,370	9,441	1,353	1,210	159	414	252,729	81	3,316	13,503	13,199	55,383
1995	1,845	8,379	66	30,685	95,230	6,077	4,056	11,727	6,937	1,199	1,189	114	476	177,589	62	13,520	42,272	10,700	70,252
1996	1,614	8,817	81	28,435	17,328	6,239	3,701	13,527	6,081	1,136	1,546	89	401	212,902	125	24,490	37,058	12,167	80,561
1997	2,048	8,420	65	28,655	138,242	6,409	3,536	11,238	4,976	1,091	1,479	80	448	233,423	116	780	49,069	21,701	70,329
1998	1,590	4,665	46	19,042	181,146	6,533	3,410	8,892	2,810	1,123	1,494	76	203	232,817	115	1,220	44,896	23,338	2,895
1999	1,337	7,048	26	17,776	128,748	8,990	1,703	10,143	2,247	948	898	84	298	224,522	105	1,835	9,154	69,570	1,557
2000	1,132	6,668	13	15,255	119,428	7,204	1,556	9,723	1,889	920	208	91	80	208,418	85	2,108	79,814	23,509	118,903
2001	1,449	5,994	10	8,841	74,708	6,362	1,080	7,647	1,510	1,108	134	144	100	182,377	98	1,342	95,146	11,457	86,203
2002	1,761	4,046	6	3,213	52,701	5,850	1,241	6,994	2,407	988	107	108	24	132,114	93	488	101,779	4,770	72,895
2003	1,197	5,761	0	1,135	42,539	6,251	1,273	8,183	1,969	1,397	51	147	22	143,492	115	1,323	73,852	4,444	45,056
2004	1,355	6,132	2	1,971	49,204	5,917	1,350	7,484	962	1,005	47	50	23	210,484	106	582	96,358	4,868	40,068
2005	<b>1,252</b>	6,585	<b>2</b>	<b>1,882</b>	<b>49,204</b>	<b>5,635</b>	<b>1,169</b>	<b>7,484</b>	<b>962</b>	1,103	51	<b>50</b>	45	259,844	76	959	97,878	3,880	55,755
2006	<b>1,215</b>	6,213	<b>2</b>	<b>1,531</b>	<b>49,204</b>	<b>5,065</b>	<b>1,186</b>	<b>7,484</b>	<b>962</b>	<b>1,004</b>	47	<b>50</b>	<b>45</b>	270,263	87	1,157	99,568	7,784	49,180
2007	<b>1,215</b>	<b>6,213</b>	<b>2</b>	<b>1,531</b>	<b>49,204</b>	<b>5,047</b>	<b>1,186</b>	<b>7,484</b>	<b>962</b>	<b>1,004</b>	<b>47</b>	<b>50</b>	<b>45</b>	203,979	79	899	138,314	6,405	49,499

Table 9. Catch (C in metric tons) and landings (L) of individual species. We combined catch and scaled landings data from this table to generate functional group catches given in Table 8. Landings were scaled using discard rates from Bellman et al. (2007). Italic values denote cases where catch and landing values were modeled due to missing data in early years; we assumed exponential increases for these cases. Bold values indicate instances where catch and landing data had not been reported in later years and we repeated the latest known value.

Year	FDF		FMN	FVV	FDS			
	English sole (C)	Starry flounder (L)	Sablefish (L)	Shortbelly rockfish (C)	Pacific ocean perch (C)	Widow rockfish (L)	Yellowtail rockfish (C)	Bocaccio (C)
1950	5,673.00	481.10	<i>1,501.62</i>	127.00	<i>976.63</i>	511.68	221.62	1,612.00
1951	4,189.00	622.30	<i>1,738.17</i>	125.00	<i>1,120.80</i>	579.67	246.90	1,697.45
1952	3,824.00	988.00	<i>2,011.98</i>	137.00	<i>1,286.24</i>	656.69	275.07	1,787.43
1953	2,911.00	905.00	<i>2,328.92</i>	143.00	<i>1,476.10</i>	743.94	306.45	1,882.18
1954	2,623.00	782.60	<i>2,695.79</i>	161.00	<i>1,693.99</i>	842.79	341.40	1,981.95
1955	2,829.00	878.60	<i>3,120.44</i>	172.00	<i>1,944.04</i>	954.77	380.35	2,087.01
1956	3,787.00	537.90	3,612.00	174.00	2,231.00	1,081.63	423.73	2,197.64
1957	4,436.00	775.10	2,965.00	154.00	2,442.00	1,225.35	472.07	2,314.14
1958	5,520.00	783.20	1,803.00	150.00	1,587.00	1,388.16	525.92	2,436.81
1959	5,427.00	493.20	2,672.00	122.00	1,958.00	1,572.61	585.91	2,565.98
1960	4,338.00	453.60	3,491.00	119.00	2,364.00	1,781.56	652.74	2,702.00
1961	4,188.00	512.70	2,538.00	140.00	4,149.00	2,018.27	727.20	2,675.78
1962	4,496.00	474.20	3,057.00	96.00	5,793.00	2,286.44	810.15	2,649.82
1963	4,489.00	623.70	2,141.00	120.00	6,788.00	2,590.24	902.56	2,624.11
1964	4,742.00	525.60	2,562.00	166.00	5,807.00	2,934.41	1,005.62	2,598.65
1965	5,043.00	488.50	2,534.00	261.00	8,063.00	3,324.30	1,120.22	2,573.44
1966	5,522.00	524.60	1,691.00	1,690.00	18,761.00	3,766.00	1,248.00	2,548.47
1967	5,192.00	1,192.90	4,508.00	8,491.00	13,289.00	4,149.00	926.70	2,523.75
1968	5,468.00	1,227.40	2,967.00	1,805.00	7,262.00	2,029.00	1,448.50	2,499.26
1969	3,788.00	543.50	5,705.00	247.00	1,197.00	377.00	1,776.10	2,475.01
1970	3,102.00	484.60	3,940.00	119.00	2,177.00	554.00	987.80	2,451.00
1971	2,851.00	454.60	4,236.00	95.00	1,951.00	701.00	588.10	2,906.75
1972	3,300.00	978.90	7,319.00	201.00	1,558.00	423.00	836.80	3,447.25
1973	3,773.00	1,077.80	5,805.00	1,228.00	2,145.00	824.00	375.80	4,088.26
1974	3,858.00	837.80	8,735.00	369.00	1,800.00	573.00	572.00	4,848.45
1975	4,579.00	1,128.20	10,825.00	973.00	1,152.00	812.00	103.90	5,750.00
1976	5,755.00	573.30	24,518.00	927.00	1,677.00	1,360.00	938.10	5,806.29
1977	3,735.00	484.10	9,250.00	142.00	1,242.00	2,201.00	1,379.10	5,863.13
1978	4,511.00	1,239.80	13,617.00	102.00	2,120.00	1,107.00	1,307.30	5,920.52
1979	4,710.00	1,350.80	24,373.00	222.00	1,952.00	3,292.00	1,678.00	5,978.48
1980	4,143.00	1,146.80	9,146.00	287.00	1,965.00	21,856.00	2,295.70	6,037.00
1981	3,780.00	996.90	11,560.00	178.00	1,720.00	27,005.00	3,140.80	5,516.62
1982	3,833.00	709.70	18,659.00	204.00	1,242.00	26,063.00	3,352.90	5,041.10
1983	3,091.00	540.20	14,699.00	161.00	2,215.00	10,564.00	3,258.90	4,606.57
1984	2,458.00	430.60	14,077.00	215.00	1,959.00	10,071.00	1,143.00	4,209.50
1985	2,955.00	831.20	14,334.00	114.00	1,792.00	9,187.00	1,218.40	3,846.65
1986	3,153.00	385.60	13,290.00	93.00	1,653.00	9,523.00	1,975.50	3,515.07
1987	3,979.00	382.70	11,988.00	89.00	1,305.00	12,944.00	1,495.60	3,212.08
1988	3,422.00	462.10	10,905.00	77.00	1,645.00	10,445.00	2,096.70	2,935.21
1989	3,780.00	601.60	10,038.00	98.00	1,706.00	12,486.00	1,860.70	2,682.20
1990	2,907.00	374.30	8,980.00	122.00	1,230.00	10,274.00	1,762.50	2,451.00
1991	3,339.00	726.10	9,514.00	96.00	1,659.00	6,301.00	1,169.30	1,617.00
1992	2,556.00	182.30	9,366.00	57.00	1,306.00	6,052.00	1,663.60	1,781.00
1993	2,534.00	156.10	8,147.00	63.00	1,500.00	8,236.00	1,947.20	1,502.00
1994	1,818.00	92.40	7,579.00	46.00	1,176.00	6,384.00	2,079.90	1,224.00
1995	1,762.00	69.10	7,905.00	66.00	965.00	6,703.00	1,735.90	777.00
1996	1,540.00	61.60	8,318.00	81.00	938.00	6,094.00	2,100.20	573.00
1997	1,911.00	114.10	7,943.00	65.00	751.00	6,492.00	778.40	480.00
1998	1,441.00	123.80	4,401.00	46.00	739.00	3,956.00	1,233.40	209.00
1999	1,245.00	76.60	6,649.00	26.00	593.00	3,943.00	1,619.70	197.00
2000	1,061.00	59.30	6,291.00	13.00	171.00	3,814.00	1,554.70	186.00
2001	1,363.00	72.00	5,655.00	10.00	307.00	1,812.00	1,041.10	207.00
2002	1,683.00	65.40	3,817.00	6.00	179.00	276.00	856.50	135.00
2003	1,125.00	60.10	5,435.00	0.00	151.00	28.00	482.60	22.00
2004	1,218.00	114.10	5,785.00	2.00	146.00	74.00	509.40	83.00
2005	1,115.00	<b>114.10</b>	6,212.00	<b>2.00</b>	75.00	113.00	<b>509.40</b>	87.00
2006	1,078.00	<b>114.10</b>	5,861.00	<b>2.00</b>	83.00	70.00	<b>509.40</b>	67.00
2007	<b>1,078.00</b>	<b>114.10</b>	<b>5,861.00</b>	<b>2.00</b>	<b>83.00</b>	<b>70.00</b>	<b>509.40</b>	<b>67.00</b>

Table 9 continued horizontally. Catch (C in metric tons) and landings (L) of individual species. We combined catch and scaled landings data from this table to generate functional group catches given in Table 8. Landings were scaled using discard rates from Bellman et al. (2007). Italic values denote cases where catch and landing values were modeled due to missing data in early years; we assumed exponential increases for these cases. Bold values indicate cases where catch and landing data had not been reported in later years and we repeated the latest known value.

Year	FDS (continued)		FVS		FVD		
	Chilipepper rockfish (L)	Vermillion rockfish (L)	Cabezon (L)	Lingcod (L)	Petrable sole (L)	Arrowtooth flounder (C)	Pacific halibut (C)
1950	575.99	191.00	9,833.00	<i>666.78</i>	3,589.90	202.00	39.89
1951	869.50	196.00	10,821.00	<i>759.39</i>	2,291.80	345.00	42.94
1952	1,054.70	186.00	15,646.00	<i>864.86</i>	2,193.80	390.00	46.22
1953	1,207.15	180.00	6,036.00	<i>984.97</i>	2,007.20	1,322.00	49.76
1954	1,215.01	182.00	2,817.00	<i>1,121.77</i>	2,537.20	80.00	53.57
1955	1,380.72	187.00	3,150.00	<i>1,277.57</i>	2,628.60	339.00	57.66
1956	1,643.29	183.00	5,624.00	1,455.00	2,153.90	5,123.00	62.08
1957	1,686.73	185.00	5,990.00	1,858.00	2,901.50	3,715.00	66.82
1958	1,888.63	195.00	8,854.00	1,979.00	2,596.10	3,193.00	71.94
1959	1,593.23	188.00	4,304.00	2,594.00	2,247.90	3,489.00	77.44
1960	1,443.46	188.00	1,388.00	2,706.00	2,558.90	2,998.00	83.37
1961	1,145.73	175.00	2,246.00	2,599.00	3,215.20	3,558.00	89.74
1962	1,118.06	177.00	1,122.00	1,904.00	2,995.40	3,235.00	96.61
1963	1,077.28	175.00	1,276.00	1,534.00	2,785.00	3,029.00	104.00
1964	883.51	179.00	2,396.00	1,712.00	2,343.10	3,318.00	111.96
1965	993.32	186.00	3,373.00	2,006.00	2,342.80	2,762.00	120.52
1966	2,182.34	199.00	5,715.00	2,311.00	2,429.20	2,848.00	129.74
1967	2,796.02	210.00	6,479.00	1,800.00	2,340.00	2,600.00	139.67
1968	1,775.00	206.00	9,120.00	2,250.00	2,280.20	2,282.00	150.35
1969	1,090.42	211.00	11,720.00	1,751.00	2,501.60	2,359.00	161.86
1970	1,272.63	220.00	4,852.00	1,546.00	2,714.20	2,169.00	174.24
1971	1,252.97	207.00	2,050.00	1,961.00	2,935.50	2,177.00	187.57
1972	1,899.29	246.00	2,655.00	2,425.00	3,190.00	2,604.00	201.92
1973	3,644.41	286.00	2,066.00	3,344.00	2,922.70	3,060.00	217.37
1974	3,960.38	298.00	6,759.00	3,683.00	3,687.10	2,910.00	234.00
1975	3,227.78	243.00	3,326.00	3,981.00	3,756.70	2,758.00	207.00
1976	3,091.89	215.00	8,693.00	3,568.00	2,823.90	3,065.00	108.00
1977	2,091.17	293.00	5,511.00	2,799.00	2,233.00	2,585.00	94.50
1978	1,933.54	246.00	12,889.00	2,664.00	3,405.60	3,250.00	45.00
1979	2,724.93	291.00	22,826.00	4,066.00	3,150.80	4,107.00	22.50
1980	3,255.02	389.00	27,230.00	5,598.00	2,515.80	3,199.00	9.00
1981	2,776.36	291.00	29,206.00	4,605.00	2,040.70	3,351.00	90.00
1982	2,491.94	478.00	28,940.00	4,844.00	2,630.30	5,074.00	94.50
1983	2,464.67	271.00	10,703.00	4,972.00	2,214.20	4,608.00	117.00
1984	2,922.54	446.00	8,473.00	4,716.00	1,739.40	4,751.00	193.50
1985	3,182.40	394.00	11,771.00	4,943.00	1,839.20	5,228.00	220.50
1986	3,147.45	541.00	7,361.00	2,930.00	1,747.60	4,337.00	261.00
1987	2,059.32	453.00	4,012.00	3,663.00	2,199.90	5,192.00	265.50
1988	2,690.75	420.00	5,781.00	3,983.00	2,149.10	4,204.00	220.50
1989	3,395.40	444.00	11,346.00	4,699.00	2,152.40	5,834.00	211.50
1990	3,110.20	532.00	11,777.00	3,844.00	1,764.30	7,802.00	144.00
1991	3,310.50	615.00	7,690.00	4,092.00	1,927.20	7,033.00	162.00
1992	2,753.22	617.00	16,672.00	2,888.00	1,551.60	5,380.00	198.00
1993	2,392.89	645.00	19,504.00	2,928.00	1,501.50	4,346.00	225.00
1994	1,876.98	631.00	41,154.00	2,443.00	1,372.40	4,482.00	166.50
1995	2,020.70	431.00	90,641.00	1,876.00	1,651.50	3,594.00	135.00
1996	1,870.29	374.00	13,988.00	2,068.00	1,828.40	3,570.00	135.00
1997	2,109.70	224.00	132,661.00	1,978.00	1,944.40	3,569.00	184.50
1998	1,429.82	298.00	176,587.00	694.00	1,461.00	4,084.00	207.00
1999	976.75	293.00	125,038.00	817.00	1,497.00	6,578.00	202.50
2000	499.01	190.00	116,470.00	425.00	1,849.70	4,523.00	216.00
2001	517.39	140.00	72,631.00	422.00	1,812.90	3,619.00	306.00
2002	328.92	154.00	50,404.00	871.00	1,775.20	3,318.00	382.50
2003	20.63	329.00	39,737.00	1,356.00	2,002.90	3,412.00	369.00
2004	235.82	254.00	47,528.00	490.00	1,935.70	3,317.00	396.00
2005	192.05	<b>254.00</b>	<b>47,528.00</b>	<b>490.00</b>	<b>1,935.70</b>	3,015.00	360.00
2006	126.66	<b>254.00</b>	<b>47,528.00</b>	<b>490.00</b>	<b>1,935.70</b>	2,407.00	373.50
2007	<b>126.66</b>	<b>254.00</b>	<b>47,528.00</b>	<b>490.00</b>	<b>1,935.70</b>	<b>2,407.00</b>	355.50

Table 9 continued horizontally. Catch (C in metric tons) and landings (L) of individual species. We combined catch and scaled landings data from this table to generate functional group catches given in Table 8. Landings were scaled using discard rates from Bellman et al. (2007). Italic values denote cases where catch and landing values were modeled due to missing data in early years; we assumed exponential increases for these cases. Bold values indicate cases where catch and landing data had not been reported in later years and we repeated the latest known value.

Year	FDO			FDP	FDC	SHR	
	Darkblotched rockfish (L)	Blackgill rockfish (C)	Shortspine thornyhead (L)	Dover sole (L)	Longspine thornyhead (L)	Black rockfish (C)	Kelp greenling (L)
1950	201.00	162.00	<i>80.00</i>	2,314.86	7.42	229.21	0.19
1951	261.00	220.00	<i>88.00</i>	2,702.81	7.72	266.60	0.26
1952	195.00	214.00	<i>96.00</i>	3,155.77	8.04	211.72	0.22
1953	194.00	244.00	<i>104.00</i>	3,684.65	8.37	216.48	0.06
1954	201.00	253.00	<i>114.00</i>	4,302.16	8.71	252.99	0.00
1955	197.00	253.00	<i>124.00</i>	5,023.17	9.06	258.44	0.34
1956	244.00	285.00	<i>136.00</i>	5,865.00	9.43	196.54	0.54
1957	269.00	318.00	<i>148.00</i>	5,591.00	9.82	224.50	0.83
1958	246.00	356.00	<i>162.00</i>	5,270.00	10.22	301.51	2.15
1959	243.00	305.00	<i>177.00</i>	5,915.00	10.64	288.18	0.00
1960	258.00	274.00	<i>193.00</i>	7,315.00	11.07	281.32	0.00
1961	203.00	216.00	<i>211.00</i>	5,933.00	11.53	208.82	0.40
1962	276.00	196.00	230.00	6,754.00	12.00	223.60	0.26
1963	323.00	235.00	285.00	7,417.00	12.49	277.10	0.00
1964	208.00	162.00	184.00	6,889.00	13.00	210.70	0.00
1965	415.00	188.00	420.00	6,604.00	30.00	393.70	0.00
1966	4,129.00	272.00	1,155.00	6,437.00	21.00	451.50	0.00
1967	3,001.00	395.00	1,233.00	4,903.00	10.00	530.70	0.00
1968	2,358.00	212.00	2,002.00	6,066.00	10.00	427.30	0.00
1969	256.00	155.00	555.00	8,767.00	29.00	660.50	0.19
1970	265.00	181.00	706.00	9,763.00	42.00	794.10	0.07
1971	441.00	231.00	842.00	9,471.00	44.00	521.30	0.00
1972	595.00	280.00	1,686.00	12,984.00	82.00	616.20	0.00
1973	836.00	331.00	3,089.00	12,450.00	93.00	555.20	0.00
1974	733.00	380.00	1,459.00	11,428.00	77.00	715.80	0.00
1975	567.00	431.00	2,272.00	12,737.00	99.00	734.80	0.00
1976	574.00	480.00	1,044.00	13,966.00	54.00	1,059.30	0.00
1977	263.00	531.00	1,450.00	13,132.00	102.00	781.00	0.02
1978	410.00	571.00	1,212.00	14,054.00	188.00	939.10	0.59
1979	992.00	884.00	1,829.00	17,938.00	263.00	1,543.10	0.13
1980	557.00	822.00	1,279.00	14,086.00	357.00	1,178.60	1.43
1981	912.00	1,061.00	1,727.00	16,467.40	111.00	1,853.60	28.08
1982	1,114.00	1,341.00	1,912.00	20,918.50	412.00	1,905.00	56.07
1983	938.00	1,035.00	2,292.00	19,992.50	296.00	2,009.40	24.55
1984	1,268.00	623.00	2,805.00	19,204.90	370.00	1,873.80	25.84
1985	1,769.00	758.00	3,387.00	20,536.60	729.00	1,839.40	18.91
1986	1,252.00	977.00	2,914.00	17,354.60	733.00	1,420.20	18.12
1987	2,386.00	885.00	2,556.00	18,410.90	1,199.00	1,282.70	23.39
1988	1,650.00	1,042.00	2,910.00	18,117.10	2,760.00	1,289.30	44.11
1989	1,271.00	547.00	4,902.00	18,743.40	3,182.00	1,458.10	26.09
1990	1,650.00	694.00	4,147.00	15,659.90	5,937.00	1,432.00	15.68
1991	1,161.00	484.00	3,534.00	18,198.20	2,979.00	1,424.40	29.58
1992	663.00	789.00	3,376.00	15,986.90	5,497.00	1,815.80	29.60
1993	1,186.00	407.00	3,852.00	14,295.30	5,374.00	1,321.10	29.60
1994	850.00	382.00	3,435.00	9,342.60	7,614.00	1,308.80	43.64
1995	732.00	357.00	1,961.00	10,565.10	5,594.00	1,181.20	17.30
1996	730.00	376.00	1,628.00	12,186.50	4,904.00	1,123.30	12.77
1997	771.00	277.00	1,491.00	10,124.30	4,013.00	1,072.40	17.99
1998	859.00	236.00	1,250.00	8,010.40	2,266.00	1,092.10	30.75
1999	350.00	49.00	834.00	9,137.40	1,812.00	929.10	18.35
2000	252.00	89.00	849.00	8,759.90	1,523.00	881.50	38.18
2001	161.00	134.00	551.00	6,889.20	1,218.00	1,065.80	41.82
2002	109.00	143.00	785.00	6,301.10	1,941.00	929.70	57.05
2003	80.00	189.00	827.00	7,372.20	1,588.00	1,298.30	96.74
2004	192.00	168.00	705.00	6,742.60	776.00	955.80	48.58
2005	105.00	<b>168.00</b>	<b>705.00</b>	<b>6,742.60</b>	<b>776.00</b>	1,050.20	51.77
2006	113.00	<b>168.00</b>	<b>705.00</b>	<b>6,742.60</b>	<b>776.00</b>	951.30	<b>51.77</b>
2007	<b>113.00</b>	<b>168.00</b>	<b>705.00</b>	<b>6,742.60</b>	<b>776.00</b>	<b>951.30</b>	<b>51.77</b>

Table 9 continued horizontally. Catch (C in metric tons) and landings (L) of individual species. We combined catch and scaled landings data from this table to generate functional group catches given in Table 8. Landings were scaled using discard rates from Bellman et al. (2007). Italic values denote cases where catch and landing values were modeled due to missing data in early years; we assumed exponential increases for these cases. Bold values indicate cases where catch and landing data had not been reported in later years and we repeated the latest known value.

Year	FPO	FBD	SHC	FMM	FVT	SSK
	Canary rockfish (C)	Gopher rockfish (C)	Yelloweye rockfish (L)	Pacific hake (C)	Albacore tuna (C)	Longnose skate (L)
1950	1,959.11	<i>9.73</i>	39.66	8,441.52	140.76	202.38
1951	1,936.32	<i>10.18</i>	42.69	10,114.61	171.71	250.00
1952	1,901.81	<i>10.65</i>	45.95	12,119.30	171.71	321.43
1953	1,753.25	<i>11.15</i>	49.46	14,521.32	108.31	482.14
1954	1,948.57	<i>11.67</i>	53.23	17,399.41	84.33	434.52
1955	1,961.38	<i>12.21</i>	57.30	20,847.93	94.14	380.95
1956	1,997.54	<i>12.78</i>	65.00	24,979.94	130.77	380.95
1957	2,575.83	<i>13.38</i>	63.95	29,930.90	145.96	333.33
1958	2,618.95	<i>14.00</i>	72.85	35,863.13	101.35	369.05
1959	2,451.60	<i>14.65</i>	65.30	42,971.11	142.71	261.90
1960	2,479.46	<i>15.33</i>	60.70	51,487.88	140.44	178.57
1961	2,160.25	<i>16.05</i>	53.90	61,692.65	110.48	351.19
1962	2,206.70	<i>16.79</i>	53.45	73,919.98	153.12	202.38
1963	2,070.84	<i>17.57</i>	61.60	88,570.74	195.36	267.86
1964	1,484.62	<i>18.39</i>	53.75	106,125.24	153.80	291.67
1965	1,756.39	19.25	61.25	127,159.00	120.27	202.38
1966	3,616.02	19.25	66.05	137,000.00	119.16	232.14
1967	1,953.68	19.25	67.35	177,662.00	153.93	190.48
1968	2,327.35	19.25	68.55	60,819.00	178.78	267.86
1969	1,559.15	31.04	101.20	86,280.00	150.87	172.62
1970	1,524.15	17.41	107.20	159,575.00	178.63	113.10
1971	1,400.22	8.66	105.60	127,913.00	161.66	35.71
1972	1,460.97	19.33	144.60	74,133.00	190.29	47.62
1973	2,316.49	19.81	174.40	147,513.00	122.26	47.62
1974	1,691.82	28.06	170.60	194,109.00	170.33	47.62
1975	1,695.81	59.17	176.10	205,656.00	155.37	47.62
1976	1,279.83	62.89	204.20	231,549.00	131.49	113.10
1977	1,895.23	39.27	216.20	127,502.00	81.84	130.95
1978	3,073.76	77.85	216.00	98,372.00	125.36	208.33
1979	3,460.84	60.94	296.80	124,680.00	48.66	261.90
1980	4,124.88	114.19	377.10	72,352.00	55.10	136.90
1981	3,532.39	94.40	406.20	114,760.00	92.48	428.57
1982	5,543.56	69.75	460.00	75,577.00	50.42	285.71
1983	4,918.49	37.98	388.00	73,150.00	68.37	220.24
1984	2,383.01	51.27	262.00	96,332.00	105.30	113.10
1985	2,726.47	47.74	298.50	85,439.00	61.79	166.67
1986	2,302.73	52.81	218.00	154,964.00	36.29	130.95
1987	3,183.48	51.04	274.60	160,448.00	21.43	148.81
1988	3,074.43	83.12	286.00	160,698.00	35.39	119.05
1989	3,332.89	68.95	358.60	210,996.00	15.97	119.05
1990	2,790.79	159.42	253.00	183,800.00	20.55	89.29
1991	3,202.97	184.25	363.90	217,505.00	15.31	53.57
1992	2,865.80	206.53	374.90	208,576.00	33.87	77.38
1993	2,234.98	208.63	312.10	141,222.00	45.67	101.19
1994	1,209.75	158.60	219.20	252,729.00	80.76	232.14
1995	1,189.33	114.46	251.90	177,589.00	62.28	946.43
1996	1,546.40	89.22	212.10	212,902.00	124.60	1,714.29
1997	1,478.82	79.97	237.30	233,423.00	115.95	779.76
1998	1,494.16	75.64	107.60	232,817.00	115.09	1,220.00
1999	898.03	83.51	157.50	224,522.00	105.22	1,835.00
2000	208.36	91.27	42.30	208,418.00	85.06	2,108.00
2001	133.58	144.29	52.90	182,377.00	98.05	1,342.00
2002	106.83	108.17	12.90	132,114.00	93.02	488.00
2003	50.99	147.11	11.60	143,492.00	115.28	1,323.00
2004	46.53	50.28	12.00	210,484.00	105.71	582.00
2005	51.43	<b>50.28</b>	23.60	259,844.00	76.17	959.00
2006	47.12	<b>50.28</b>	<b>23.60</b>	270,263.00	86.71	1,157.00
2007	<b>47.12</b>	<b>50.28</b>	<b>23.60</b>	203,979.00	78.73	899.00



Table 9 continued horizontally. Catch (C in metric tons) and landings (L) of individual species. We combined catch and scaled landings data from this table to generate functional group catches given in Table 8. Landings were scaled using discard rates from Bellman et al. (2007).

Year	FPS		FPL		CEP
	Northern anchovy (L)	Pacific sardine (L)	Pacific mackerel (L)	Jack mackerel (L)	Market squid (L)
1950	817.90	5.32	22,580.65	420.13	499.23
1951	935.31	5.50	15,268.82	474.08	565.29
1952	1,069.57	5.69	14,408.60	534.96	640.08
1953	1,223.10	5.88	9,032.26	603.65	724.77
1954	1,398.68	6.08	3,870.97	681.17	820.67
1955	1,599.45	6.29	12,258.06	768.64	929.25
1956	1,829.05	6.50	12,258.06	867.34	1,052.21
1957	2,091.61	6.72	25,591.40	978.72	1,191.42
1958	2,391.85	6.95	25,161.29	1,104.40	1,349.06
1959	2,735.19	7.19	11,182.80	1,246.22	1,527.56
1960	3,127.82	7.43	18,494.63	1,406.25	1,729.68
1961	3,576.81	7.69	18,064.52	1,586.83	1,958.53
1962	4,090.25	7.95	19,784.95	1,790.59	2,217.67
1963	4,677.39	8.22	20,645.16	2,020.53	2,511.10
1964	5,348.82	8.50	15,493.87	2,279.99	2,843.34
1965	6,116.63	8.79	11,182.80	2,572.76	3,219.55
1966	6,994.65	9.08	3,440.86	2,903.14	3,645.54
1967	7,998.71	9.39	1,935.48	3,275.93	4,127.88
1968	9,146.90	9.71	645.16	3,696.60	4,674.05
1969	10,459.91	10.04	1,505.38	4,171.29	5,292.49
1970	11,961.40	10.38	645.16	4,706.94	5,992.74
1971	13,678.43	10.74	0.00	5,311.36	6,785.66
1972	15,641.92	11.10	0.00	5,993.41	7,683.48
1973	17,887.27	11.48	0.00	6,763.03	8,700.09
1974	20,454.94	11.87	0.00	7,631.49	9,851.22
1975	23,391.19	12.27	0.00	8,611.46	11,154.65
1976	26,748.92	12.69	0.00	9,717.27	12,630.55
1977	30,588.65	13.12	2,580.65	10,965.09	14,301.72
1978	34,979.56	13.57	7,526.88	12,373.14	16,194.01
1979	40,000.77	14.03	18,709.68	13,962.00	18,336.67
1980	45,742.76	14.51	27,526.88	15,754.88	20,762.83
1981	52,309.00	15.00	35,388.00	17,778.00	23,510.00
1982	42,155.00	2.00	36,065.00	19,617.00	16,308.00
1983	4,430.00	1.00	41,479.00	9,829.00	1,824.00
1984	2,899.00	1.00	44,086.00	9,154.00	564.00
1985	1,638.00	6.00	37,772.00	6,876.00	10,276.00
1986	1,557.00	388.00	48,089.00	4,777.00	21,278.00
1987	1,467.00	439.00	46,725.00	8,020.00	19,984.00
1988	1,518.00	1,188.00	50,864.00	5,068.00	37,316.00
1989	2,511.00	837.00	47,713.00	10,745.00	40,974.00
1990	3,259.00	1,664.00	40,092.00	3,254.00	28,447.00
1991	4,068.00	7,587.00	32,067.00	1,712.00	37,389.00
1992	1,166.00	18,056.00	19,045.00	1,526.00	13,112.00
1993	2,003.00	15,347.00	12,129.00	1,950.00	42,830.00
1994	1,859.00	11,644.00	10,293.00	2,906.00	55,383.00
1995	2,016.00	40,256.00	8,823.00	1,877.00	70,252.00
1996	4,505.00	32,553.00	9,730.00	2,437.00	80,561.00
1997	5,779.00	43,290.00	20,168.00	1,533.00	70,329.00
1998	1,584.00	43,312.00	21,561.00	1,777.00	2,895.00
1999	9,094.00	60.00	9,094.00	1,557.00	92,101.00
2000	11,832.00	67,982.00	22,058.00	1,451.00	118,903.00
2001	19,345.00	75,801.00	7,618.00	3,839.00	86,203.00
2002	4,882.00	96,897.00	3,744.00	1,026.00	72,895.00
2003	1,929.00	71,923.00	4,213.00	231.00	45,056.00
2004	7,019.00	89,339.00	3,708.00	1,160.00	40,068.00
2005	11,414.00	86,464.00	3,586.00	294.00	55,755.00
2006	12,960.00	86,608.00	6,610.00	1,174.00	49,180.00
2007	10,548.00	127,766.00	5,759.00	646.00	49,499.00



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# Appendix A: Sources for Diets

Below are summaries of the sources for each species' diet and subsequently each functional group's diet. Two or three letter abbreviations for each functional group are listed for consistency with Brand et al. (2007) and Dufault et al. (2009).

## Fish

### Small Planktivorous Fish (FPS)

Species included: herring (*Clupea harengus*, *C. pallasii*), Pacific sardine (*Sardinops sagax*), Northern anchovy (*Engraulis mordax*), flying fish (Exocoetidae), Pacific argentine (*Argentina sialis*), eulachon (*Thaleichthys pacificus*), Pacific saury (*Cololabis saira*), American shad (*Alosa sapidissima*), zebraperch (*Hermosilla azurea*), smelts (Osmeridae), deepsea smelts (Bathylagidae), blacksmelt (*Bathylagus* spp.), whitebait smelt (*Allosmerus elongatus*), night smelt (*Spirinchus starksi*), and longfin smelt (*S. thaleichthys*).

Anchovy, sardine, and herring are the dominant members of this group in terms of biomass. Sardine life history parameters (length-weight, von Bertalanffy 1938, and mortality) were taken from the 2007 stock assessment (Hill et al. 2007); anchovy and herring parameters were taken from A Spatially Explicit Ecosystem Model of the California Current Food Web and Oceanography (EMOCC) by Brand et al. (2007), as was the biomass estimate for the group. Herring and anchovy diets were summarized by Brodeur et al. (1987) from samples collected from 1981 to 1984. Fifteen anchovy nonempty stomachs were collected in 1984 and a total of 94 nonempty herring stomachs were collected during annual sampling from 1981 to 1984. Emmett et al. (2005) examined 184 sardine stomachs from 1999 to 2002.

### Large Planktivorous Fish (FPL)

Species included: Pacific chub mackerel (*Scomber japonicus*) and jack mackerel (*Trachurus symmetricus*).

Pacific chub mackerel life history parameters (length-weight and von Bertalanffy 1938) were updated from the 2007 stock assessment (Dorval et al. 2007). The jack mackerel biomass estimate (900,000 mt) came from Stauffer and MacCall (Stauffer and Charter 1982, MacCall and Stauffer 1983), as cited in EMOCC, and was added to the stock assessment biomass estimate for Pacific mackerel (359,290 mt). Brodeur et al. (1987) sampled jack and Pacific chub mackerel diets from 1982 to 1984. Since only one source of diet was available and it did not contain age class information, adult and juvenile diets were not distinguished.

### Miscellaneous Nearshore Fish (FDE)

Species included: northern ronquil (*Ronquilus jordani*), plainfin midshipman (*Porichthys notatus*), sculpins (Cottidae), flabby sculpin (*Zesticelus profundorum*), sculpins (*Icelinus* spp.), threadfin sculpin (*I. filamentosus*), northern sculpin (*I. borealis*), spotfin sculpin (*I. tenuis*), fringed sculpin (*I. fimbriatus*), dusky sculpin (*I. burchami*), threaded sculpin (*Gymnocanthus pistilliger*), slim sculpin (*Radulinus asprellus*), blackfin sculpin (*Malacocottus kincaidi*), roughspine sculpin (*Triglops macellus*), roughback sculpin (*Chitonotus pugetensis*), Pacific staghorn sculpin (*Leptocottus armatus*), buffalo sculpin (*Enophrys bison*), bull sculpin (*E. taurina*), spinyhead sculpin (*Dasycottus setiger*), sailfin sculpin (*Nautichthys oculofasciatus*), longspine combfish (*Zaniolepis latipinnis*), shortspine combfish (*Z. frenata*), white croaker (*Genyonemus lineatus*), giant wrymouth (*Cryptacanthodes giganteus*), bluebarred prickleback (*Plectobranthus evides*), whitebarred prickleback (*Poroclinus rothrocki*), medusafish (*Icichthys lockingtoni*), king-of-the-salmon (*Trachipterus altivelis*), opaleye (*Girella nigricans*), tubesnout (*Aulorhynchus flavidus*), wolf-eel (*Anarrhichthys ocellatus*), blackeye goby (*Rhinogobiops nicholsii*), monkeyface prickleback (*Cebidichthys violaceus*), halfmoon (*Medialuna californiensis*), halfblind goby (*Lethops connectens*), pipefish (Syngnathidae), kelpfish (*Chironemus marmoratus*), sarcastic fringehead (*Neoclinus blanchardi*), longfin sculpin (*Jordania zonope*), sixspot prickleback (*Kasatkia seigeli*), gunnels (Pholidae), snubnose sculpin (*Orthonopias triacis*), mosshead warbonnet (*Chirolophus nugator*), pricklebacks (Stichaeidae), manacled sculpin (*Synchirus gilli*), kelp clingfish (*Rimicola muscarum*), coralline sculpin (*Artedius corallinus*), gobies (Gobiidae), and bay goby (*Lepidogobius lepidus*).

The miscellaneous nearshore fish group is comprised of a variety of mostly nearshore fish. This group was maintained from EMOCC, but updated with information from Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) survey data. Life history parameters were taken from EMOCC. Diet data for this group was scarce, but Hart (1973) suggests these species consume many bottom invertebrates and various crustaceans, including shrimps and isopods. These feeding habits were proportioned among equivalent Central California Atlantis Model (CCAM) prey groups.

### Nearshore Fish (FDM)

Species included: butterfish (unidentified Stromateidae), Pacific pompano (aka butterfish, *Peprilus simillimus*), California sheephead (*Semicossyphus pulcher*), señorita (*Oxyjulis californica*), rock wrasse (*Halichoeres semicinctus*), surfperches (Embiotocidae), redbtail surfperch (*Amphistichus rhodoterus*), shiner perch (*Cymatogaster aggregata*), pink seaperch (*Zalembeus rosaceus*), striped seaperch (*Embiotoca lateralis*), black perch (*E. jacksoni*), pile perch (*Rhacochilus vacca*), rubberlip seaperch (*R. toxotes*), rainbow seaperch (*Hypsurus caryi*), white seaperch (*Phanerodon furcatus*), sharpnose seaperch (*P. atripes*), kelp perch (*Brachyistius frenatus*), blacksmith (*Chromis punctipinnis*), spotfin surfperch (*Hyperprosopon anale*), silver surfperch (*H. ellipticum*), and walleye surfperch (*H. argenteum*).

This group consists largely of surfperch species, as well as butterfish, señorita, sheephead, garibaldi (*Hypsypops rubicundus*), and blacksmith. Nearshore fish biomass was estimated exclusively from PISCO dive surveys by the methods described above. We estimated the coast-wide biomass to be 685,808 mt by this method. Life history parameters for this group

came from the Web site FishBase ([www.fishbase.org](http://www.fishbase.org)) and Cailliet et al. (2000). The only diet data available were purely qualitative (Hart 1973), and as such, all quantities were best guesses.

### **Deep Vertical Migrators (FBP)**

Species included: lanternfish (Myctophidae), Pacific viperfish (*Chauliodus macouni*), myctophid (*Lampanyctus* spp.), longfin dragonfish (*Tactostoma macropus*), highfin dragonfish (*Bathophilus flemingi*), scaleless dragonfish (Melanostomiinae), black-belly dragonfish (*Stomias atriventer*), shiny loosejaw (*Aristostomias scintillans*), loosejaw (Malacosteinae), California headlightfish (*Diaphus theta*), barreleye (*Macropinna microstoma*), Pacific blackdragon (*Idiacanthus antrostomus*), blue lanternfish (*Tarletonbeania crenularis*), tubeshoulder (Platytroctidae), shining tubeshoulder (*Sagamichthys abei*), pearleye (*Benthalbella* spp.), northern pearleye (*B. dentata*), bristlemouth (Gonostomatidae), hatchetfish (Sternoptychidae), tropical hatchetfish (*Argyropelecus* spp.), tropical hatchetfish (*A. lychnus*), Pacific hatchetfish (*A. affinis*), hatchetfish (*Sternoptyx* spp.), diaphanous hatchet fish (*S. diaphana*), bigscale (Melamphidae), crested bigscale (*Poromitra crassiceps*), highsnout bigscale (*Melamphaes lugubris*), Panama snaggletooth (*Borostomias panamensis*), smooth dreamer (*Chaenophryne draco*), redmouth whalefish (*Rondeletia loricata*), benttooth bristlemouth (*Cyclothone acclinidens*), North Pacific daggertooth (*Anotopterus nikparini*), pinpoint lampfish (*Nannobranchium regale*), duckbill barracudina (*Magnisudis atlantica*), longnose lancetfish (*Alepisaurus ferox*), and black scabbardfish (*Aphanopus carbo*).

This group was largely unchanged from EMOCC. Biomass and life history parameters are the same, but quantitative diet data were incorporated. A large number of northern lanternfish stomachs were available from central California (n = 494, Cailliet and Ebeling 1990) and Oregon (n = 440, Tyler 1970). Tyler (1970) also analyzed two species of lampfish diets (n = 326). Pacific viperfish was the only species for which adults and juveniles were differentiated (Balanov 1994). Seven stomachs of each stage were analyzed, but unfortunately this study was conducted in the Bering Sea. Four adult longfin dragonfish were also analyzed from the Bering Sea (Beamish et al. 1999). Because diet data was so sparse for this group, we included these data from outside the model's range.

### **Deep Miscellaneous Fish (FDD)**

Species included: ragfish (*Icosteus aenigmaticus*), Pacific lamprey (*Lampetra tridentata*), slickhead (*Bajacalifornia erimoensis*), soft eelpout (*Bothrocara molle*), wattled eelpout (*Lycodes plearis*), shortfin eelpout (*L. brevipes*), cusk-eels (Ophidiidae), paperbone cusk-eel (*Lamprogrammus niger*), Pacific blackchin (*Scopelogys tristis*), snipe eel (Nemichthyidae), Pacific hagfish (*Eptatretus stoutii*), poacher (Agonidae), northern spearnose poacher (*Agonopsis vulsa*), eelpout (Zoarcidae), sturgeon poacher (*Podothecus accipenserinus*), Maul's searsid (*Maulisia maui*), wolf-eel (*Anarrhichthys ocellatus*), threadfin cusk-eel (*Dicrolene filamentosa*), filamented rattail (*Coryphaenoides filifer*), hundred-fathom codling (*Physiculus rastrelliger*), tadpole snailfish (*Nectoliparis pelagicus*), snailfish (*Rhinoliparis* spp.), brownsnout spookfish (*Dolichopteryx longipes*), warty poacher (*Chesnonia verrucosa*), Pacific sand lance (*Ammodytes hexapterus*), northern smoothtongue (*Leuroglossus schmidti*), basketweave cusk-eel (*Ophidion scrippsae*), softhead grenadier (*Malacocephalus laevis*), black swallower (*Chiasmodon niger*), pink snailfish (*Paraliparis rosaceus*), broadfin snailfish (*Paraliparis pectoralis*), longnose

snailfish (*Rhinoliparis barbifer*), eels (*Avocettina* spp.), eelpouts (*Lycenchelys* spp.), looseskin eelpout (*Lycodapus dermatinus*), and blackmouth eelpout (*L. fierasfer*).

The deep miscellaneous fish group was also changed very little from EMOCC, with the exception of diets. Diets were based on giant grenadier, Pacific grenadier, and eelpouts. For adult diets, Buckley et al. (1999) collected 29 giant grenadier and 33 Pacific grenadier stomachs from the 1992 trawl survey, and Percy and Ambler (1974) described 2 additional Pacific grenadier stomachs. Eelpout diets came from 385 northern smoothtongues off Santa Barbara, California, and 228 twoline eelpout stomachs off central California (Monterey Bay) and the Columbia River plume (Cailliet and Ebeling 1990, Ferry 1997). Juvenile diet data were available for 304 giant grenadiers and 483 Pacific grenadiers from the 1997 NMFS slope survey from Point Conception to the U.S.-Canada border (Drazen et al. 2001).

### **Shallow Large Rockfish (SHR)**

Species included: greenspotted rockfish (*Sebastes chlorostictus*), redstripe rockfish (*S. proriger*), silvergray rockfish (*S. brevispinis*), kelp greenling (*Hexagrammos decagrammus*), brown rockfish (*S. auriculatus*), copper rockfish (*S. caurinus*), pink rockfish (*S. eos*), quillback rockfish (*S. maliger*), blue rockfish (*S. mystinus*), tiger rockfish (*S. nigrocinctus*), greenblotched rockfish (*S. rosenblatti*), and starry rockfish (*S. constellatus*).

The CCAM shallow large rockfish group consists primarily of redstriped, blue, brown, greenspotted, and silverygrey rockfish and kelp greenling. Relative proportions of these species were calculated from the 1999–2007 NWFSC shelf-slope trawl surveys (Builder Ramsey et al. 2002, Keller et al. 2005, 2006a, 2006b, 2007). The biomass for this group is currently the same as for the group in EMOCC, although this may be updated in the future. Stock assessments were completed for black rockfish (Wallace et al. 2007), blue rockfish, and kelp greenling (Cope and MacCall 2005) and we used these to update life history parameters for those species from EMOCC. Diet data came from redstripe and blue rockfishes. Steiner (1979) also surveyed 51 blue rockfish off the Oregon coast. Redstripe stomachs came from Shaw (1999) as mentioned in Field (2004). Juvenile large shallow rockfish diets consisted of copper rockfish and blue rockfish data. Singer (1982) analyzed 38 juvenile copper rockfish stomachs and 23 juvenile blue rockfish stomachs, all from central California.

### **Yelloweye and Cowcod (SHC)**

Species included: yelloweye rockfish (*Sebastes ruberrimus*) and cowcod (*S. levis*).

This new group was created for CCAM to capture the dynamics of yelloweye rockfish and cowcod. Both species were assessed in 2007, and we used the current biomass estimates from these analyses. Yelloweye were estimated at 503.4 mt (Wallace 2007). The cowcod population that is assessed is actually in the Southern California Bight. Dick et al. (2007) reported that historically approximately 80% of landings occurred south of Point Conception. We therefore made an assumption that the population in the Southern California Bight represents 80% of the combined north and south stocks, such that we estimate the northern part of the stock within our model bounds (north of Conception) to be 91.75 mt. Life history parameters for yelloweye and cowcod were taken from the stock assessments (Dick et al. 2007, Wallace 2007).

For diets, Steiner (1979) sampled an unknown number of yelloweye stomachs off the Oregon coast and York (2005) sampled nine stomachs off the Oregon coast.

### **Deep Small Rockfish (FDC)**

Species included: longspine thornyhead (*Sebastolobus altivelis*), splitnose rockfish (*Sebastes diploproa*), aurora rockfish (*S. aurora*), and sharpchin rockfish (*S. zacentrus*).

The composition of the group remains unchanged from the coast-wide model. The relative proportion of each species was updated to reflect current NWFSC shelf-slope trawl survey data from 1999 to 2006. The biomass for this group was also updated, as a stock assessment was completed for longspine thornyhead in 2005 (Fay 2005). This estimate (257,530 mt) was extrapolated to the functional group based on the proportion of longspine thornyhead (0.53) within the group in the trawl surveys. This gave a total biomass of 489,619 mt. Life history parameters were not updated from EMOCC. Diets were obtained from compiling sharpchin rockfish, longspine thornyhead, and splitnose rockfish. York (2005) collected 36 sharpchin stomachs from Oregon and Shaw (1999) collected 8 stomachs. Brodeur and Pearcy (1984) analyzed 62 splitnose stomachs, longspine thornyhead data were taken from Laidig (unpublished data) as described in Field (2004), and Buckley et al. (1999) sampled 281 longspine thornyhead stomachs. Because stomachs were not specified as adult or juvenile and no juvenile data were available, these stomachs were used for both adult and juvenile diets. Juveniles were assumed to only eat juvenile prey. The only exception to this was for small-sized prey groups such as small planktivorous fish and deep vertical migrators.

### **Deep Large Rockfish (FDO)**

Species included: shortspine thornyhead (*Sebastolobus alascanus*), darkblotched rockfish (*Sebastes crameri*), redbanded rockfish (*S. babcocki*), blackgill rockfish (*S. melanostomus*), rougheye rockfish (*S. aleutianus*), and bank rockfish (*S. rufus*).

The deep large rockfish group was kept intact from EMOCC and is composed of shortspine thornyhead, blackgill, rougheye, darkblotched, and similar rockfish. Species weights were updated with NWFSC shelf-slope trawl survey data from 1999 to 2006, as with the previous group, and biomass estimates were updated with recent stock assessments. Blackgill rockfish were estimated at 13,051 mt (Helser 2005), darkblotched at 11,094 mt (Rogers 2005), and shortspine thornyhead at 144,512 mt (Hamel 2005). These three together make up 98% of the biomass of this group, so the final estimate for the group is 172,270 mt. Darkblotched rockfish life history parameters were updated from the 2007 assessment, but all other species remained unchanged. Diets were based on darkblotched and rougheye rockfish and shortspine thornyhead. Shaw (1999) collected 7 rougheye stomachs, Brodeur and Pearcy (1984) collected 30 darkblotched stomachs, and Buckley et al. (1999) collected 473 shortspine thornyhead stomachs. Diets were not differentiated between adults and juveniles.

### **Canary Rockfish (FPO)**

Species included: *Sebastes pinniger*.

Canary rockfish is assigned its own functional group. This species was assessed in 2007 and we updated life history parameters and biomass from this assessment (Stewart 2007). Adult canary diets came from 561 stomach samples. Brodeur et al. (1987) collected 368 stomachs from Oregon and Washington, Lee (2002) collected 104 stomachs off Oregon and Washington, and York (2005) analyzed 29 stomachs from Oregon. An additional 60 stomachs were analyzed from the NOAA-AFSC food-habits database from the west coast trawl survey. Juvenile data were adapted from Lea et al. (1999), which were frequency of occurrence data.

### **Shallow Small Rockfish (FDB)**

Species included: stripetail rockfish (*Sebastes saxicola*), greenstriped rockfish (*S. elongatus*), rosethorn rockfish (*S. helvomaculatus*), pygmy rockfish (*S. wilsoni*), halfbanded rockfish (*S. semicinctus*), Puget Sound rockfish (*S. emphaeus*), calico rockfish (*S. dallii*), northern rockfish (*S. polyspinis*), harlequin rockfish (*S. variegatus*), black-and-yellow rockfish (*S. chrysomelas*), China rockfish (*S. nebulosus*), dwarf-red rockfish (*S. rufinanus*), flag rockfish (*S. rubrivinctus*), gopher rockfish (*S. carnatus*), honeycomb rockfish (*S. umbrosus*), kelp rockfish (*S. atrovirens*), rosy rockfish (*S. rosaceus*), swordspine rockfish (*S. ensifer*), stripetail rockfish (*S. saxicola*), and rock greenling (*Hexagrammos lagocephalus*).

Shallow small rockfish were not changed from EMOCC, with the exception of shortbelly rockfish, which became its own group. We estimated the biomass by using the estimate from EMOCC and subtracting the assessed biomass of shortbelly. Life history parameters remained the same as EMOCC after removing shortbelly. Adult diets were determined by data from greenstriped, rosethorn, and pygmy rockfish stomachs. York (2005) analyzed 49 pygmy, 60 rosethorn, and 51 greenstriped rockfish stomachs from Oregon. Juvenile diets came from 1,027 shortbelly rockfish from central California (Chess et al. 1988, Reilly et al. 1992). We used these shortbelly diets even though they were in a different functional group because the species used to be grouped together and are morphologically and behaviorally similar.

### **Shortbelly Rockfish (FVV)**

Species included: *Sebastes jordani*.

Shortbelly rockfish comprise their own group. Biomass and life history parameters for the group come from a recent assessment by Field et al. (2007). Diets were differentiated between adults and juveniles. Adult data came from 190 stomachs (Chess et al. 1988) and juvenile data came from the sources mentioned previously (Chess et al. 1988, Reilly et al. 1992).

### **Midwater Rockfish (FDS)**

Species included: chilipepper rockfish (*Sebastes goodei*), Pacific ocean perch (*S. alutus*), bocaccio (*S. paucispinis*), canary rockfish, widow rockfish (*S. entomelas*), yellowtail rockfish (*S. flavidus*), shorttraker rockfish (*S. borealis*), yellowmouth rockfish (*S. reedi*), vermilion rockfish (*S. miniatus*), squarespot rockfish (*S. hopkinsi*), dusky rockfish (*S. ciliatus*), and speckled rockfish (*S. ovalis*).

The members of the midwater rockfish group remain unchanged from the coast-wide model. The largest contributors to biomass in this group are bocaccio, chilipepper rockfish,

Pacific ocean perch, widow rockfish, and yellowtail rockfish. Many of the species have been assessed since EMOCC was developed and we updated the biomass of this group based on these assessments. Pacific ocean perch were estimated to be 10,168 mt (Hamel 2008b). The stock assessment for widow rockfish reported 120,989 mt (He et al. 2007), for bocaccio 10,752 mt (MacCall 2007), for chilipepper rockfish 33,619 mt (Field 2007), and for yellowtail rockfish 74,217 mt (Wallace and Lai 2005). We summed these to estimate the group-wide biomass. Life history parameters were also updated based on the assessment, as were the weights of each species in the group. Adult midwater rockfish diets were derived from yellowtail rockfish, widow rockfish, and Pacific ocean perch stomachs.

Yellowtail rockfish made up the greatest number of stomachs. Pereyra et al. (1969) collected 22 off Vancouver Island, Brodeur and Percy (1984) collected 264 off Oregon and Washington, and Lee (2002) collected 167 stomachs off Oregon. Addition unpublished data (526 stomachs) were summarized by Field (2004). Unpublished diet data (186 stomachs) for Pacific ocean perch were also summarized by Field (2004). Brodeur and Percy (1984) collected 73 stomachs off Washington and Oregon. Widow rockfish stomachs were analyzed from Oregon and northern California by Adams (1987) and Lee (2002). Ressler (unpubl. data) analyzed 41 stomachs from Oregon in 2003. Field (2004) also summarized unpublished diets from Livingston. Juvenile midwater rockfish diets came from bocaccio, chilipepper rockfish, yellowtail rockfish, and widow rockfish stomachs. Reilly et al. (1992) analyzed 195 juvenile widow rockfish stomachs, 97 yellowtail rockfish, 145 chilipepper rockfish, and 128 bocaccio from central California.

### **Small Flatfish (FDF)**

Species included: flatfish (Pleuronectiformes), English sole (*Parophrys vetulus*), rex sole (*Glyptocephalus zachirus*), slender sole (*Lyopsetta exilis*), deepsea sole (*Embassichthys bathybius*), flathead sole (*Hippoglossoides elassodon*), butter sole (*Isopsetta isolepis*), fantail sole (*Xystreureys liolepis*), rock sole (*Lepidopsetta bilineata*), sand sole (*Psettichthys melanostictus*), curlfin sole (*Pleuronichthys decurrens*), spotted turbot (*P. ritteri*), hornyhead turbot (*P. verticalis*), starry flounder (*Platichthys stellatus*), sanddab (*Citharichthys* spp.), Pacific sanddab (*C. sordidus*), and longfin sanddab (*C. xanthostigma*).

The small flatfish group consists of the same species as in EMOCC, except we placed Dover sole in its own functional group (FDP). The biomass estimate for this group changed significantly, since Dover sole made up more than one-half of the small flatfish biomass in EMOCC. Since only one species was assessed (English sole), we used the assessment biomass (62,172 mt, Stewart 2005) and extrapolated based on the relative species weights within the 1998–2003 NMFS trawl surveys, which we restandardized from EMOCC. Life history parameters for English sole were updated from the assessment, but all other species parameters remained the same. Flatfish diets were available for multiple species (deepsea sole, rex sole, English sole, and Pacific sanddab), but were not differentiable to adult and juvenile stages. Deepsea sole stomachs were analyzed from the trawl survey (n = 131, Buckley et al. 1999), and rex sole diets (n = 614) were analyzed by Percy and Hancock (1978). Percy and Hancock also looked at Pacific sanddab diets (n = 723), and Wakefield (1984) collected a few Pacific sanddab stomachs (n = 8), both from Oregon. Wakefield (1984) collected 49 English sole stomachs off

Newport, Oregon. Because no lengths were associated with these data and no juvenile data were available, these stomachs were used for both adult and juvenile parameterization.

### **Dover Sole (FDP)**

Species included: *Microstomus pacificus*.

Dover sole were assessed in 2005 (Sampson 2005), and that document formed the basis for our life history parameters and biomass estimate for this group. Dover sole diets were available coast wide; 770 stomachs were analyzed from the NMFS trawl survey (Buckley et al. 1999). The remainder of samples were from Oregon: 326 from Percy and Hancock (1978), 265 from Gabriel and Percy (1981), 243 from Gabriel (1981), and 24 from Wakefield (1984).

### **Hake (FMM)**

Species included: Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), Pacific tomcod (*Microgadus proximus*), and walleye pollock (*Theragra chalcogramma*).

Hake were assessed in 2007 (Helser and Martell 2007) and we updated the hake initial biomass based on that estimate. The von Bertalanffy “k” was also updated from the assessment, and “L” infinity and length-weight parameters were updated from the FishBase Web site. Adult and juvenile diets were available from multiple studies coast wide. In Washington and Oregon, Brodeur et al. (1987) collected 156 adult stomachs, Livingston (1983) analyzed 1,499 adult stomachs, and Livingston and Alton (1982) examined 164 adult stomachs. Gotshall (1969) collected 450 stomachs from the California-Oregon border south to Point Conception and Rextad and Pikitch (1986) analyzed 347 stomachs off the West Coast. Additionally, 1,201 stomachs were available from the NMFS trawl survey, with approximately twice as many samples from north of Cape Blanco than south of this point (Buckley et al. 1999), and 253 adult stomachs were examined from more recent surveys (Ressler unpubl. data). Juvenile hake diets were available from Oregon and Washington (n = 40, Livingston and Alton 1982) and 364 were analyzed from the coast-wide trawl survey.

### **Sablefish (FMN)**

Species included: *Anoplopoma fimbria*.

Sablefish were assessed to be 156,676 mt in 2007 (Schirripa 2007). We also updated length-weight parameters from the assessment, but all other life history parameters remained the same. Sablefish diets have been examined coast wide. Adult stomachs (601) were collected in the trawl survey from Washington to Point Conception in the mid-1990s (Buckley et al. 1999). Laidig and Adams (1997) reported on 1,868 stomachs collected from Oregon to central California and Cailliet et al. (1988) analyzed 249 from central California as well. Brodeur et al. (1987) reported on juvenile stomachs from Oregon and Washington and Cailliet et al. (1988) examined 65 juveniles from central California.



### **Large Flatfish (FVD)**

Species included: arrowtooth flounder (*Atheresthes stomias*), petrale sole (*Eopsetta jordani*), Pacific halibut (*Hippoglossus stenolepis*), and California halibut (*Paralichthys californicus*).

The large flatfish group consists mostly of arrowtooth flounder, Pacific halibut, and petrale sole. Biomass estimates for this group came from recent assessment documents. Petrale was assessed to be 13,411 mt in 2005 (Lai et al. 2005), but life history parameters remained as in EMOCC. The most recent halibut assessment occurred in 2006 and the portion of the stock in U.S. waters was estimated to be 2,253.45 mt (Clark and Hare 2007). Life history parameters were not updated. Arrowtooth flounder were estimated to be 83,301 mt in 2007 (Kaplan and Helser 2007). Arrowtooth life history parameters were also updated from that document. Large flatfish diets have been well sampled. Arrowtooth flounder diet studies have largely been concentrated in the Gulf of Alaska; however, we used them to parameterize diets in the California Current. Buckley (1999) collected 178 adult stomachs, Yang (1994) collected 337, Gotshall (1969) collected 253, and Yang and Nelson (2000) analyzed nearly 3,000. Yang and others (Yang 1994, Yang and Nelson 2000) also analyzed 1,657 adult halibut diets from the Gulf of Alaska. Petrale sole diet data is less abundant, with Wakefield (1984) being the only source of percent by weight data. Juvenile piscivorous flatfish diets rely again on Yang (1994), who analyzed diets from 201 juvenile arrowtooth flounder and 91 juvenile halibut from the Gulf of Alaska.

### **Large Demersal Predators (FVS)**

Species included: lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), red Irish lord (*Hemilepidotus hemilepidotus*), and brown Irish lord (*H. spinosus*).

This group consists mostly of lingcod and cabezon. Both have been assessed since EMOCC was developed and we updated the biomass estimates and life history parameters for this group accordingly. Lingcod were estimated to be 34,017 mt (north and south populations combined) and the northern stock of cabezon (north of Point Conception) was estimated to be 727 mt (Cope and Punt 2005, Jagielo and Wallace 2005). Lingcod diets were not widely available from the EMOCC regions, and cabezon diets have not been reported quantitatively to date. Wakefield (1984) collected four adult stomachs off Newport. A larger sample size was available from just north of the border of the model. Beaudreau and Essington (2007) collected 160 adults and 400 juveniles from the San Juan Islands in Washington.

### **Salmon (FVB)**

Species included: Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*).

Salmon biomass and life history parameters were from Brand et al. (2007). Because Chinook salmon contribute 95% of the biomass of this group, only their diets were used to represent this group. For adults, Brodeur et al. (1987) collected 86 stomachs off Washington and Oregon from 1979 to 1984, Silliman (1941) analyzed 818 stomachs from 1939 off Washington, and Merkel (1957) collected 1,004 near San Francisco. For juveniles, Brodeur and Percy

(1990) collected 795 stomachs off Oregon and Washington, Landingham et al. (1998) collected 38 from British Columbia waters, and Schabetsberger et al. (2003) collected 249 from the Columbia River plume.

### **Large Pelagic Predators (FVT)**

Species included: albacore tuna (*Thunnus alalunga*).

Albacore tuna biomass and life history parameters are from Brand et al. (2007). All available albacore tuna diets were from relatively small individuals, which would be immature when compared with our calculated size at maturity (90 cm). Most of the data were older, collected in the 1950s and 1960s. Iverson (1971) collected 905 stomachs from 1968 and 1969 from central California and south. McHugh (1952) looked at 107 stomachs, mostly from the most southern area covered by EMOCC, as well as south of Point Conception. In the early 1980s, Bernard et al. (1985) examined 94 stomachs from the same region.

### **Skates and Rays (SSK)**

Species included: longnose skate (*Raja rhina*), skates (*Bathyraja* spp.), Bering (aka sandpaper) skate (*Bathyraja interrupta*), deepsea skate (*B. abyssicola*), rougtail skate (*B. trachura*), skate unidentified (Rajidae), skates (*Raja* spp.), starry skate (*R. stellulata*), Aleutian skate (*B. aleutica*), big skate (*R. binoculata*), California skate (*R. inornata*), and Pacific electric ray (*Torpedo californica*).

We maintained the skates and rays functional group and relative species weights from the coast-wide model (Brand et al. 2007). We updated the biomass estimate for this group based on a recent stock assessment for longnose skate (Gertseva and Schirripa 2007). Longnose skate make up 63% of the biomass of this group, followed by Bering skate with 13%. From 1999 to 2003 NWFSC trawl survey data, the third largest biomass contributor was unidentified skates with 11%. Therefore, for the purposes of the biomass estimate only, we assumed that unidentified skates were actually longnose and extrapolated the stock assessment estimate of 71,217 mt to represent 73% of the biomass of this group. Even so, our new group total biomass was 96,239 mt, more than 75% higher than the biomass estimate for the coast-wide model (Brand et al. 2007). We updated life history parameters for longnose skate from the assessment (Gertseva and Schirripa 2007), which affected the group-wide parameters. Skate and ray diets were not available by life stage, and longnose, Bering, and big skates were used to represent this group's diet. Longnose skate stomachs were available from central California (n = 563, Robinson et al. 2007) and Newport, Oregon (n = 4, Wakefield 1984). Bering (1) and big skate (98) stomachs were all from Wakefield (1984), caught off Newport.

### **Small Demersal Sharks (SHB)**

Species included: catshark (*Apristurus* spp.), brown cat shark (*A. brunneus*), spotted ratfish (*Hydrolagus colliei*), spiny dogfish (*Squalus acanthias*), filetail cat shark (*Parmaturus xaniurus*), longnose cat shark (*A. kampae*), cat shark unidentified (Scyliorhinidae), and swell shark (*Cephaloscyllium ventriosum*).

Small demersal sharks primarily include dogfish, catsharks, and ratfish. Biomass and life history parameters are from Brand et al. (2007), although we were able to update relative weights of species from 1999 to 2006 NWFSC trawl survey data. Dogfish stomachs made up the majority of the diet data. For adults, 185 dogfish from Washington (Bonham 1954) and 28 ratfish from Oregon (Wakefield 1984) determined diet. Juvenile data were only available for dogfish. Brodeur et al. (1987) examined 113 stomachs from Washington and Oregon. Since this was the only data source within the model bounds, we also included 3,396 juvenile stomachs off Vancouver Island (Tanasichuck et al. 1991).

### **Large Demersal Sharks (SHD)**

Species included: Pacific sleeper shark (*Somniosus pacificus*), bluntnose sixgill shark (*Hexanchus griseus*), and broadnose sevengill shark (*Notorynchus cepedianus*).

Biomass and life history parameters for this group came from Brand et al. (2007). Sleeper shark diets made up the majority of this group's diet data, with a small contribution from sixgill shark data. All shark diets were adapted from a review of shark diets worldwide (Cortes 1999). Adult and juvenile diets were not differentiated.

### **Miscellaneous Pelagic Sharks (SHP)**

Species included: tope (aka soupfin) shark (*Galeorhinus galeus*) and gray smoothhound (*Mustelus californicus*).

The miscellaneous pelagic shark group members, biomass, and life history parameters remain unchanged from the coast-wide model (Brand et al. 2007). Tope (aka soupfin) sharks make up 88% of the biomass of this group, and were the only source of diet information. Diets were not differentiable to adult and juvenile life stages. Brodeur et al. (1987) collected 12 stomachs off Oregon and Washington from 1981 to 1984, Bonham (1949) analyzed 50 off Washington, and Ripley (1946) examined 170 off California.

## **Seabirds**

Most of the life history data for seabirds was obtained from Birds of North America Online (<http://bna.birds.cornell.edu/bna>), a database maintained by the Cornell Lab of Ornithology. This database provides the most comprehensive revision of information for any given species, including but not limited to conservation, management, feeding, migration, breeding, distribution, and demography. Abundances were taken from colony counts in central California as reported in the Biogeography of Central California Project and updated by the Point Reyes Bird Observatory.<sup>3</sup> Weights of individual species were taken from Hunt et al. (2000), which lists individual weights by species in the subarctic North Pacific.

Initial numbers and length-weight relationships for each seabird species were developed based on an age-structure model using surrogate survivorship curves scaled to each species life span (Barlow and Boveng 1991). Numbers-at-age and individual species life history parameters

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<sup>3</sup> J. Thayer, Point Reyes Bird Observatory, Petaluma, CA. Pers. commun., October 2007.

(maturity, incubation, male/female mass, and lengths) were added and weighted by species abundance to obtain values representative of the functional group. Length-to-weight relationships were estimated using size of birds for total length (as opposed to wingspan in the methodology used for the EMOCC). By the time most juvenile seabirds leave the colony, their weight is the same as or higher than that of adults, hence growth from juvenile to adults is almost negligible.

### **Planktivorous Seabirds (SB)**

Species included: Leach's storm petrel (*Oceanodroma leucorhoa*), Cassin's auklet (*Ptychoramphus aleuticus*), and red-necked phalarope (*Phalaropus lobatus*).

Abundance data and life history parameters for Cassin's auklet were taken from Manuwal and Thoresen (1993). Phalarope abundance was derived from Page et al. (1999) and Leach's storm petrel abundance was taken from Point Reyes Bird Observatory records.<sup>4</sup> Because Cassin's auklets comprise 93% of the biomass for this group, life history parameters were based on those described by Manuwal and Thoresen (1993).

### **Piscivorous Seabirds (SP)**

Species included: Brandt's cormorant (*Phalacrocorax penicillatus*), pelagic cormorant (*P. pelagicus*), double-crested cormorant (*P. auritus*), western gull (*Larus occidentalis*), common murre (*Uria aalge*), pigeon guillemot (*Cepphus columba*), Xantus' murrelet (*Synthliboramphus hypoleucus*), marbled murrelet (*Brachyramphus marmoratus*), rhinoceros auklet (*Cerorhinca monocerata*), tufted puffin (*Fratercula cirrhata*), Caspian tern (*Hydroprogne caspia*), and brown pelican (*Pelecanus occidentalis*).

Piscivorous seabird abundances within California were derived from Point Reyes Bird Observatory records<sup>5</sup> for all species except marbled murrelet. Marbled murrelet abundances for the entire model region were taken from Huff et al. (2006). Oregon and Washington abundances for all other species were taken from Parrish and Loggerwell (2000).

The diving seabird group's diet was largely informed by two studies: a review of bird and mammal diets in the subarctic North Pacific (Hunt et al. 2000) and a broad survey of bird diets in central California (Sydeman et al. 1997). For cormorant, pigeon guillemot, and rhinoceros auklet, the review and the empirical study were given equal weights. Murrelet and tufted puffin diets were only available from the review. Common murre make up the largest proportion of biomass of this group and multiple empirical studies exist on their diets. Sydeman et al. (1997) described 1,985 chick-feeding events and Ainley et al. (1996) observed 554 feeding bouts, both in central California. We supplemented common murre data from these central California studies with data from Hunt et al. (2000), which included more northern populations.

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<sup>4</sup> See footnote 3

<sup>5</sup> See footnote 3.

## Migrating Seabirds (FVO)

Species included: black-footed albatross (*Phoebastria nigripes*), Laysan albatross (*P. immutabilis*), black-legged kittiwake (*Rissa tridactyla*), short-tailed shearwater (*Puffinus tenuirostris*), sooty shearwater (*P. griseus*), and northern fulmar (*Fulmarus glacialis*).

Abundance data for the migrating seabird group were derived from Parrish and Loggerwell (2001). Life history parameters for black-footed and Laysan albatrosses were taken from Whittow (1993a, 1993b), data for black-legged kittiwake were obtained from Baird (1994), and data for northern fulmar were taken from Hatch and Nettleship (1998). Reproductive and migration information for sooty and short-tailed shearwaters was not available.

Diets for migratory birds were based on sooty shearwaters, with no data for differentiating adult and juvenile diets. Hunt et al. (2000) conducted a review of abundance and bird and mammal diets in the subarctic North Pacific, and broke down the area into regions, one of which approximates the area covered by the California Current. Wiens and Scott (1975) also estimated energetic fluxes to sooty shearwaters in Oregon. Because neither data source had a sample size associated with it, estimates from the two sources were averaged to come up with the final diet for this group.

## Marine Mammals

The most recent population estimates of cetacean populations come from Barlow and Forney (2007), who estimated species stocks along the entire U.S. West Coast. These estimates are unique in that they included the entire exclusive economic zone, as opposed to a fixed distance from shore. Barlow and Forney estimated abundances for four regions: south, central, and northern California, and Washington/Oregon. These regions were overlaid on a grid for central California and region estimates were allocated proportionally to the model. The region of southern California fell outside the boundaries of our model and hence was not considered. Barlow and Forney are working on increasing the spatial resolution of the abundance estimates and will be able to provide inshore to offshore distribution of the cetacean stocks. In the meantime, all inshore to offshore distribution was considered to be uniform, per recommendation.<sup>6</sup>

Initial numbers and length-weight relationships for each cetacean species were developed based on an age-structure model using surrogate survivorship curves scaled to each species life span (Barlow and Boveng 1991). Numbers at age and individual species life history parameters (maturity, gestation period, male/female mass, and lengths) were added and weighted by species biomass to obtain values representative of the functional group. Body mass and life span estimates were obtained from Trites and Pauly (1998). Recruits per adult were the product of calves per female, pregnancy rates, sex ratio, and pregnancy interval. We based most marine mammal diets on data from a review on diet composition and trophic levels of marine mammals (Pauly et al. 1998).

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<sup>6</sup> J. Barlow, Southwest Fisheries Science Center, La Jolla, CA. Pers. commun., 29 October 2007.

### **Toothed Whales (WHT)**

Species included: resident orca (aka killer whale, *Orcinus orca*), pygmy sperm whale (*Kogia breviceps*), sperm whale (*Physeter macrocephalus*), Baird's beaked whale (*Berardius bairdii*), Cuvier's beaked whale (*Ziphius cavirostris*), mesoplodon beaked whales, Blainville's beaked whale (*Mesopoldon densirostris*), Hector's beaked whale, (*M. hectori*), Stejneger's beaked whale (*M. stejnegeri*), ginkgo-toothed beaked whale (*M. ginkgodens*), and Hubbs' beaked whale (*M. carlhubbsi*).

Abundance data for the toothed whale group were derived from Barlow and Forney (2007) for all species except resident orca. Orca abundance was taken from NMFS stock assessment (Carretta et al. 2006). Life history parameters, body masses, and life span estimates were taken from Trites and Pauly (1998) and Perrin et al. (2002). Toothed whale diets consisted of contributions from sperm whales, Baird's beaked and Cuvier's beaked whales, and resident orcas. All diet data came from a review of marine mammal diets by Pauly et al. (1998).

### **Baleen Whales (WHB)**

Species included: gray whale (*Eschrichtius robustus*), humpback whale (*Megaptera novaeangliae*), blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*), sei whale (*B. borealis*), and minke whale (*B. acutorostrata*).

Baleen whale abundance estimates were obtained from Barlow and Forney (2007) for all except gray whales, for which we obtained estimates from Angliss and Outlaw (2008). Life history parameters, body masses, and life span estimates were taken from Trites and Pauly (1998) and Perrin et al. (2002). Diet data were available for blue, humpback, gray, and fin whales (Pauly et al. 1998).

### **Transient Orca (REP)**

Species included: *Orcinus orca*.

Transient orca abundance estimates were obtained from Barlow and Forney (2007). Life history parameters, body masses, and life span estimates were taken from Trites and Pauly (1998) and Perrin et al. (2002). Transient orca feeding has not been observed enough for empirical quantitative diet information to be available. Most ecosystem models have aggregated transient and resident orcas. To estimate transient diets, we adapted diets from a marine mammal diet review (Pauly et al. 1998).

### **Small Cetaceans (WHS)**

Species included: Dall's porpoise (*Phocoenoides dalli*), harbor porpoise (*Phocoena phocoena*), short-beaked common dolphin (*Delphinus delphis*), long-beaked common dolphin (*D. capensis*), bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), short-finned pilot whale (*Globicephala macrorhynchus*), Risso's dolphin (*Grampus griseus*), northern right whale dolphin (*Lissodelphis borealis*), and Pacific white-sided dolphin (*Lagenorhynchus obliquidens*).

Small cetacean abundance estimates were taken from Barlow and Forney (2007) for all species except harbor porpoise. Harbor porpoise estimates came from Caretta and Forney (2004). Life history parameters, body masses, and life span estimates were taken from Trites and Pauly (1998) and Perrin et al. (2002). Diet compositions were available from Pauly et al. (1998) for Pacific white-sided dolphins, bottlenose dolphins, northern right whale dolphins, harbor porpoises, and Dall's porpoises.

### **Pinnipeds (PIN)**

Species included: California sea lion (*Zalophus californianus*), Steller sea lion (*Eumetopias jubatus*), harbor seal (*Phoca vitulina*), northern elephant seal (*Mirounga angustirostris*), and northern fur seal (*Callorhinus ursinus*).

Abundances for all pinniped species except California sea lions were derived from stock assessments (Carretta et al. 2007). California sea lion abundance was estimated from Lowry and Forney (2005). Life history parameters, body masses, and life span estimates were taken from Trites and Pauly (1998) and Perrin et al. (2002).

Diets of California sea lion, fur seal, Steller sea lion, and elephant seal were available for this group. Adult California sea lion diets were sampled from three beached individuals in California (Fiscus and Baines 1966). Adult northern fur seals were sampled from the California coast from 1958 to 1966 (n = 2,566, Antonelis and Fiscus 1980). Perez and Biggs (1986) also described the diets of 3,798 individuals from Washington to California. Fiscus and Baines (1966) examined six northern fur seals from California and three Steller sea lions: two from California and one from Oregon. Clemens and Wilby (1933) sampled 25 juvenile fur seals off Vancouver Island, Sinclair (1994) looked at 20 juvenile elephant seals from the Channel Islands, and Fiscus and Baines (1966) examined 1 juvenile Steller sea lion and 3 juvenile California sea lions from California.

### **Sea otter (WDG)**

Species included: *Enhydra lutris*.

Sea otter abundance and life history parameters were taken from Lance et al. (2004). We used a surrogate survivorship curve (Barlow and Boveng 1991) to estimate initial numbers at age; this model rescales the survivorship to the estimated life span of sea otters. The method of data collection for sea otter diets is visual identification of prey items that animals retrieve on each dive. As such, sample size is the number of successful dives observed and diet is represented by percent frequency of prey types. Van Blaricom and Estes (1988) observed 1,025 successful dives from central California and the Channel Islands. Twenty years prior, Hall and Schaller (1964) observed 455 dives, McLean (1962) observed 5,882 dives, and Ebert (1968) observed 243 dives off central California. Adults and juveniles were not differentiated in any of these studies; however, since juveniles are thought to learn feeding preferences directly from their mothers (Estes et al. 2003), it can reasonably be assumed that adults and juveniles have similar diets.





## Appendix B: Sources for Catch and Landing Data

As described in the Model Performance section of this technical memorandum, our third phase of calibration tested the model's ability to replicate historical biomass trends under historical fishing pressure. Both biomass trends and historical catches or landings were derived from stock assessment projections or inputs. These single species stock assessments are the core scientific tool that the Pacific Fishery Management Council uses to estimate target species' abundance and to set quotas and closed areas. The majority of the stock assessments are based on Stock Synthesis (Methot 2000, Methot 2009), which is an age-structured estimation model following the methods of Fournier and Archibald (1982). Catch data for these assessments come from the PacFIN landings database (for years after 1981), onboard observers (e.g., Bellman et al. 2008), and historical sources for years prior to 1981 (e.g., PSMFC 1981 and the National Marine Fisheries Service Annual Commercial Landings Database, online at [http://www.st.nmfs.gov/st1/commercial/landings/annual\\_landings.html](http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html)).

We compiled historical fishing data (annual catch or landings) for 19 functional groups for the period from 1950 to 2007 (Table 8 and Table 9). For groundfish species, we took catch or landings data directly from single species stock assessments. For pelagic species (small planktivores, large planktivores, and market squid [*Loligo opalescens*]) we took landings data from the PacFIN database reports (online at [http://pacfin.psmfc.org/pacfin\\_pub/pfmc\\_pub/coastal\\_pelag\\_pfmc.php](http://pacfin.psmfc.org/pacfin_pub/pfmc_pub/coastal_pelag_pfmc.php)), available for years after 1981. In cases where only landings data (not total catch) were available from groundfish stock assessments, we incorporated discard estimates from the West Coast Groundfish Observer Program (Bellman et al. 2008). For groups that migrated out of the Atlantis model region (e.g., hake, Table 7), we concentrated the catches to occur only when the group was within the model domain; otherwise, catches were imposed evenly throughout the year. We applied catches beginning in 1950. For species that lacked catches in the earlier years, we assumed an exponential increase in catches from 1900 to the first year that catch or landings data were available (typically the late 1950s or 1960s). For some species, the stock assessments reported catches only through 2004 or 2006; in these cases we repeated the last available year's catch through 2007.

We had biomass time series from stock assessments for 18 of the 19 functional groups for which catch and landings data were available (all but the cephalopod group). In cases where only a fraction of species within the functional group were assessed, we scaled the assessed biomass up to the functional group level, multiplying by the ratio of total biomass to assessed biomass.

The stock assessments used for both catch and biomass time series included the following:

- Small flatfish: English sole (*Parophrys vetulus*) (Stewart 2008b) and starry flounder (*Platichthys stellatus*) (Ralston 2006).
- Sablefish (*Anoplopoma fimbria*) (Schirripa 2008).
- Shortbelly rockfish (*Sebastes jordani*) (Field et al. 2008).
- Canary rockfish (*S. pinniger*) (Stewart 2008a).
- Midwater rockfish: Pacific ocean perch (*S. alutus*) (Hamel 2008b), widow rockfish (*S. entomelas*) (He et al. 2008), yellowtail rockfish (*S. flavidus*) (Wallace and Lai 2006), bocaccio (*S. paucispinis*) (MacCall 2008), chilipepper rockfish (*S. goodie*) (Field 2008), and vermilion rockfish (*S. miniatus*) (MacCall 2005).
- Large demersal predators: cabezon (*Scorpaenichthys marmoratus*) (Cope and Punt 2006) and lingcod (*Ophiodon elongatus*) (Jagiello and Wallace 2006).
- Large flatfish: petrale sole (*Eopsetta jordani*) (Lai et al. 2006), arrowtooth flounder (*Atheresthes stomias*) (Kaplan and Helser 2008), and Pacific halibut (*Hippoglossus stenolepis*) (Hare and Clark 2008, Area 2a only).
- Deep large rockfish: darkblotched rockfish (*Sebastes crameri*) (Hamel 2008a), blackgill rockfish (*S. melanostomus*) (Helser 2005, 2006), and shortspine thornyhead (*Sebastolobus alascanus*) (Hamel 2006).
- Shallow small rockfish: gopher rockfish (*Sebastes carnatus*) (Key et al. 2005).
- Dover sole: (*Microstomus pacificus*) (Sampson 2006).
- Deep small rockfish: longspine thornyhead (*Sebastolobus altivelis*) (Fay 2006).
- Shallow large rockfish: black rockfish (*Sebastes melanops*) (Sampson 2008, Wallace et al. 2008) and kelp greenling (*Hexagrammos decagrammus*) (Cope and MacCall 2006).
- Yelloweye rockfish (*Sebastes ruberrimus*) and cowcod (*S. levis*): yelloweye rockfish (Wallace et al. 2006).
- Pacific hake (*Merluccius productus*): (Helser et al. 2008, U.S. catches only).
- Large pelagic predators: albacore tuna (*Thunnus alalunga*), scaled by ratio of the stock in the model region (ISCT 2008).
- Skates and rays: longnose skate (*Raja rhina*) (Gertseva and Schirripa 2008).

PacFIN catch data for 1981–2008 were used for the following groups:

- Small planktivorous fish: northern anchovy (*Engraulis mordax*) and Pacific sardine (*Sardinops sagax*).
- Large planktivorous fish: Pacific mackerel (*Scomber japonicus*) and jack mackerel (*Trachurus symmetricus*).
- Market squid.

We obtained biomass trends for Pacific sardines from Hill et al. (2008) and biomass trends for Pacific mackerel from Dorval et al. (2008).

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