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AN ATLANTIS ECOSYSTEM MODEL FOR THE GULF OF MEXICO WITH UPDATES TO 2023

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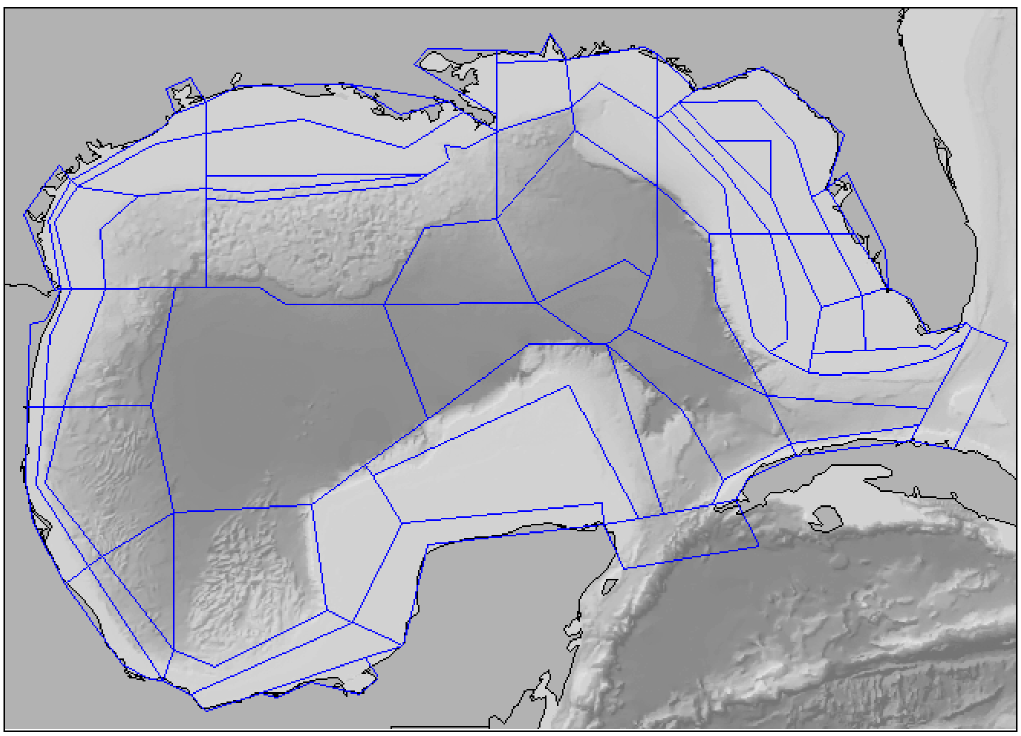

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NOTICE

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Table of Contents

Acknowledgments

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Executive Summary

The Gulf of Mexico (GOM) Atlantis model was developed to support ecosystem-based fisheries management (EBFM) in the Gulf of Mexico. This technical memorandum provides an overview of the major assumptions, parameterization, and performance of the GOM Atlantis model. Major updates and innovations reported here reflect recent efforts to improve the representation of nearshore habitat (particularly seagrass), predator-prey dynamics, larval dispersal dynamics, and fisheries dynamics. Efforts to improve the representation of nearshore habitat include: 1) migrating GOM Atlantis to V. 6665 and moving from the Windows development branch to the Linux trunk; 2) implementing a novel pseudo-age-structured representation of seagrass to better represent herbivory and seagrass habitat dependence; 3) parameterizing fish habitat affinities for seagrass habitat using new statistical analysis of fisheries-independent monitoring fish community data; and 4) revising spatial distributions of group biomasses using statistical species distribution models. Recent revisions to predator-prey dynamics resulted in the development of an updated food web. We used a statistical method to characterize the error distributions around diet composition for some pelagic diet linkages. Larval dispersal dynamics were added to the GOM Atlantis model based on a Lagrangian particle tracking model using outputs from the West Florida Coastal Ocean Model. Fisheries dynamics were updated in several aspects, with the major changes including: 1) refining the structure of the fleets; 2) refining the areas of accessibility for U.S. fleets; 3) incorporating discarding to fleets associated with the U.S. shrimp trawl fishery and U.S. recreational fishing; and 4) updating fishing mortalities for groups caught by U.S. fleets. We present feedback on the GOM Atlantis model from an internal NOAA review panel consisting of panelists from the Southeast Fisheries Science Center (SEFSC) and the Office of Science and Technology (OST). Participants were led through a series of five model review workshops over the course of a year. Lastly, we present model performance criteria (spanning simulated population dynamics, productivity, life history parameters, and ecology) to diagnose the performance of the revised GOM Atlantis model. Shrimp were highlighted to showcase the capabilities of Atlantis in incorporating fisheries and environmental effects. The material presented in this technical memorandum was included in the model technical documentation presented to a review panel by the Center of Independent Experts (CIE) on March 28–30, 2023.

List of Figures

List of Tables

Abbreviations and Acronyms

Acronym	Definition
AMSEAS	American Seas Model
CIE	Center of Independent Experts
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CPUE	Catch-per-unit-effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DWH	Deepwater Horizon
EEZ	Exclusive Economic Zone
EwE	Ecopath with Ecosim
F	Fishing mortality (-ln(1-H))
FIM	Fisheries-Independent Monitoring
F_{MSY}	Fishing mortality which produces maximum sustainable yield
FLRACEP	Florida RESTORE Act Centers of Excellence Program
FWC	Florida Fish and Wildlife Conservation Commission
FWRI	Fish and Wildlife Research Institute
GAM	Generalized Additive Models
GOM	Gulf of Mexico
GLM	Generalized Linear Models
GLMM	Generalized Linear Mixed Models
GoMexSi	Gulf of Mexico Species Interactions Database
GOMRI	Gulf of Mexico Research Initiative
H	Harvest rate (catch/biomass)
IBM	Individual based model
IEA	Integrated Ecosystem Assessment
MRIP	Marine Recreational Information Program
MSY	Maximum sustained yield
NCOM	Navy Coastal Ocean Model
NH	Ammonia
NMFS	National Marine Fisheries Service
NO	Nitrate
NOAA	National Oceanic and Atmospheric Administration
PSAT	Pop-up satellite archival tag
RESTORE Act	Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act
SEAMAP	Southeast Area Monitoring and Assessment Program
SEDAR	SouthEast Data, Assessment, and Review
SEFSC	Southeast Fisheries Science Center
SIMMP	Seagrass Integrated Mapping and Monitoring Program
t	Metric tons
USF	University of South Florida
UM	University of Miami
WFCOM	West Florida Coastal Ocean Model
WFS	West Florida Shelf

Introduction

The Gulf of Mexico (GOM) Atlantis model was developed to support ecosystem-based fisheries management (EBFM) in the Gulf of Mexico. The model was first described in a 2015 NOAA Technical Memorandum (Ainsworth et al. 2015). This technical memorandum updates and supersedes that effort to provide an overview of the major assumptions, parameterization, and performance of the GOM Atlantis model. We refer the reader back to Ainsworth et al. (2015) for still useful descriptions of functional group species compositions (Section Functional Group Design, p. 18 and Table A.1, p. 71) and a description of the ecological setting and map design elements (Section Map Design, p. 15–16).

Major updates and innovations reported here reflect efforts to improve the representation of nearshore habitat, predator-prey dynamics, larval dispersal dynamics, and fisheries dynamics. Recent efforts to improve the representation of nearshore habitat, particularly seagrass, resulted in model updates supported by the Florida RESTORE Act Centers of Excellence Program (FLRACEP). These include: 1) migrating GOM Atlantis to V. 6665 and moving from the Windows development branch to the Linux trunk; 2) implementing a novel pseudo-age-structured representation of seagrass to better represent herbivory and seagrass habitat dependence; 3) parameterizing fish habitat affinities for seagrass habitat using new statistical analysis of fisheries-independent monitoring fish community data; and 4) revising spatial distributions of group biomasses using statistical species distribution models. Recent revisions to predator-prey dynamics resulted in the development of an updated food web. We used a statistical method to characterize the error distributions around diet composition estimates to support probabilistic studies (Morzaria-Luna et al. 2018). Larval dispersal dynamics were added to the GOM Atlantis model based on a Lagrangian particle tracking model using outputs from the West Florida Coastal Ocean Model (WFCOM) outputs (Vasbinder et al. 2023). This document also summarizes recent CIMAS-funded efforts (Mar. 2021–present) to improve the representation of fisheries. Major changes include: 1) refining the structure of the fleets; 2) refining the areas of accessibility for U.S. fleets; 3) incorporating discarding from fleets associated with the U.S. shrimp trawl fishery and U.S. recreational fishing; and 4) updating fishing mortalities for groups caught by U.S. fleets.

This technical memorandum includes feedback from an internal NOAA review panel with contributions from the Southeast Fisheries Science Center (SEFSC) and the Office of Science and Technology (OST). Participants were led through a series of five model review workshops over the course of a year. The internal panel included Lewis Coggins, Mandy Karnauskas, Howard Townsend, Jennifer Leo, Matthew Nuttall, Skyler Sagarese, Steve Giordano, Molly Stevens, and Kevin Craig. The internal panel provided input on model parameterization and calibration, as well as diagnostic outputs. With the internal panel's direction, updates were made on functional group abundance, catch totals, and fisheries configurations as described throughout this document. Part of this CIMAS-funded project involves an external review by the Center of Independent Experts (CIE) with the goal of evaluating model status. Shrimp were chosen as a good candidate to showcase the capabilities of Atlantis in incorporating fisheries and environmental effects. This technical memorandum was developed to help facilitate the CIE review and showcase Atlantis's updated capabilities in combining information relative to shrimp population dynamics and fisheries. The CIE review was held March 28–30, 2023, at the Florida Fish and Wildlife Research Institute in St. Petersburg, FL.

Applications of the GOM Atlantis model have investigated implications of larval connectivity (Drexler 2018, Vasbinder 2020), management strategy evaluation (Masi et al. 2018), ecosystem indicators (Masi et al. 2017), and climate change (Olsen et al. 2018). Other applications of the GOM Atlantis model include oil pollution (Dornberger et al. 2023, Morzaria-Luna et al. 2022, Ainsworth et al. 2018) and point-source nutrient introduction (Dornberger et al. 2023). Numerous NOAA programs have provided funding for model development since 2011, including Sea Grant, Marine Fisheries Initiative Program (MARFIN), Integrated Ecosystem Assessment (IEA), NOAA's Quantitative Ecology and Socioeconomics Training (QUEST) Program, Cooperative Institute for Marine and Atmospheric Studies (CIMAS), and the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE). These efforts helped to develop spatial biomass data, diet data, and hydrodynamic data for Atlantis. NOAA has also invested in visualization tools for GOM Atlantis (Virtual Ecosystem Scenario Viewer, McDonald et al. 2022) and provided significant in-kind support. For example, NOAA's Integrated Ecosystem Assessment (IEA) program provided hydrodynamic data for Atlantis through the Geophysical Fluid Dynamics Laboratory. Additional funding for model development has been provided by the Gulf of Mexico Research Initiative (GOMRI). GOMRI administered research funds from BP following the Deepwater Horizon (DWH) oil spill. Atlantis model development was supported by the Center for the Integrated Modeling and the Analysis of Gulf Ecosystem (C-IMAGE) and Deep-C Consortia. These were both multi-institute consortia with a wide range of scientific products. This work highlighted the usefulness of GOM Atlantis as a synthesis tool. Innovations included coupling GOM Atlantis with an oil fate model (Ainsworth et al. 2018, Berenshtein et al. 2020), coupling GOM Atlantis with an economics model (Court et al. 2020), use of toxicological relationships (Dornberger et al. 2016), uptake-depuration dynamics (Ainsworth et al. 2018, Dornberger et al. 2020), and modeling associated river and nutrient changes (Dornberger et al. 2022). Through the DWH work, new functionality was added to Atlantis through collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) that allows spatial-temporal forcing of mortality, growth and reproduction rates.

The Atlantis Approach

Atlantis is a three-dimensional, spatially explicit deterministic model of marine ecosystems and fisheries. The C++ code base is developed, maintained, and shared by CSIRO Australia (Fulton et al. 2004; Fulton et al. 2011). Documentation and user support are available from a User Manual and other material on the Atlantis website (https://research.csiro.au/atlantis/, Audzijonyte et al. 2017a,b) and from a recent summary publication (Audzijonyte et al. 2019). Link et al. (2011) review major process equations.

Atlantis straddles the worlds of low- and high-trophic level ecology. It offers an ideal testbed for hypothesis testing and simulations at the intersection of fisheries management and the environment (Fulton et al. 2004). It is built upon a nutrient-phytoplankton-zooplankton-detritus (NPZD) model sharing heritage with the European Regional Seas Model (ERSEM). Growth rates of primary producers are affected by nutrient, light, and space limitations. In the GOM, light penetration affects coastal productivity and is important to model in applications involving algal blooms and river outflow conditions. Decomposition and nutrient uptake are modeled using ammonia and nitrate tracers. Thus, primary producer growth is limited by the liberation of nutrients. In the GOM, this can be relevant to the modeling of harmful algal blooms and point-source nutrient introductions from the Mississippi River (Dornberger et al. 2023). A multispecies model governs interactions between predator and prey. Interaction rates can be made to consider saturation effects or prey switching effects, or they can become limited due to overlap and movement in 3D space. Availability is the main tuning parameter affecting the feeding functional response. Fisheries are explicitly defined in the polygons, depth layers, and habitats that they operate in, as well as what species they catch (retain) and what species are caught as bycatch (dead discards).

Vertebrate functional groups in the GOM Atlantis model are age-structured. Atlantis tracks abundance and weight per individual in structural and reserve nitrogen pools (mg rN/individual) (Fulton et al. 2004). Structural nitrogen represents hard body parts, while reserve nitrogen represents somatic and gonadal soft body tissue. These tissue types respond differently to growth and starvation. Atlantis represents invertebrates and primary producers as homogenous biomass pools on a per-volume basis for pelagic invertebrates and infaunal invertebrates (mg N/m^3) and a per-area basis for epibenthic groups (mg N/m^2).

The Gulf of Mexico Atlantis model

The Gulf of Mexico Atlantis model (GOM Atlantis) has 91 functional groups: 61 are age-structured while 30 are simpler aggregated biomass pools. Groups include reef fish (11 groups), demersal fish (12), pelagic fish (15), forage fish (4), elasmobranchs (6), shrimp (4), seabirds (2), mammals (4), and sea turtles (3). Biomass pool groups include commercial benthos (3), structural species (4), macrobenthos (3), filter feeders (3), primary producers (8), pelagic invertebrates (4), and nutrient cyclers (4) (Table A.1). Charismatic species include three sea turtle species: green (TUR), Kemp's ridley (KMP), and loggerhead (LOG), four marine mammal groups: dolphins (DOL), West Indian manatees (MAN), Odontoceti (DDO), and Mysticeti (MYS) and two seabird groups: diving (DBR) and surface-feeding birds (SBR). All 61 age-structured groups use 10 age classes. The stanzas are equally spaced, each corresponding to one tenth of the maximum age for the group. There is no plus group. Individuals terminate after the last age class. Table A.3 in Ainsworth et al. (2015) provides life history parameters used to initialize the age structure.

There are four abiotic habitat types in Atlantis and five biogenic habitat types, which are associated with habitat forming functional groups. The abiotic habitats are rock, mud, sand and canyon. Canyon is used to describe continental slope areas of high relief. Rock includes all hard bottom habitat except coral reefs. Coral reefs are handled as a biogenic habitat based on the coral group (COR). The other biogenic habitats are oysters (OYS), bivalves (BIV), seagrass (GRS), and macroalgae (ALG). Habitats are described by a coverage valve for each polygon. Biogenic habitat coverage scales with local biomass. Age structured groups distinguish between these nine habitat types for the purposes of calculating recruitment and food availability (Audzijonyte et al. 2017a). Only the feeding rate is affected for non-age structured groups. Atlantis uses a two-parameter model to describe affinity for each physical and biogenic habitat type. Spatial recruitment patterns may be further affected by temperature, pH, salinity, and larval dispersal dynamics.

The GOM Atlantis model uses 66 polygons (Fig. 1). The first and last polygons (0 and 65) correspond to the Yucatan Strait and Florida Strait, which are both (non-dynamic) boundary boxes. Up to 6 water column layers are used in the deepest polygons: 0 – 10 m, 10 – 20 m, 20 – 50 m, 50 – 200 m, 200 – 2000 m, 2000 – 4000 m, and a sediment layer. The 200 m isobath is significant on the West Florida Shelf (WFS) as it reflects the approximate extent of the Loop Current interaction with the WFS. Major features such as high rugosity and sediment types are also represented. Hard bottom reefs and corals that are important to offshore fish production are represented in the Florida Keys National Marine Sanctuary (polygon 28), the Flower Garden Banks National Marine Sanctuary (polygons 43 and 56), the Florida Middle Grounds (polygon 42) and in stands of coral around Mexico and Cuba (polygons 44, 48 and 49). Estuarine polygons correspond to the National Estuary Program locations (polygons 19, 52, 53, 54, and 55). The exclusive economic zones of the United States, Mexico, and Cuba are delineated. Sediment type (sand, mud, and hard bottom) and biogenic habitats (corals, oysters, seagrass, and epiphytes) were estimated based on substrate maps from the Florida Wildlife Commission and the NOAA Gulf of Mexico Data Atlas (FWC 2005, MRGIS 2014, NCEI 2023) or through statistical methods (Grüss et al. 2019).

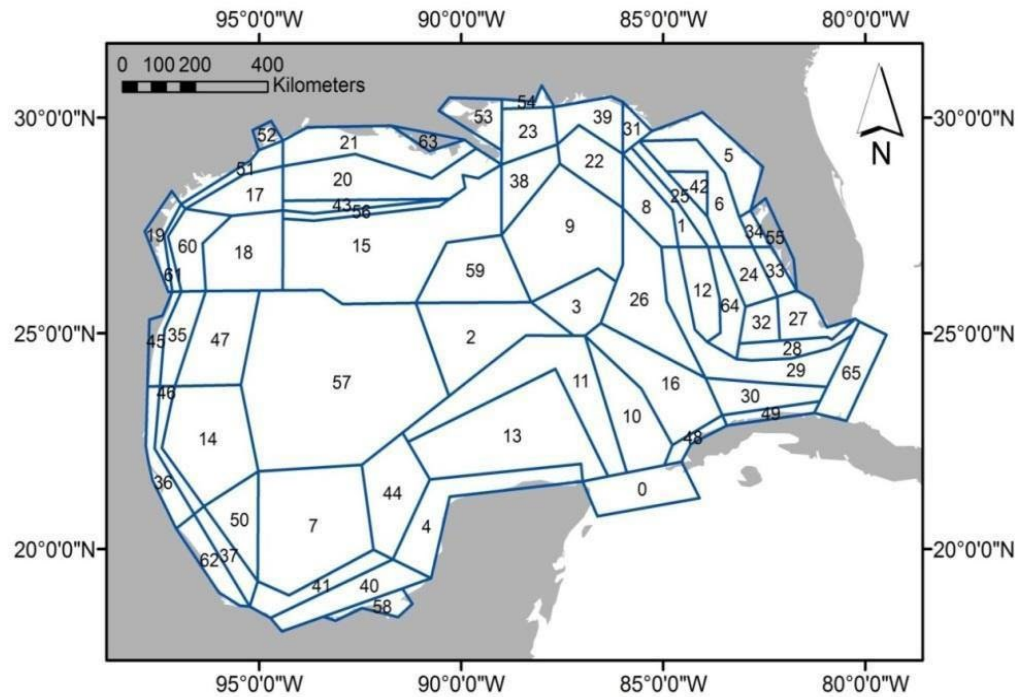


Figure 1. Polygon geometry for GOM Atlantis model.

Hydrodynamic forcing data

Atlantis uses hydrodynamic information for advection of nutrients, and optionally for larval dispersal. The larval dispersal in GOM Atlantis is controlled by the GOM Hybrid Coordinate Ocean Model (HYCOM; see section Larval Dispersal) (Vasbinder 2020, Vasbinder et al. 2023). To control the movement of nutrients, we employ the Navy Coastal Ocean Model (NCOM) American Seas model (AMSEAS). AMSEAS is based on the U.S. Naval Research Laboratory's (NRL)-developed NCOM, and has a resolution of 1/36 degree (~3 km) horizontal and 40 levels in the vertical. This resolution is sufficient to capture fronts, eddies, Loop Current intrusion onto the WFS and other regional features and so provides accurate seasonal concentration and retention forcing patterns affecting Atlantis' nutrient concentrations and primary production distributions. The AMSEAS circulation data are computed at 3-hour time steps but aggregated to daily time steps for Atlantis. Outputs from the model include ocean temperature, salinity, eastward and northward currents and elevation along with atmospheric forcing fields provided by a 15 km application of the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) model. AMSEAS, developed by the Northern Gulf Institute, assimilates quality control observations including satellite sea surface temperature and altimetry, surface and profile temperature, and salinity data using the Navy Coupled Ocean Data Assimilation (NCODA) system. Boundary conditions are applied from the Naval Oceanographic Office (NAVOCEANO) operational 1/8 degree global NCOM. At present, the GOM Atlantis model is looping a single year of oceanographic data based on 2012. Looping a single year allows us to capture seasonal variation although not interannual variation. Atlantis can also be forced by a longer time series of historical oceanographic data or by future climate-oceanographic projections, for example, using downscaled global climate model data. This is an area for future research. There are oceanographic models available for the GOM that could be coupled to Atlantis for this reason including Gulf HYCOM (Chassignet et al. 2007, Chassignet and Srinivasan 2015). In addition to flow fields for nutrient advection, Atlantis takes ocean temperature and salinity. These are used to scale biological processes through effects on the functional response (Audzijonyte et al. 2017a) and effects on movement (temperature-related movement tolerances are in Table A.2). Groups set with a wide temperature tolerance range (5-40 ºC) effectively deactivates temperature-driven movement. Initial conditions in Atlantis for temperature, salinity, and oxygen were collated from the National Oceanographic Data Center, while nitrates and oxygen data are from NOAA's Gulf of Mexico Data Atlas (NCEI 2023). These represent winter means as the model initialization state represents January 1.

Predator-Prey Dynamics

All of the availability interactions in GOM Atlantis currently use a Hollings Type 2 saturating response curve. The availability matrix of GOM Atlantis was originally published by Masi et al. (2014) and was subsequently updated by Tarnecki et al. (2016) and Morzaria-Luna et al. (2018; Fig. 2). These efforts utilized a multivariate statistical methodology based on Ainsworth et al. (2010) to describe diet composition. Atlantis is deterministic and uses a point value for the availability parameter. Nevertheless, it is useful to describe the error around diet interactions using a probability density function. For example, this allowed Morzaria-Luna et al. (2018) to make an important advancement in the treatment of uncertainty in Atlantis. Those authors resampled the availability matrix with replacement to perform a sensitivity analysis of DWH oil spill simulations. They used a combination of cloud computing, emulators, and statistical sampling to increase the effective number of samples, allowing quantification of uncertainty due to diet data quality.

This report offers a fourth revision to the diet. Updated Gulf of Mexico diet data were obtained in 2020 from the Gulf of Mexico Species Interactions (GoMexSi) database developed by Texas A&M University in Corpus Christi, Texas (Simons et al. 2013), and the FWC FIM survey (FWRI 2021). This effort incorporated an abundance of samples from the western GOM, to somewhat address a bias in the availability matrix (where older versions of the GOM Atlantis model were argued to strongly reflect FWC data taken on the WFS). This brought the total number of stomachs to 30,908 represented in the Atlantis diet matrix, a 46% increase over the previous diet dataset (Morzaria-

Luna et al. 2018, Tarnecki et al. 2016). These additional stomachs include new diet analysis for five pelagic predator functional groups caught via Gulf of Mexico longline surveys: deep-water fish (DWF), large pelagic fish (LPL), large sharks (LGS), yellowfin tuna (YTN), and swordfish (SWD).

The new diet dataset was formatted into Atlantis functional groups and prey amounts were normalized so that proportions summed to one for each stomach. Diet values were then fit to a mixed continuous-discrete distribution model. This combines a degenerate discrete binomial distribution with a continuous beta distribution. The binomial model can be thought of as describing the probability of a predator encountering a prey patch. The beta distribution is appropriate for describing proportional diet data as it is bounded by 0 and 1. This is referred to as the zero-inflated beta model and is outlined further in Ospina and Ferrari (2010). This method was employed to address the zero-inflated nature of diet data. This work is being prepared as a chapter of a Ph.D. Dissertation (Scott, R., in prep).

The zero-inflated beta models provide us an estimate of the mean contribution of prey item i to the predator's diet ($\hat{\mu}_{Zi}$). Atlantis availability parameters are bounded from zero to infinity, so larger values imply higher feeding rates. It was therefore necessary to rescale the proportional diet data into new availability parameters (A_{Zi}) that reflect the zero-inflated means. We did this by multiplying the proportional data by the sum of the availability vector across the set of prey items I as in Eq 1. This ensured that the total consumption of the predator did not change much, which would necessitate re-tuning of the model. The new diet information added 40 new trophic linkages to our model (out of approximately 4,800 existing linkages) including information for 25 different predator groups.

$$\hat{\mu}_{Zi} \cdot \sum_I A_i = A_{Zi} \qquad \text{Eq 1.}$$

In addition to the new seagrass dynamics, we made ad hoc modifications to the diet matrix to clearly emphasize the direct relationships involving seagrass grazing. An availability of 0.5, representing a strong trophic linkage in Atlantis, was applied to manatees (MAN) grazing on seagrass leaves, roots/rhizomes and epiphytes (GRS1, GRS2 and GRS3). An availability of 0.2, representing a moderate trophic linkage, was applied to the following grazers: bioeroding fish (BIO), large reef fish (LRF), differentiating between leaves, roots/rhizomes, and epiphytes. Both juvenile and adult diets of the Kemp's Ridley (KMP) and Other Turtles (TUR) groups were updated based on recent Gulf-specific diet studies. Diet estimates for KMP came from Schmid and Tucker (2018), Servis et al. (2015), and Witzell and Schmid (2005). The TUR group was parameterized to reflect green sea turtle (*Chelonia mydas*) diets in order to support an ongoing research project. The juvenile and adult diet estimates for TUR came from Howell et al. (2016) and Howell and Shaver (2021), respectively. Lastly, discussions with the Southeast Fisheries Science Center (SEFSC) GOM Atlantis Model Review Panel resulted in adjustments to the availabilities for some (focal) predator groups (i.e., brown shrimp, BSH; white shrimp, WSH; pink shrimp, PSH; gag grouper, GAG; red drum, RDR; red grouper, RGR; red snapper, RSN; seatrout, SEA; and snook, SNK). These focal predators were selected with input from the Model Review Panel as those groups expected to be heavily influenced by shrimp dynamics. These adjustments were to address realized diets compositions shifting away from parameterized diet compositions (Fig. A.1 displays the current diet compositions for these groups).

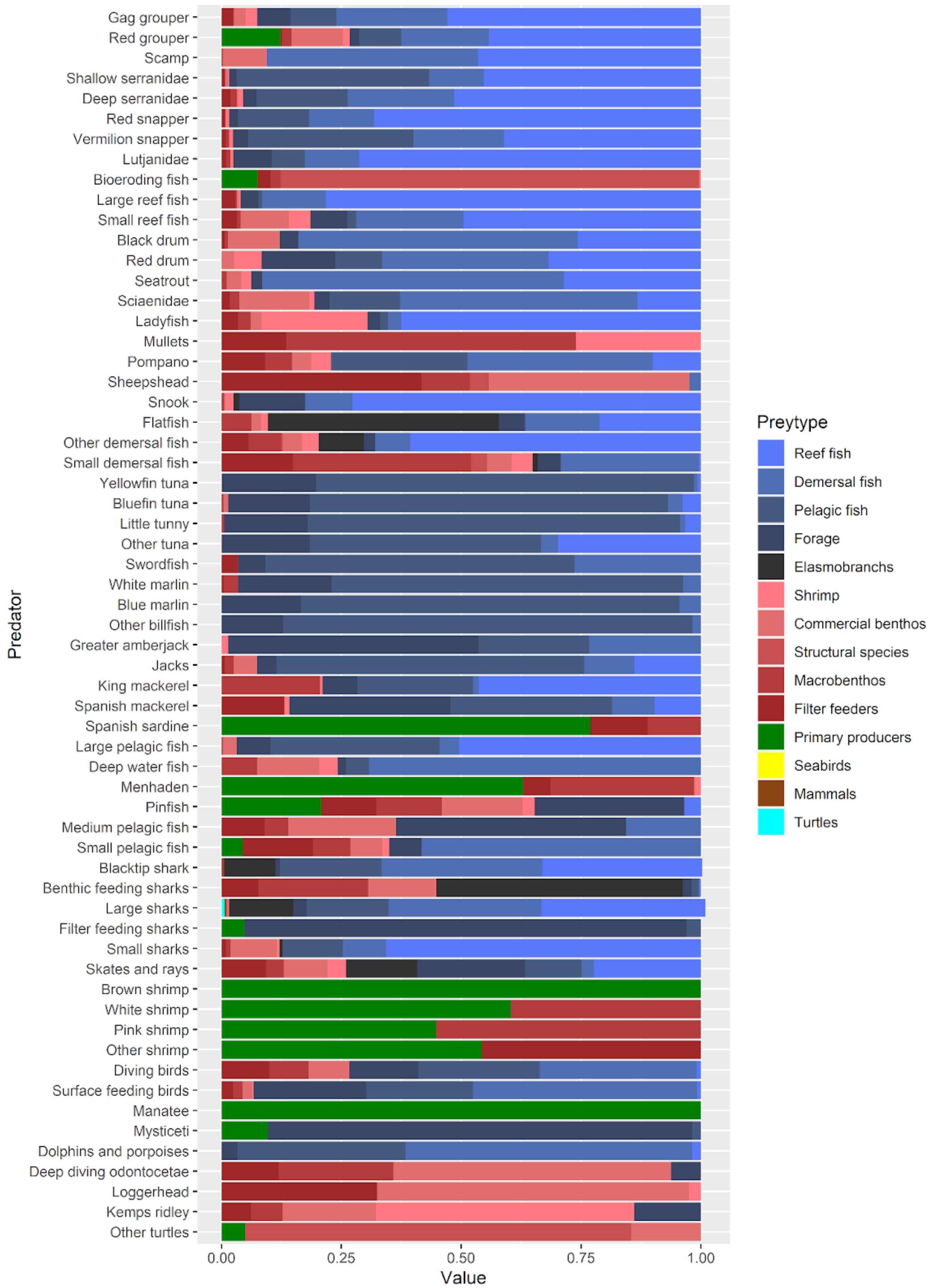


Figure 2: Diet matrix representing normalized availability parameters for vertebrate predators. Prey groups are aggregated into fish (blue) and invertebrate (red) categories for clarity (Preytype). Predator represents Atlantis functional groups. Diet represents recent updates by Morzaria-Luna et al. (2018) and changes described in this document.

Horizontal distributions

This report introduces a major revision of spatial distribution of group biomass over those used in the original GOM Atlantis model described by Ainsworth et al. (2015). The revision is based mostly on the products of a FLRACEP project (PI: Babcock, Project No. 1RCEGR020002-01-00), "Improving the use of products derived from monitoring data in ecosystem models of the Gulf of Mexico"). Biomass distributions were updated for fifty-six Atlantis functional groups (out of 91) based on the results of species distribution models developed for this project. This project gathered empiricists working in the GOM to contribute to a database supporting ecosystem modeling, particularly using the Object-oriented Simulator of Marine Ecosystems (OSMOSE), Ecopath with Ecosim (EwE) and Atlantis modeling frameworks. An ecosystem modeling workshop was held in Miami on January 15, 2016. Empiricists in attendance included Tracy Sutton (NOVA Southeastern University), Ted Switzer (FWC), Doug DeVries, Gary Fitzhugh, Chris Gardner and Patrick Raley (SEFSC-Panama City), Walter Ingram Jr, Adam Pollack, William Driggers, Matthew Campbell and Christopher Gledhill (SEFSC-Pascagoula), Redwood Nero (SEFSC-Stennis), Tom Minello, Harmon Brown, and Elizabeth Scott-Denton (SEFSC Galveston). Atlantis biomass distributions were calculated at the level of polygons. Data products from that project are archived in the following GRIIDC datasets (https://data.gulfresearchinitiative.org/): FL.x703.000:0001, FL.x703.000:0002, FL.x703.000:0003, FL.x703.000:0004, FL.x703.000:0005, FL.x703.000:0006, FL.x703.000:0007, FL.x703.000:0008, FL.x703.000:0009, FL.x703.000:0010, FL.x703.000:0011. Archived data also includes environmental data suitable for species distribution modeling.

The horizontal distribution of functional group biomass used in the initial time step is calculated by statistical models. Drexler and Ainsworth (2013) provided the initial biomass distributions used in Ainsworth et al. (2015) by using negative binomial GAMs to estimate biomass density of 40 fish and invertebrate functional groups. GAMs are a natural choice for modeling species distributions because the spline can easily accommodate domed shaped environmental preferences typically associated with physiological optima. They allow the data to drive the shape of the relationship between predictor and response variables and so are useful in situations where there is little information about the relationship being modeled. Grüss et al. (2014) subsequently revised the method to use a delta GAM approach to produce distribution maps for PSH. The delta methodology is used to deal with zero-inflated data. It refers to modeling presence/absence separately from the conditional biomass density when present. The former is described by a binomial model and the latter by a continuous function such as gamma. Biomass is estimated as the product of these two functions.

More recent work funded by the Florida RESTORE Act Centers of Excellence Program (FLRACEP) provided updated spatial distributions. This work used generalized linear and additive models (GLMs and GAMs). Grüss et al. (2018a) developed a methodology to combine disparate sampling methodologies using generalized linear mixed models (GLMMs), treating sampling programs as a random effect. These models included geostatistical covariates for spatial autocorrelation, an innovation to help synthesize data from different cruises. This is done for 32 functional groups. Since there was less species abundance information available in the southern GOM, predictions from binomial GAMs were extrapolated from the northern GOM to the southern GOM in Gruss et al. (2018). This process trained binomial GAMs based on US data and applied them to Mexican and Cuban waters. To facilitate this, the method accounted for spatial autocorrelation via a geostatistical predictor variable. Grüss et al. (2018b) used a similar statistical approach as Grüss et al. (2018a) in combination with a large monitoring database of the GOM to produce distribution maps for 61 fish and invertebrate groups. Grüss et al. (2018c) presented methodologies for producing distribution maps for mammal and turtle groups of GOM Atlantis. Grüss et al. (2019) used binomial GAMs integrating environmental covariates to produce distribution maps for the bird functional groups. In 2022, in preparation for the CIE review and in discussions with the SEFSC internal review panel, horizontal distribution profiles for commercially important shrimp groups (BSH; WSH; and PSH) were slightly adjusted to more realistically align with biomass distributions seen in SEAMAP survey data. Horizontal distribution profiles for functional groups are presented in Figures A.2 (adults) and A.3 (juveniles). The species distributions models were used to allocate the biomass spatially and the total amount of biomass was estimated based on a literature review of recent stock assessments for commercially important species (Table 1). Based on expert opinion, the initial biomass of BSH was modified to be on the same order of magnitude as WSH. This decision was made as the historical stock assessment model outputs for both the BSH and WSH stocks are undergoing a peer-review due to technical concerns with the historical model configurations and diagnostics. What we do know for certain is that BSH and WSH have very similar annual landings (in pounds of tails), and that some portion of either BSH or WSH is attainable to the fishery.

Table 1. Biomass for GOM Atlantis functional groups.

Updated biomass estimates of some commercially important species were approximated based on SEDAR stock assessment reports (available at https://sedarweb.org) and NOAA reports. The biomass data represent 2020 and may include data from nearby years for some species. Spawning stock biomass (SSB, in units of metric tons [t]) is presented in brackets, where NA refers to SSB estimates not in units of metric tons (e.g., number of eggs). F = fishing mortality.

	Initialized Biomass [SSB] (t)		
Functional Group	**Whole system**	**USA waters**	**Estimates; Source**
Reef Fish			
Gag grouper (GAG)	9,334 [8,848]	7,592 [7,197]	5,450 [2,102]; SEDAR (2021a). 9,189 SEDAR (2014a)
Red grouper (RGR)	15,243 [12,901]	13,167 [11,144]	[NA] 14,446; SEDAR (2019). 19,759 [NA]; SEDAR (2009a)
Scamp (SCM)	7,241 [6,263]	4,579 [3,961]	1,658 [1,462]; SEDAR (2021b)
Shallow Serranidae (SSR)	826,188 [327,149]	525,911 [208,247]	
Deep Serranidae (DSR)	232,640 [158,119]	122,261 [83,097]	
Red snapper (RSN)	145,721 [131,957]	75,758 [68,602]	75,600 [NA]; SEDAR (2018a)
Vermilion snapper (VSN)	14,305 [13,555]	10,394 [9,849]	18,861 [NA]; SEDAR (2020a)
Lutjanidae (LUT)	666,691 [477,063]	363,587 [260,171]	
Bioeroding fish (BIO)	41,840 [29,177]	24,521 [17,100]	
Large reef fish (LRF)	215,748 [151,439]		126,442 [88,753]
Small reef fish (SRF)	99,011 [51,665]	58,335 [30429]	
Demersal Fish			
Black drum (BDR)	37,962 [33,143]	25,999 [22,699]	
Red drum (RDR)	70,510 [58,698]	49,562 [41,259]	
Seatrout (SEA)	34,296 [29,390]	21,821 [18,700]	34,296 [NA]; Assumes F=0.2 Ainsworth et al. (2015)
Sciaenidae (SCI)	234,336 [158,949]	144,939 [98,311]	520,748 [NA]; Assumes F=0.4 Ainsworth et al. (2015)
Ladyfish (LDY)	75,762 [73,571]	46,938 [45,581]	
Mullets (MUL)	101,174 [61,488]	72,651 [44,154]	
Pompano (POM)	146,252 [121,241]	81,520 [67,579]	
Sheepshead (SHP)	321,855 [278,627]	179,247 [155,172]	
Snook (SNK)	192,526 [125,564]	107,203 [69,917]	
Flatfish (FLT)	152,656 [107,651]	93,055 [65,621]	
Other demersal fish (ODF)	516,881 [357,328]	288,995 [199,787]	1,846,005[NA]; Assumes F=0.2 Ainsworth et al. (2015)
Small demersal fish (SDF)	125,260 [66,813]	82,991 [44,267]	

Table 1 (continued). Biomass for GOM Atlantis functional groups.

Functional Group	Initialized Biomass [SSB] (t) Whole system	USA waters	Estimates; Source
Pelagic Fish			
Yellowfin tuna (YTN)	15,351 [12,602]	8,973 [7,366]	
Bluefin tuna (BTN)	6,953 [5,666]	4,064 [3,312]	
Little tunny (LTN)	130,387 [109,334]	76,214 [63,908]	
Other tuna (OTN)	12,569 [9,725]	7,347 [5,685]	
Swordfish (SWD)	13,927 [13,100]	8,292 [7,799]	
White marlin (WMR)	7,664 [7,212]	3,177 [2,989]	
Blue marlin (BMR)	2,046 [1,885]	848 [781]	
Other billfish (BIL)	918 [641]	381 [266]	
Greater amberjack (AMB)	3,773 [3,567]	1,718 [1,624]	4,850 [2,432]; SEDAR (2020b). 15,092 [NA]; Assumes F=0.2 Ainsworth et al. 2015; 1,328 [NA]; SEDAR (2011)
Jacks (JCK)	77,507 [35,225]	34,348 [15,610]	
King mackerel (KMK)	6,049 [5,787]	3,222 [3,082]	NA [2,353]; SEDAR (2014b). 9,703 [NA}; SEDAR (2009b)
Spanish mackerel (SMK)	30,624 [20,993]	16,973 [11,635]	
Spanish sardine (SAR)	118,876 [95,834]	84,447 [68,078]	289,000 [NA]; Chagaris (2013)
Large pelagic fish (LPL)	4,552,108 [3,648,975]	1,567,001 [1,256,110]	
Deep water fish (DWF)	120,519 [58,638]	50,234 [24,441]	
Forage Fish			
Menhaden (MEN)	2,053,298 [1,836,000]	1257032 [1,124,002]	NA [2,500,000]; SEDAR (2018b). b. 10,266,490[NA]; F=0.4 Ainsworth et al. (2015)
Pinfish (PIN)	194,294 [133,749]	147,967 [101,859]	
Medium pelagic fish (MPL)	229,458 [117,376]	95,114 [48,655]	
Small pelagic fish (SPL)	2,087,225 [1,112,344]	1,542,714 [822,158]	
Elasmobranchs			
Blacktip shark (TIP)	54,096 [36,771]	28,201 [19,169]	29,725 [NA]; SEDAR (2012)
Benthic feeding sharks (BEN	3,442,740 [3,268,684]	1,855,896 [1,762,067]	
Large sharks (LGS)	1,530,106 [1,240,405]	824,843 [668,672]	1,961,675 [NA]; Assumes F=0.1 Ainsworth et al. (2015)
Filter feeding sharks (FIL)	883 [842]	646 [616]	
Small sharks (SMS)	354,985 [349,054]	241,234 [237,204]	
Skates and rays (RAY)	609,450 [519,522]	314,212 [267,848]	

Table 1 (continued). Biomass for GOM Atlantis functional groups.

Functional Group	Initialized Biomass [SSB] (t)		Estimates; Source
	Whole system	USA waters	
Shrimps			
Brown shrimp (BSH)	485,955 [430,258]	383,176 [339,259]	NA [12,156]; Hart (2018a)
White shrimp (WSH)	493,091 [401,234]	312,285 [254,110]	NA [291,841]; Hart (2018b)
Pink shrimp (PSH)	39,316 [33,095]	33,698 [28,366]	NA [28,259]; Hart (2018c)
Other shrimp (OSH)	836,357 [603,997]	389,806 [281,509]	
Seabirds			
Diving birds (DBR)	1,064,857 [978,416]	779,224 [715,969]	
Surface feeding birds (SBR)	2,180,769 [2,139,074]	1,595,809 [1,565,299]	
Mammals			
Manatee (MAN)	1,385 [1,188]	767 [658]	
Mysticeti (MYS)	895 [774]	391 [338]	
Dolphins and porpoise (DOL)	48,571 [44,167]	20,971 [19,070]	
Deep diving odontocete (DDO)	49,730 [47,211]	21,169 [20,097]	
Turtles			
Loggerhead (LOG)	18,668 [16,874]	8,013 [7,243]	
Kemp's ridley (KMP)	197,656 [195,245]	86,046 [84,996]	
Other turtles (TUR)	40,639 [34,152]	17,691 [14,867]	
Commercial Benthos			
Blue crab (BCR)	134,475 [NA]	63,208 [NA]	
Stone crab (SCR)	85,497 [NA]	59,786 [NA]	
Crabs and lobsters (LOB)	34,415 [NA]	18,827 [NA]	
Structural Species			
Stony corals (COR)	4436 [NA]	1734 [NA]	
Crustose coralline algae (CCA)	10,141 [NA]	3,964 [NA]	
Octocorals (OCT)	2,898 [NA]	1,133 [NA]	
Sponges (SPG)	17,865 [NA]	8,918 [NA]	
Macrobenthos			
Carnivorous macrobenthos (CMI	436,202 [NA]	244,857 [NA]	
Infaunal meiobenthos (INF) (INI	14,688,560 [NA]	8,041,653 [NA]	
Herbivorous echinoderms (ECH)	5,586,937 [NA]	3,640,716 [NA]	
Filter Feeders			
Oysters (OYS)	5,916,470 [NA]	5,222,533 [NA]	
Bivalves (BIV)	2,954,171 [NA]	1,688,202 [NA]	
Sessile filter feeders (SES)	358,543 [NA]	180,601 [NA]	

Table 1 (continued). Biomass for GOM Atlantis functional groups.

Functional Group	Initialized Biomass [SSB] (t) Whole system	USA waters	Estimates; Source
Primary Producers			
Epiphytes (EPI)	31,267 [NA]	16,654 [NA]	
Seagrass (GRS)	234,216 [NA]	124,755 [NA]	
Macroalgae (ALG)	50,824 [NA]	27,071 [NA]	
Microphytobenthos (MPB)	315,837 [NA]	153,392 [NA]	
Large phytoplankton (LPP)	68,832,481 [NA]	46,515,093 [NA]	
Small phytoplankton (SPP)	137,663,721 [NA]	93,029,348 [NA]	
Toxic dinoflagellates (DIN)	77,866 [NA]	52,620 [NA]	
Protists (PRO)	3,104,832 [NA]	1,376,601 [NA]	
Pelagic Invertebrates			
Jellyfish (JEL)	1,054,656 [NA]	413,880 [NA]	
Squid (SQU)	4,237,229 [NA]	1,145,376 [NA]	
Large zooplankton (LZP)	29,769,006 [NA]	11,074,582 [NA]	
Small zooplankton (SZP)	59,537,482 [NA]	22,148,967 [NA]	
Nutrient Cycle			
Bacteria (PB)	866,473,139 [NA]	345,772,223 [NA]	
Sediment bacteria (BB)	36,099,639 [NA]	30,316,358 [NA]	
Carrion detritus (DC)	30,458,797,808 [NA]	11,660,954,522 [NA]	
Labile detritus (DL)	122,548,551 [NA]	45,967,247 [NA]	
Refractory detritus (DR)	122,548,551 [NA]	45,967,247 [NA]	

Vertical distributions

Polygons making up the modeling domain have a varying number of depth layers to represent the water column. Depth layers range from a single layer (e.g., an inshore box) to a maximum of six layers (e.g., an open-ocean box in the central Gulf). Additionally, each polygon has a sediment layer. A system was developed to vertically partition functional group biomasses based on a description of the ecology from Fishbase (Ainsworth et al. 2015). Herein, the vertical day/night biomass distributions were updated for a selection of large, pelagic functional groups: yellowfin tuna (YTN), other tuna (OTN), and large pelagic fish (LPL). Updated diel parameterizations for these groups were based on Pop-up satellite archival tag (PSAT) tagging data from the Cooperative Tagging Center at SEFSC. Diel vertical biomass distribution was based on the average percentage of time that tagged fish spent in each GOM Atlantis depth layer during day versus night hours. For example, if tagged fish spent an average of 50% of daytime hours in the 50-200 m box then 50% of their daytime biomass was designated to that layer. Current parameterized vertical distributions are shown in Table A.3.

Migration and movement

Horizontal movement in GOM Atlantis consists of seasonal, internal movement and annual, external migrations. The seasonal, internal movement patterns of each group were set according to the vertebrate and invertebrate concentrations per polygon determined by generalized additive models (GAMs), as described in the *Horizontal distributions* section, or using survey data when available. When no data were available, we assumed one of five standard movement patterns (temperature-dependent, spring spawner, summer spawner, fall spawner, uniform distribution) based on each group's spawning date (Ainsworth et al. 2015). Standard movement patterns were selected based on each group's spawning window (Fig. 3) as detailed in Ainsworth et al. (2015). A summary of the external migration assumptions and data sources is shown in Table A.4. There are also species-level comments on migration in Ainsworth et al. (2015) section Migration and Movement. Initial (Jan. - Mar.) functional group distributions are shown in Figures A.2 (adults) and A.3 (juveniles). The annual, external migrations are parameterized for the highly migratory pelagic groups (i.e., blue marlin, *Makaira nigricans*; white marlin, *Tetrapturus albidus*; swordfish, *Xiphias gladius*; bluefin tuna, *Thunnus thynnus*; yellowfin tuna, *Thunnus albacares*; king mackerel, *Scomberomorus cavalla*; Spanish mackerel, *Scomberomorus maculatus*; and other billfish, Istiophoridae), seabirds (i.e., diving birds; surface feeding birds), sea turtles (i.e., Kemp's ridley, *Lepidochelys kempii*; loggerhead, *Caretta caretta*; other turtles), large sharks, and mysticeti. With the exception of yellowfin and bluefin tunas, we assumed that juveniles will also migrate outside of the model domain. See Ainsworth et al. (2015) for more details.

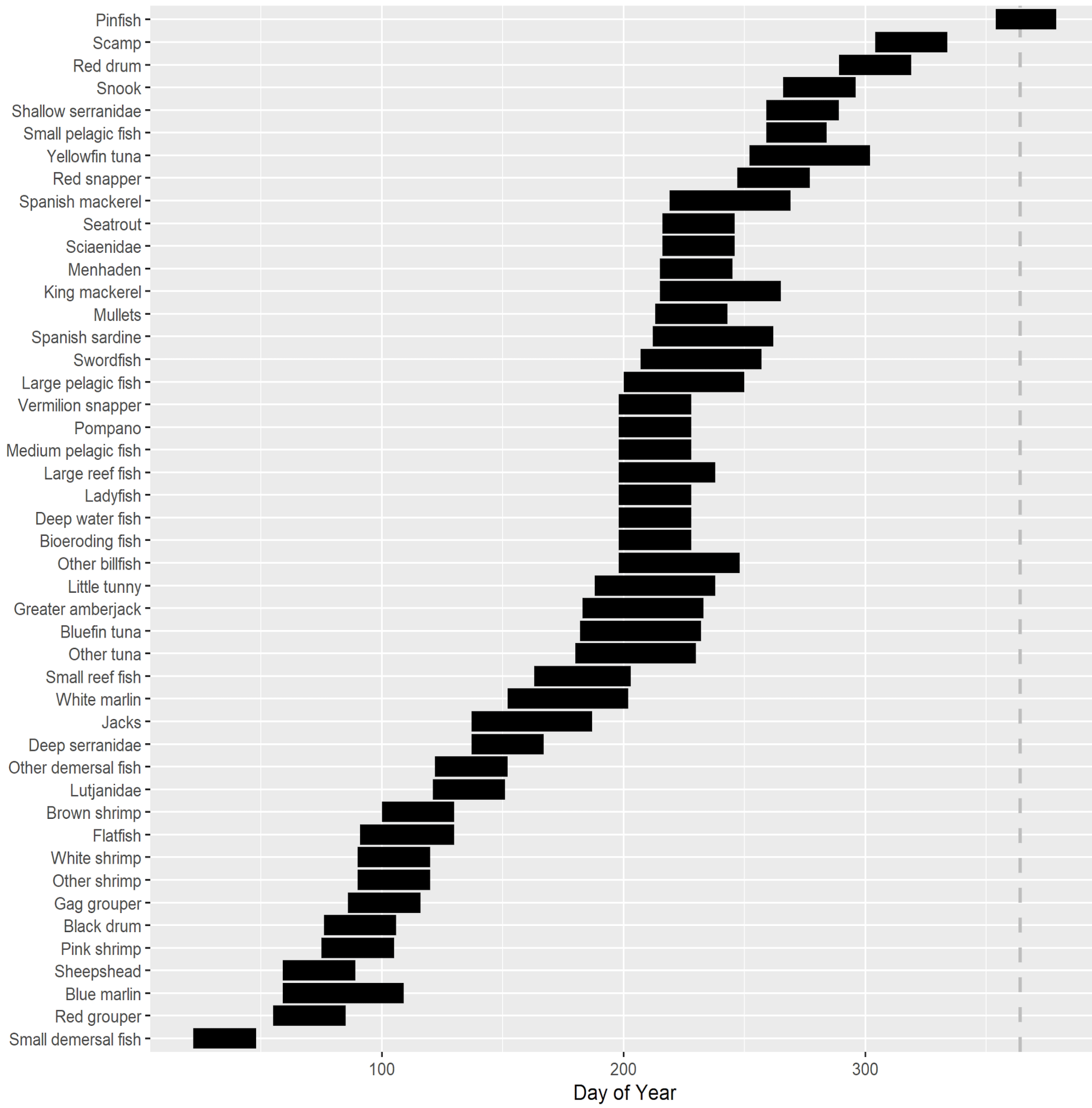


Figure 3. Spawning dates and larval durations. Start of bars represents the date of spawning; length of bars represents the length of the larval stage. Day one corresponds to January 1st.

Seagrass update

In this volume, we introduce two innovations to improve representation of seagrass habitats in GOM Atlantis. The first innovation is that we have updated parameters for Atlantis's habitat refuge model to better represent the latest FIM inshore sampling community composition data. Parameters are developed based on a novel statistical methodology explained in section 'Statistical habitat effects model'. In the second innovation, we developed new Atlantis code with assistance from CSIRO to divide the seagrass functional group GRS into slow-turnover biomass pools (roots/rhizomes) and fast-turnover growth (leaves/epiphytes). This is described below in section

'Pseudo-age structured seagrass model'. Seagrass coverage by polygon is also brought up to date in section 'Seagrass coverage'.

Statistical habitat effects model

Atlantis uses a prey habitat refuge model where the amount of habitat in a polygon influences a recruitment scaler for habitat-associated functional groups. The GOM Atlantis model has three static abiogenic habitat types (rock, mud, and canyon), and five biogenic habitat types corresponding to structure-forming functional groups in Atlantis: Coral (COR), Bivalves (BIV), Oysters (OYS), Macroalgae (ALG), and Seagrass (GRS). Each of these habitats has its own set of associated fish and invertebrate species. Refuge benefits change dynamically as the biomasses of these structural groups change in simulations. GOM Atlantis uses the optional prey habitat refuge model to allow the biogenic habitat types to provide prey some degree of refuge from predation even when predators are present (Atlantis parameters to achieve this are set in the biology.prm file and include flaghabdepend=1, [GROUP]_habdepend=1, and flag_refuge_model=1, see Audzijonyte et al. 2017a). In this report we use new statistical models to set fish and invertebrate groups' habitat affinities for seagrass. Ainsworth et al. (2015) describe how FWC mapping resources were used to set the other habitat types very simply.

Habitat helps define the availability of prey. A predator situated in a favorable habitat has increased rates of feeding. The available pool of prey is influenced in direct proportion to $\delta_{habitat}$ (Audzijonyte et al. 2017a) as in Eq. 2.

$$\delta_{habitat} = Acov_{prey} \cdot \left(e^{(-Kprey \cdot cover_{habitat} + Bcov_{prey})} + \frac{1}{K_{prey}} \right), \qquad \text{Eq. 2}$$

where $Acov_{prey}$ is a linear scalar of the overall habitat refuge effect, K_{prey} is the exponent of refuge effect, $cover_{habitat}$ is the availability of suitable cover, and $Bcov_{prey}$ is a steepness coefficient. The availability of suitable cover is calculated from biogenic and abiogenic habitat coverage in the polygon.

We develop generalized additive models (GAMs) to help set habitat parameters $Acov_{prey}$ and K_{prey} for 31 fish, invertebrate, and turtle functional groups. We consulted FIM data from the Florida Wildlife Research Institute for fish community data (FWRI 2021). The dataset includes an estimate of species abundance, environmental variables, and percent seagrass coverage, which we assume are representative of vascular seagrasses. The habitat parameters are based on GAM regression statistics and scaled using a procedure discussed below. The GAMs make a univariate prediction of fish abundance counts as in Eq. 3.

$$g(\mu) = \beta_0 + \beta_1(seagrass) + s(Depth) + s(Secchi) + s(Salinity) + s(O_2) + s(pH). \qquad \text{Eq. 3}$$

where g is the log link function, μ is the mean response for the Poisson model, β_0 is the intercept, β_1 is the *seagrass* coefficient, and s represents a smoothing function applied to the predictor. Seagrass percent cover (*seagrass*) is an observational unit of the percentage of the bottom covered by any type of seagrass, depth is in meters, Secchi depth is the deepest depth in meters at which Secchi disk could be seen, salinity is water salinity at sampling site in parts per thousand (ppt), oxygen (O_2) is the dissolved oxygen in water at the sampling site in mg/l, pH is the water pH at the sampling site, and temperature is the water temperature in Celsius at the sampling site.

Instead of Akaike Information Criterion (AIC), a double penalty approach was used for variable selection recommended by Marra and Wood (2011). This method penalizes the null and range space of a smoother and can shrink them to zero, so it functions as a one-step shrinkage variable selection method instead of an iterative knock out method. This method shrinks the smoothing coefficients, variables that are less significant in the model, so that they are essentially down-weighted or removed from the model completely. Thus, variables showing a high p-value (for example $p>0.05$) have had their importance in the model shrunk by this selection method. Instead of iteratively fitting models and dropping terms each time, this shrinkage method fits the multivariable model in one step (Marra and Wood 2011). Coefficients of the GAM for each Atlantis functional group with a seagrass association according to FIM data are available in Table A.5.

The GAM corrects for environmental effects at FIM sampling locations and so isolates the influence of seagrass cover on species abundance. GAMs can accommodate domed shaped environmental preference functions associated with physiological optima. We modeled vegetation cover as a simple linear predictor of fish and invertebrate abundance. There were (n = 5,071) species count data points present in the fisheries independent trawl monitoring data taken from 2015 to 2019. These data were provided by the Florida Wildlife Research Institute (FWRI) FIM program (FWRI 2021). The survey is conducted by 21.3 m offshore seines. Monitoring was conducted monthly using a stratified-random sampling design in Tampa Bay. We queried for data that were associated with seagrass, or anywhere vegetation cover on the bottom was greater than zero. For these data, catch per unit effort (CPUE) data were summed by species across all sampling events. Species were grouped into corresponding Atlantis functional groups. Figure 4 demonstrates what relationships with these environmental factors look like for a common seagrass prey species, pinfish. The model demonstrates increasing pinfish biomass with seagrass cover with a relatively even distribution of sample sites in vegetation cover types.

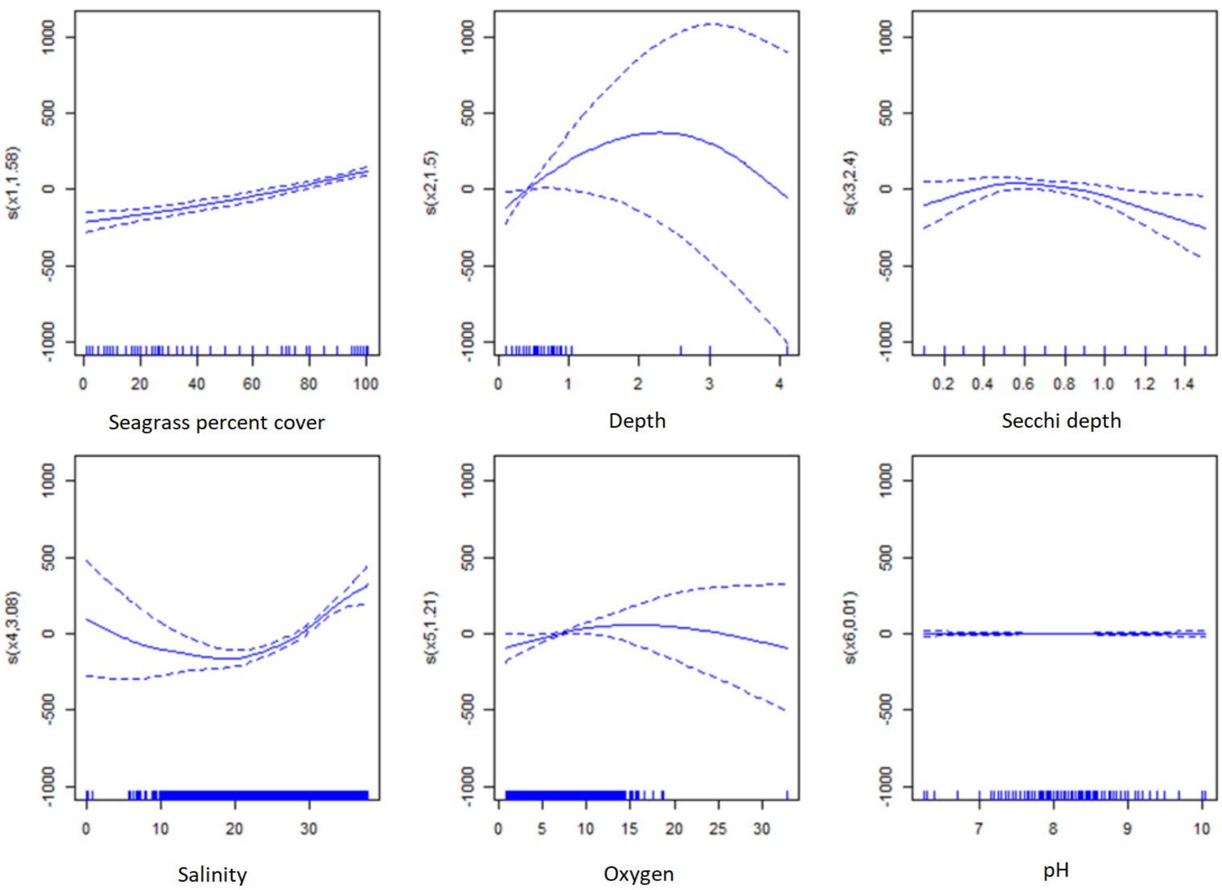


Figure 4: Generalized additive predictions for adult Pinfish abundance over six environmental predictor variables. Predictors include seagrass percent cover, depth, Secchi depth, salinity, oxygen, and pH. Dotted lines show 95% Bayesian credible interval, and vertical lines on the *x*-axis reflect input data. *Y*-axis shows an output of the *mgcv* R package, which are smoothing terms resulting from the GAM. The values are coefficients of the thin plate spline penalty function used to control the local smoothness of the spline.

We used the "mgcv" package in R with a gamma distribution and a log link (Wood 2022). Thin plate splines, or low rank isotropic smoothers were used as the smoothing functions (Wood 2022). Smoothing terms (s) were used for environmental effects. We modeled seagrass percent cover (*veg_cover*) as a simple linear predictor of fish and invertebrate abundance. We determined the coefficient and intercept for *veg_cover* for each functional group (Table A.5). The *veg_cover* coefficient indicates a direct effect of the vegetation cover on population abundance, where a positive coefficient indicates increasing abundance in proportion to vegetation cover. Groups with large values derive more benefit from vegetation cover. Thus, this represents a refuge benefit scaling parameter and it is appropriate to use this value to scale $Acov_{prey}$, which has a linear effect on prey availability (Eq. 2, Fig. 5). We set $Acov_{prey}$ to reflect *veg_cover* coefficient values for 17 groups that had statistical significance at $p = 0.1$ (Table A.5). We used a two-tailed T test to determine which functional groups have statistically significant coefficients and intercepts. The *veg_cover* coefficients were scaled by factor θ to ensure all groups fall within the $Acov_{prey}$ range 0.1 - 3 (Eq. 4). The scaling factor is based only on the interquartile range (IQR) of group coefficients rather than the entire range to omit the influence of outlier groups and ensure dispersion in the behavior of weakly and moderately-habitat associated groups (Eq. 5). We assumed a median $\underline{\beta}$ $Acov_{prey}$ term of 1, where a 1 indicates no effect of the habitat on prey availability. Uninformed groups use a value of $Acov_{prey}$ = 1.

$$Acov_{prey} = \theta \cdot \left(\beta_{1,i} - \bar{\beta}\right) + 1 \qquad \text{Eq. 4}$$

$$\theta = (IQR_{veg\_cover}/[3 - 0.1]) \qquad \text{Eq. 5}$$

We set *Kprey* values to reflect the *veg_cover* intercepts for 13 functional groups that had statistically significant intercepts at p = 0.1 (Table A.5). The *veg_cover* intercept is the theoretical population abundance at zero vegetation cover. Groups with a zero (or negative) intercept will have zero abundance at zero (or low) vegetation cover. These can be considered obligate occupants of seagrass habitat. Groups with a positive intercept will have a non-zero abundance at zero vegetation cover. These are facultative occupants of seagrass habitat. Thus, this parameter relates to habitat fidelity. Groups with low *Kprey* values benefit from high prey availability in seagrass habitat (Fig. 5). This is therefore a suitable model for obligate occupants of seagrass habitat. Groups with high *Kprey* experience smaller prey availability in seagrass habitat. This is a suitable model for facultative occupants of seagrass habitat as there is an implication that other habitats provide foraging opportunities. The value of seagrass habitat as foraging habitat decreases as *Kprey* increases. *Kprey* was calculated similarly to *Acovprey* by scaling the IQR of the GAM intercepts and then adjusting the median to equal 3. Uninformed groups use a value of *Kprey* = 3. *Kprey* values are typically in the range from 2 to 3.5 in Atlantis (Link et al. (2011) Northeast U.S. [NEUS] Kcov 2.1 – 3; Fulton et al. (2007) Eastern Tasmania [SETas] Kcov 2.1 - 3.5; Horne et al. (2010) California Current [EMOCC] Kcov 2.1 - 3.5),

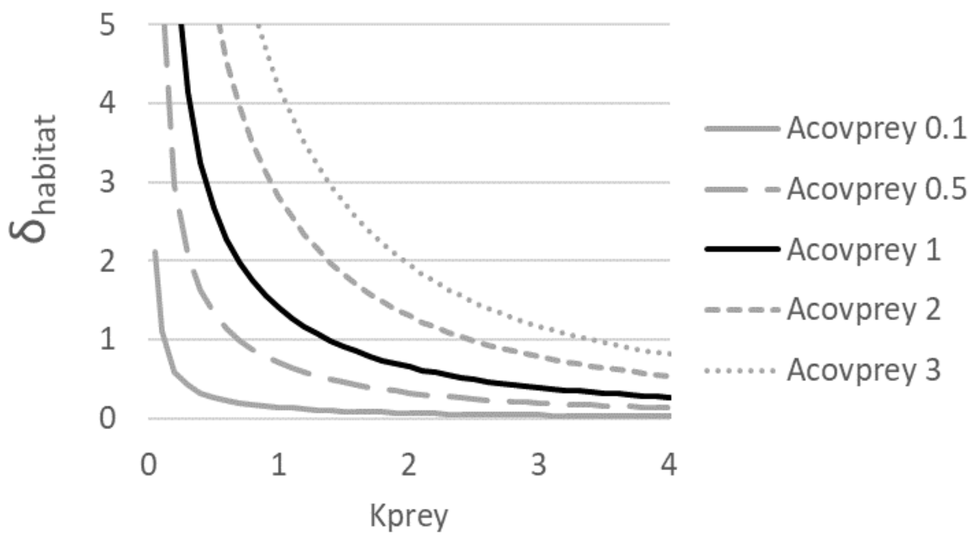


Figure 5. Prey availability ($\delta_{habitat}$) versus the exponent of refuge effect (*Kprey*) under various assumptions for the habitat refuge effect (*$Acov_{prey}$*). *Kprey* reflects habitat fidelity and $Acov_{prey}$ reflects refuge benefit. *Kprey*=3 and $Acov_{prey}$=1 are commonly used values.

Pseudo-age structured seagrass model

Herein, we introduce a unique seagrass formulation for Atlantis. The routine uses a pseudo-age structure to divide the seagrass functional group into slow-growing pools (roots and rhizomes) and faster-growing leaves and epiphytes. With this articulated model, we can better represent different types of herbivory and the keystone role played by manatees as habitat organizers. The routine has its origin in unpublished work by M. Savina and B. Fulton (CSIRO) in the 2000s. It partitions the seagrass functional group into biomass pools with different turn-over rates. We define above-ground biomass (i.e., the leaves), below-ground biomass (e.g., roots and rhizomes), and epiphyte biomass. In the GOM Atlantis model, herbivores feed on epiphytes or leaves, but manatees are able to graze on the slower-growing below-ground biomass pool. This pool has a longer regrowth time than leaves or epiphytes so manatees have the potential to act in a keystone role, affecting habitat and the assemblage. Under seasonal variation, below-ground biomass does not vary as much as the above-ground biomass. Growth of seagrass depends on the interaction of growth and mortality dynamics (Audzijonyte et al. 2017a) according to Eq. 6.

$$\frac{dB}{dt} = G - M1 - \sum_{i} M2i \qquad \text{Eq. 6}$$

where B is seagrass biomass, G is the growth term, *M1* is other mortality, and $M2i$ is predation mortality of predator i. Other mortality consists of linear density-dependent mortality, treated as a tuning parameter, and epiphyte fouling (e.g., under high nutrient conditions), each in d-1. Wave stress mortality referencing hydrodynamic data is also an option in Atlantis, but it is not employed in the current configuration of GOM Atlantis. Predation mortality is summed across predators. The equations and processes governing primary production in Atlantis have been adapted from the Port Phillip Bay Integrated Model (PPBIM) of Murray and Parslow (1997). The growth term is determined based on the maximum per capita growth rate (*mum*), seagrass biomass, and scalar limitation factors δ for light, nutrients, and space (Eq. 7-10).

$$G = mum \cdot B \cdot \delta_{light} \cdot \delta_{nutrient} \cdot \delta_{space} \qquad \text{Eq. 7}$$

$$\delta_{nutrient} = \frac{NH3 + NO3}{KN + NH3 + NO3} \qquad \text{Eq. 8}$$

$$\delta_{light} = min(PAR/KI, 1) \qquad \text{Eq. 9}$$

$$\delta_{space} = \frac{B}{B_{max} \cdot P_{area}} \qquad \text{Eq. 10}$$

Nutrient limitation is determined based on ammonia (NH_3) and nitrate (NO_3) concentrations and the half-saturation constant of nutrient uptake (*KN*, mgN·m^{-3}). Light limitation is determined based on photosynthetically active radiation (*PAR*) and the light saturation coefficient (*KI*, W·m^{-2}). Space limitation is determined based on seagrass biomass, maximum seagrass biomass density (B_{max}, mgN·m^{-2}), and the proportion of the polygon covered with seagrass habitat (P_{area}). *KI* and *mum* are both affected by local temperature as an increasing power function. Additionally, the growth of above-ground biomass (i.e., leaves) is determined based on shading relationships (Fong and Harwell 1994), and the growth of epiphyte biomass is limited by available seagrass based on space limitation (Bartleson et al. 2005). The shading relationship only applies to the epiphyte age class (i.e., the oldest age class) of the pseudo-age structured seagrass group (GRS age 3) and not to any other biogenic habitat forming groups such as algae (ALG) or epiphytes (EPI). Since the addition of the pseudo-age structured seagrass dynamics in this document, we have updated the definition of group EPI to represent all non-seagrass-associated epiphytes.

Seagrass coverage

Seagrass distribution was obtained by consulting the National Centers for Coastal Ocean Science Gulf of Mexico Data Atlas (Handley 2011) which combines geographic information from state and academic sources for Gulf-wide submerged aquatic vegetation. The data used shows all seagrass footprints recorded for the Gulf of Mexico from three separate datasets: (i) Texas Seagrass Areas which combines data from Texas Parks and Wildlife, U.S. Fish and Wildlife, Texas A&M, and Texas General Land Office from 1991 to 2007; (ii) Seagrass Information for Alabama, Florida, Mississippi, and Texas which were a compilation of seagrass information from various source agencies mapped from aerial photography taken from 1987 to 1999; and (iii) U.S. Geological Survey (USGS) Gulf-wide submerged aquatic vegetation GIS (Geographic Information Systems) maps developed using various surveying and image analysis techniques from 1940 to 2003. Not all datasets contain seagrass density or species composition information; those that do may describe density differently (e.g. using a more precise leaf area index method to differentiate patchy and dense beds). However, patchiness is not necessarily of critical influence on the abundance of seagrass-associated species due to the plasticity of foraging behavior (Howell and Shaver 2021). For the purpose of this study, we therefore represent seagrass as percent cover over model polygons. From the combined distribution map created from the data described above, we calculated the area (and percentage) of seagrass coverage for each Atlantis model polygon. Values for Mexican and Cuban polygons are assumed to have similar seagrass coverage by depth as US cells.

Larval dispersal

Atlantis uses a source-sink matrix that apportions young-of-the-year (YOY) spatially. Vasbinder et al. 2023 developed the larval dispersal matrix using outputs from a Lagrangian individual based model (IBM). Larval particles make choices on which depth strata to occupy on the basis of taxon-specific statistical behavioral models. The models are fitted to observations from SEAMAP ichthyoplankton surveys (https://www.gsmfc.org/seamap.php) and predict water column occupancy by larval age. The agent-based dispersal model then integrates larval position using current vector fields at depth from the West Florida Coastal Ocean Model (http://ocgweb.marine.usf.edu/Models/WFCOM/wfcom_index.html) to track particles in two hour time steps forward to settling sites and backwards to spawning sites based on their pelagic larval durations. The IBM works well in concert with the above-mentioned statistical modeling of adult populations by A. Grüss and others since spatial breeder abundance can be used to represent larval particle seeding weights in the IBM. Atlantis is currently only capable of applying a static dispersal matrix but there is potential in our data to support a more sophisticated treatment (e.g., seasonal). This source-sink matrix represents the percentage of spawned larvae in a starting polygon (source) that end up settling in an ending polygon (sink). Polygon-by-polygon interactions are then compiled into a source-sink matrix by functional group. The resulting matrix is a source-sink matrix that directs larval transport and settlement to rearing habitats.

Fisheries

Ainsworth et al. (2015) described the model's fishing fleets. This included defining areas of the polygon map in which fleets were allowed to operate. Also described is the collation of a historical catch time series, a country- and species-specific marine landings dataset used to develop the historical GOM Atlantis model and parameterize the fishing mortalities in the GOM Atlantis model. Herein, updates have been made to the fleet structure, spatial restrictions, landings, and discards.

Fleet structure

The structure of the fleets within the GOM Atlantis model were first based on fleets defined in the Walters et al. (2008) EwE-GOM model, then expanded upon to represent fisheries in the U.S. shelf and pelagic waters, fisheries in Mexico, and fisheries in Cuba. Since the development of the GOM Atlantis model, the fleet names have been refined for clarification based on the NOAA gear types originally designated to USA-based fleets (Table 2), and feedback from the SEFSC internal review panel:

1. Recreational fishery in the USA (estuarine/coastal spp.)

This fleet represents U.S. recreational fishing within estuarine and inshore waters. As such, the primary targets include coastal fish (e.g., red drum, seatrout, sheepshead, and mullet). This fleet encompasses all modes/gears of recreational fishing (e.g., charter boats, private boats, diving, etc.).

2. Recreational fishery in the USA (offshore spp.)

This fleet represents U.S. recreational fishing operating in offshore waters. The primary targets are a mixture of reef fish (e.g., gag grouper, vermilion snapper, red grouper, and red snapper) and pelagic fish (e.g., Spanish mackerel, jacks, tunas, and marlins), but also retains various shark species (e.g., blacktip shark). This fleet encompasses all modes/gears of recreational fishing (e.g., charter boats and private boats).

3. Gillnet fishery in the USA

This fleet represents U.S. gillnet fishing, which primarily targets fish in estuarine and inshore waters along the coast. The primary target species are demersal fish (i.e., mullet, ladyfish, black drum, and seatrout), but some miscellaneous reef fish (e.g., small reef fish and large reef fish) and migratory fish (e.g., Spanish mackerel, sharks, and jacks) are also caught.

4. Oyster fishery in the USA

This fleet represents the U.S. oyster fishery, which primarily operates within estuary and inshore waters. The oyster fishery is highly selective, landing only oysters.

5. Crab pot fishery in the USA

This fleet represents the U.S. pot fishery, which targets crabs. This fleet can operate inshore and offshore. While this fleet primarily targets crabs, a variety of fish are landed (e.g., black drum, mullet, and Serranidae).

6. Lobster pot fishery in the USA

This fleet represents the U.S. pot fishery. While spiny lobsters are the target group, a variety of other species are sometimes landed (e.g., stone crab, large reef fish, and Lutjanidae).

7. Fish and shrimp pot fishery in the USA

This fleet represents the U.S. pot fishery, which primarily lands fish and shrimp. Pots used are a mixture of wire and wooden traps. Landings consist of a variety of demersal fish (e.g., Serranidae, Lutjanidae, other demersal fish, pinfish, and red grouper).

8. Shrimp net and trawl fishing in the USA - inshore

This fleet represents fixed trap nets and shrimp trawling operating within estuarine and inshore waters along the U.S. coast. The primary targets include BSH and WSH, but various fish are landed as bycatch (e.g., black drum, seatrout, sheepshead, flatfish, and Spanish mackerel).

9. Shrimp trawl fishing in the USA - offshore

This fleet represents otter trawls operating in the shallow and mid-shelf waters along the U.S. coast. This fleet primarily targets BSH and PSH, but there are various fish that are sometimes landed (e.g., black drum, seatrout, flatfish, and miscellaneous reef fish).

10. Royal red shrimp fishery in the USA

This fleet represents the U.S. fishery targeting royal red shrimp in deep areas of the shelf. Vessels fish in deep areas of the central Gulf of Mexico shelf and use the same gear and vessels as the fleet targeting WSH and BSH groups in the shallower areas of the shelf. While there are many species caught as bycatch, this fleet only catches royal red shrimp.

11. Menhaden seine fishery in the USA

This fleet represents the U.S. purse seine fishing. Menhaden is the primary target but, based on NOAA landings data, the fleet lands relatively small amounts of finfish (e.g., mullet).

12. Handline fishery in the USA

This fleet represents commercial handline fishing operating throughout inshore and shelf waters along the U.S. coast. The primary targets include various reef fish (e.g., gag grouper, red snapper, and scamp) as well as some coastal pelagics (e.g., jacks, mackerel, and sharks).

13. Reef fish longline fishery in the USA

This fleet represents the U.S. longline fleet operating throughout inshore and shelf waters targeting various reef fish (e.g., red grouper, black drum, gag grouper, and scamp). While there are many species caught and discarded as bycatch, some of this catch is landed (e.g., jacks, sharks, and mackerels).

14. Shark longline fishery in the USA

This fleet represents the U.S. longline fleet operating throughout the shelf and offshore waters. The primary targets include various elasmobranch groups (i.e., blacktip sharks and large sharks).

15. Pelagic longline fishery in the USA

This fleet represents the U.S. longline fleet operating throughout offshore waters. The primary targets include various pelagic species (e.g., yellowfin tuna, swordfish, mackerels, marlins, and sharks).

16. Mixed fishery representing other fishing in the USA

Several of the NOAA-gear types were not encompassed by the other U.S. commercial GOM Atlantis fleets, so a mixed fishery was defined to model landings associated with these gears (Table 2). This fleet lands a wide range of species including demersal groups (e.g., sponges, lobsters, and shrimps), reef fish (e.g., gag grouper, red grouper, and red snapper), and pelagics (e.g., jacks, mackerels, and sharks).

17. Shrimp trawl fishery in Mexico

This fleet represents shrimp trawling in Mexico. The fleet primarily targets shrimp groups (i.e., BSH, PSH, and WSH), but lands other demersal groups (e.g., carnivorous macrobenthos, skates and rays, and flatfish).

18. Reef fish longline fishery in Mexico

This fleet represents the Mexican longline fishing operations targeting reef fish. This consists of demersal longliners. The fleet targets red grouper, red snapper, vermilion snapper, Lutjanidae, and Serranidae.

19. Shark longline fishery in Mexico

This fleet represents Mexican longline fishing, which targets sharks and pelagics. The fleet catches some demersal groups (e.g., large sharks, blacktip sharks, skates, and rays) and various pelagics (e.g., mackerels, billfish, jacks, and tunas).

20. Mackerel gillnet fishery in Mexico

This fleet represents the Mexican gillnet fishery targeting mackerel. While the fleet primarily targets mackerel (i.e., Spanish mackerel and king mackerel), landings also include mullet, sheepshead, flatfish, and large pelagic fish.

21. Octopus fishery in Mexico

This fleet represents the Mexican octopus fishery. Operations are mainly in the Gulf of Campeche and north of Yucatan using pots. This fishery is highly selective, thus it lands only octopus (i.e., carnivorous macrobenthos).

22. Mixed fishery representing other fishing in Mexico

There are a number of small artisanal vessels that fish with a variety of gear in coastal areas of Mexico. They mostly target a mixture of coastal finfish for the local market. This mixed fishery was defined to govern landings resulting from these operations. This fleet lands a wide range of species including pelagics (e.g., billfish, jacks, and marlins), reef fish (e.g., red grouper, red snapper, and vermilion snapper), and demersals (e.g., crabs, lobsters, and drums).

23. Mixed fishery representing fishing in Cuba

The Cuban fisheries are primarily small-scale operations targeting reef fish in the shelf and pelagic fish in the areas next to the coast off the shelf. This fleet aggregates all of the Cuban fisheries into a single fleet. This fleet lands a variety of groups such as demersals (e.g., lobsters and crabs), some reef fish (e.g., red snapper), and pelagics (e.g., billfish, tunas, and marlins).

Table 2. NOAA gear-types assigned to GOM Atlantis fleets.
Gear types identified in the NOAA 2011 species-specific commercial landings data (bullet points) were assigned to the fleets of the GOM Atlantis model (bold headers). Some of the NOAA gear types were not assigned to any fleet as the gear was deemed too ambiguous (e.g., "Combine gears") or the associated landings were not significant for the GOM Atlantis model (e.g., Pots and traps crayfish(freshwater)).

Gillnet fishery in the USA	**Oyster fishery in the USA**	**Crab pot fishery in the USA**	**Fish and shrimp pot fishery in the USA**	**Lobster pot fishery in the USA**
● Entangling nets (gill) unspecified ● Gill nets, drift, runaround ● Trammel nets ● Gill nets, stake ● Gill nets, sink/anchor, other	● Rakes, other ● Dredge other ● Tongs and grabs, oyster ● Tongs and grabs, other	● Brush trap ● Pots and traps, crab, blue ● Pots and traps, crab, other ● Pots and traps, eel	● Pots and traps, fish ● Pots and traps, other ● Pots and traps, shrimp	● Pots and traps, spiny lobster

Shrimp net and trawl fishing in the USA - inshore	**Shrimp trawl fishing in the USA - offshore**	**Royal red fishery in the USA**	**Menhaden Seine Fishery in the USA**	**Handline fishery in the USA**
● Beam trawls, shrimp butterfly nets ● Skimmer net	● Otter trawl bottom, shrimp ● Otter trawl bottom, fish ● Otter trawl bottom, scallop ● Trawls, unspecified	● Otter trawl bottom, shrimp ● Skimmer net	● Encircling nets (purse) ● Purse seines, other ● Purse seines, menhaden	● Reel, electric or hydraulic ● Rod and Reel ● Lines hand, other ● Lines long, vertical

Reef fish longline fishery in the USA	**Shark longline fishery in Mexico**	**Pelagic longline fishery in the USA**	**Mixed fishery representing other fishing in the USA**	***Not assigned to any fleet***
● Lines long, reef fish ● Lines trot with baits	● Lines long, shark	● Lines troll, other ● Lines long set with hooks ● Lines long drift with hooks	● By hand, other ● By hand, oyster ● Cast nets ● Diving outfits, other ● Dip nets, drop ● Dip nets, common ● Fyke and hoop nets, fish ● Haul seines, beach ● Haul seines, long ● Hooks, sponge ● Lampara & ring nets, other ● Spears	● Not coded ● Combined gears ● Unspecified gear ● Troll & hand lines combined ● Pots and traps, crayfish (freshwater) ● Slat traps (Virginia) ● Forks

Spatial Restrictions

Spatial restrictions for the fleets in GOM Atlantis are driven by marine protected areas and the defined areas of fleet accessibility, both of which have been revised since the predecessor GOM Atlantis model. For some group-fleet interactions, these revisions have little influence on the catches as the overlap between the fleet operational area and the functional group spatial distribution has not significantly changed. For example, oysters reside within estuaries which have, and continue to be, accessible to the U.S. oyster fleet. For many other group-fleet interactions, however, these additional spatial restrictions influence catches, thereby improving the representation of fishing within the GOM Atlantis model. The spatial distribution of simulated catches (Fig. A.4, A.5) reflects the relative spatial distribution of species' abundance and the updated fleet spatial restrictions.

Marine protected areas

Marine protected areas are integrated into the GOM Atlantis model using fleet-specific catch restrictions within respective polygons. Catch restrictions are proportional to the specifications of the protected area and the percentage of the polygon encompassing the protected area. Twenty-four marine protected areas were accounted for in the historic GOM Atlantis model (Ainsworth et al. 2015). Additional marine protected areas have since been added. The current GOM Atlantis model now includes 71 marine protected areas (Table A.6). Table A.6 shows polygons affected by each MPA. The impact on Atlantis fleets operating within those polygons was calculated based on the area of the polygon closed (see column Fleets affected). For all fleets, we assumed a homogeneous distribution of effort within the polygon and reduced catches in proportion to the area of the polygon closed. In cases where the MPA extends over multiple polygons, the net effect on the fleet is calculated by scaling catches in proportion to the total closed area.

It is important to note that protected areas included in the GOM Atlantis model have varied depending on the application. For example, studies using the GOM Atlantis model to explore impacts from the *Deepwater Horizon* oil spill (Ainsworth et al. 2018; Dornberger et al. 2020) utilized versions of the GOM Atlantis model that included all of the emergency fishery closures and openings in the Gulf of Mexico due to the *Deepwater Horizon* oil spill (NOAA National Centers for Environmental Information; https://www.nodc.noaa.gov/deepwaterhorizon/fisheries_closures.html).

Areas of fleet accessibility

In the previous GOM Atlantis model (Ainsworth et al. 2015), a simple assumption was made with respect to the areas of fleet accessibility: fleets extract biomass from polygons within their respective EEZ zones. In the current model, this was refined such that fleets only extract biomass from polygons that correspond to known areas of operation within their respective EEZ zones (Fig. 6). The updated areas of fleet accessibility were reviewed and approved by the SEFSC internal review panel. The following summarizes the polygon-selection process for different fishing fleets/gears:

- Recreational Fishing:

  Bottom depth and distance from shore were the main considerations when selecting polygons accessible to the recreational fleets. According to the Marine Recreational Information Program (MRIP) database, recreational fishing operations can occur over 10 nm from shore, however operating far from shore can be costly. Thus, we assumed that recreational fishing would likely not extend far beyond the Territorial Sea (12 nm). For the *Recreational fishery in the USA (estuarine/coastal spp.)* fleet, in some regions i) adjacent polygons were included if the bottom depth was less than or equal to 50 m, and ii) selected polygons were excluded if the bottom depth exceeded 200 m. For the *Recreational fishery in the USA (offshore spp.)* fleet, in some regions i) selected polygons were excluded if the bottom depth was less than or equal to 10 m.

- <u>Gillnet Fishing:</u>

  Gillnet fishing in the Gulf of Mexico primarily targets fish in estuarine and inshore waters along the coast. Thus, accessible areas were limited to polygons with depths less than or equal to 200 m. This was done for both *Gillnet fishery in the USA* and *Mackerel gillnet fishery in Mexico*.

- <u>Oyster Fishery:</u>

  Only estuarine polygons are accessible to the *Oyster fishery in the USA* fleet.

- <u>Pot and Trap Fishing:</u>

  For trap and pot fisheries within U.S. waters (i.e., the *Crab pot fishery in the USA* fleet, the *Lobster pot fishery in the USA* fleet, and the *Fish and shrimp pot fishery in the USA* fleet), accessible areas were limited to polygons with depths less than or equal to 200 m. For the pot fishery within Mexican waters (i.e., the *Octopus fishery in Mexico* fleet), accessible areas were limited to polygons with depths less than or equal to 50 m as Octopuses of the genus *Octopus* do not reside at depths beyond 50 m (Luis et al. 2020).

- <u>Net and Trawl Fishing:</u>

  Bottom depth was the main parameter considered when selecting polygons accessible to the fleet representing trawling activities targeting Penaeidae (Scott-Denton et al. 2020). For the *Shrimp net and trawl fishing in the USA - inshore* fleet, accessible areas were limited to polygons with depths less than or equal to 20 m. For the *Shrimp trawl fishing in the USA - offshore* fleet, accessible areas were limited to polygons with depths less than or equal to 200 m, excluding estuaries. For the *Shrimp trawl fishery in Mexico* fleet, accessible areas were limited to polygons with depths less than or equal to 200 m.

- <u>Deep-water Trawl Fishing:</u>

  Bottom depth was the main parameter considered when selecting polygons accessible to the fleet representing deep-water trawling (i.e., *Royal red fishery in the USA*). Deep-water trawling in the northern Gulf of Mexico for rock shrimp (i.e., royal red shrimp) covers areas that have bottom depths that range from 20 m to 140 m (Scott-Denton et al. 2020). Comparing this region on a bathymetry map of the Gulf of Mexico to the spatial map for the GOM Atlantis model, polygons with maximum bottom depths of either 200 m or 2000 m were selected.

- <u>Seine Fishing:</u>

  Accessible areas for the *Menhaden seine fishery in the USA* fleet were selected by visually comparing the spatial map for the GOM Atlantis model to the spatial distribution of sets from the commercial menhaden fishery (1986-2011) (SEDAR 2013).

- Handline Fishing:

  Accessible areas for the *Handline fishery in the USA* fleet were selected by visually comparing the spatial map for the GOM Atlantis model to the spatial distribution of sampling effort of the U.S. vertical line reef fish fishery (Scott-Denton et al. 2011).

- Longline Fishing:

  The various longline fleets were spatialized primarily via visual analysis. First, accessible areas for the *Reef fish longline fishery in the USA* fleet were selected by visually comparing the spatial map for the GOM Atlantis model to the spatial distribution of sampling effort of the U.S. bottom longline reef fish fishery (Scott-Denton et al. 2011). The accessible areas for the *Shark longline fishery in the USA* fleet were selected by visually comparing the spatial map for the GOM Atlantis model to the spatial distribution of observer data (Morgan et al. 2009; Mathers et al. 2018). The accessible areas for the *Pelagic longline fishery in the USA* fleet were selected by visually comparing the spatial map for the GOM Atlantis model to the spatial distribution of pelagic longline fishing locations (Gardner et al. 2008). Next, considering that the U.S. reef fish longline fishing seems to occur in waters no deeper than 200 m, and that regulations pertaining to Mexican reef fish longline fishing could not be located, accessible areas for the *Reef fish longline fishery in Mexico* fleet were limited to polygons with depths less than or equal to 200m. Lastly, accessible areas for the *Shark longline fishery in Mexico* fleet were first determined by comparing the spatial map for the GOM Atlantis model to the Mexican shark fishery grounds in the Gulf of Mexico (Castillo-Géniz et al. 1998), however the *Shark longline fishery in Mexico* fleet also represents landings from the longline tuna fishery (Fig. A.6). After comparing the Mexican shark fishery grounds to the spatial distributions of cumulative fishing effort by the Mexican longline fleet operating within the Gulf of Mexico (Abad-Uribarren et al. 2019), polygons deeper than 10 m were selected as accessible areas for the *Shark longline fishery in Mexico* fleet.

- Mixed Fisheries:

  The *Mixed fishery representing other fishing in the USA* fleet is a diverse mix of miscellaneous NOAA gear-types (Table 2). Given the lack of pelagic gear types, accessible areas were limited to polygons with depths less than or equal to 200 m. The *Mixed fishery representing other fishing in Mexico* fleet is a diverse fleet catching a variety of groups. As such, additional spatial restrictions were not imposed and the accessible areas include the entire Mexican EEZ. The *Mixed fishery representing fishing in Cuba* fleet represents all Cuban fisheries, thus additional spatial restrictions were not imposed and the accessible areas include the entire Cuban EEZ.

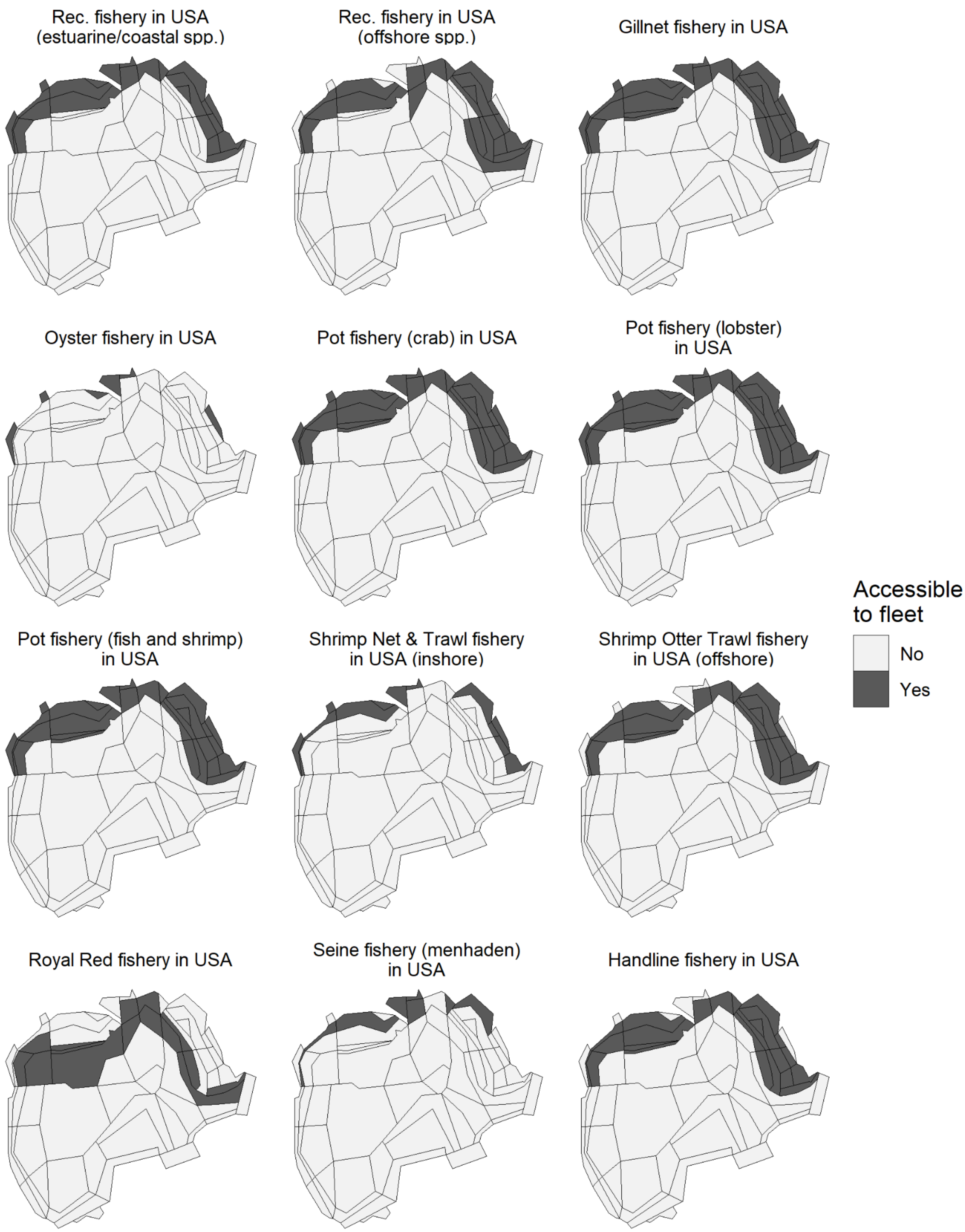


Figure 6. Polygons accessible to the fleets in GOM Atlantis.

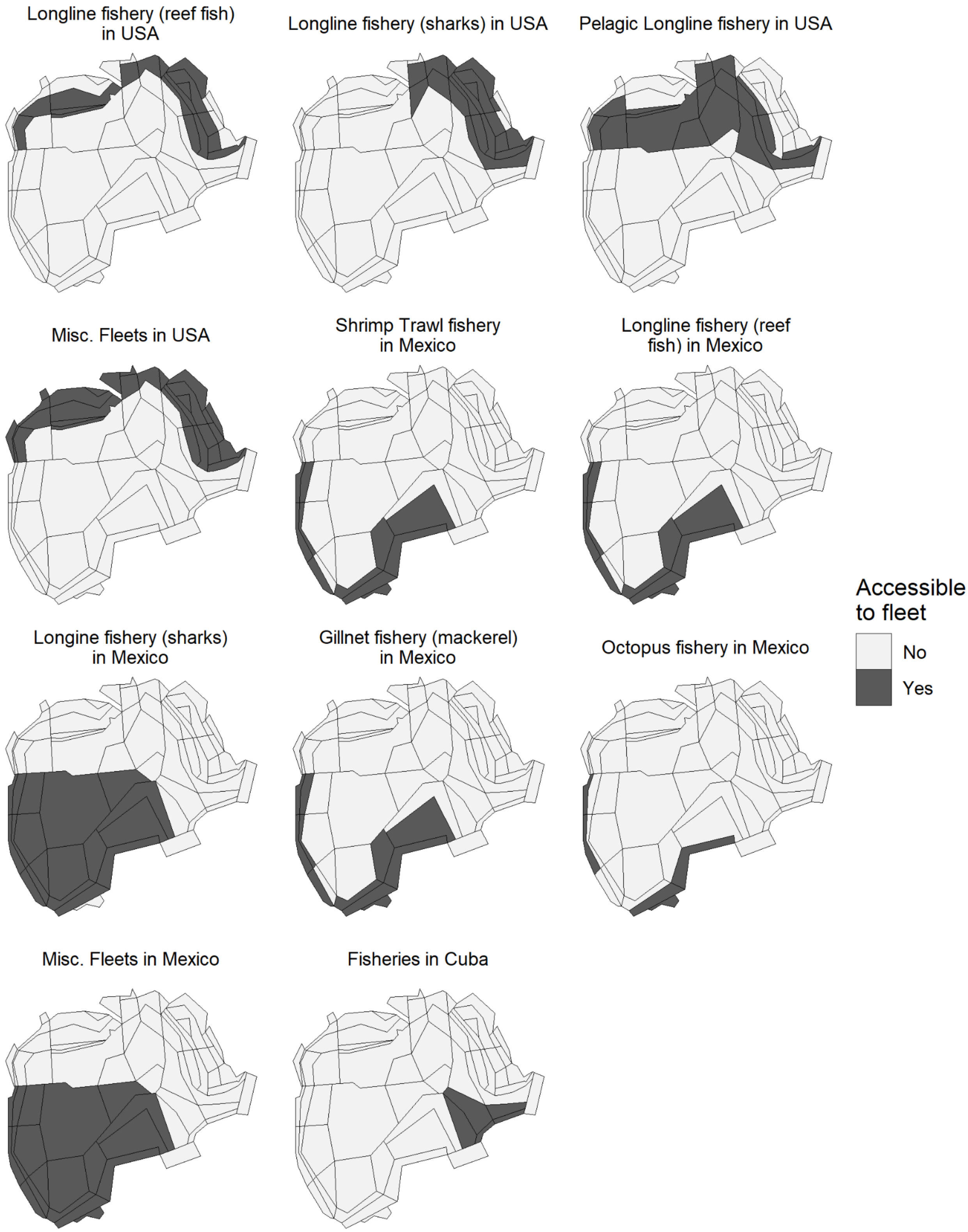


Figure 6. (continued)

Landings and Discards

The SEFSC GOM Atlantis internal review panel encouraged the incorporation of dead discarding to the fleets associated with the U.S. otter trawl fishery and U.S. recreational fishing, in addition to updating fishing mortalities for key commercial groups. First, dead discarding was set up for the related fleets. Then, the fishing mortality parameter (*mFC*) was adjusted to align, to the best of our abilities, GOM Atlantis fishing metrics to U.S. data.

Dead discard setup: U.S. otter trawl fishery

Bycatch has been a long-running issue for the shrimp otter-trawl fisheries of the Gulf of Mexico (NMFS 2006). As these were initial efforts to incorporate discarding into GOM Atlantis, we focused on two of the key bycatch finfish species from the U.S. otter trawl (as recommended by the SEFSC internal model review panel): red snapper (*Lutjanus campechanus*; RSN), and Atlantic croaker (*Micropogonias undulatus*; SRF). For both species, juveniles are the most susceptible to trawling (SEDAR 2018a, 2010). Fleets within GOM Atlantis, however, use knife-edge selectivity (with the parameter *mFC_startage* setting the first age class susceptible to the fishery). Thus, we revised the structural code of Atlantis to incorporate a new parameter (*mFC_endage*) to apply, essentially, reverse knife-edge selectivity. This allows the fleet representing the U.S. otter trawl fishery (*Shrimp Otter Trawl fishery in USA (offshore)*) to discard only the youngest age classes of the RSN and SRF groups. These code revisions have been shared with the Commonwealth Scientific and Industrial Research Organization (CSIRO), and are now available in the recent versions of the Atlantis code.

Discarding was applied to the first age-group of both RSN and SRF. Atlantis parameterizes each functional group with 10 age groups of equal length (e.g., a group with a 10 year lifespan would have age groups 0-1, 1-2, … 9-10). Thus, RSN age group 1 represents individuals 0-4 years old and SRF age group 1 represents individuals 0-0.3 years old. For red snapper, juveniles (age 0-1) are accidently captured by shrimp nets (SEDAR 2018a), which corresponds to the first age class of the RSN group in the GOM Atlantis model. For Atlantic croaker, juveniles (age 0) are accidently captured by shrimp nets (SEDAR 2010), which corresponds to the first age group of the SRF group in the GOM Atlantis model. All RSN and SRF in the first age-stanza caught by the *Shrimp Otter Trawl fishery in USA (offshore)* fleet are discarded. While there are several discard options within Atlantis (Audzijonyte et al. 2017b), we used simple constant discarding, setting the proportion of discarding (*FFCDR*) to 1. The proportion of catch that die after discarding (*incidmort*) was set to 1, so that all age group 1 RSN and SRF discarded by the *Shrimp Otter Trawl fishery in USA (offshore)* fleet die after discarding with the discarded biomass sent to the carrion detritus pool.

Dead discard setup: U.S. recreational fishing

Recreational discarding in the Gulf of Mexico is an important consideration as (i) the recreational sector provides a meaningful source of fishing mortality, (ii) participation in the Gulf of Mexico recreational sector has grown substantially since the mid-2000s, and (iii) data suggests that less than half of the catch (numbers) has been landed (Keithly and Roberts 2017). We received U.S. recreational catch data from MRIP, which includes observed landings (type A; caught and brought back to the dock), reported harvest (type B1; reported to be caught and killed but not seen/verified by the dockside sampler), and live-released discards (type B2; reported to be caught and released alive). First, species identifications provided in the MRIP data were used to aggregate the data by GOM Atlantis functional groups. The full species composition list for GOM Atlantis functional groups is provided by Ainsworth et al. (2015). Next, to parameterize the proportion of discarding (Atlantis parameter *FFCDR*), we computed the ratios of B1 data to A+B1 data to estimate the proportion of the recreational harvest discarded dead. Lastly, the proportion of catch that die after discarding (Atlantis parameter *incidmort*) was set to 1, so that all groups discarded by U.S. recreational fleets die after discarding. This allows the discarded biomass to be sent to the carrion detritus pool.

Parameterize fishing mortality

Fishing mortality in the GOM Atlantis model is governed by a matrix defining the daily mortality for each group-fleet interaction (*mFC*; Audzijonyte et al. 2017b). Ainsworth et al. (2015) detail the collated GOM historical catch dataset and the original parameterization of the fishing mortalities for the historical GOM Atlantis model. Herein, the parameterization of the fishing mortalities from U.S. fleets were updated based on U.S. catch data. U.S. commercial landings data were collected from NOAA's annual landing statistics database (https://www.fisheries.noaa.gov/national/sustainable-fisheries/commercial-fisheries-landings). Data were species-specific and included 2020 landings and the average landings from 2020-2018. U.S. commercial shrimp trawl discard data were collated from Scott-Denton et al. (2020). U.S. recreational catch data were pulled from NOAAs annual landing statistics database and MRIP (Personal Communication from the National Marine Fisheries Service, 2021). Data from NOAAs annual landing statistics database were of landings, and included 2020 data and the average from 2018-2020. Data from MRIP were of catches (landings + dead discards), and included the 2020 data. Fishing mortalities were collected from recent SEDAR assessments and NOAA assessment reports (Table 1).

Values in the *mFC* matrix were fine-tuned in order to i) align simulated U.S. catches at the end of one year to the collated U.S. catch data, and/or ii) align the resulting fishing mortalities to those collated from SEDAR and NOAA. The current comparisons are shown in Table 3 (with the resulting fleet catch compositions are shown in Figure A.6). Many of the functional groups are producing simulated U.S. catches at the end of year-1 that collate reasonably with U.S. catch data. For example, with respect to gag grouper, the average U.S. commercial landings from 2018-2020 were 268 (t), and the model simulates 299 (t). Similarly, MRIPs 2020 catch metric was 1,381 (t), and the model simulates 1,466 (t). It is worth noting that there are some groups where there is one-to-two orders of magnitude difference between the 2020 landings and the average landings from 2020-2018. Often, this due to reduced catches in 2020. Moving forward, care is needed in interpreting 2020 data, and further tuning of the *mFC* matrix may be necessary to ensure projected catches are a reasonable reflection of reality.

Table 3. Summary of the simulated U.S. catches and fishing mortalities.

Species-specific catches at the end of 1 simulated year and the resulting fishing mortalities are compared to catch data. U.S. commercial landings data were collected from NOAAs annual landing statistics database (https://www.fisheries.noaa.gov/national/sustainable-fisheries/commercial-fisheries-landings). Fishing mortalities were collected from recent SEDAR assessments and NOAA assessment reports (Table 1). Modeled U.S. commercial landings are presented alongside, within brackets, NOAAs 2020 landings metric and the average of the NOAA annual landings between 2018 and 2020. Data regarding commercial shrimp trawl discards are presented in the table footnotes. Modeled U.S. recreational catches (landings + dead discards) are presented alongside, within brackets, NOAAs 2020 landings metric, the average of the NOAA annual landings between 2018-2020, and MRIPs 2020 catch metric. Fishing mortality (F), based on the total U.S. catch and the total harvestable biomass within U.S. waters, is presented. Harvest rate (H) is presented if H exceeds 1 (bold values). Within the corresponding bracket is the F estimate from the most recent assessment.

Functional Group	US Com. landings (t) modeled [data]	US Rec. catches (t) modeled [data]	F modeled [data]
Reef Fish			
Gag grouper (GAG)	299 [255; 268]	1,466 [1,367; 1,189; 1,381]	0.28 [0.398]
Red grouper (RGR)	1,266 [1,274; 1,209]	1,397 [1,306; 1,048; 1,310]	0.27 [0.16]
Scamp (SCM)	120 [63; 67]	142 [151; 151; 180]	0.07 [0.109]
Shallow Serranidae (SSR)	45 [50; 49]	135 [208; 160; 146]	0.0009 [NA]
Deep Serranidae (DSR)	546 [504; 564]	218 [136; 199; 160]	0.009 [NA]
Red snapper[1] (RSN)	3,402 [3,421; 3,286]	4,627 [4,655; 5,456; 5,461]	0.12 [0.052]
Vermilion snapper (VSN)	456 [390; 543]	744 [513; 793; 706]	0.13 [0.08]
Lutjanidae (LUT)	694 [788; 1021]	3,590 [3,510; 2,946; 3,601]	0.02 [NA]
Large reef fish (LRF)	30 [44; 46]	499 [677; 547; 553]	0.006 [NA]
Small reef fish[2] (SRF)	233 [209; 263]	733 [620; 670; 739]	0.06 [NA]
Demersals			
Black drum (BDR)	1,311 [1,116; 1,790]	854 [623; 863; NA]	0.1 [NA]
Red drum (RDR)	21 [23; 24]	2,813 [2,349; 2,972; 5,498]	0.07 [NA]
Seatrout (SEA)	15 [28; 30]	2,604 [3,220; 4,353; NA]	0.15 [NA]
Sciaenidae (SCI)	104 [95; 90]	392 [610; 868; NA]	0.005 [NA]
Ladyfish (LDY)	670 [557; 684]	398 [309; 425; NA]	0.02 [NA]
Mullets (MUL)	2,733 [2,526; 3,154]	2,253 [2,097; 2,374; NA]	0.12 [NA]
Pompano (POM)	61 [61;67]	188 [315; 330; NA]	0.004 [NA]
Sheepshead (SHP)	258 [227; 529]	3361 [2,231; 2,127; 3,090]	0.02 [NA]
Snook (SNK)	0 [NA; NA]	54 [NA; NA; NA]	0.0008 [NA]
Flatfish (FLT)	26 [38; 65]	105 [386; 349; NA]	0.002 [NA]
Other demersal fish (ODF)	202 [266; 301]	1,850 [1,989; 1,842; 1,838]	0.01 [NA]
Small demersal fish (SDF)	3 [5; 5]	0 [NA; NA; NA]	0.00007 [NA]
Pelagic Fish			
Yellowfin tuna (YTN)	189 [189; 275]	99 [108; 92; NA]	0.04 [NA]
Bluefin tuna (BTN)	6 [0; 2]	0 [NA; NA; NA]	0.002 [NA]
Little tunny (LTN)	33 [65; 33]	1,241 [1,015; 1,128; 972]	0.02 [NA]
Swordfish (SWD)	116 [129; 109]	41 [70; 70; NA]	0.02 [NA]

Table 3 (continued). Summary of the simulated U.S. catches and fishing mortalities.

Functional Group	US Com. landings (t) modeled [data]	US Rec. catches (t) modeled [data]	F modeled [data]
Blue marlin (BMR)	0 [NA; NA]	27 [NA; NA; NA]	0.04 [NA]
Greater amberjack (AMB)	135 [193; 222]	836 [659; 680; 788]	0.91 [0.28]
Jacks (JCK)	450 [351; 492]	3,759 [4,111; 2,646; 3,920]	0.31 [NA]
King mackerel (KMK)	984 [1,017; 1,214]	1,674 [1,525; 1,906; 1,801]	1.98 [0.507]
Spanish mackerel (SMK)	295 [243; 402]	3,196 [2,731; 3,349; 2,813]	0.36 [NA]
Spanish sardine (SAR)	251 [299; 412]	17 [12; 58; NA]	0.004 [NA]
Large pelagic fish (LPL)	557 [501; 326]	1,435 [2,582; 2,200; 1,651]	0.002 [NA]
Forage Fish			
Menhaden (MEN)	405,720 [412,202; 476,163]	168 [NA; NA; NA]	0.45 [0.63]
Pinfish (PIN)	177 [96; 59]	1,311 [1,009; 1205; NA]	0.015 [NA]
Medium pelagic fish (MPL)	35 [102; 117]	15 [NA; 8; NA]	0.0010 [NA]
Small pelagic fish (SPL)	2,692 [2,454; 3,141]	686 [668; 2,286; NA]	0.004 [NA]
Elasmobranchs			
Blacktip shark (TIP)	206 [270; 102]	57 [43; 39; NA]	0.014 [0.0013]
Large sharks (LGS)	129 [157; 158]	97 [104; 225; NA]	0.0003 [NA]
Skates and rays (RAY)	58 [41; 26]	114 [NA; NA; NA]	0.0006 [NA]
Shrimps			
Brown shrimp (BSH)	19,300 [29,358; 36,343]	0 [NA; NA; NA]	**1.27** [1.93]
White shrimp (WSH)	48,435 [40,001; 41,023]	0 [NA; NA; NA]	0.17 [1.58]
Pink shrimp (PSH)	7,319 [5,387; 6,667]	0 [NA; NA; NA]	0.25 [0.34]
Other shrimp (OSH)	3,866 [4,133; 3,750]	0 [NA; NA; NA]	0.014 [NA]
Commercial Benthos			
Blue crab (BCR)	22,572 [19,823; 22,122]	0 [NA; NA; NA]	0.44 [NA]
Stone crab (SCR)	944 [979; 982]	0 [NA; NA; NA]	0.02 [NA]
Crabs and lobsters (LOB)	1,268 [1,796; 2,236]	212 [NA; NA; NA]	0.08 [NA]
Filter Feeders			
Oysters (OYS)	4,531 [4,114; 5,648]	0 [NA; NA; NA]	0.0009 [NA]
Bivalves (BIV)	6 [5; 7]	0 [NA; NA; NA]	0.000004 [NA]
Pelagic Invertebrates			
Squid (SQU)	28 [15; 22]	0 [NA; NA; NA]	0.00002 [NA]

Model tuning and diagnostics

Previously, model tuning and diagnostics of the GOM Atlantis model centered around a historical reconstruction, with the 1980 model being driven forward to 2010 using time series inputs representing catch trends, seasonal fishing closures, and spatial fishing closures (Ainsworth et al. 2015). Following historical fitting, Ainsworth et al. (2015) transferred biological rate parameters (i.e., the biol.prm) to the 2010 model, thus assuming stationarity since 1980. All simulations presented in the current memorandum begin with the updated 2020 initial conditions and project forward 50 years under the assumptions of (i) a one-year loop of oceanographic forcing, (ii) the habitat refuge model turned off, and (iii) fishing and discarding rates held constant. In these simulations, we expect a 20 year 'spin-up' period, as the model adjusts from initial assumptions to an approximate quasi-equilibrium. We, therefore, focus primarily on results for simulation years 20-50. We evaluate the performance of modeled biological groups and fisheries, paying particular attention to the single-species shrimp groups (BSH, WSH, and PSH), and the key shrimp predators and prey. These key predator and prey groups (Table 4) were identified by the SEFSC internal review panel. The internal review panel discussion highlighted the inclusion of Epiphytes due to their potential of being an important prey item for Penaeids (Hewitt et al. 2020).

Table 4. Key groups associated with Gulf of Mexico shrimp identified by the SEFSC internal review panel.

Functional Group	Category
Brown shrimp (BSH)	focal group
White shrimp (WSH)	focal group
Pink shrimp (PSH)	focal group
Red snapper (RSN)	key predator
Red drum (RDR)	key predator
Seatrout (SEA)	key predator
Snook (SNK)	key predator
Flatfish (FLT)	key predator
Skates and Rays (RAY)	key predator
Lutjanidae (LUT)	key predator
Infaunal meiobenthos (INF)	key prey
Epiphytes (EPI)	key prey
Seagrass (GRS)	key habitat

We evaluate model performance in terms of criteria suggested by Kaplan and Marshall (2016), based on their experience with the review of a California Current Atlantis model. The model performance criteria span simulated population dynamics, productivity, life history parameters, and ecology. The evaluation of simulated population dynamics consists of ensuring (i) the persistence of functional groups, (ii) that the model achieves equilibrium, and (iii) the reproduction of patterns of temporal variability at many time scales (i.e., seasonal, decadal, etc.). The evaluation of simulated life history consists of ensuring that (i) the natural mortality (*M*), including predation, decreases with age for the majority of functional groups, and (ii) the age and length structure from the model qualitatively matches expected age and length structures for the majority of functional groups. The evaluation of simulated ecology consists of ensuring that the realized diets from the model qualitatively match diet data from empirical studies for the majority of functional groups. The evaluation of simulated productivity for the focal shrimp groups consists of simulating the equilibrium response of aggregated shrimp biomass to a range of constant fishing rates.

Population dynamics

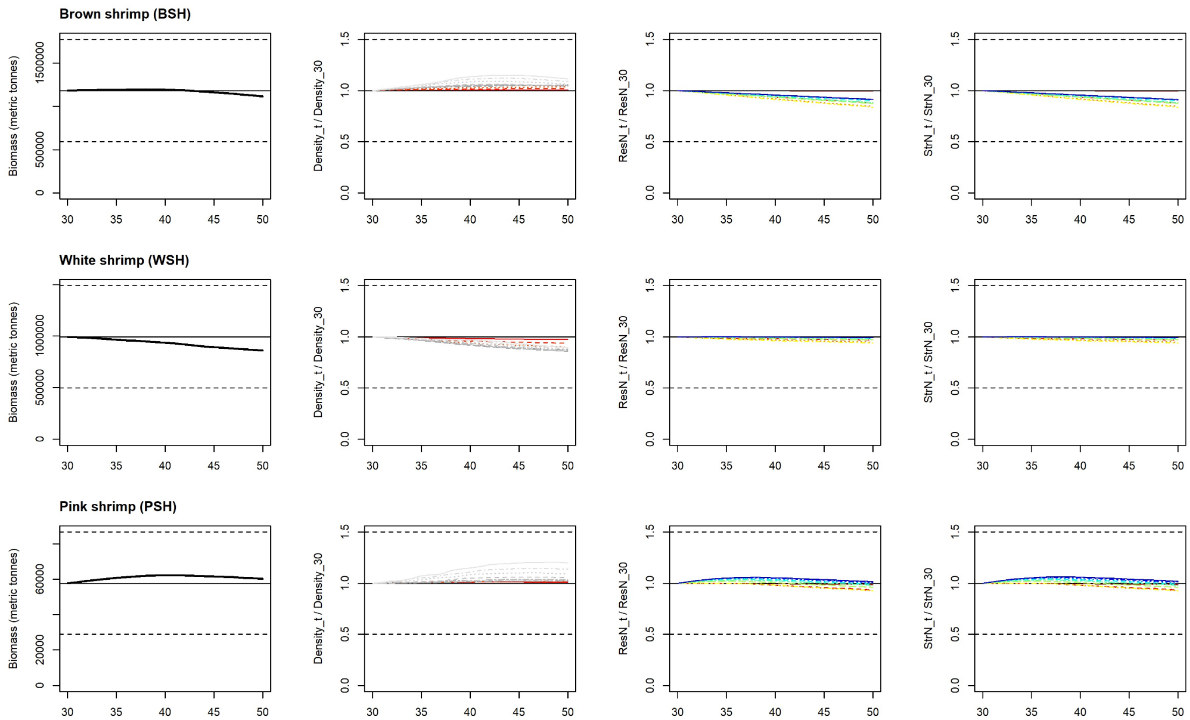
The three focal shrimp groups show long-term persistence of biomass and density (Fig. 7A). Biomass trends of white shrimp show signs of a minor long-term shift due to density. Biomass trends of brown shrimp and pink shrimp slightly shift due to nitrogen, with long-term biomass of brown shrimp slightly decreasing and long-term biomass of pink shrimp slightly increasing. All of these long-term trends, however, are within 50% of the value post-burn-in, which is considered acceptable for long-term stability (Horne et al. 2010, Audzijonyte et al. 2017a, Pethybridge et al. 2019). With respect to key groups, there is some variability (Fig. 7B). Biomass trends for seatrout, snook, red snapper, red drum, infaunal meiobenthos, epiphytes, and seagrass are all within 50% of the value post-burn-in, while biomass trends for skates and rays, Lutjanidae, and flatfish are bordering the 50% threshold. Abundance trends for red snapper and red drum show signs of long-term instability. For example, red snapper density indicates a gradual shift in age structure over 50 years with younger age classes becoming more abundant and older age classes becoming less abundant (Fig. 7B). Abundance trends for Lutjanidae, seatrout, snook, flatfish, and skates and rays are within the 50% threshold. The biomass for most focal groups seems to be influenced by a gradual decline in long-term nitrogen (i.e., loss of soft tissue and hard structure).

When considering the remaining groups (Fig. B.1), there is a lot of variability. There are several groups that show signs of long-term abundance stability, including large reef fish, black drum, ladyfish, pompano, little tunny, large pelagic fish, and menhaden. There are some groups that show long-term increases in density across all age classes, such as deep Serranidae, other demersal fish, small demersal fish, other billfish, and deep water fish. Lastly, there are some groups that show long-term decreases in density across all age classes, including red grouper, shallow Serranidae, vermillion snapper, swordfish, blue marlin, white marlin, large sharks, and filter feeding sharks. Tuning pertinent dynamics, such as predator-prey interactions and recruitment, is being conducted to find solutions to these long-term abundance declines and, although some of the up-to-date results are not shown herein, solutions have been found for some functional groups and will be presented at the CIE Review. While unstable trends in abundance seem to drive unstable biomass trends for some groups (e.g., other tuna, swordfish, white marlin), long-term trends in biomass are also influenced by long-term trends in nitrogen (see subsection *Individual weights*).

Changes in reserve nitrogen (i.e., muscle, fats, gonads, and other soft tissue) and structural nitrogen (i.e., bones and other hard parts) relative to initialization over time, and ii) weight-at-age over time. For the former, a relative ratio of 0.5-1.5 is considered optimum for vertebrates. With respect to reserve nitrogen, a lower relative ratio is an indication of starvation which can be attributed to a variety of outcomes, such as low prey abundance and low consumption rates. A higher relative ratio, however, is an indication of overconsumption which can be attributed to outcomes such as high consumption rates. Structural nitrogen is less sensitive to the effects of starvation, however could be indicative of other issues. For instance, sudden drops of nitrogen can be related to issues with recruitment. Diagnosing trends in relative nitrogen is discussed further by Pethybridge et al. (2019).

Considering a 50-year simulation, nitrogen trends for most of our focal and key groups are within an acceptable relative ratio range (Fig. 7). Nitrogen trends of our focal groups (BSH, WSH, and PSH) exhibit optimum and stable long-term relative ratios for all age-classes (Fig. 7A). Long-term nitrogen trends for BSH slightly decrease while long-term nitrogen trends for PSH slightly increase, however these shifts are relatively minor. With respect to the key groups (Fig. 7B), long-term nitrogen trends are within optimum ranges but groups red snapper, Lutjanidae, red drum, seatrout, flatfish, and skates and rays show some signs of long-term nitrogen loss (particularly for older ages classes). With respect to the remaining functional groups (Fig. B.1), there is much variability. There are several groups that display long-term nitrogen stability, including other shrimp, gag grouper, deep Serranidae, menhaden, large pelagic fish, and benthic feeding sharks. Deep water fish is the only group showing signs of long-term nitrogen incline (overconsumption) across all age-classes. There are several groups that show signs of long-term nitrogen decline (starvation), including shallow Serranidae, sheepshead, other billfish, and Spanish mackerel, and Spanish sardine. These long-term signs of nitrogen decline are contributing to the long-term biomass decline across groups, but these trends were not present until after a recent code update, thus we think this is occurring due to changes to the Atlantis code. We must use the most up-to-date code of Atlantis due to the recent advances that have been made to GOM Atlantis (i.e., the pseudo-age-structured seagrass model, reverse knife-edge selectivity). Tuning assimilation efficiencies and individual growth rates has helped to find solutions to these long-term population declines and have been incorporated.

A



B (see next page)

Figure 7. Time series displaying biomass, density relative to simulation year 30, reserve nitrogen relative to simulation year 30, and structural nitrogen relative to simulation year 30. Diagnostics for relative density and nitrogens, which are only available for age-structured groups, are plotted for individual age classes. For relative density, sexually immature age classes are plotted using a heat scale (with the red line being the youngest immature age class and the orange line being the oldest immature age class), while sexually mature age classes are plotted using a gray scale (with the darkest color being the youngest mature age class and the lightest color being the oldest mature age class). For relative nitrogens, age classes are plotted using a rainbow scale, with the solid red line representing the youngest age class and the solid blue line representing the oldest age class. The following images are presented relative to simulation year-30, dropping the burn-in period.

B

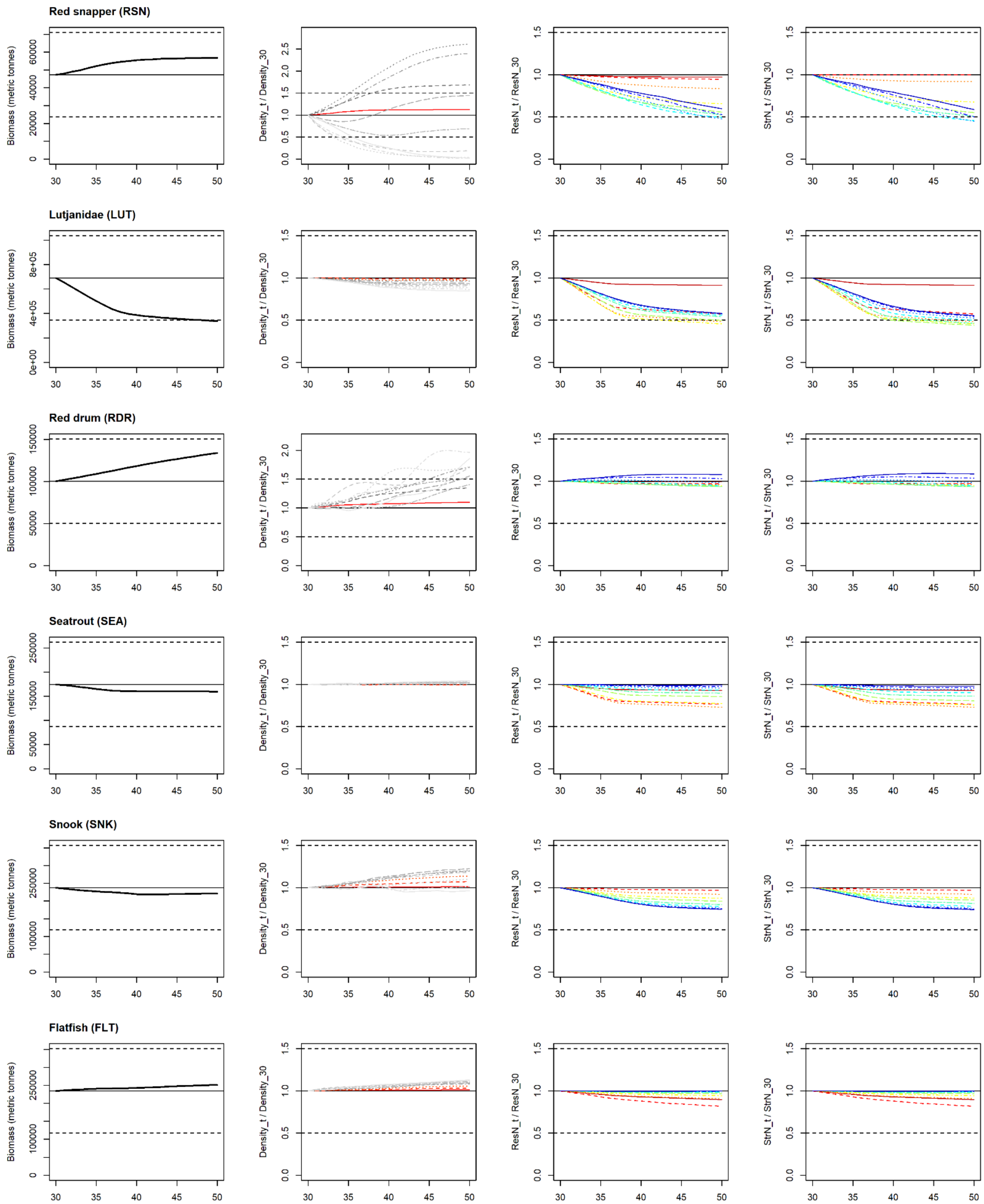


Figure 7. (continued).

B (continued)

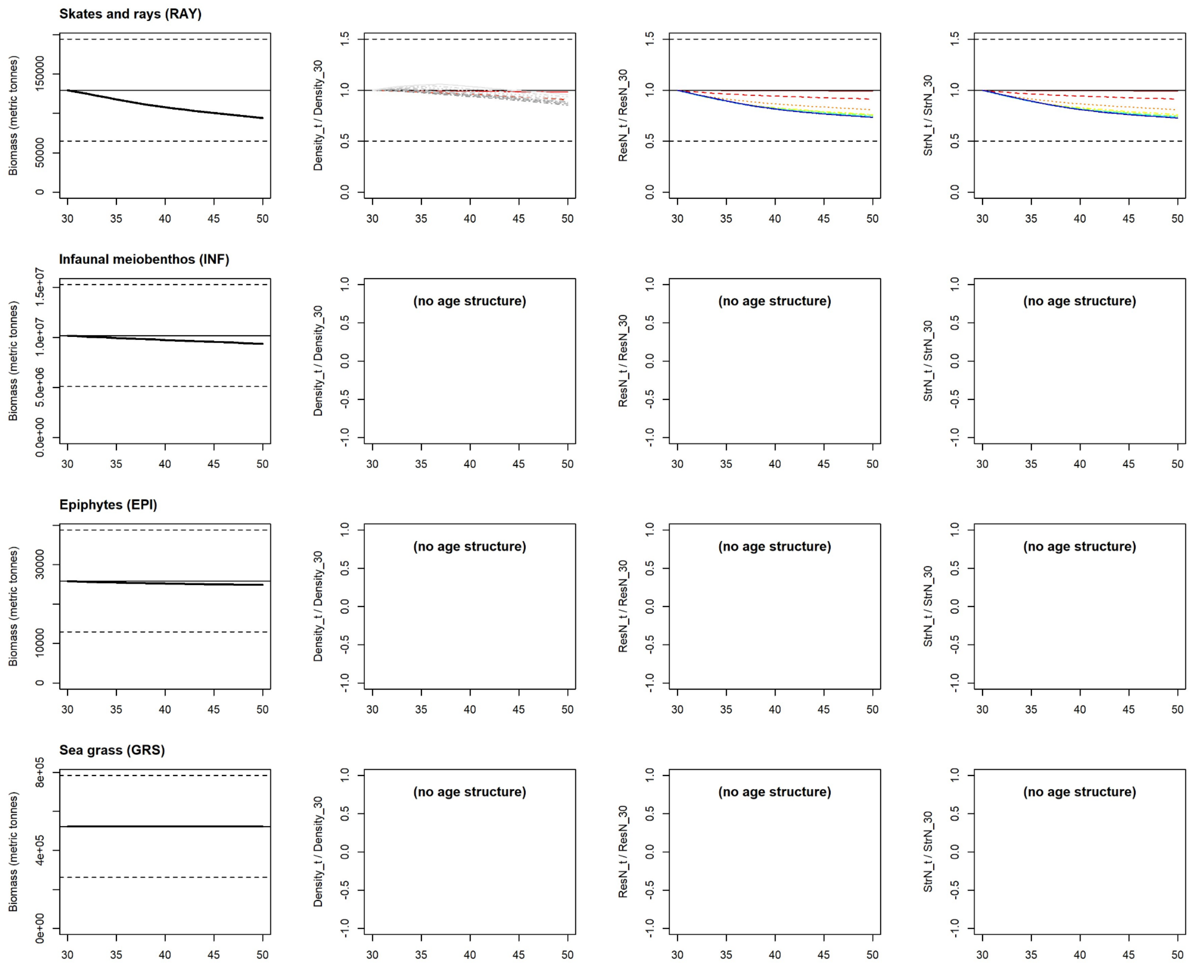


Figure 7. (continued).

Life history and ecology

Individual weights are diagnosed with weight-at-age over time (Fig. 8, B.2). For most of the focal and key groups, the realized weight-at-age drifts away from the initial state. This is not ideal. For some groups, the drift occurs relatively swiftly. For instance, within the first 10 years, weight-at-age stabilizes to a reduced S-curve trend for all shrimp groups (Fig. 8). This could be reflecting improper initialization of weight-at-age parameters, as there are some groups displaying weight-at-age structures post-burn-in (after year 20) that are qualitatively comparable to estimates (e.g., red snapper; SEDAR 2018a, Fischer et al. 2004). We can handle this shift with the use of a burn-in until it can be addressed in-model. For other key groups like RSN, the transition to a new stable age structure occurs gradually throughout the 50-year simulation (Fig. 8). It is worth noting that there are many groups trending towards smaller weight-at-age over time (Fig. 8, B.2). Life history and ecology dynamics should also be diagnosed with predator-prey dynamics. Average prey proportions for a select group of predators are presented here (Fig. A.1), but this is to be expanded on for the CIE review to diagnose the stability of predator-prey dynamics throughout a simulation.

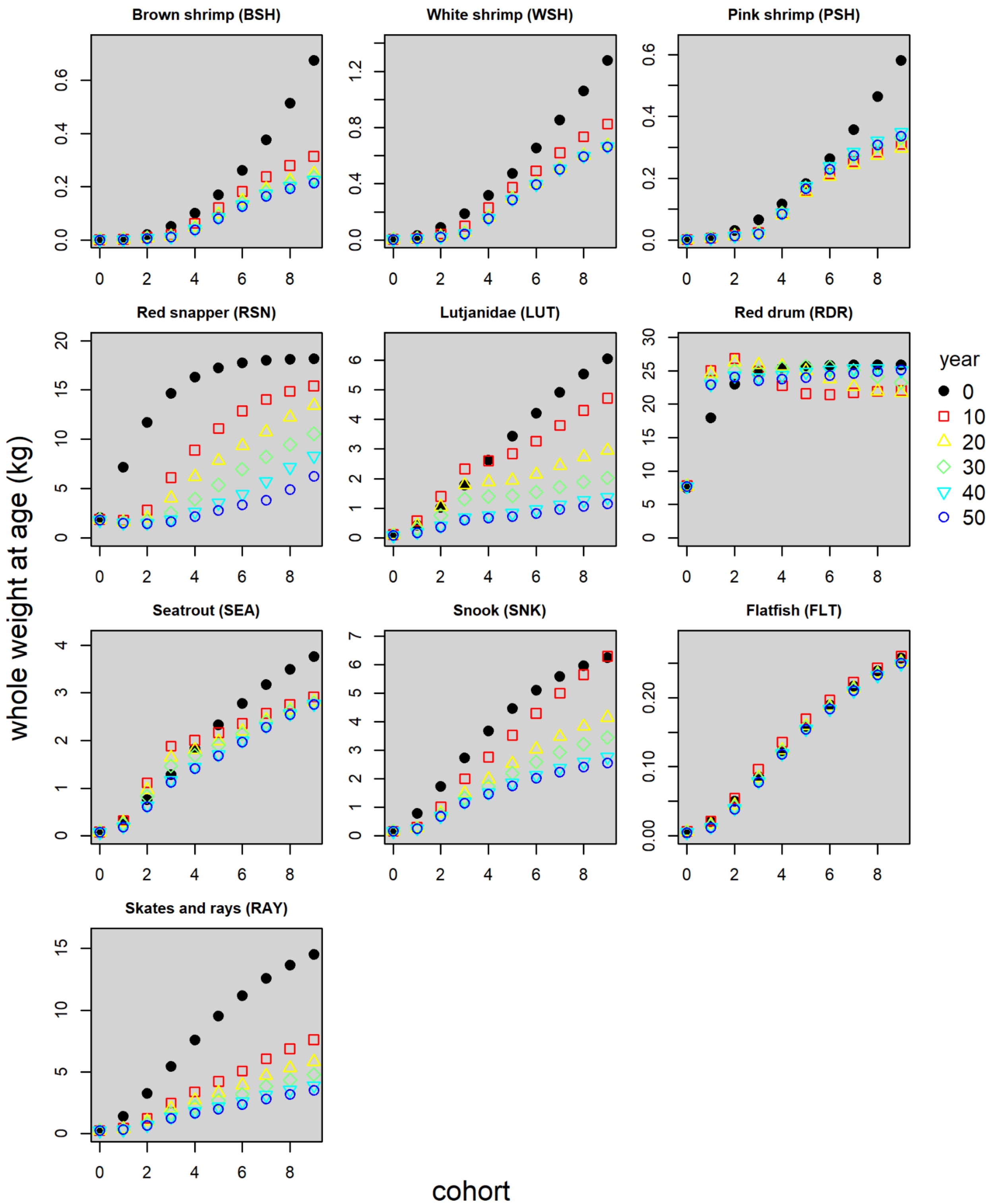


Figure 8. Individual weight-at-age over time for focal groups. The x-axis shows ten age classes (cohort) labeled from 0 to 9.

Productivity for Penaeids

The productivity of modeled species can be evaluated by simulating the equilibrium response of biomass to a range of constant fishing rates (Kaplan and Marshall 2016). Typically, this would be compared to productivity (e.g., maximum sustainable yield, MSY; fishing mortality at maximum sustainable yield, F_{MSY}; biomass at maximum sustainable yield, B_{MSY}) estimates from stock assessments. However, for shrimp specifically, the Southeast Fisheries Science Center and the Gulf's Scientific and Statistical Committee identified a number of technical concerns with the historic Penaeid shrimp stock assessment models. Since 2020, those shrimp assessment models have been deemed unreliable and are no longer used to provide stock determination criteria. The three Penaeid stocks are scheduled to go through a formal model development and review process beginningin late 2023. Presently, no assessment models are available to provide reliable productivity estimates for these three Penaeid stocks. Therefore, to provide some level of evaluation, herein we compare Atlantis estimates of productivity to those from a selection of Ecopath with Ecosim (EwE) models of subsystems within the Gulf of Mexico.

EcoBase, an open-access database of EwE models, was used to select and access a small collection of EwE models of subsystems within the Gulf of Mexico (Table 5). While GOM Atlantis has individual groups for BSH, WSH, and PSH, all of the selected EwE models have a single, aggregate shrimp group. For each EwE model, we generated estimates of MSY and F_{MSY}. An estimate of maximum sustainable yield ($M\hat{S}Y$) was ascertained based on the following:

$$M\hat{S}Y \approx (PB - M) \times B \qquad \text{Eq. 11 1}$$

where *PB* is the group's production over biomass ratio, *M* is the group's natural mortality, and *B* is the group's biomass (computed by multiplying the groups biomass in habitat area, t/km^2, by the modeling area, km^2). This formula provides the biomass left over after the predators have eaten, which we assume to be an estimate of MSY. Estimates of F_{MSY} were ascertained based on the F_{MSY} tool in Ecosim, which provided estimates of F_{MSY} estimates under the Stationary System approach ($F_{MSY,SS}$) and the Full Compensation approach ($F_{MSY,FC}$). Under the Stationary System approach, there are no interactions between species (i.e., biomasses for groups not assessed are kept constant through the simulation) while the Full Compensation approach takes into account the indirect changes in biomass of other species (Walters et al. 2005). The resulting estimates for each of the selected EwE models are summarized in Table 5.

Table 5. Estimates of shrimp MSY and F_{MSY} from a selection of Ecopath with Ecosim models of the Gulf of Mexico.

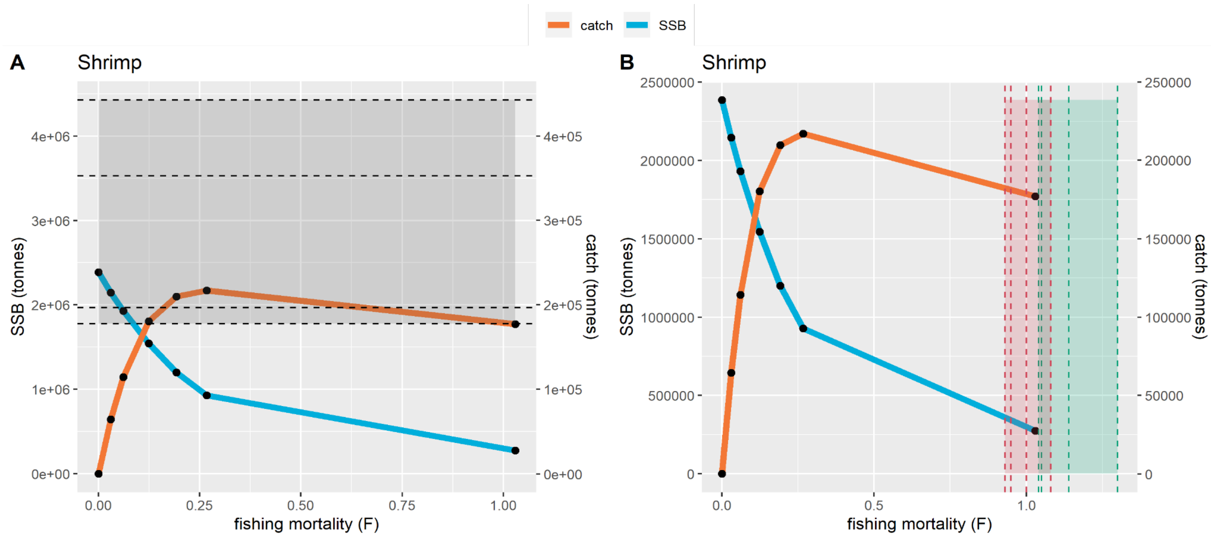
A selection of Ecopath with Ecosim models of the Gulf of Mexico accessed via EcoBase. An estimate of maximum sustainable yield ($M\hat{S}Y$) was made using Eq. 11. Estimates for F_{MSY} were made based on the Full Compensation approach ($F_{MSY,FC}$) and the Stationary System approach ($F_{MSY,SS}$). See Fig. 9 for the comparison to shrimp productivity from GOM Atlantis.

Reference	Domain	Area (km^2)	PB	M	Biomass (t/km^2)	*MSY* (t)	$F_{MSY,FC}$	$F_{MSY,SS}$
Walters et al. (2008)	Northern GOM	310,000[i]	2.4	0.97	1	442,680	1.05	0.93
Sagarese et al. (2017)	Northern GOM	310,000	3.8	3.33	2.4	352,656	1.14	1.00
Vilas et al. (2020)	WFS	170,000	3.7	2.81	1.36	196,924	1.30	1.08
Chagaris et al. (2015)	WFS	170,000	3.7	2.13	0.68	177,881	1.04	0.95

[i] Based on area from Sagarese et al. (2017) model.

To attain shrimp productivity in GOM Atlantis, a range of constant fishing rates were simulated to develop the equilibrium response of catch and biomass. Recall, GOM Atlantis has individual groups for BSH, WSH, and PSH while all of the selected EwE models have a single, aggregate shrimp group. Thus, in order to properly compare shrimp productivity in GOM Atlantis to the $M\hat{S}Y$ and F_{MSY} estimates from the selected EwE models, the range of constant fishing rates were simulated by simultaneously scaling fishing mortalities (the mFC matrix in Atlantis) of BSH, WSH, and PSH. Scaled fishing moralities were simulated for 50-years. The equilibrium penaeid catch and biomass curves resulting from GOM Atlantis are compared to the $M\hat{S}Y$ and F_{MSY} estimates from the selection of EwE models in Fig. 9. Equilibrium curves are presented based on catch and biomass across the entire GOM modeling domain, and catch and biomass from polygons making up USA-waters. Estimates of F_{MSY} for Atlantis are lower than the Ecopath estimates (Fig. 9B), but Atlantis also has a very broad F-vs-catch curve, in which even higher levels of $F > F_{MSY}$ still give fairly high catches. In other words, our model supports the high Fs suggested by Ecopath F_{MSY}, though it assumes this will lead to lower levels of stock biomass.

GOM-wide:



USA-waters:

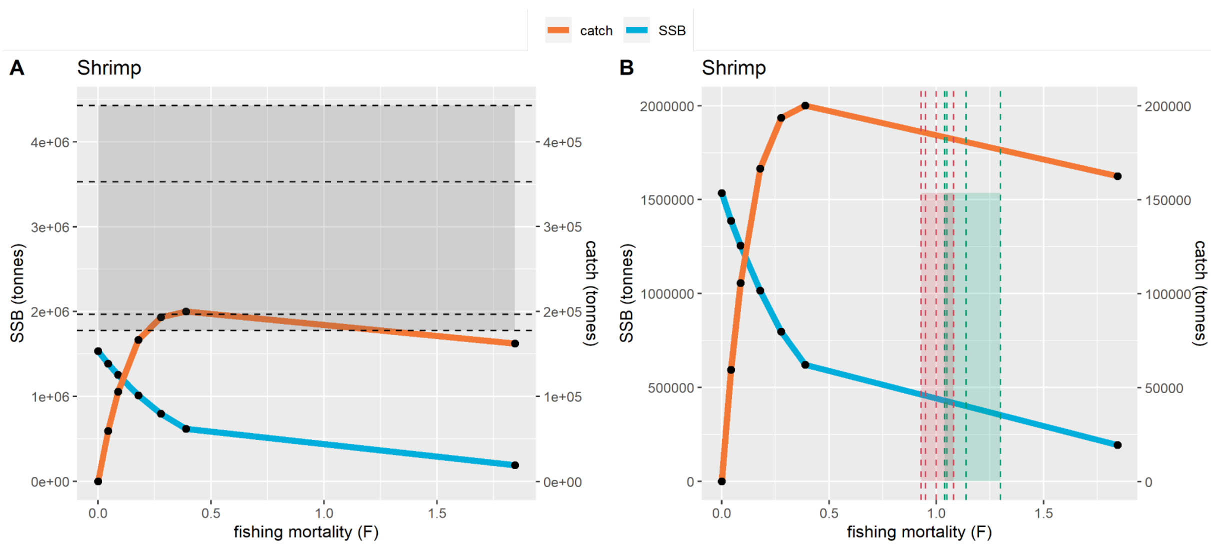


Figure 9. Comparing equilibrium catch and biomass curves for focal shrimp groups (aggregated) from GOM Atlantis to estimates of shrimp MSY and Fmsy for the selected EwE models.

Shrimp (aggregated across BSH, WSH, and PSH) fishing mortalities (computed as -ln(1-(catch/SSB)) at the end of a 50-year baseline simulation are presented against aggregated shrimp spawning stock biomasses (SSB; solid blue line) and catches (solid orange line). Shrimp equilibrium catch curves from GOM Atlantis are presented with MSY estimates (Panel A) and F_{MSY} estimates (Panel B) from a selection of Ecopath with Ecosim (EwE) models of subsystems within the Gulf of Mexico (Table 4). In Panel A, MSY estimates from the individual EwE models are indicated with black, dashed lines (with the entire range highlighted with the gray shaded region). In Panel B, F_{MSY} estimates from individual EwE models are indicated. Estimates from the Stationary System approach are indicated with red dashed lines (with the entire range highlighted with the red shaded region), and those from the Full Compensation approach are indicated with green dashed lines (with the entire range highlighted with the green shaded region).

Discussion

This document provides an overview of the revised GOM Atlantis model, including the major updates, innovations, and model performance, which served as model technical documentation presented to the CIE review panel. Recent work is highlighted that improved the model's parameterization but also broadened its simulation capabilities. The updates made to the pelagic food web reflect lessons learned from the Deepwater Horizon oil spill. That work indicated the importance of considering the diel movement of fish in quantifying pelagic interactions on the WFS and highlighted the vulnerability of deepwater ecosystems to oil spills (Sutton et al. 2022). We now better represent the connection of the mesopelagic ecosystem with epipelagic predators. The development of new Atlantis code (i.e. the pseudo-age-structured seagrass model, reverse knife-edge selectivity) also has a connection with oil spill science as RESTORE Act-funded efforts continue to emphasize habitat rehabilitation and cross-shelf connections.

Future work on the GOM Atlantis model is necessary to address data and model configuration issues identified during the CIE review, which are expanded upon below. Nonetheless, this work represents meaningful advancements in modeling tools for supporting EBFM in the GOM, strengthening collaborations across SEFSC and cross-regionally, and meeting the objectives of the EBFM Road Map, Climate Regional Action Plan, and Stock Assessment Improvement Plan by enhancing the SEFSC's ecosystem modeling capacity. The CIE review process helped model developers to engage with scientists from four NOAA offices (SERO, SEFSC, NWFSC, Chesapeake), FWC, and other institutes.

Initial project objectives were focused on Gulf shrimp species with clear end goals of bringing environmental considerations into the Gulf shrimp stock assessments. However, the future of Gulf shrimp assessments (i.e., what modeling platform, etc.) changed considerably during our project, and is currently being considered during the SEDAR 87 Gulf Shrimp Research Track Assessment. The CIE review of the GOM Atlantis model occurred on March 28–30, 2023, and remained focused on Gulf shrimp dynamics and applications. The diagnostics presented here formed the baseline of the full suite of diagnostics discussed during the CIE review. Ultimately, the CIE review identified a number of parameterization and configuration issues to address before the model could be used to provide management advice. The identified issues were ranked according to priority by the CIE review panel, the modeling team, and the project team to strengthen model readiness. The priority issues that were identified include:

- Fix unrealistic predator-prey linkages. This will involve reviewing diet data used to develop the initial conditions of the availability matrix and the realized predator-prey interactions to ensure interspecific interactions remain realistic throughout a simulation.
- For applicable focal and key groups, improve stability in the temporal trends of key life history parameters (growth and mortality) and group biomasses. For example, make the necessary adjustments to ensure weight-at-age remains within a realistic range throughout the hindcast and forecast.

- Fix shrimp dynamics by reducing the length of the age categories to an appropriate range and adjust the recruitment window for shrimp groups (using multiple windows if possible).
- Fix the temporal stability of the growth and mortality of red snapper.
- Expand the focus to one of the key finfish species, as this might help show the potential of Atlantis in terms of management use.
- Expand on the existing diagnostics, and, whenever possible, all outputs of the model should be sanity-checked against available data and expert knowledge. For example, present natural mortality-at-age and fishing mortality-at-age for all focal and key groups, which can be directly compared with stock assessment.

Formal model reviews are an important step towards integrating ecosystem models into the development of strategic management advice, but it is not common for ecosystem models to be subject to formal review. This project, however, underwent a unique experience with the GOM Atlantis model being subject to both an informal peer review (with regional experts) and a formal peer review (with independent experts). Future work will offer our perspectives to aid future model reviews and propose quality control standards to consider for end-to-end models for use in EBFM.

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Appendix A – Model information

Table A.1. Functional groups in GOM Atlantis.
A detailed functional group species composition list is provided by Ainsworth et al. (2015).

Functional group	species	Functional group	species
Gag grouper (GAG)	*Mycteroperca microlepis*	Small sharks (SMS)	e.g., *Etmopterus* spp.
Red grouper (RGR)	*Epinephelus morio*	Skates and rays (RAY)	e.g., *Dasyatis* spp.
Scamp (SCM)	*Mycteroperca phenax*	Brown shrimp (BSH)	*Farfantepenaeus aztecus*
Shallow Serranidae (SSR	e.g., *Mycteroperca* spp.	White shrimp (WSH)	*Litopenaeus setiferus*
Deep Serranidae (DSR)	e.g., *Epinephelus* spp.	Pink shrimp (PSH)	*Farfantepenaeus duorarı*
Red snapper (RSN)	*Lutjanus campechanus*	Other shrimp (OSH)	e.g., *Acanthephyra* spp.
Vermilion snapper (VSN	*Rhomboplites aurorubens*	Diving birds (DBR)	e.g., *Anas* spp., *Larus* spp
Lutjanidae (LUT)	e.g., *Lutjanus* spp.	Surface feeding birds (SBR)	e.g., *Chararius* spp.
Bioeroding fish (BIO)	e.g., *Sparisoma* spp.	Manatee (MAN)	*Trichechus manatus*
Large reef fish (LRF)	e.g., *Halichoeres* spp.	Mysticeti (MYS)	e.g., *Megaptera novaeangliae*
Small reef fish (SRF)	e.g., *Labrisomus* spp.	Dolphins and porpoises (DOL	e.g., *Stenella* spp
Black drum (BDR)	*Pogonias cromis*	Deep diving odontocete (DDC	e.g., *Kogia* spp.
Red drum (RDR)	*Sciaenops ocellatus*	Loggerhead (LOG)	*Caretta caretta*
Seatrout (SEA)	e.g., *Cynoscion* spp.	Kemps Ridley (KMP)	*Lepidochelys kempii*
Sciaenidae (SCI)	e.g., *Menticirrhus* spp.	Other turtles (TUR)	e.g., *Chelonia mydas*
Ladyfish (LDY)	e.g., *Elops* spp.	Blue crab (BCR)	*Callinectes* spp.
Mullets (MUL)	e.g., *Mugil* spp.	Stone crab (SCR)	*Menippe mercenaria*
Pompano (POM)	e.g., *Trachinotus* spp.	Crabs and lobsters (LOB)	e.g., *Munida* spp.
Sheepshead (SHP)	*Archosargus probatocephalus*	Stony corals (COR)	e.g., *Scleractinia* spp.
Snook (SNK)	e.g., *Centropomus* spp.	Crustose coralline algae (CCA	e.g., *Corallinaceae* spp.
Flatfish (FLT)	e.g., *Symphurus* spp.	Octocorals (OCT)	e.g., *Chrysogorgia* spp.
Other demersal fish (ODI	e.g., *Gymnothorax* spp.	Sponges (SPG)	e.g., *Axinellidae* spp.
Small demersal fish (SDI	e.g., *Diaphus* spp.	Carnivorous macrobenth (CMB)	e.g., *Munida* spp.
Yellowfin tuna (YTN)	*Thunnus albacares*	Infaunal meiobenthos (INF)	e.g., *Lestrigonus* spp.
Bluefin tuna (BTN)	*Thunnus thynnus*	Herbivorous echinoder (ECH)	e.g., *Echinoidea* spp.
Little tunny (LTN)	*Euthynnus alletteratus*	Oysters (OYS)	e.g., *Crassostrea* spp.
Other tuna (OTN)	e.g., *Auxis* spp.	Bivalves (BIV)	e.g., *Bivalvia* spp.
Swordfish (SWD)	*Xiphias gladius*	Sessile filter feeders (SES)	e.g., *Amphibalanus* spp.
White marlin (WMR)	*Tetrapturus albidus*	Epiphytes (EPI)	e.g., *Polysiphonia* spp.
Blue marlin (BMR)	*Makaira nigricans*	Seagrass (GRS)	e.g., *Angiosperm* spp.
Other billfish (BIL)	e.g., *Istiophorus* spp	Macroalgae (ALG)	e.g., *Chondria* spp.
Greater amberjack (AMB	*Seriola dumerili*	Microphytobenthos (MPB)	
Jacks (JCK)	e.g., *Caranx* spp., *Seriola* spp.	Large phytoplankton (LPP)	
King mackerel (KMK)	*Scomberomorus cavalla*	Small phytoplankton (SPP)	
Spanish mackerel (SMK)	*Scomberomorus maculatu*	Toxic dinoflagellates (DIN)	

Table A.1. Continued. Functional groups in GOM Atlantis.
A detailed functional group species composition list is provided by Ainsworth et al. (2015).

Functional group	species	Functional group	species
Spanish sardine (SAR)	*Sardinella aurita*	Protists (PRO)	e.g., *Eutintinnus* spp.
Large pelagic fish (LPL)	e.g., *Remora* spp.	Jellyfish (JEL)	e.g., *Cnidaria* spp.
Deep water fish (DWF)	e.g., *Peristedion* spp.	Squid (SQU)	e.g., *Cephalopoda* spp.
Menhaden (MEN)	*Brevoortia* spp.	Large zooplankton (LZP)	
Pinfish (PIN)	*Lagodon rhomboides*	Small zooplankton (SZP)	
Medium pelagic fish (MI	e.g., *Eucinostomus* spp.	Bacteria (PB)	
Small pelagic fish (SPL)	e.g., *Harengula* spp.	Sediment bacteria (BB)	
Blacktip shark (TIP)	*Carcharhinus limbatus*	Carrion detritus (DC)	
Benthic feeding sharks (BEN)	e.g., *Pristis* spp.	Labile detritus (DL)	
Large sharks (LGS)	e.g., *Sphyrna* spp.	Refractory detritus (DR)	
Filter feeding sharks (FIL	e.g., *Manta birostris*		

Table A.2. Minimum and maximum tolerated temperatures of modeled functional groups.

Functional Group	Min. temp (°C)	Max. temp (°C)	Functional Group	Min. temp (°C)	Max. temp (°C)
Gag grouper (GAG)	5	40	Large sharks (LGS)	5	40
Red grouper (RGR)	5	40	Filter feeding sharks (FIL)	5	40
Scamp (SCM)	5	40	Small sharks (SMS)	5	40
Shallow Serranidae (SSR)	5	40	Skates and rays (RAY)	5	40
Deep Serranidae (DSR)	5	32	Brown shrimp (BSH)	5	40
Red snapper (RSN)	5	40	White shrimp (WSH)	5	40
Vermilion snapper (VSN)	5	40	Pink shrimp (PSH)	5	40
Lutjanidae (LUT)	5	40	Other shrimp (OSH)	5	40
Bioeroding fish (BIO)	5	40	Diving birds (DBR)	5	40
Large reef fish (LRF)	5	40	Surface feeding birds (SBR)	5	40
Small reef fish (SRF)	5	40	Manatee (MAN)	13	40
Black drum (BDR)	5	40	Mysticeti (MYS)	5	40
Red drum (RDR)	5	40	Dolphins and porpoises (DOL)	5	40
Seatrout (SEA)	5	40	Deep diving odontocete (DDO)	5	40
Sciaenidae (SCI)	5	40	Loggerhead (LOG)	5	40
Ladyfish (LDY)	5	40	Kemps Ridley (KMP)	5	40
Mullets (MUL)	5	40	Other turtles (TUR)	5	40
Pompano (POM)	5	40	Blue crab (BCR)	5	40
Sheepshead (SHP)	5	40	Stone crab (SCR)	5	40
Snook (SNK)	5	40	Crabs and lobsters (LOB)	5	40
Flatfish (FLT)	5	40	Stony corals (COR)	5	40
Other demersal fish (ODF)	5	40	Crustose coralline algae (CCA)	5	40
Small demersal fish (SDF)	5	40	Octocorals (OCT)	5	40
Yellowfin tuna (YTN)	5	32	Sponges (SPG)	5	40

Table A.2 (continued). Minimum and maximum tolerated temperatures of modeled functional groups.

Functional Group	Min. temp (°C)	Max. temp (°C)	Functional Group	Min. temp (°C)	Max. temp (°C)
Bluefin tuna (BTN)	5	32	Carnivorous macrobenthos (CMB)	5	40
Little tunny (LTN)	5	32	Infaunal meiobenthos (INF)	5	40
Other tuna (OTN)	5	32	Herbivorous echinoderms (ECH)	5	40
Swordfish (SWD)	5	32	Oysters (OYS)	5	40
White marlin (WMR)	5	32	Bivalves (BIV)	5	40
Blue marlin (BMR)	5	32	Sessile filter feeders (SES)	5	40
Other billfish (BIL)	5	32	Epiphytes (EPI)	5	40
Greater amberjack (AMB)	5	32	Seagrass (GRS)	5	40
Jacks (JCK)	5	32	Macroalgae (ALG)	5	40
King mackerel (KMK)	5	40	Microphytobenthos (MPB)	5	40
Spanish mackerel (SMK)	5	40	Large phytoplankton (LPP)	5	40
Spanish sardine (SAR)	5	40	Small phytoplankton (SPP)	5	40
Large pelagic fish (LPL)	5	40	Toxic dinoflagellates (DIN)	5	40

Table A.3. Vertical distributions of functional groups in GOM Atlantis.
Atlantis parameters specify the daytime and nighttime vertical distributions for adults and juveniles. GOM Atlantis polygons can have up to 6 depth layers, plus a sediment layer. The symbol "..." means the next intermediate depth layer when transitioning between the shallowest and the deepest depth layers in the polygon.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
Gag grouper	DAY, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
(GAG)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Red grouper	DAY, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
(RGR)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Scamp	DAY, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
(SCM)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Shallow serranidae	DAY, adult	0.00	0.00	0.00	0.01	0.03	0.97	0.0
(SSR)	DAY, juvenile	0.00	0.00	0.00	0.01	0.06	0.92	0.0
	NIGHT, adult	0.00	0.00	0.00	0.01	0.06	0.92	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.01	0.06	0.92	0.0
Deep serranidae	DAY, adult	0.00	0.00	0.00	0.01	0.08	0.89	0.0
(DSR)	DAY, juvenile	0.01	0.01	0.01	0.04	0.21	0.72	0.0
	NIGHT, adult	0.04	0.02	0.01	0.03	0.19	0.71	0.0
	NIGHT, juvenile	0.01	0.01	0.02	0.04	0.20	0.72	0.0
Red snapper	DAY, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
(RSN)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Vermilion snapper	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(VSN)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Lutjanidae	DAY, adult	0.00	0.00	0.00	0.01	0.03	0.96	0.0
(LUT)	DAY, juvenile	0.00	0.00	0.00	0.02	0.05	0.93	0.0
	NIGHT, adult	0.00	0.00	0.00	0.02	0.05	0.93	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.02	0.05	0.93	0.0
Bioeroding fish	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(BIO)	DAY, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0

Table A.3 (continued). Vertical distributions of functional groups in GOM Atlantis.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
Large reef fish	DAY, adult	0.01	0.01	0.01	0.03	0.12	0.83	0.0
(LRF)	DAY, juvenile	0.02	0.01	0.01	0.06	0.16	0.74	0.0
	NIGHT, adult	0.06	0.03	0.01	0.05	0.14	0.72	0.0
	NIGHT, juvenile	0.02	0.01	0.02	0.06	0.15	0.73	0.0
Small reef fish	DAY, adult	0.00	0.01	0.01	0.00	0.01	0.97	0.0
(SRF)	DAY, juvenile	0.02	0.00	0.00	0.01	0.05	0.92	0.0
	NIGHT, adult	0.02	0.00	0.00	0.00	0.05	0.92	0.0
	NIGHT, juvenile	0.02	0.00	0.00	0.01	0.05	0.92	0.0
Black drum	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(BDR)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Red drum	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(RDR)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Seatrout	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(SEA)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Sciaenidae	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(SCI)	DAY, juvenile	0.00	0.00	0.00	0.00	0.16	0.84	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.16	0.84	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.16	0.84	0.0
Ladyfish	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(LDY)	DAY, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
Mullets	DAY, adult	0.06	0.09	0.11	0.04	0.10	0.60	0.0
(MUL)	DAY, juvenile	0.22	0.06	0.04	0.05	0.12	0.50	0.0
	NIGHT, adult	0.32	0.07	0.03	0.03	0.07	0.48	0.0
	NIGHT, juvenile	0.25	0.04	0.06	0.05	0.10	0.50	0.0
Pompano	DAY, adult	0.02	0.02	0.02	0.02	0.13	0.80	0.0
(POM)	DAY, juvenile	0.03	0.03	0.03	0.07	0.10	0.73	0.0
	NIGHT, adult	0.13	0.07	0.03	0.03	0.03	0.70	0.0
	NIGHT, juvenile	0.03	0.03	0.07	0.07	0.07	0.73	0.0
Sheepshead	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(SHP)	DAY, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0

Table A.3 (continued). Vertical distributions of functional groups in GOM Atlantis.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
Snook	DAY, adult	0.02	0.02	0.02	0.02	0.13	0.80	0.0
(SNK)	DAY, juvenile	0.03	0.03	0.03	0.07	0.17	0.67	0.0
	NIGHT, adult	0.13	0.07	0.03	0.03	0.10	0.63	0.0
	NIGHT, juvenile	0.03	0.03	0.07	0.07	0.13	0.67	0.0
Flatfish	DAY, adult	0.00	0.00	0.00	0.01	0.06	0.92	0.0
(FLT)	DAY, juvenile	0.00	0.00	0.00	0.03	0.19	0.77	0.0
	NIGHT, adult	0.01	0.01	0.00	0.03	0.18	0.77	0.0
	NIGHT, juvenile	0.00	0.00	0.01	0.03	0.18	0.77	0.0
Other demersal fish	DAY, adult	0.01	0.01	0.03	0.04	0.18	0.74	0.0
(ODF)	DAY, juvenile	0.05	0.03	0.03	0.07	0.21	0.62	0.0
	NIGHT, adult	0.48	0.08	0.01	0.01	0.05	0.37	0.0
	NIGHT, juvenile	0.44	0.04	0.04	0.03	0.06	0.39	0.0
Small demersal fish	DAY, adult	0.03	0.04	0.08	0.05	0.22	0.58	0.0
(SDF)	DAY, juvenile	0.16	0.07	0.06	0.07	0.21	0.44	0.0
	NIGHT, adult	0.48	0.08	0.01	0.01	0.05	0.37	0.0
	NIGHT, juvenile	0.44	0.04	0.04	0.03	0.06	0.39	0.0
Yellowfin tuna	DAY, adult	0.20	0.30	0.40	0.10	0.00	0.00	0.0
(YTN)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.90	0.05	0.05	0.00	0.00	0.00	0.0
Bluefin tuna	DAY, adult	0.20	0.30	0.40	0.10	0.00	0.00	0.0
(BTN)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.90	0.05	0.05	0.00	0.00	0.00	0.0
Little tunny	DAY, adult	0.80	0.15	0.05	0.00	0.00	0.00	0.0
(LTN)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
Other tuna	DAY, adult	0.80	0.15	0.05	0.00	0.00	0.00	0.0
(OTN)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
Swordfish	DAY, adult	0.20	0.30	0.40	0.10	0.00	0.00	0.0
(SWD)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.90	0.05	0.05	0.00	0.00	0.00	0.0
White marlin	DAY, adult	0.20	0.30	0.40	0.10	0.00	0.00	0.0
(WMR)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.90	0.05	0.05	0.00	0.00	0.00	0.0

Table A.3 (continued). Vertical distributions of functional groups in GOM Atlantis.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
Blue marlin	DAY, adult	0.20	0.30	0.40	0.10	0.00	0.00	0.0
(BMR)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.90	0.05	0.05	0.00	0.00	0.00	0.0
Other billfish	DAY, adult	0.20	0.30	0.40	0.10	0.00	0.00	0.0
(BIL)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.90	0.05	0.05	0.00	0.00	0.00	0.0
Greater amberjack	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(AMB)	DAY, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
Jacks (JCK)	DAY, adult	0.04	0.06	0.07	0.03	0.08	0.73	0.0
	DAY, juvenile	0.14	0.04	0.03	0.04	0.07	0.68	0.0
	NIGHT, adult	0.22	0.06	0.02	0.02	0.03	0.66	0.0
	NIGHT, juvenile	0.16	0.03	0.05	0.04	0.05	0.68	0.0
King mackerel	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(KMK)	DAY, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
Spanish mackerel	DAY, adult	0.02	0.02	0.04	0.05	0.36	0.51	0.0
(SMK)	DAY, juvenile	0.08	0.08	0.08	0.14	0.28	0.34	0.0
	NIGHT, adult	0.32	0.16	0.08	0.10	0.12	0.22	0.0
	NIGHT, juvenile	0.08	0.08	0.12	0.18	0.22	0.32	0.0
Spanish sardine	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(SAR)	DAY, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
Large pelagic fish	DAY, adult	0.12	0.18	0.24	0.07	0.09	0.29	0.0
(LPL)	DAY, juvenile	0.49	0.11	0.05	0.04	0.07	0.25	0.0
	NIGHT, adult	0.61	0.10	0.02	0.02	0.02	0.22	0.0
	NIGHT, juvenile	0.55	0.05	0.06	0.05	0.05	0.24	0.0
Deep water fish	DAY, adult	0.01	0.01	0.05	0.06	0.37	0.50	0.0
(DWF)	DAY, juvenile	0.09	0.07	0.07	0.12	0.31	0.33	0.0
	NIGHT, adult	0.48	0.08	0.01	0.01	0.05	0.37	0.0
	NIGHT, juvenile	0.44	0.04	0.04	0.03	0.06	0.39	0.0
Menhaden	DAY, adult	0.20	0.30	0.40	0.10	0.00	0.00	0.0
(MEN)	DAY, juvenile	0.80	0.15	0.05	0.00	0.00	0.00	0.0
	NIGHT, adult	0.90	0.10	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.90	0.05	0.05	0.00	0.00	0.00	0.0

Table A.3 (continued). Vertical distributions of functional groups in GOM Atlantis.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
Pinfish	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(PIN)	DAY, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.20	0.80	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.20	0.80	0.0
Medium pelagic fish	DAY, adult	0.07	0.11	0.15	0.04	0.02	0.61	0.0
(MPF)	DAY, juvenile	0.30	0.06	0.02	0.01	0.08	0.53	0.0
	NIGHT, adult	0.35	0.05	0.01	0.01	0.07	0.52	0.0
	NIGHT, juvenile	0.34	0.02	0.02	0.01	0.08	0.53	0.0
Small pelagic fish	DAY, adult	0.09	0.14	0.21	0.07	0.14	0.35	0.0
(SPL)	DAY, juvenile	0.41	0.10	0.05	0.04	0.11	0.28	0.0
	NIGHT, adult	0.55	0.11	0.03	0.04	0.05	0.22	0.0
	NIGHT, juvenile	0.46	0.05	0.05	0.07	0.10	0.27	0.0
Blacktip shark	DAY, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
(TIP)	DAY, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, adult	0.00	0.00	0.00	0.00	0.00	1.00	0.0
	NIGHT, juvenile	0.00	0.00	0.00	0.00	0.00	1.00	0.0
Benthic feeding sharks	DAY, adult	0.01	0.01	0.01	0.04	0.17	0.77	0.0
(BEN)	DAY, juvenile	0.01	0.01	0.01	0.09	0.21	0.66	0.0
	NIGHT, adult	0.06	0.03	0.01	0.07	0.19	0.64	0.0
	NIGHT, juvenile	0.01	0.01	0.03	0.09	0.20	0.66	0.0
Large sharks	DAY, adult	0.03	0.05	0.07	0.02	0.02	0.82	0.0
(LGS)	DAY, juvenile	0.13	0.03	0.01	0.01	0.04	0.78	0.0
	NIGHT, adult	0.16	0.02	0.00	0.00	0.03	0.78	0.0
	NIGHT, juvenile	0.15	0.01	0.02	0.01	0.03	0.78	0.0
Filter feeding sharks	DAY, adult	0.13	0.20	0.27	0.07	0.00	0.33	0.0
(FIL)	DAY, juvenile	0.53	0.10	0.03	0.00	0.00	0.33	0.0
	NIGHT, adult	0.60	0.07	0.00	0.00	0.00	0.33	0.0
	NIGHT, juvenile	0.60	0.03	0.03	0.00	0.00	0.33	0.0
Small sharks	DAY, adult	0.00	0.00	0.00	0.08	0.33	0.59	0.0
(SMS)	DAY, juvenile	0.01	0.01	0.01	0.15	0.35	0.46	0.0
	NIGHT, adult	0.04	0.02	0.01	0.15	0.34	0.45	0.0
	NIGHT, juvenile	0.01	0.01	0.01	0.16	0.35	0.46	0.0
Skates and rays	DAY, adult	0.01	0.01	0.01	0.04	0.16	0.77	0.0
(RAY)	DAY, juvenile	0.03	0.01	0.01	0.08	0.24	0.63	0.0
	NIGHT, adult	0.05	0.01	0.01	0.07	0.23	0.63	0.0
	NIGHT, juvenile	0.03	0.01	0.01	0.08	0.23	0.63	0.0
Brown shrimp	DAY, adult	0.03	0.03	0.03	0.03	0.30	0.60	0.0
(BSH)	DAY, juvenile	0.03	0.03	0.03	0.03	0.30	0.60	0.0
	NIGHT, adult	0.60	0.30	0.03	0.03	0.03	0.03	0.0
	NIGHT, juvenile	0.60	0.30	0.03	0.03	0.03	0.03	0.0

Table A.3 (continued). Vertical distributions of functional groups in GOM Atlantis.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
White shrimp	DAY, adult	0.03	0.03	0.03	0.03	0.30	0.60	0.0
(WSH)	DAY, juvenile	0.03	0.03	0.03	0.03	0.30	0.60	0.0
	NIGHT, adult	0.60	0.30	0.03	0.03	0.03	0.03	0.0
	NIGHT, juvenile	0.60	0.30	0.03	0.03	0.03	0.03	0.0
Pink shrimp	DAY, adult	0.03	0.03	0.03	0.03	0.30	0.60	0.0
(PSH)	DAY, juvenile	0.03	0.03	0.03	0.03	0.30	0.60	0.0
	NIGHT, adult	0.60	0.30	0.03	0.03	0.03	0.03	0.0
	NIGHT, juvenile	0.60	0.30	0.03	0.03	0.03	0.03	0.0
Other shrimp	DAY, adult	0.03	0.03	0.03	0.03	0.30	0.60	0.0
(OSH)	DAY, juvenile	0.03	0.03	0.03	0.03	0.30	0.60	0.0
	NIGHT, adult	0.60	0.30	0.03	0.03	0.03	0.03	0.0
	NIGHT, juvenile	0.60	0.30	0.03	0.03	0.03	0.03	0.0
Diving birds	DAY, adult	0.40	0.30	0.30	0.00	0.00	0.00	0.0
(DBR)	DAY, juvenile	0.40	0.30	0.30	0.00	0.00	0.00	0.0
	NIGHT, adult	0.40	0.30	0.30	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.40	0.30	0.30	0.00	0.00	0.00	0.0
Surface feeding birds	DAY, adult	1.00	0.00	0.00	0.00	0.00	0.00	0.0
(SBR)	DAY, juvenile	1.00	0.00	0.00	0.00	0.00	0.00	0.0
	NIGHT, adult	1.00	0.00	0.00	0.00	0.00	0.00	0.0
	NIGHT, juvenile	1.00	0.00	0.00	0.00	0.00	0.00	0.0
Manatee	DAY, adult	0.40	0.30	0.30	0.00	0.00	0.00	0.0
(MAN)	DAY, juvenile	0.40	0.30	0.30	0.00	0.00	0.00	0.0
	NIGHT, adult	0.40	0.30	0.30	0.00	0.00	0.00	0.0
	NIGHT, juvenile	0.40	0.30	0.30	0.00	0.00	0.00	0.0
Mysticeti	DAY, adult	0.00	0.10	0.20	0.30	0.20	0.20	0.0
(MYS)	DAY, juvenile	0.00	0.10	0.20	0.30	0.20	0.20	0.0
	NIGHT, adult	0.00	0.10	0.20	0.30	0.20	0.20	0.0
	NIGHT, juvenile	0.00	0.10	0.20	0.30	0.20	0.20	0.0
Dolphins and porpoise	DAY, adult	0.30	0.20	0.20	0.10	0.10	0.10	0.0
(DOL)	DAY, juvenile	0.30	0.20	0.20	0.10	0.10	0.10	0.0
	NIGHT, adult	0.30	0.20	0.20	0.10	0.10	0.10	0.0
	NIGHT, juvenile	0.30	0.20	0.20	0.10	0.10	0.10	0.0
Deep diving odontoce	DAY, adult	0.05	0.05	0.10	0.30	0.25	0.25	0.0
(DDO)	DAY, juvenile	0.05	0.05	0.10	0.30	0.25	0.25	0.0
	NIGHT, adult	0.05	0.05	0.10	0.30	0.25	0.25	0.0
	NIGHT, juvenile	0.05	0.05	0.10	0.30	0.25	0.25	0.0
Loggerhead	DAY, adult	0.25	0.25	0.25	0.25	0.00	0.00	0.0
(LOG)	DAY, juvenile	0.25	0.25	0.25	0.25	0.00	0.00	0.0
	NIGHT, adult	0.25	0.25	0.25	0.25	0.00	0.00	0.0
	NIGHT, juvenile	0.25	0.25	0.25	0.25	0.00	0.00	0.0

Table A.3 (continued). Vertical distributions of functional groups in GOM Atlantis.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
Kemps ridley	DAY, adult	0.25	0.25	0.25	0.25	0.00	0.00	0.0
(KMP)	DAY, juvenile	0.25	0.25	0.25	0.25	0.00	0.00	0.0
	NIGHT, adult	0.25	0.25	0.25	0.25	0.00	0.00	0.0
	NIGHT, juvenile	0.25	0.25	0.25	0.25	0.00	0.00	0.0
Other turtles	DAY, adult	0.25	0.25	0.25	0.25	0.00	0.00	0.0
(TUR)	DAY, juvenile	0.25	0.25	0.25	0.25	0.00	0.00	0.0
	NIGHT, adult	0.25	0.25	0.25	0.25	0.00	0.00	0.0
	NIGHT, juvenile	0.25	0.25	0.25	0.25	0.00	0.00	0.0
Blue crab	DAY	0.05	0.10	0.10	0.10	0.10	0.15	0.4
(BCR)	NIGHT	0.05	0.10	0.10	0.10	0.10	0.15	0.4
Stone crab	DAY	0.05	0.10	0.10	0.10	0.10	0.15	0.4
(SCR)	NIGHT	0.05	0.10	0.10	0.10	0.10	0.15	0.4
Crabs and lobsters	DAY	0.05	0.10	0.10	0.10	0.10	0.15	0.4
(LOB)	NIGHT	0.05	0.10	0.10	0.10	0.10	0.15	0.4
Stony corals	DAY	0.00	0.00	0.00	0.00	0.00	0.40	0.6
(COR)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.40	0.6
Crustose coralline alga	DAY	0.00	0.00	0.00	0.00	0.00	0.40	0.6
(CCA)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.40	0.6
Octocorals	DAY	0.00	0.00	0.00	0.00	0.00	0.40	0.6
(OCT)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.40	0.6
Sponges	DAY	0.00	0.00	0.00	0.00	0.00	0.40	0.6
(SPG)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.40	0.6
Carnivorous	DAY	0.00	0.00	0.00	0.00	0.10	0.70	0.2
macrobenthos (CMB)	NIGHT	0.00	0.00	0.00	0.00	0.10	0.70	0.2
Infaunal meiobenthos	DAY	0.00	0.00	0.00	0.00	0.00	0.10	0.9
(INF)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.10	0.9
Herbivorous	DAY	0.00	0.00	0.00	0.00	0.00	1.00	0.0
echinoderms (ECH)	NIGHT	0.00	0.00	0.00	0.00	0.00	1.00	0.0
Oysters	DAY	0.00	0.00	0.00	0.00	0.00	0.40	0.6
(OYS)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.40	0.6
Bivalves	DAY	0.00	0.00	0.00	0.00	0.00	0.40	0.6
(BIV)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.40	0.6
Sessile filter feeders	DAY	0.00	0.00	0.00	0.00	0.00	0.40	0.6
(SES)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.40	0.6
Epiphytes	DAY	0.00	0.00	0.00	0.00	0.00	0.90	0.1
(EPI)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.90	0.1
Seagrass	DAY	0.00	0.00	0.00	0.00	0.00	0.90	0.1
(GRS)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.90	0.1
Macroalgae	DAY	0.00	0.00	0.00	0.00	0.00	0.90	0.1
(ALG)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.90	0.1

Table A.3 (continued). Vertical distributions of functional groups in GOM Atlantis.

Functional Group	Time of Day, Stage	Shallowest	...	...	...	...	Deepest	Sediment
Microphytobenthos	DAY	0.00	0.00	0.00	0.00	0.00	0.90	0.1
(MPB)	NIGHT	0.00	0.00	0.00	0.00	0.00	0.90	0.1
Large phytoplankton	DAY	0.40	0.30	0.20	0.10	0.00	0.00	0.0
(LPP)	NIGHT	0.40	0.30	0.20	0.10	0.00	0.00	0.0
Small phytoplankton	DAY	0.40	0.30	0.20	0.10	0.00	0.00	0.0
(SPP)	NIGHT	0.40	0.30	0.20	0.10	0.00	0.00	0.0
Toxic dinoflagellates	DAY	0.40	0.30	0.20	0.10	0.00	0.00	0.0
(DIN)	NIGHT	0.40	0.30	0.20	0.10	0.00	0.00	0.0
Protists	DAY	0.20	0.20	0.15	0.15	0.15	0.15	0.0
(PRO)	NIGHT	0.20	0.20	0.15	0.15	0.15	0.15	0.0
Jellyfish	DAY	0.20	0.20	0.15	0.15	0.15	0.15	0.0
(JEL)	NIGHT	0.30	0.30	0.30	0.04	0.03	0.03	0.0
Squid	DAY	0.20	0.20	0.15	0.15	0.15	0.15	0.0
(SQU)	NIGHT	0.20	0.20	0.15	0.15	0.15	0.15	0.0
Large zooplankton	DAY	0.05	0.05	0.05	0.25	0.30	0.30	0.0
(LZP)	NIGHT	0.30	0.30	0.25	0.05	0.05	0.05	0.0
Small zooplankton	DAY	0.05	0.05	0.05	0.25	0.30	0.30	0.0
(SZP)	NIGHT	0.30	0.30	0.25	0.05	0.05	0.05	0.0
Bacteria	DAY	0.15	0.15	0.15	0.15	0.15	0.15	0.1
(PB)	NIGHT	0.15	0.15	0.15	0.15	0.15	0.15	0.1

Table A.4. Summary of the migration assumptions for externally migrating groups.

Highly migratory groups migrate into and out of the Gulf of Mexico (GOM) modeling domain. The following are the assumptions with respect to the percent of the group leaving the GOM (which for some groups differs between juveniles and adults), the period (days) of time the migration lasts, the day of year the group starts leaving the GOM domain, and the day of year the group begins to return to the GOM domain. DOY = day of year (0-364). Data sources: YTN, SWD (Eric Orbensen, pers. comm.), KMK, SMK (Michael Schirripa, pers. comm.), BMR (Witzell and Scott 1990), BIL (assumed as BMR), BTM (based on GOM catch data), WMR, MYS (assumed summer migrator), LGS, DBR, SBR (assumed spring migrator), LOG, KMP, TUR (assumed spring migrator into GOM).

Functional Group		Percent leaving domain	Migration period (days)	DOY leaving domain	DOY returning to domain
Other billfish (BIL)		50%	90	304 (Nov)	121 (May)
Blue marlin (BMR)		50%	90	304 (Nov)	121 (May)
Bluefin tuna (BTN)	juvenile	0%	-	-	-
	adult	100%	60	135 (May)	340 (Dec)
Diving birds (DBR)		80%	21	60 (Mar)	335 (Dec)
King mackerel (KMK)		10%	90	274 (Oct)	121 (May)
Kemps ridley (KMP)	juvenile	70%	14	243 (Sep)	91 (Apr)
	adult	50%	14	243 (Sep)	91 (Apr)
Large sharks (LGS)		95%	14	59 (Mar)	320 (Nov)
Loggerhead (LOG)	juvenile	70%	14	273 (Oct)	91 (Apr)
	adult	50%	14	273 (Oct)	91 (Apr)
Mysticeti (MSY)		15%	14	335 (Dec)	152 (Jun)
Surface feeding birds (SBR)		50%	21	60 (Mar)	335 (Dec)
Spanish mackerel (SMK)		10%	90	274 (Oct)	121 (May)
Swordfish (SWD)	juvenile	15%	90	274 (Oct)	80 (Mar)
	adult	70%	90	274 (Oct)	80 (Mar)
Other turtles (TUR)	juvenile	23%	14	212 (Aug)	60 (Mar)
	adult	19%	14	212 (Aug)	60 (Mar)
White marlin (WMR)		70%	90	152 (Jun)	243 (Sep)
Yellowfin tuna (YTN	juvenile	0%	-	-	-
	adult	40%	60	59 (Mar)	181 (Jul)

Table A.5. Regression statistics, *p* value and R^2 for seagrass as a predictor of functional group abundance. Generalized additive models were used to isolate the effect of seagrass presence on group abundance. Intercept and coefficient (β_0 and β_1 respectively in Eq.3) presented for seagrass as a predictor of group abundance. Groups with a positive coefficient are positively associated with seagrass habitat (underline shows significance at $\alpha = 0.05$, LPL is at $\alpha = 0.1$). Groups with a positive intercept have a non-zero expected abundance in the absence of seagrass.

Functional Group	Intercept (β_0) for seagrass effect on species abundance	Coefficient (β_1) for seagrass effect on species abundance	Standard error of intercept	Standard error of coefficient	T statistic of intercept	T statistic of coefficient	Level of significance Pr(>|t|) for intercept	Level of significance Pr(>|t|) for coefficient	R^2
Blue crab (BCR)	-0.167	0.002	0.157	0.002	-1.064	0.909	0.287	0.363	0.007
Deep Serr. (DSR)	-5.844	0.027	12.037	0.104	-0.485	0.259	0.627	0.796	
Flatfish (FLT)	-0.085	-0.003	0.099	0.001	-0.862	-2.093	0.389	0.036	0.034
Gag grouper (GAG)	-200.089	0.091	138.014	0.074	-1.450	1.222	0.147	0.222	0.571
Jacks (JCK)	-2.322	0.002	0.996	0.001	-2.332	1.971	0.020	0.049	0.157
Ladyfish (LDY)	-88.444	0.268	95.028	0.513	-0.931	0.523	0.352	0.601	0.752
L. pelagic fish (LPL)	-112.912	0.047	62.703	0.202	-1.801	0.233	0.072	0.816	0.632
L. reef fish (LRF)	-418.108	-0.020	834.571	0.064	-0.501	-0.316	0.616	0.752	0.262
Lutjanidae (LUT)	-143.626	0.138	19.927	0.044	-7.207	3.149	0.000	0.002	0.437
M. pelagic fish (MPL)	1.938	0.003	0.220	0.001	8.812	2.872	0.000	0.004	0.147
Mullet (MUL)	-100.475	0.005	64.363	0.015	-1.561	0.328	0.119	0.743	0.008
Oth. dem. fish (ODF)	1.655	0.017	0.508	0.005	3.256	3.023	0.001	0.003	0.005
Oth. shrimp (OSH)	-6.425	-0.005	1.364	0.020	-4.711	-0.238	0.000	0.812	0.000
Oth. turtles (TUR)	-61.430	-0.193	120.679	0.028	-1.561	-6.947	0.611	0.000	0.039
Pinfish (PIN)	3.055	0.0283	0.417	0.004	7.335	6.539	0.000	0.000	0.032
Pink shrimp (PSH)	0.883	0.0179	0.276	0.003	3.204	6.727	0.001	0.000	0.030
Pompano (POM)	-2.294	-0.0050	1.119	0.017	-2.051	-0.295	0.040	0.768	0.000
Red drum (RDR)	0.664	-0.0007	0.452	0.006	1.470	-0.118	0.142	0.906	0.000
Sciaenidae (SCI)	-51.978	0.470	42.042	0.412	-1.236	1.142	0.216	0.254	0.187
Seatrout (SEA)	1.043	0.007	0.148	0.002	7.030	4.460	0.000	0.000	0.031
Shallow serranid (SSR)	-5.442	0.010	0.995	0.011	-5.470	0.888	0.000	0.374	0.000

Functional Group	Intercept (β_0) for seagrass effect on species abundance	Coefficient (β_1) for seagrass effect on species abundance	Standard error of intercept	Standard error of coefficient	T statistic of intercept	T statistic of coefficient	Level of significance Pr(>|t|) for intercept	Level of significance Pr(>|t|) for coefficient	R^2
Sheepshead (SHP)	-1.254	0.018	0.503	0.005	-2.491	3.312	0.013	0.001	0.009
Skates and rays (RAY)	-62.847	0.161	55.048	0.021	-1.142	7.669	0.254	0.000	0.375
S. dem. fish (SDF)	2.469	0.026	0.496	0.005	4.973	4.983	0.000	0.000	0.013
S. pel. fish (SPL)	5.922	0.005	0.357	0.004	16.585	1.157	0.000	0.247	0.002
S. reef fish (SRF)	3.132	0.003	0.107	0.001	29.188	2.437	0.000	0.015	0.018
Snook (SNK)	-3.836	0.012	0.716	0.008	-5.356	1.430	0.000	0.153	0.001
Spanish mackerel (SMK)	-4.857	0.010	1.873	0.021	-2.593	0.448	0.010	0.654	0.000
Spanish sardine (SAR)	-8.295	0.110	21.080	0.212	-0.393	0.519	0.694	0.604	0.000
Stone crab (SCR)	-69.638	0.393	83.358	0.500	-0.835	0.785	0.404	0.432	0.006

Table A.6. Marine protected areas represented in GOM Atlantis.

Under fleets affected, the proportion of restriction imposed on the fleet (0 - no fishing allowed; 1 - full fishing allowed) is included within parenthesis. Under polygons affected, the percentage of the polygon that contains the MPA is included within parenthesis. SprtEst = Recreational fishery in the USA (estuarine/coastal spp.). SprtShf = Recreational fishery in the USA (offshore spp.). GillnetEst = Gillnet fishery in the USA. OytEst = Oyster fishery in the USA. PotCrbEst = Crab pot fishery in the USA. PotLbtShf = Lobster pot fishery in the USA. PotCrbShf = Fish and shrimp pot fishery in the USA. TwlShpEst = Shrimp net and trawl fishing in the USA - inshore. TwlShpShf = Shrimp trawl fishing in the USA - offshore. RoyalRed = Royal red fishery in the USA. SeineMenShf = Menhaden seine fishery in the USA. HLReefShf = Handline fishery in the USA. LLReefShf = Reef fish longline fishery in the USA. LLShkShf = Shark longline fishery in the USA. LLPelgc = Pelagic longline fishery in the USA. OtherUS = Mixed fishery representing other fishing in the USA. TwlShpMX = Shrimp trawl fishery in Mexico. LLReefMX = Reef fish longline fishery in Mexico. LLShkMX = Shark longline fishery in Mexico. GillnetMackMX = Mackerel gillnet fishery in Mexico. OctpsMX = Octopus fishery in Mexico. MixedMX = Mixed fishery representing other fishing in Mexico. MixedCuba = Mixed fishery representing fishing in Cuba.

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

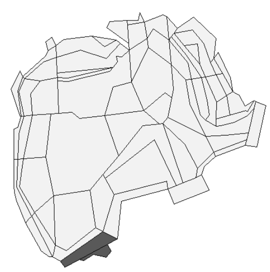
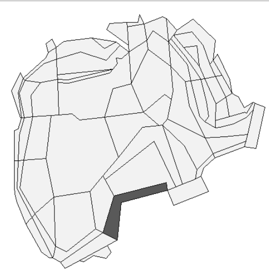
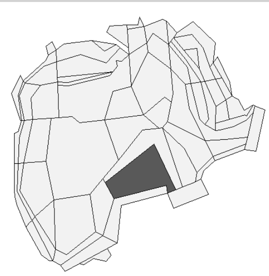
Name	Fleets affected	Polygons affected	Map
Área de Protección de Flora y Fauna de Términos	TwlShpMX (0.075); LLReefMX (0.075); LLShkMX (0.075); GillnetMackMX (0.075); OctpsMX (0.075); MixedMX (0.075)	40 (0.06%); 58 (53.71%)	
Área de Protección de Flora y Fauna Yum Balam	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (1.92%)	
Arrecife Alacranes	MixedMX (0)	13 (4.15%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

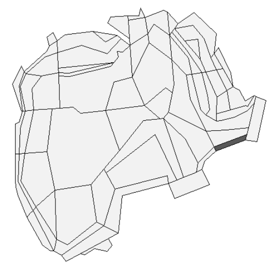
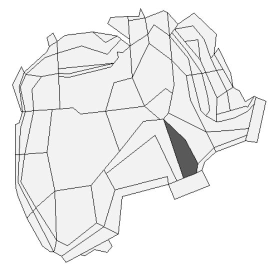
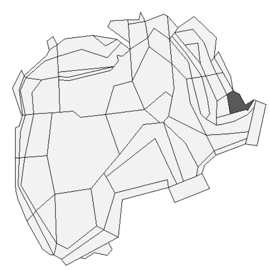
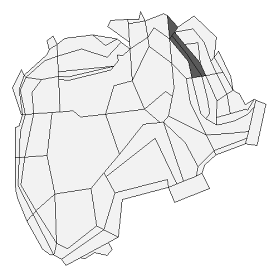
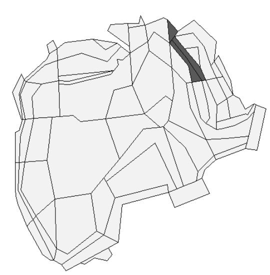
Name	Fleets affected	Polygons affected	Map
Bacunayagua	MixedCuba (0.99)	49 (0.1%)	
Banco del Noroeste (Knoll)	MixedCuba (0.99)	10 (0.23%)	
Biscayne Bay-Card Sound Spiny Lobster Sanctuary	PotLbtShf (0)	27 (0.12%)	
Closure of the Madison and Swanson Sites-Summer	GillnetEst (0); PotCrbEst (0); PotCrbShf (0); PotLbtShf (0); HLReefShf (0); LLReefShf (0); LLShkShf (0); LLPelgc (0); RoyalRed (0); OtherUS (0); SprtShf (0); SprtEst (0); SeineMenShf (0)	1 (3.02%); 25 (1.07%); 31 (0.01%)	
Closure of the Madison and Swanson Sites-Winter	GillnetEst (0); PotCrbEst (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); HLReefShf (0); LLReefShf (0); LLShkShf (0); LLPelgc (0); RoyalRed (0); OtherUS (0); SprtShf (0); SprtEst (0); SeineMenShf (0)	1 (3.02%); 25 (1.07%); 31 (0.01%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

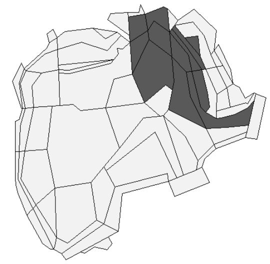
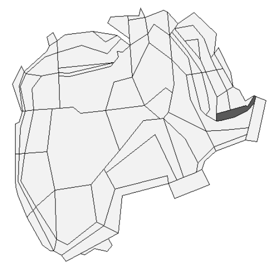
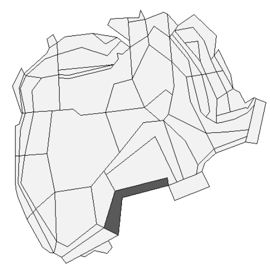
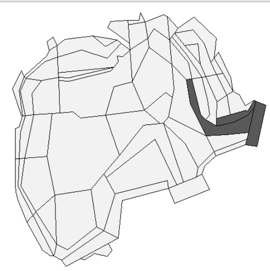
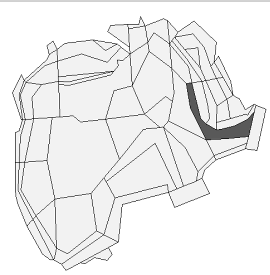
Name	Fleets affected	Polygons affected	Map
Desoto Canyon Closed Area	LLPelgc (0)	1 (51.3%); 8 (57.5%); 9 (15.8%); 12 (34.7%); 22 (99.4%); 23 (16.6%); 25 (26.7%); 26 (36.6%); 29 (13.9%); 38 (18.1%); 39 (55.7%); 42 (3.8%)	
Dry Tortugas National Park	PotLbtShf (0); OtherUS (0.99)	28 (2.25%)	
Dzilam (reserva estatal)	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (1.65%)	
East Florida Coast Closed Area	LLPelgc (0)	28 (10%); 29 (13.66%); 65 (20.08%)	
East Hump MPA	LLShkShf (0)	29 (0.43%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

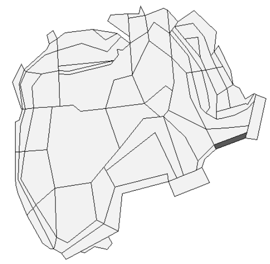
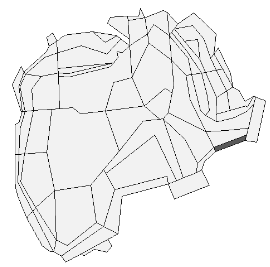
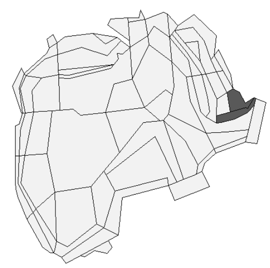
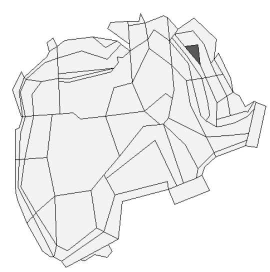
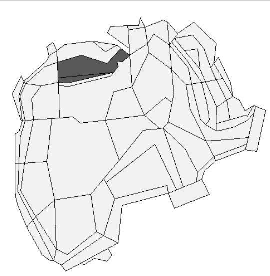
Name	Fleets affected	Polygons affected	Map
Ensenada de Portier - Lamas	MixedCuba (0.99)	49 (0.03%)	
Ensenada de Sibarimar	MixedCuba (0.99)	49 (0.47%)	
Everglades National Park	PotLbtShf (0)	27 (18.70%); 28 (1.88%)	
Florida Middle Grounds Habitat Area of Particular Concern	PotCrbEst (0); SprtShf (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); LLReefShf (0); LLShkShf (0)	42 (20.33%)	
Flower Garden Banks National Marine Sanctuary	PotCrbEst (0); SprtShf (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); LLReefShf (0); LLPelgc (0); RoyalRed (0)	20 (0.01%); 43 (1.84%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

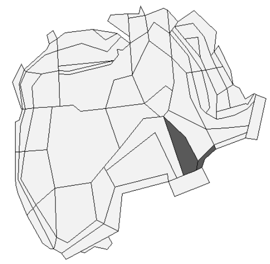
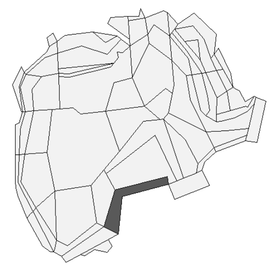
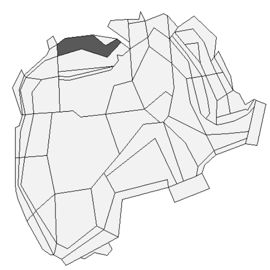
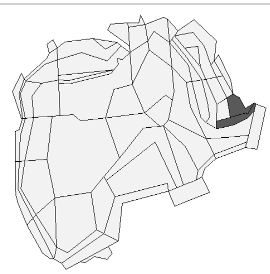
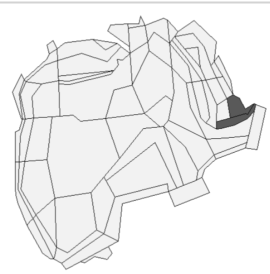
Name	Fleets affected	Polygons affected	Map
Guanahacabibes	MixedCuba (0.99)	10 (0.51%); 48 (0.59%)	
Humedal de Importancia Especialmente para la Conservación de Aves Acuáticas Reserve Ría Lagartos	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (1.09%)	
Isles Dernieres Barrier Islands Refuge	SprtEst (0.99); GillnetEst (0.99); TwlShpEst (0.99); PotCrbEst (0.99); SprtShf (0.99); TwlShpShf (0.99); PotCrbShf (0.99); PotLbtShf (0.99); HLReefShf (0.99); SeineMenShf (0.99); OtherUS (0.99)	21 (0.04%)	
John Pennekamp Coral Reef State Park	OtherUS (0.99)	27 (0.02%); 28 (2.06%)	
John Pennekamp Coral Reef State Park, Harvest Prohibited or Restricted Area	PotLbtShf (0); OtherUS (0.99)	27 (0.02%); 28 (2.06%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

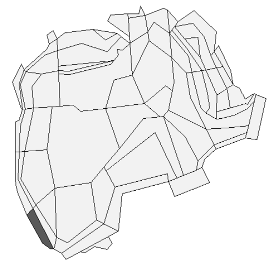
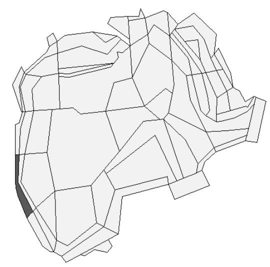
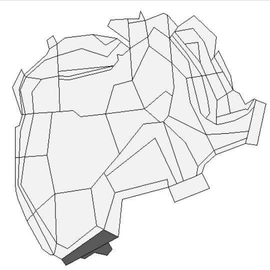
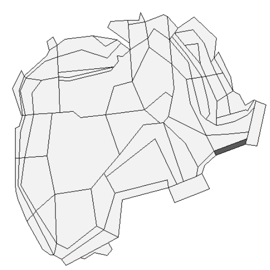
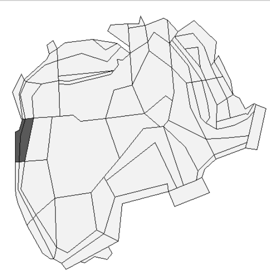
Name	Fleets affected	Polygons affected	Map
La Mancha y El Llano	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); MixedMX (0.99)	62 (0.11%)	
Laguna de Tamiahua	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	36 (3.04%)	
Laguna de Terminos	TwlShpMX (0.075); LLReefMX (0.075); LLShkMX (0.075); GillnetMackMX (0.075); OctpsMX (0.075); MixedMX (0.075)	40 (0.06%); 58 (53.84%)	
Laguna del Cobre - Itabo	MixedCuba (0.99)	49 (0.12%)	
Laguna Madre	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); MixedMX (0.99); OctpsMX (0.99)	35 (3.23%); 45 (23.66%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

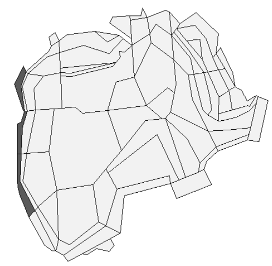
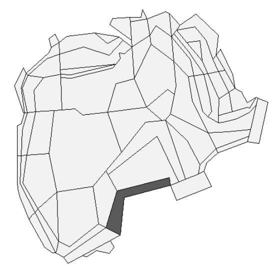
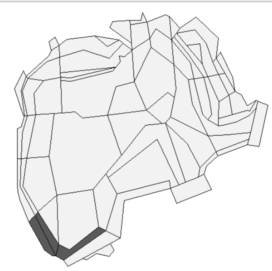
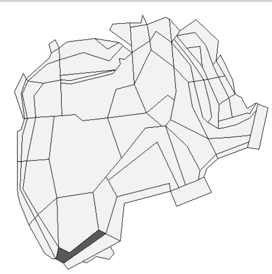
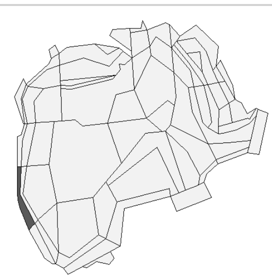
Name	Fleets affected	Polygons affected	Map
Laguna Madre y Delta del Río Bravo	SprtEst (0.99); GillnetEst (0.99); TwlShpEst (0.99); OytEst (0.99); PotCrbEst (0.99); PotCrbShf (0.99); PotLbtShf (0.99); OtherUS (0.99); TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	19 (0.01%); 36 (0.6%); 45 (31.65%)	
Los Petenes	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (10.70%)	
Los Tuxtlas	LLShkMX (0.99); MixedMX (0.99); TwlShpMX (0.99); LLReefMX (0.99); GillnetMackMX (0.99)	37 (0.07%); 41 (1.57%); 62 (0.05%)	
Manglares y humedales de la Laguna de Sontecomapan	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); MixedMX (0.99)	41 (0.06%)	
Manglares y humedales de Tuxpan	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	36 (0.12%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

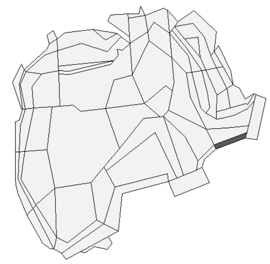
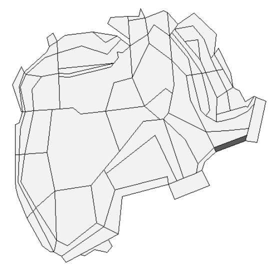
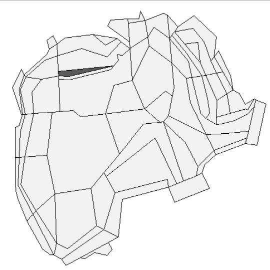
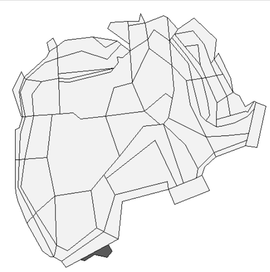
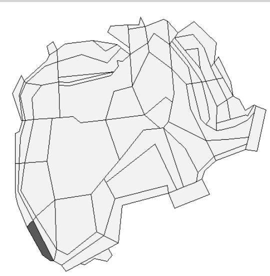
Name	Fleets affected	Polygons affected	Map
Manigua Costera Celimar - RíoTarará	MixedCuba (0.99)	49 (0.01%)	
Mariel - Mosquito	MixedCuba (0.99)	49 (0.79%)	
McGrail Bank Habitat Area of Particular Concern	PotCrbEst (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); LLReefShf (0); RoyalRed (0)	43 (0.62%);	
Pantanos de Centla	TwlShpMX (0.99); LLReefMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	58 (0.12%)	
Parque Nacional Sistema Arrecifal Veracruzano	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); MixedMX (0.99)	62 (3.96%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

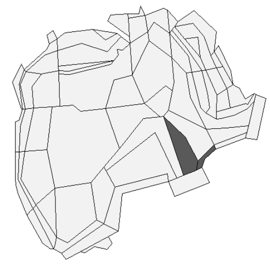
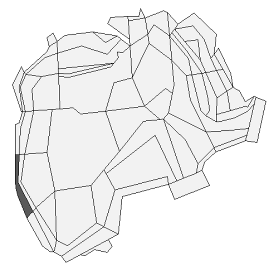
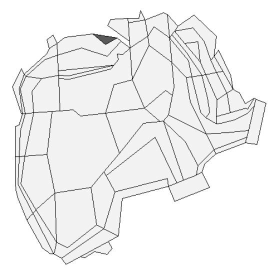
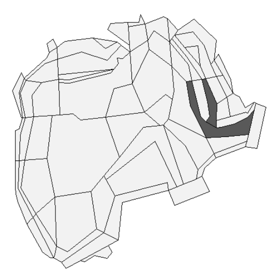
Name	Fleets affected	Polygons affected	Map
Peninsula de Guanahacabibes	MixedCuba (0.99)	10 (0.45%); 48 (0.59%)	
Playa Tortuguera Rancho Nuevo	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	36 (0.002%)	
Pointe aux Chenes Wildlife Management Area	SprtEst (0.99); GillnetEst (0.99); TwlShpEst (0.99); OytEst (0.99); PotCrbEst (0.99); PotCrbShf (0.99); PotLbtShf (0.99); OtherUS (0.99)	63 (3.49%)	
Pulley Ridge Habitat Area of Particular Concern	SprtShf (0); LLShkShf (0); RoyalRed (0); PotCrbEst (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); LLReefShf (0)	29 (0.02%); 64 (2.38%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

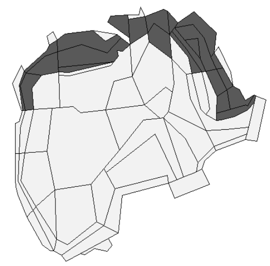
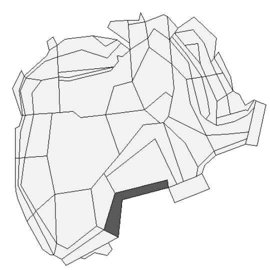
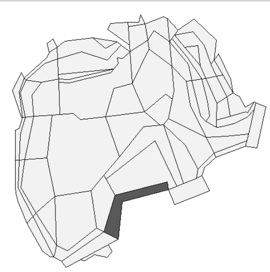
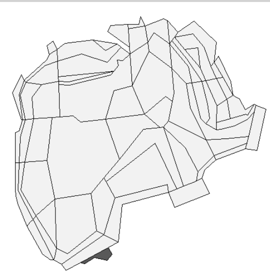
Name	Fleets affected	Polygons affected	Map
Reef Fish Longline and Buoy Gear Restricted Area	HLReefShf (0.9); LLReefShf (0)	1 (2.7%); 5 (53.5%); 6 (72.9%); 17 (88.5%); 20 (92.7%); 21 (64.4%); 22 (0.1%); 23 (67.4%); 24 (58.4%); 25 (7.5%); 27 (57.5%); 28 (2.1%); 31 (63.9%); 32 (60.6%); 33 (47.2%); 34 (34.9%); 39 (53.7%); 42 (46.2%); 43 (12.03%); 51 (45.5%); 53 (2.2%); 60 (74.2%); 61 (8.4%)	
Reserva de Dzilam	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (1.88%)	
Reserva de la Biosfera Los Petenes	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (4.02%)	
Reserva de la Biosfera Pantanos de Centla	TwlShpMX (0.99); LLReefMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	58 (0.06%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

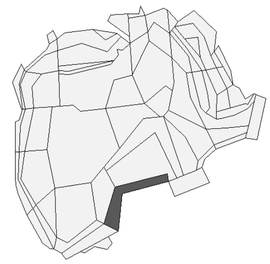
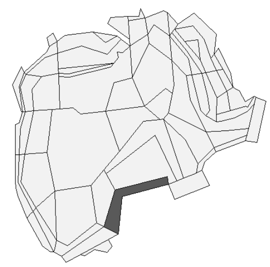
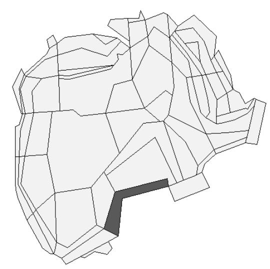
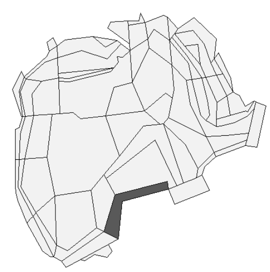
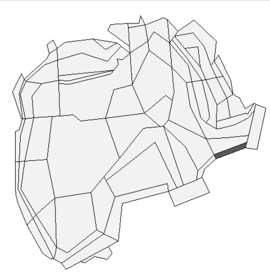
Name	Fleets affected	Polygons affected	Map
Reserva de la Biosfera Ría Celestún	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (0.91%)	
Reserva Estatal El Palmar	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (0.06%)	
Ría Celestún	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (0.99%)	
Ría Lagartos	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (1.09%)	
Rincon de Guanabo	MixedCuba (0.99)	49 (0.09%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

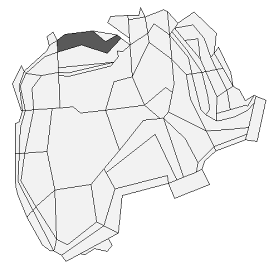
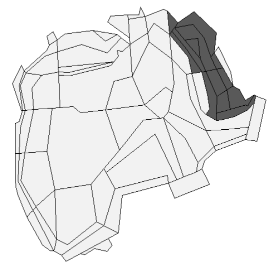
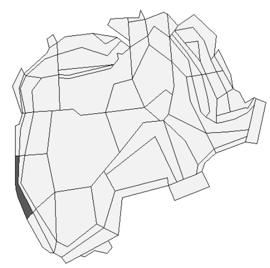
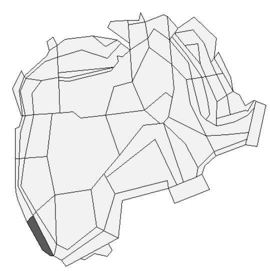
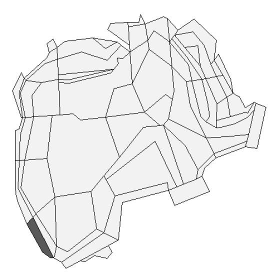
Name	Fleets affected	Polygons affected	Map
Rockefeller Wildlife Management Area and Game Preserve	SprtEst (0); GillnetEst (0); TwlShpEst (0); PotCrbEst (0); SprtShf (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); HLReefShf (0); SeineMenShf (0); OtherUS (0)	21 (1.01%)	
Seasonal prohibitions applicable to bottom longline fishing for Gulf reef fish	LLReefShf (0)	1 (0.03%); 5 (53.1%); 6 (99.6%); 24 (100%); 25 (47.8%); 27 (57.5%); 28 (14.05%); 31 (0.2%); 32 (99.6%); 33 (47.01%); 34 (34.7%); 42 (100%); 64 (52.6%)	
Sistema Arrecifal Lobos Tuxpan	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	36 (2.21%)	
Sistema Arrecifal Veracruzano	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); MixedMX (0.99)	62 (3.96%)	
Sistema Lagunar Alvarado	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); MixedMX (0.99)	62 (0.22%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

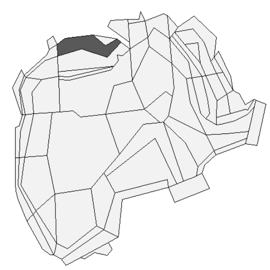
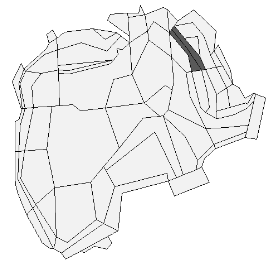
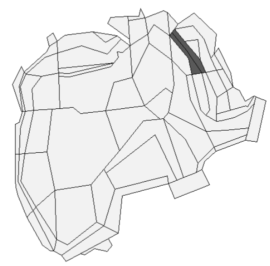
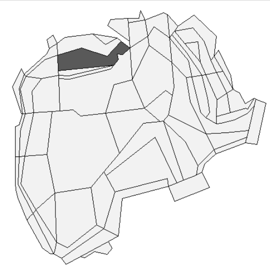
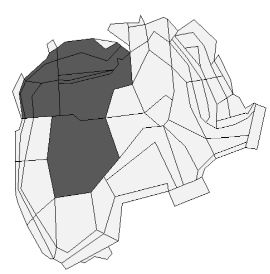
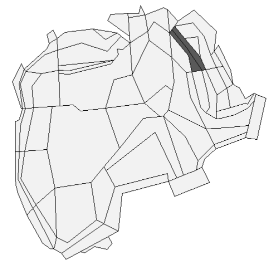
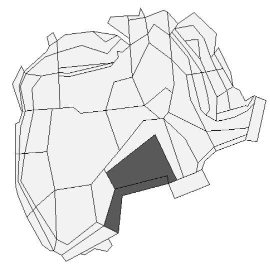
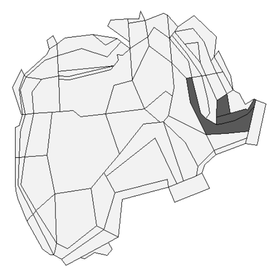
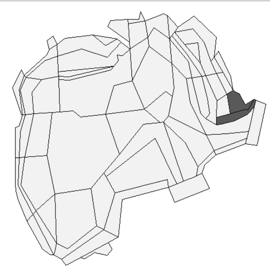
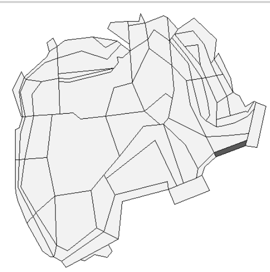
Name	Fleets affected	Polygons affected	Map
State Wildlife Management Area and Game Preserve	SprtEst (0.99); GillnetEst (0.99); TwlShpEst (0.99); PotCrbEst (0.99); SprtShf (0.99); TwlShpShf (0.99); PotCrbShf (0.99); PotLbtShf (0.99); HLReefShf (0.99); SeineMenShf (0.99); OtherUS (0.99)	21 (0.17%)	
Steamboat Lumps-Summer	GillnetEst (0); PotCrbEst (0); PotCrbShf (0); PotLbtShf (0); HLReefShf (0); LLReefShf (0); LLShkShf (0); LLPelgc (0); RoyalRed (0); OtherUS (0); SprtShf (0)	1 (1.74%); 25 (2.03%)	
Steamboat Lumps-Winter	GillnetEst (0); PotCrbEst (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); HLReefShf (0); LLReefShf (0); LLShkShf (0); LLPelgc (0); RoyalRed (0); OtherUS (0); SprtShf (0)	1 (1.74%); 25 (2.03%)	
Stetson Bank Habitat Area of Particular Concern	PotCrbEst (0); SprtShf (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); LLReefShf (0)	20 (0.01%)	
Texas closure	TwlShpShf (0); TwlShpEst (0)	15 (22.98%); 17 (99.99%); 18 (98.71%); 20 (19.1%); 21 (12.07%); 43 (40.07%); 51 (44.92%); 56 (30.02%); 57 (0.003%); 60 (97.78%); 61 (8.71%)	

Table A.6 (continued). Marine protected areas represented in GOM Atlantis.

Name	Fleets affected	Polygons affected	Map
The Edges	GillnetEst (0); PotCrbEst (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); HLReefShf (0); LLReefShf (0); LLShkShf (0); LLPelgc (0); RoyalRed (0); OtherUS (0); SprtShf (0)	1 (2.5%); 25 (11.29%)	
Tiburón Ballena	TwlShpMX (0.99); LLReefMX (0.99); LLShkMX (0.99); GillnetMackMX (0.99); OctpsMX (0.99); MixedMX (0.99)	4 (2.3%); 13 (0.63%)	
Tortugas Marine Reserves	SprtEst (0); GillnetEst (0); PotCrbEst (0); SprtShf (0); TwlShpShf (0); PotCrbShf (0); PotLbtShf (0); HLReefShf (0); LLReefShf (0); LLShkShf (0); LLPelgc (0); RoyalRed (0); OtherUS (0)	28 (1.32%); 29 (0.19%); 32 (0.02%)	
Tortugas Shrimp Sanctuary	TwlShpEst (0); TwlShpShf (0); RoyalRed (0)	27 (25.51%); 28 (2.6%); 28 (0.19%); 28 (0.54%); 28 (0.92%)	
Valle del Yumuri	MixedCuba (0.99)	49 (0.38%)	

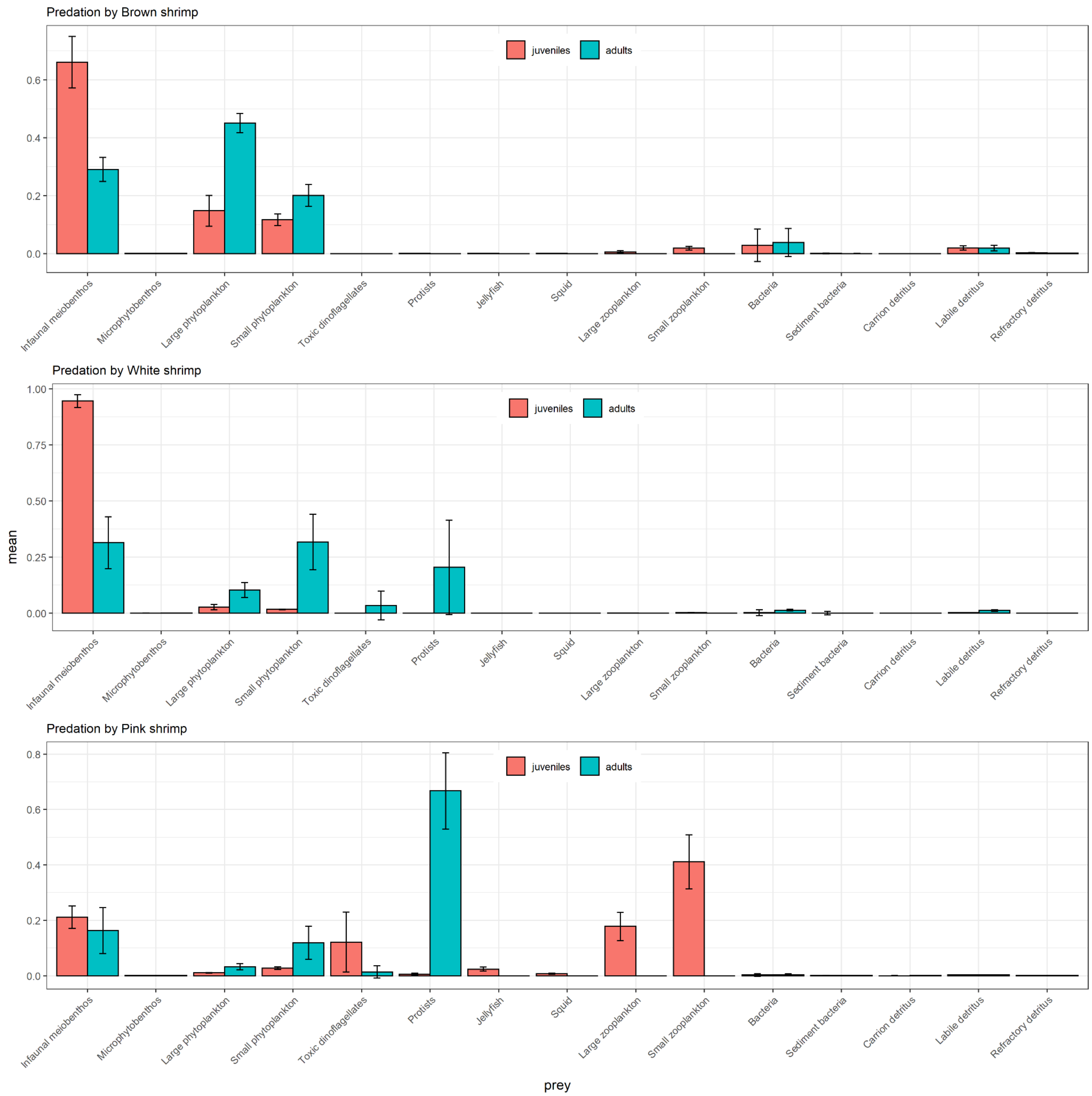


Figure A.1. Average prey proportions for a select group of predators.

Data from the Atlantis output file DietCheck.txt were used to compute average prey proportions for a select group of predators. The mean and standard deviation of the proportional diet data were computed across a one-year simulation, printing output daily, for the juvenile and adult age cohorts.

Figure A.1. (continued).

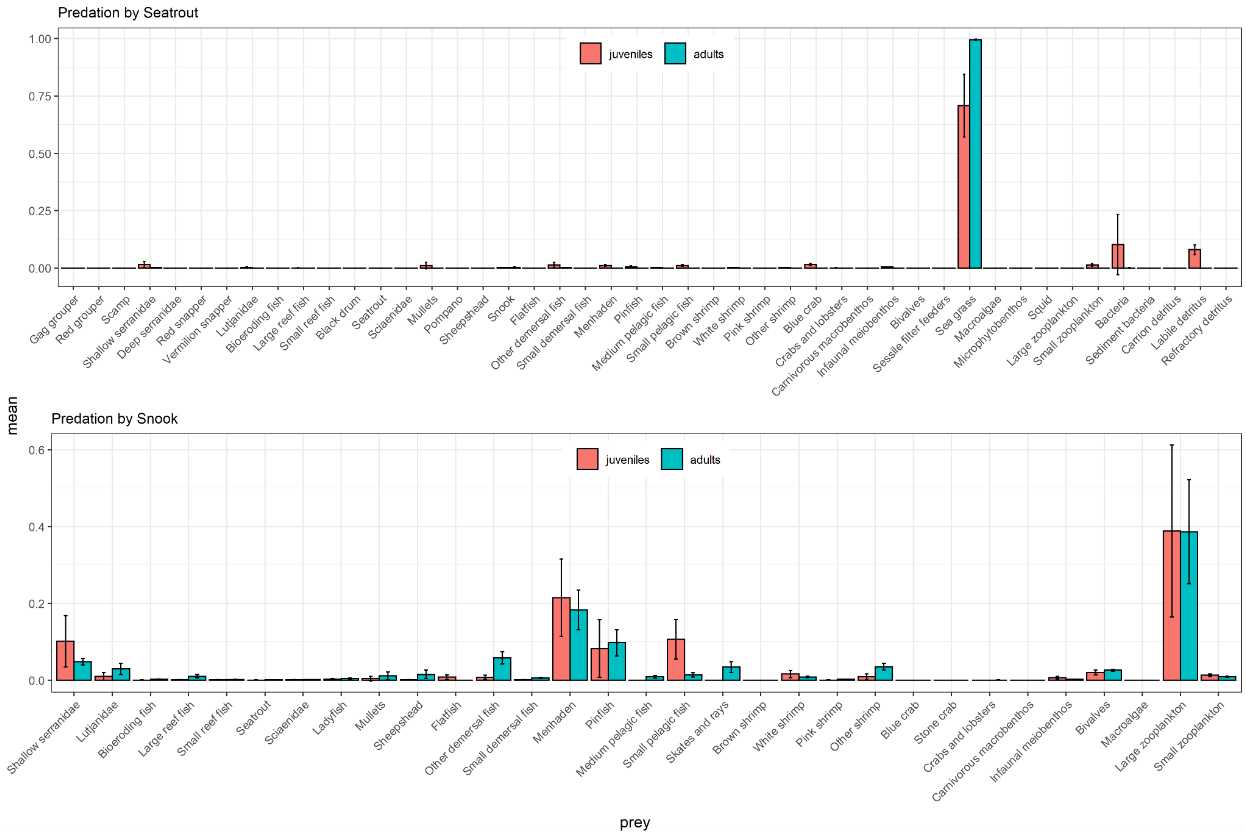


Figure A.1. (continued).

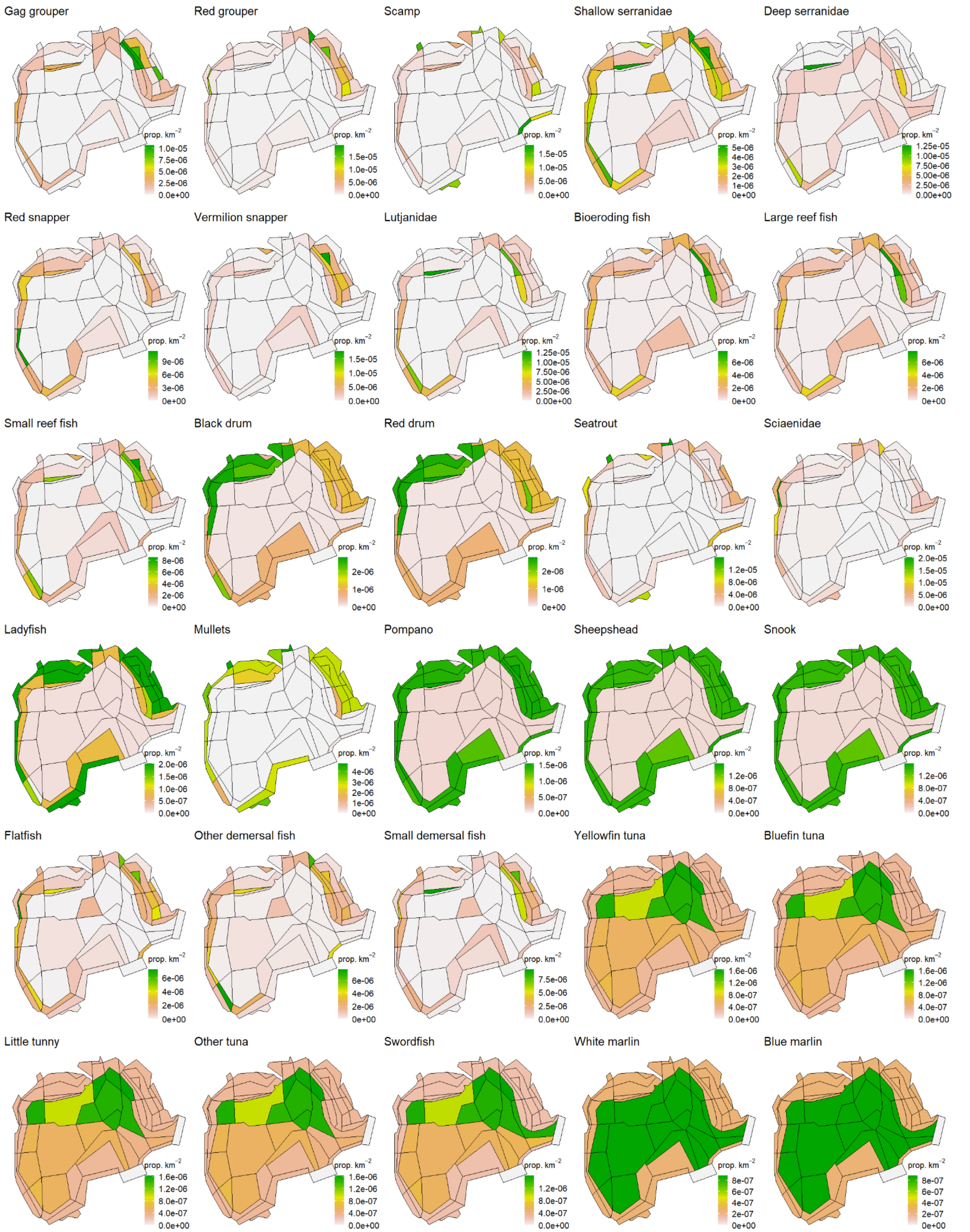


Figure A.2. Horizontal distributions of functional groups (adults and biomass pools) within GOM Atlantis (Jan. - Mar.; based on parameterization in the Atlantis biology.prm file).

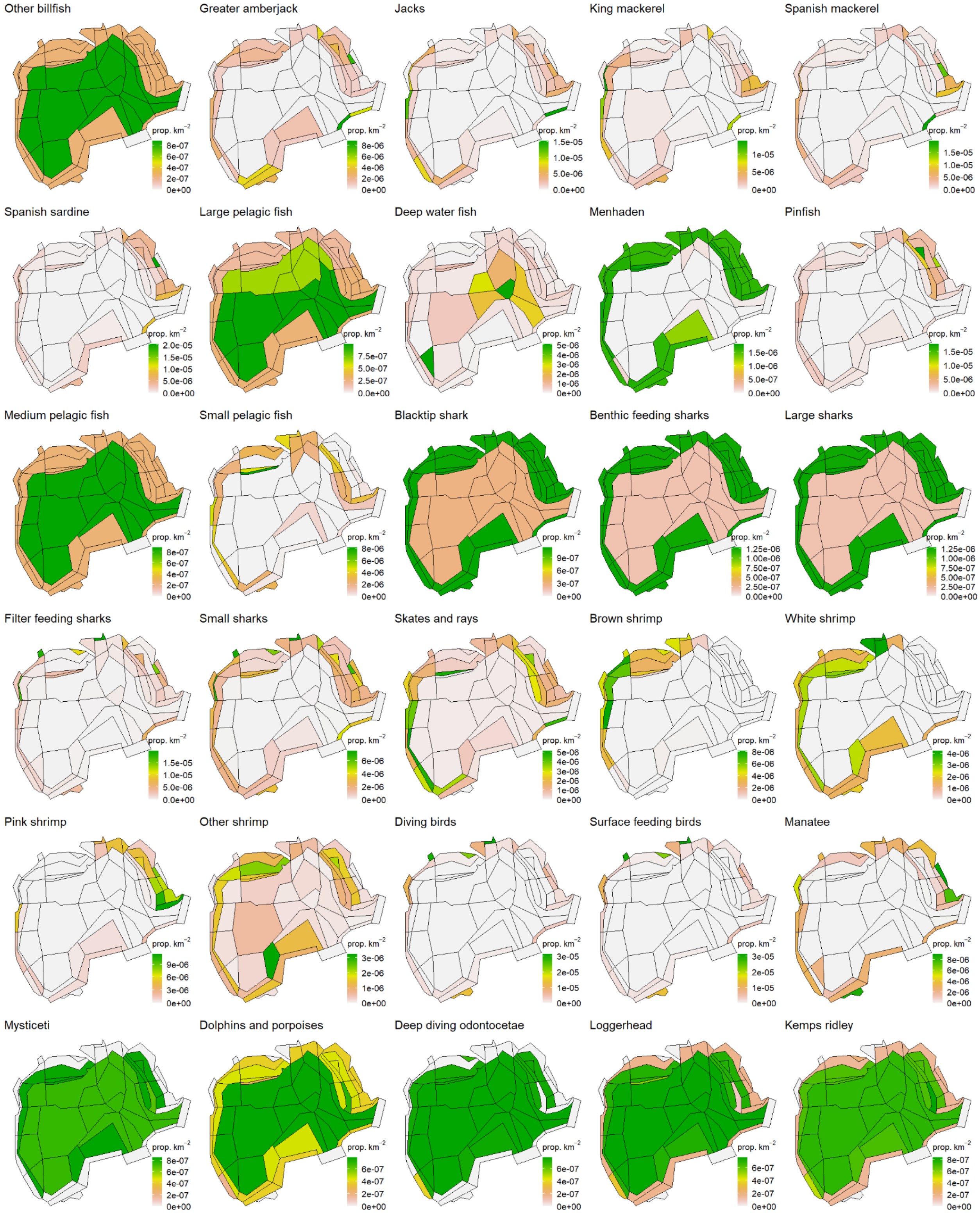


Figure A.2. (cont.)

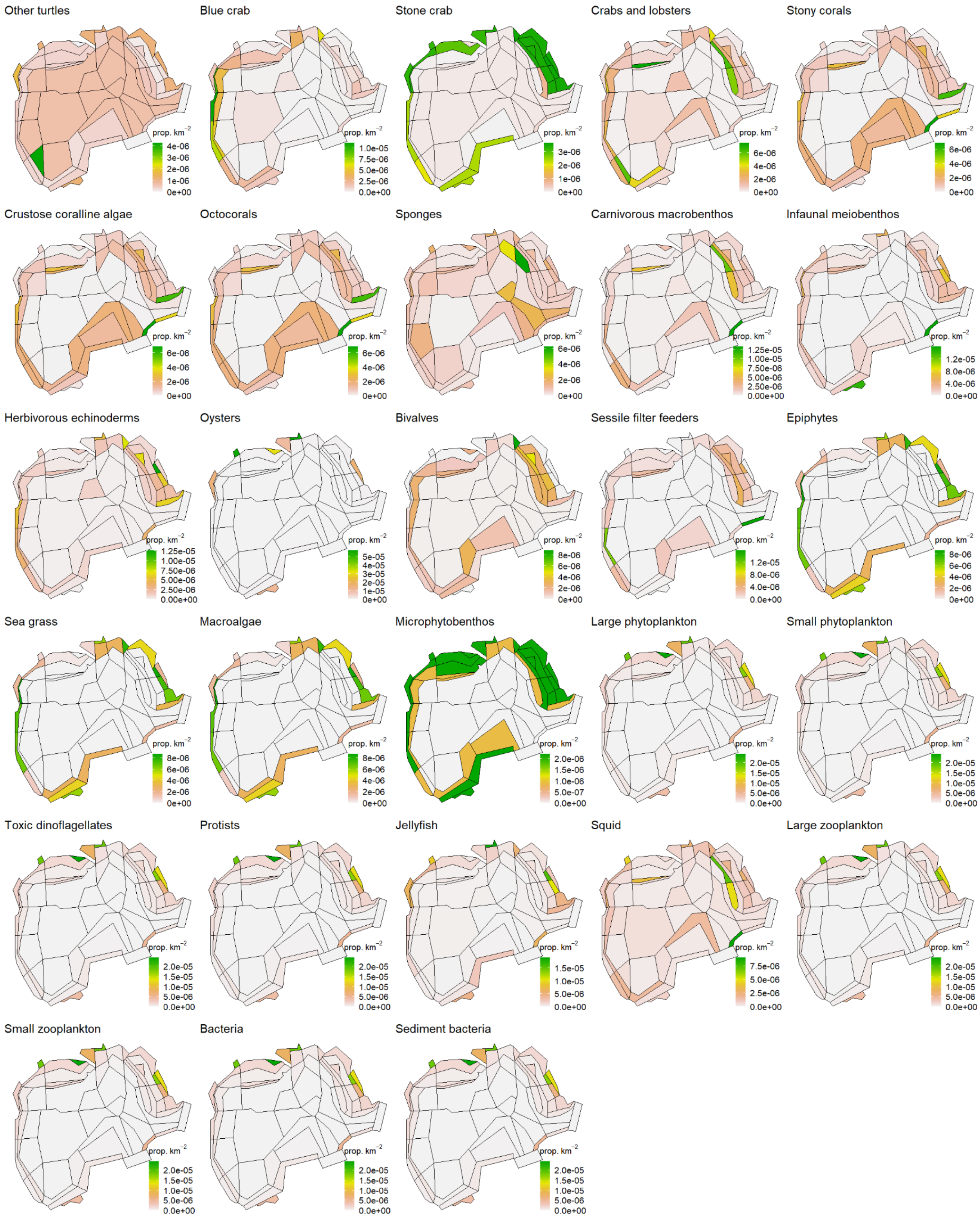


Figure A.2. (cont.)

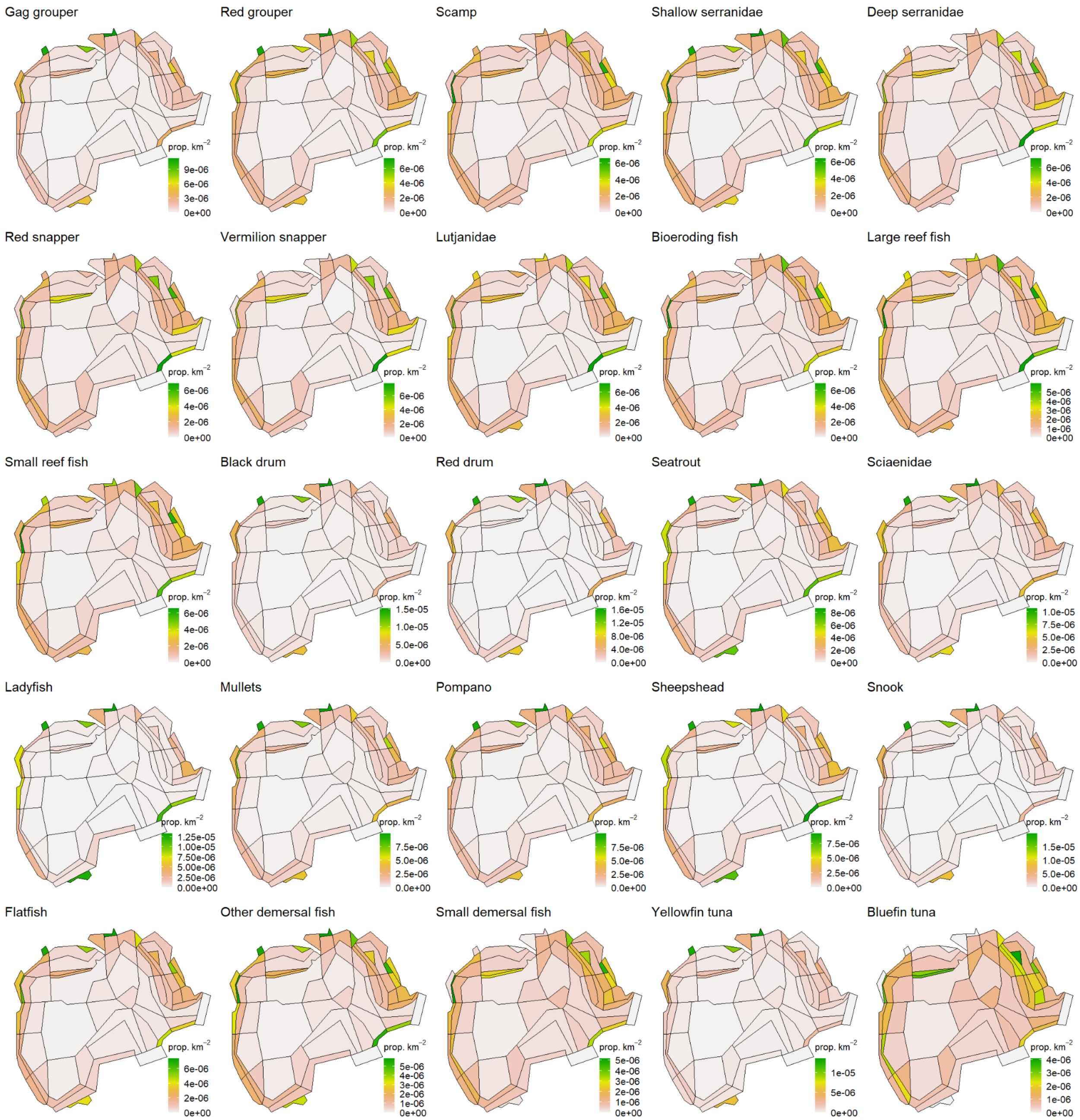


Figure A.3. Horizontal distributions of functional groups (juveniles) within GOM Atlantis (Jan. - Mar.; based on parameterization in the Atlantis biology.prm file).

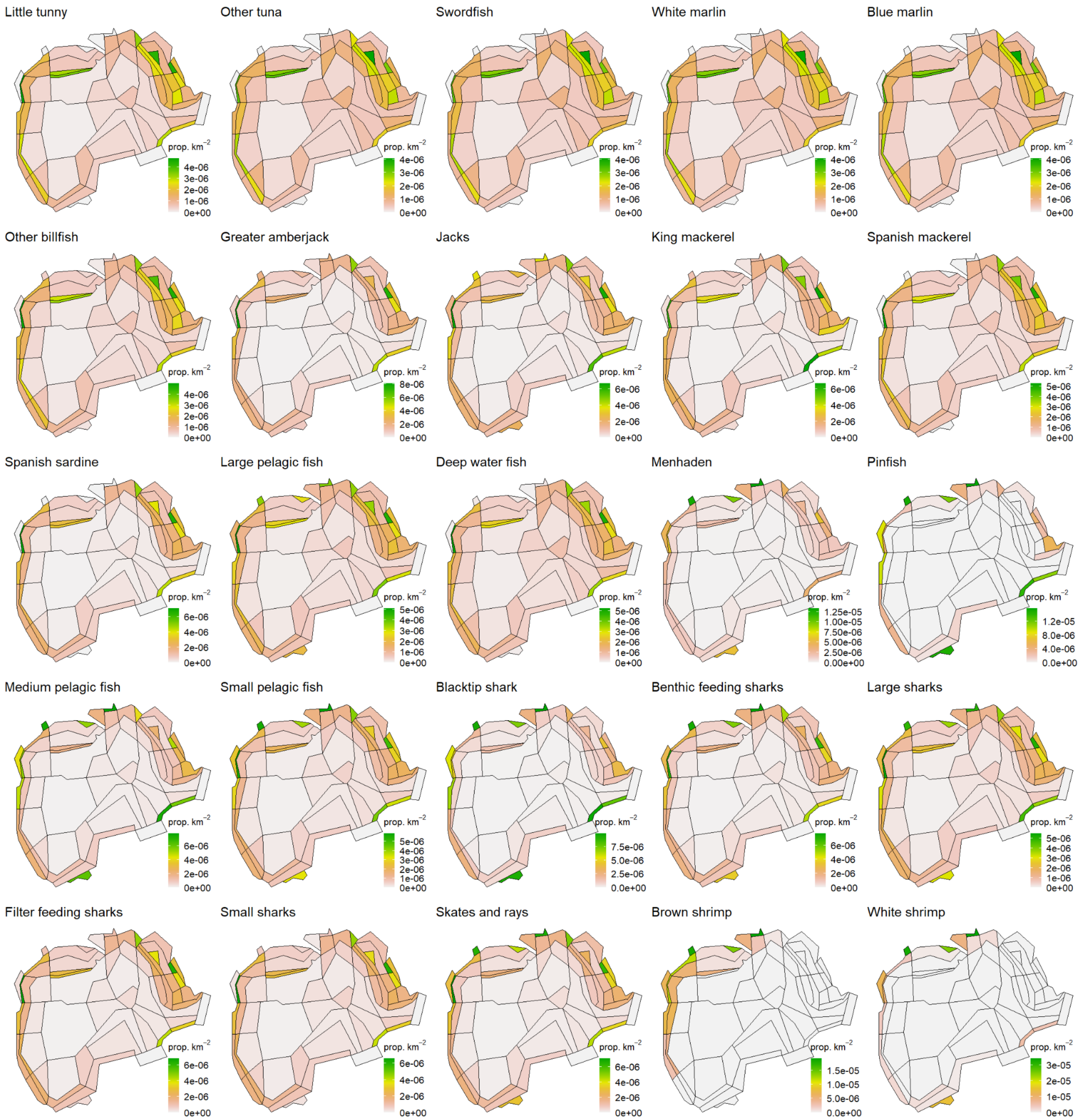


Figure A.3. (cont.)

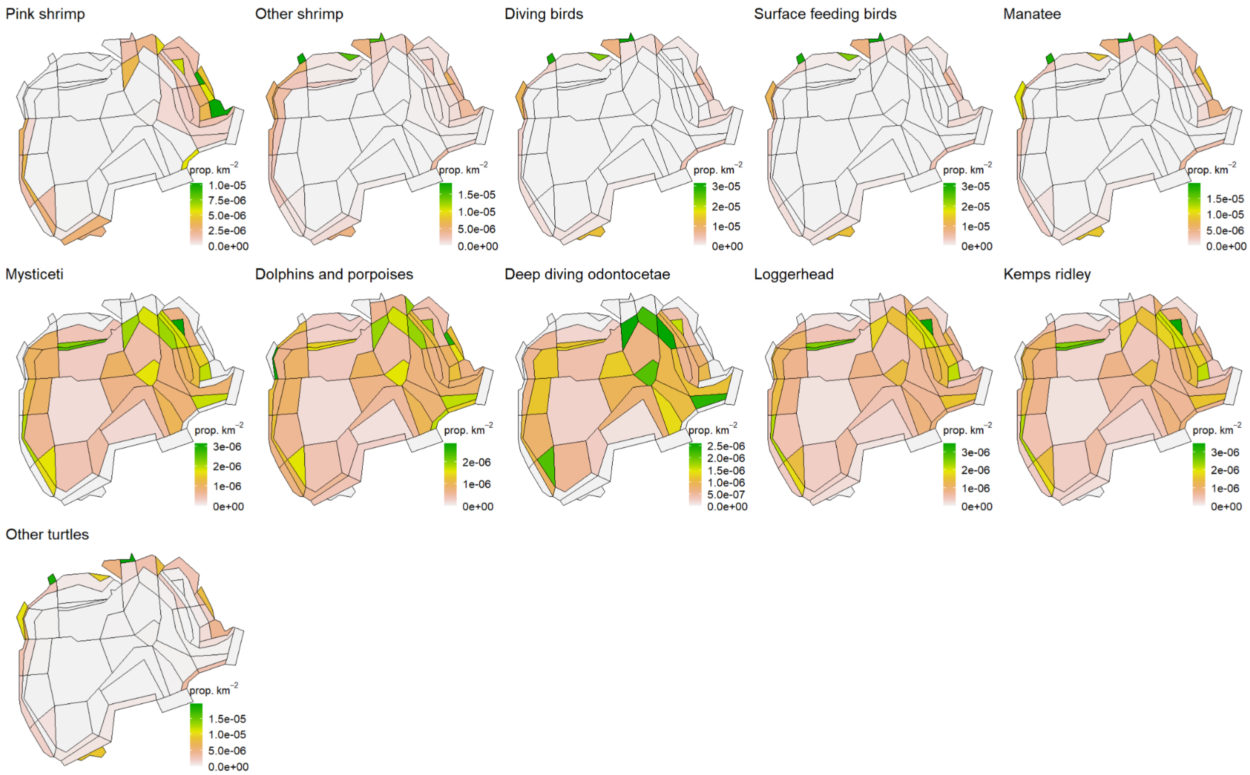


Figure A.3. (cont.)

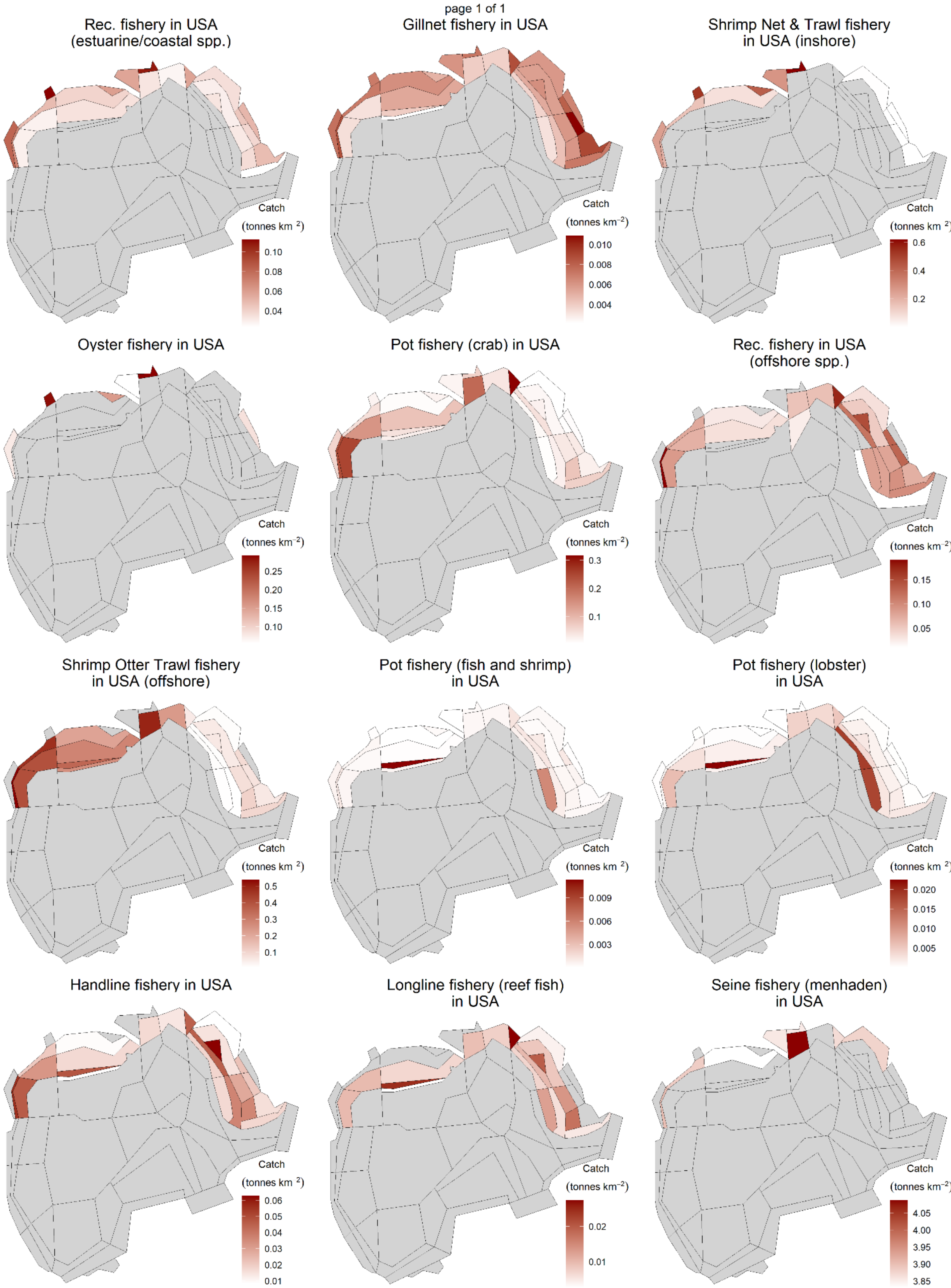


Figure A.4. Horizontal distribution of catches within GOM Atlantis by fleets.

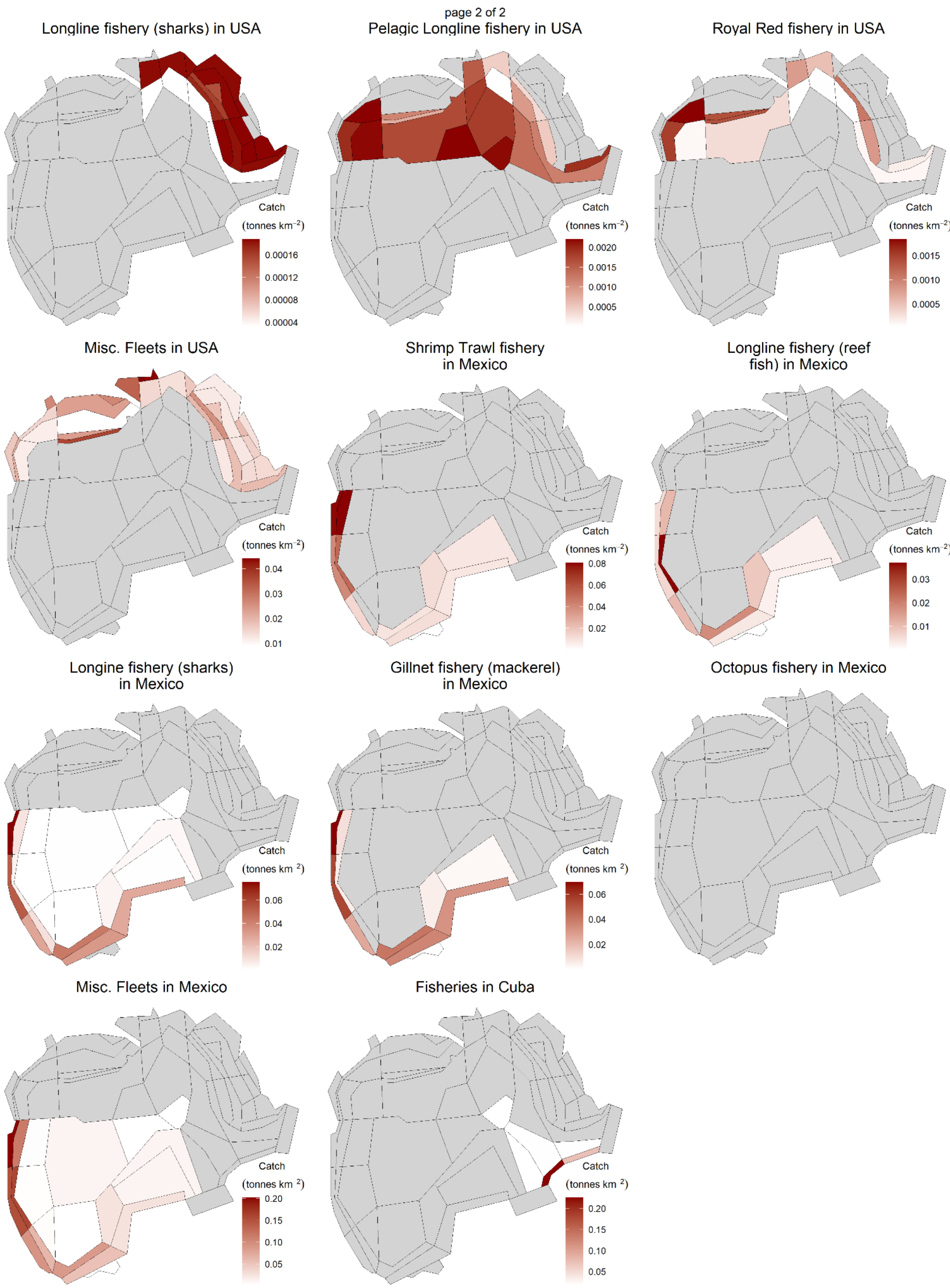


Figure A.4. (continued).

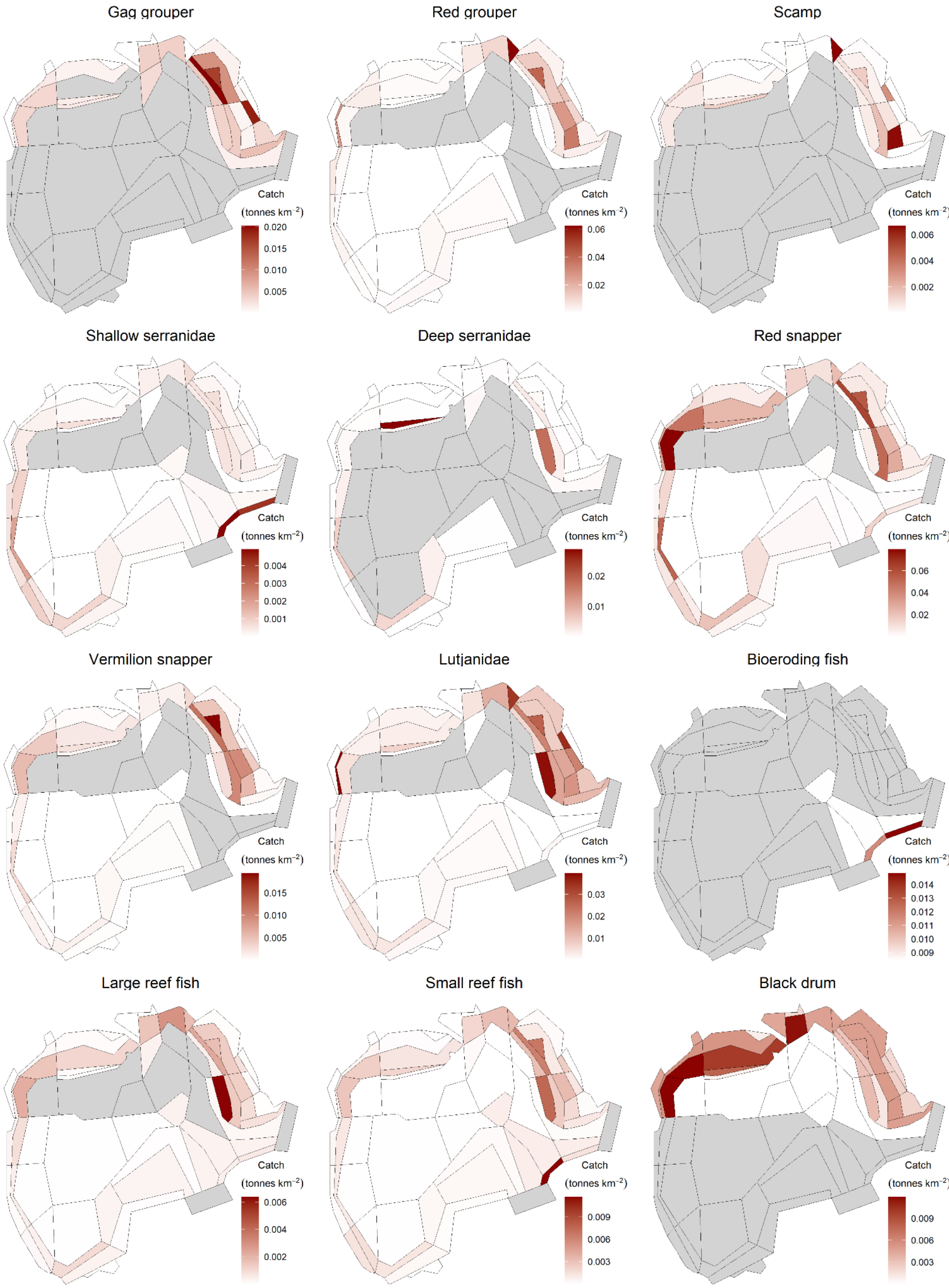


Figure A.5. Horizontal distribution of catches within GOM Atlantis by functional groups.

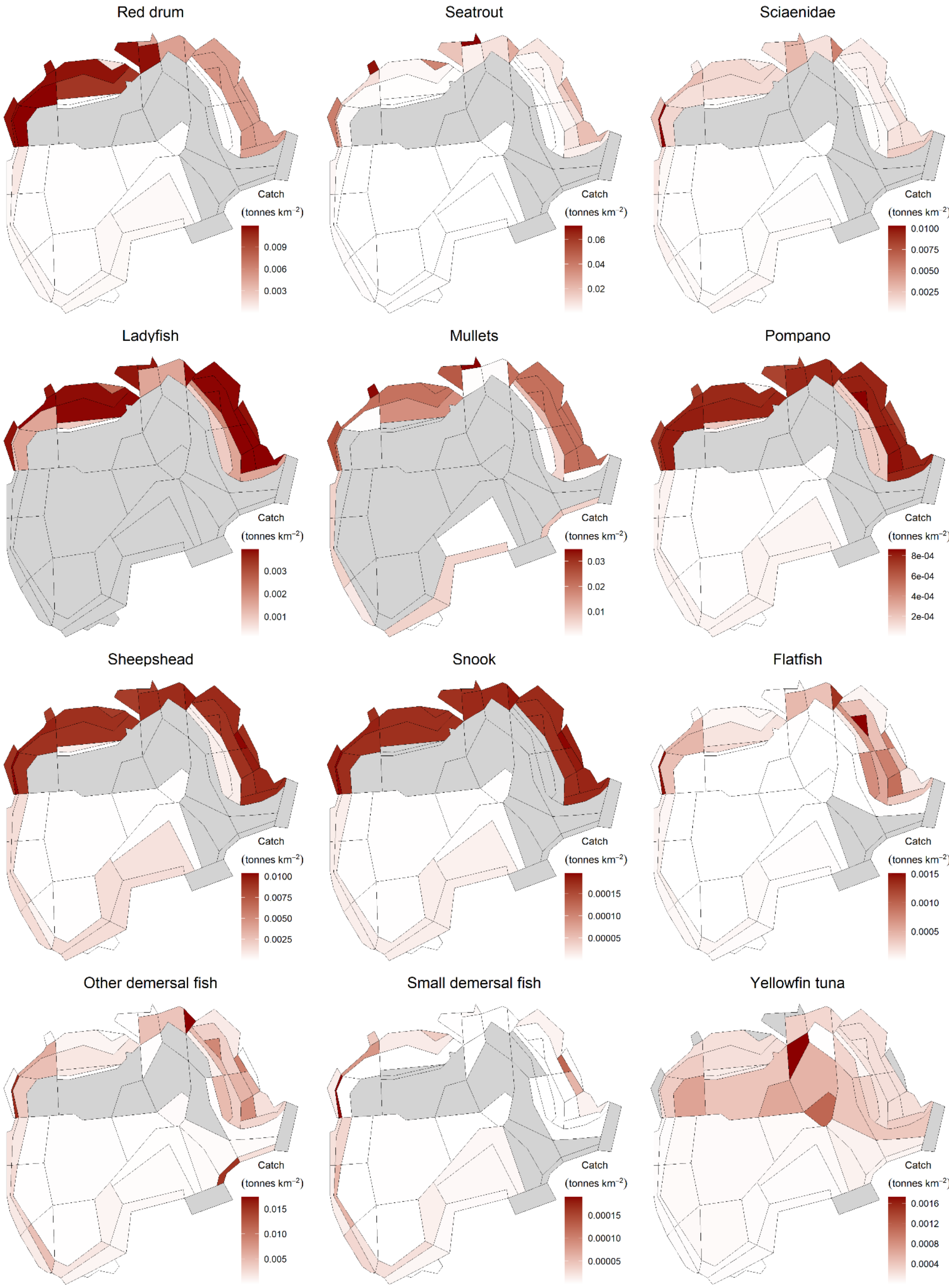


Figure A.5. (continued).

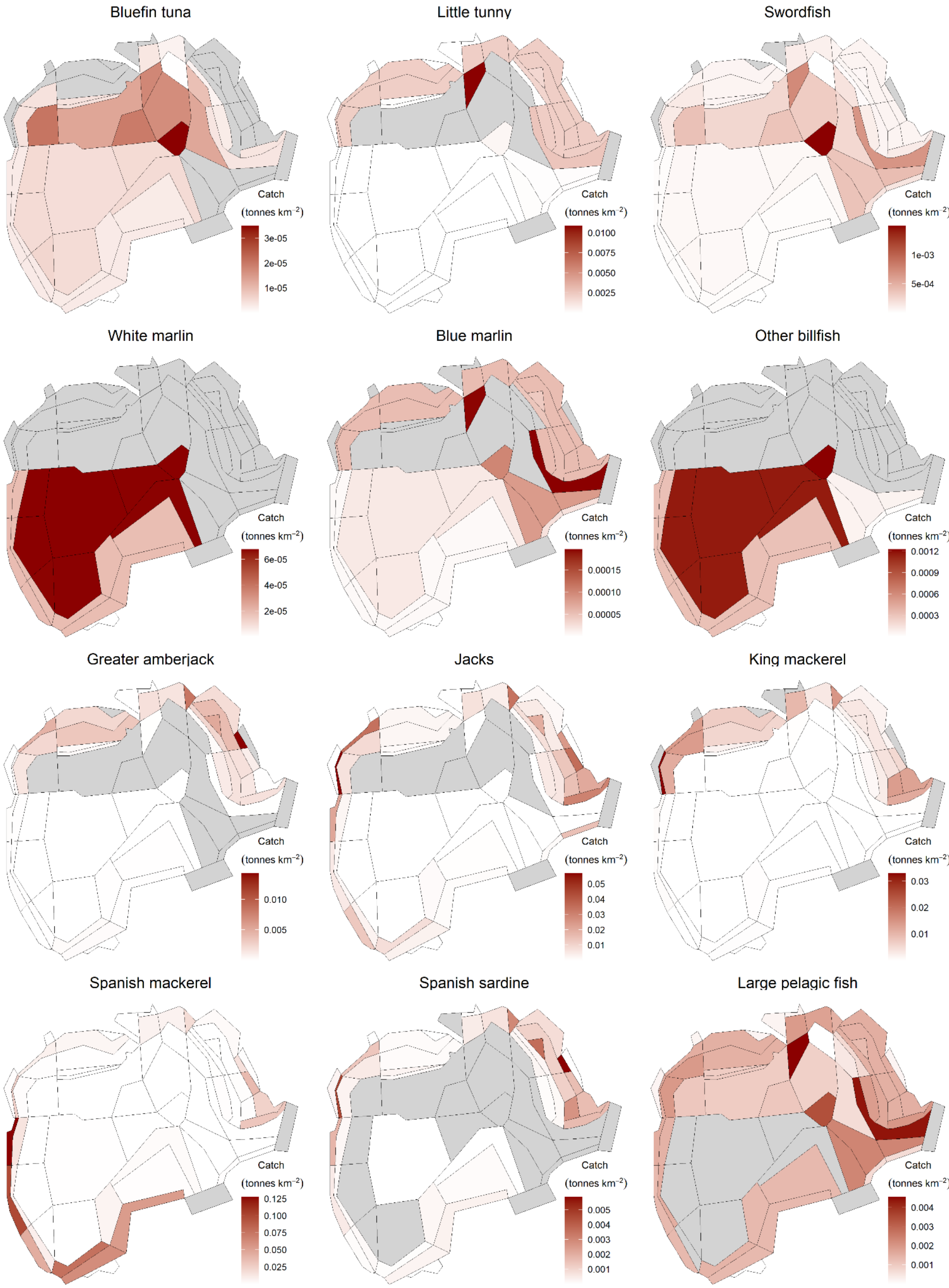


Figure A.5. (continued).

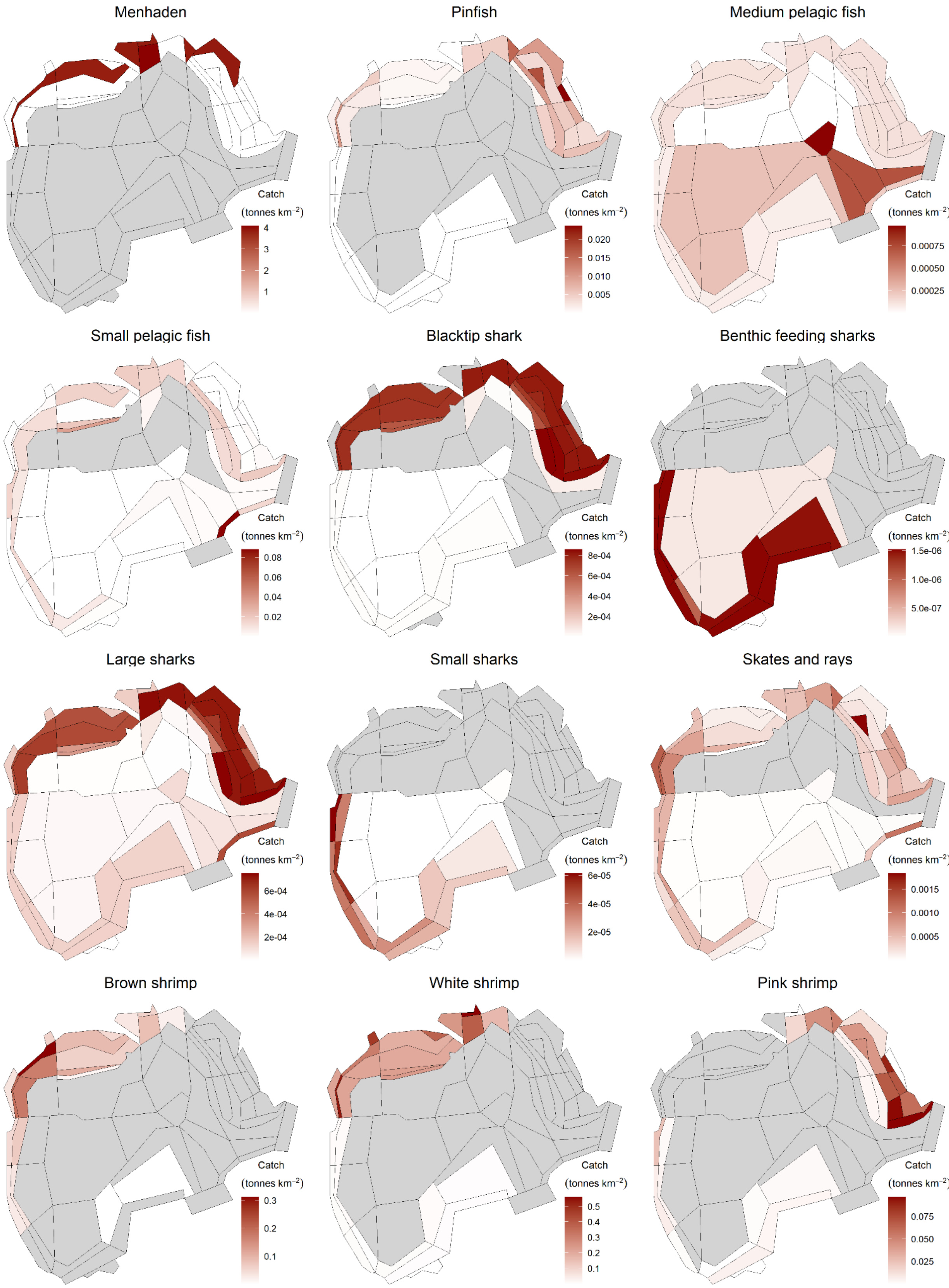


Figure A.5. (continued).

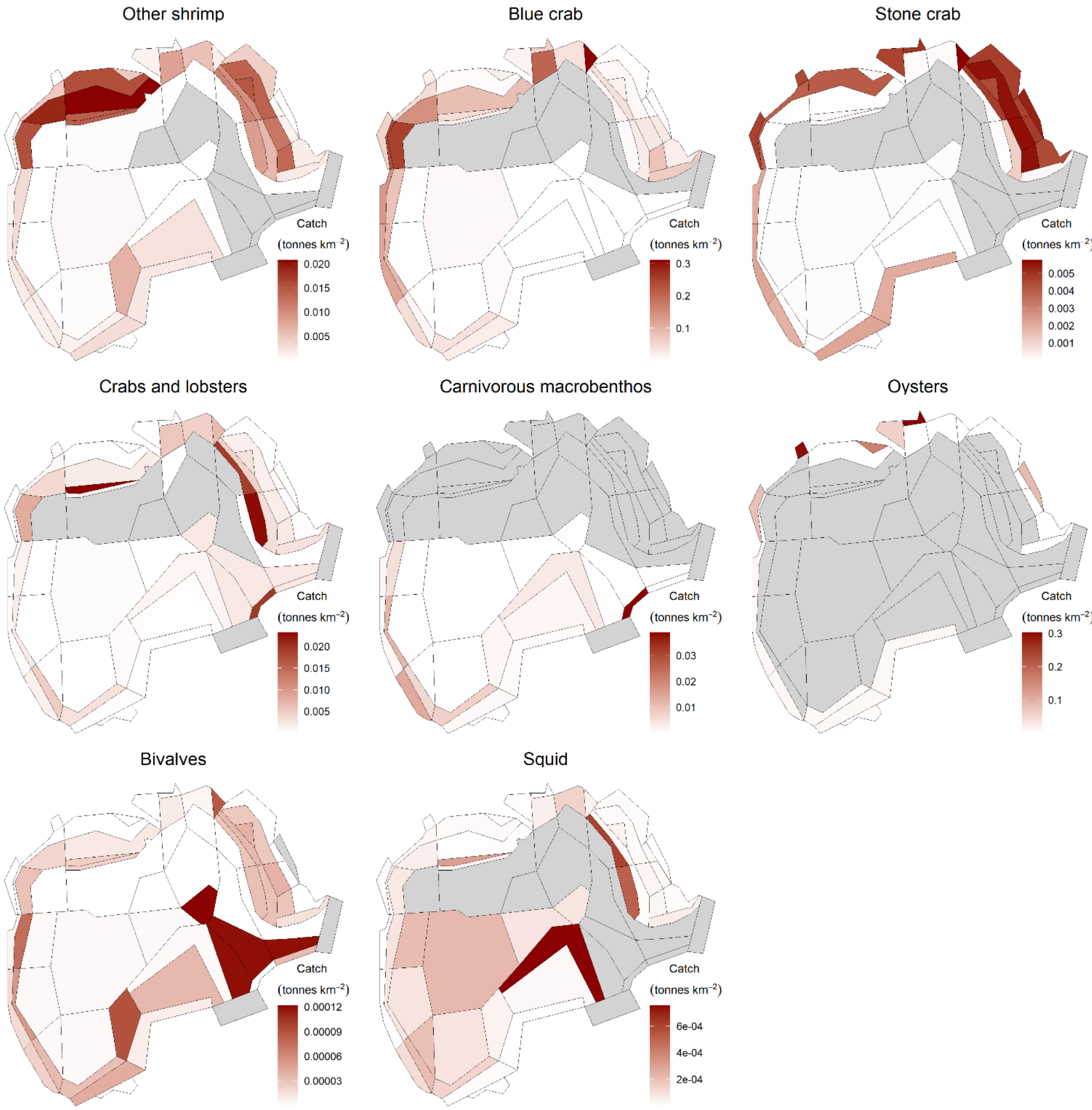


Figure A.5. (continued).

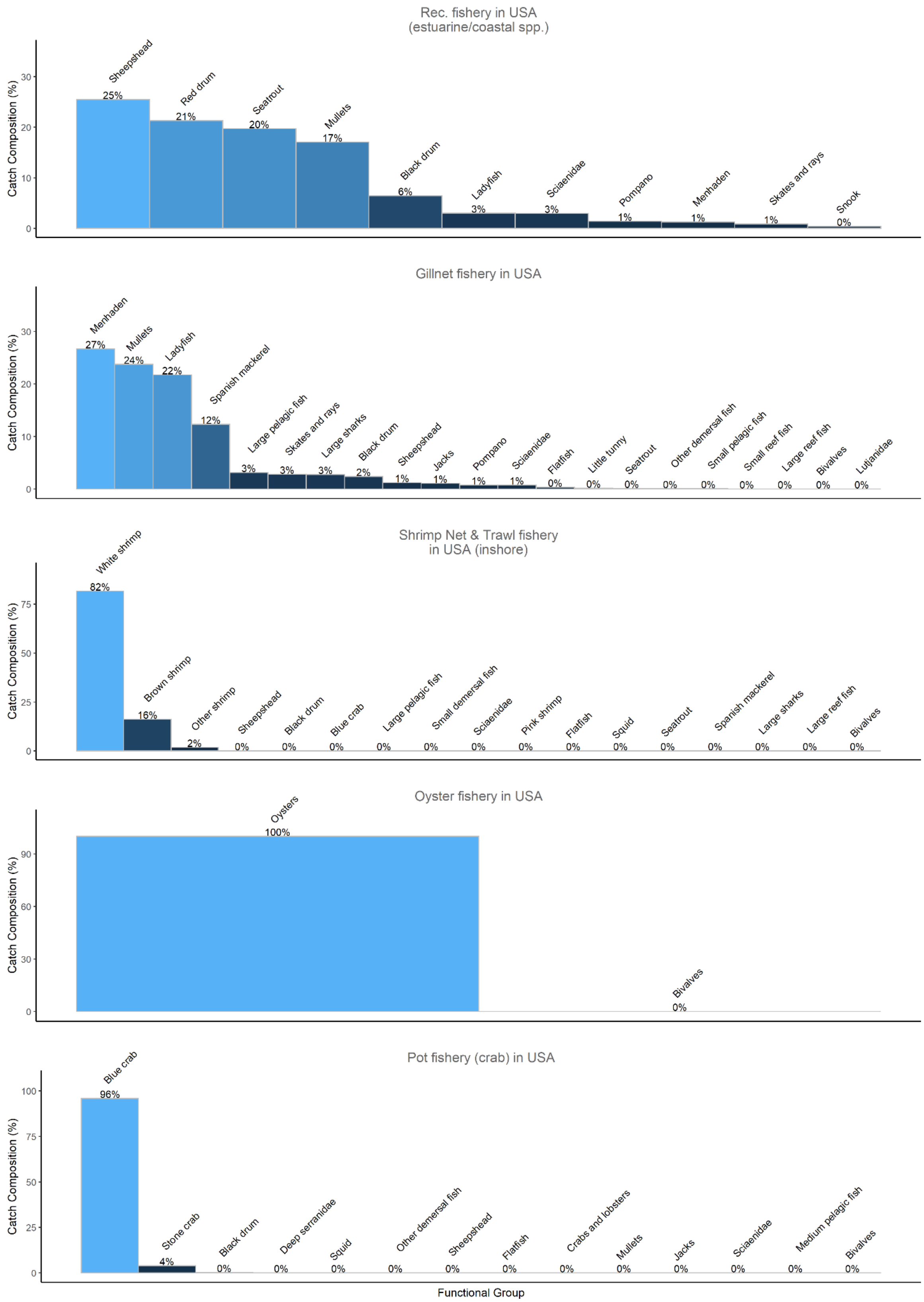


Figure A.6. Catch composition of fleets within the GOM Atlantis model.

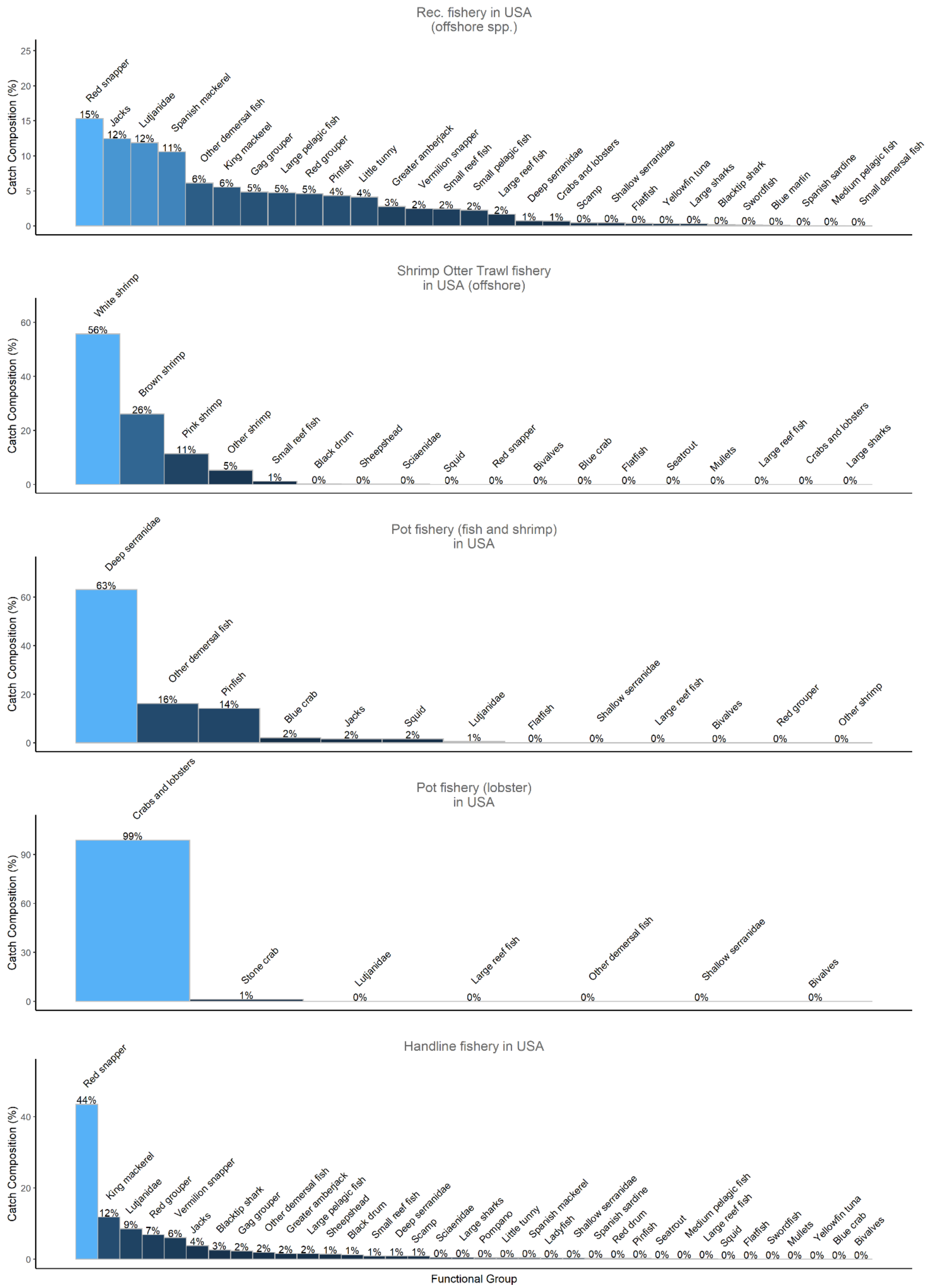


Figure A.6. (continued).

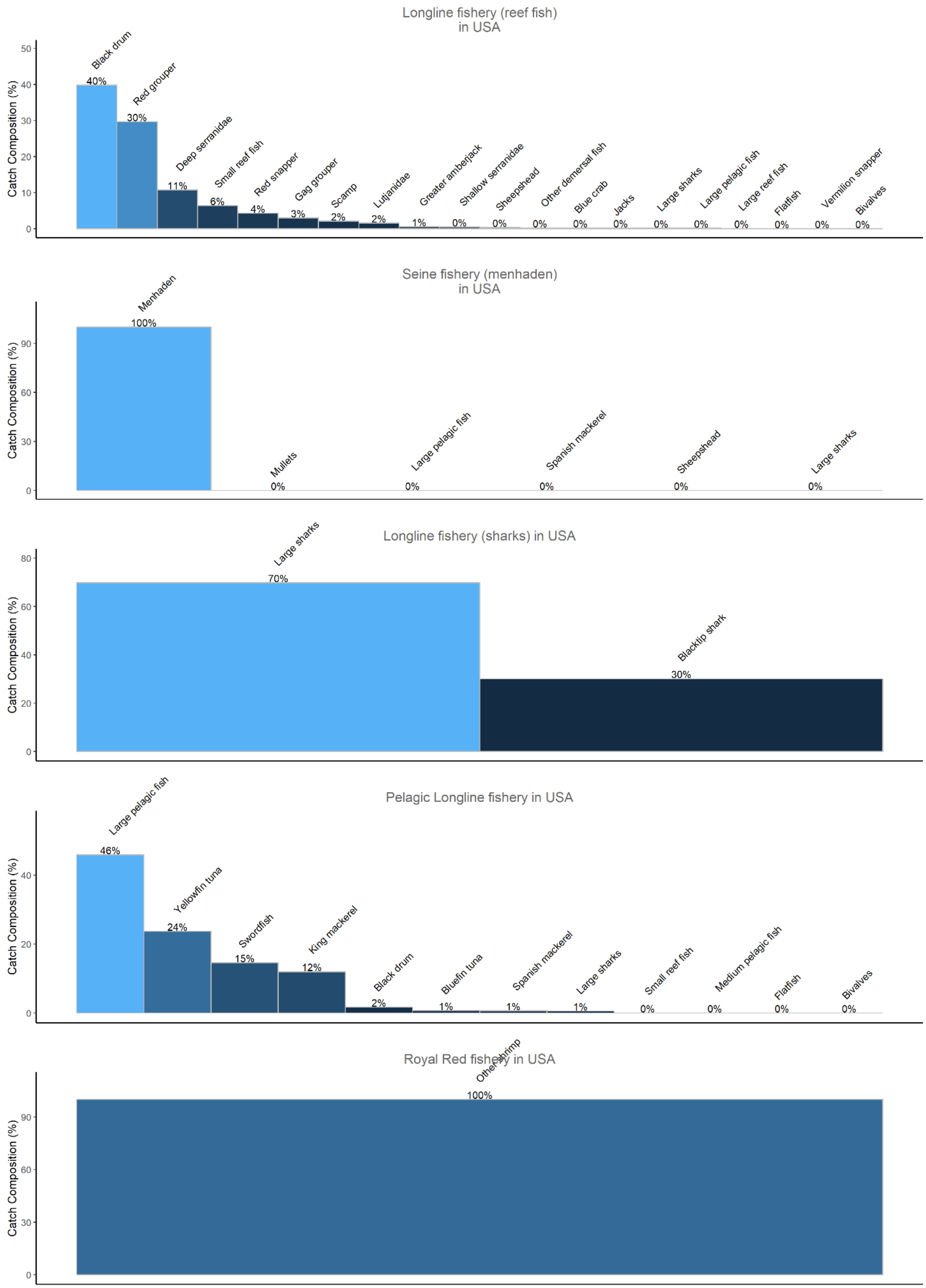


Figure A.6. (continued).

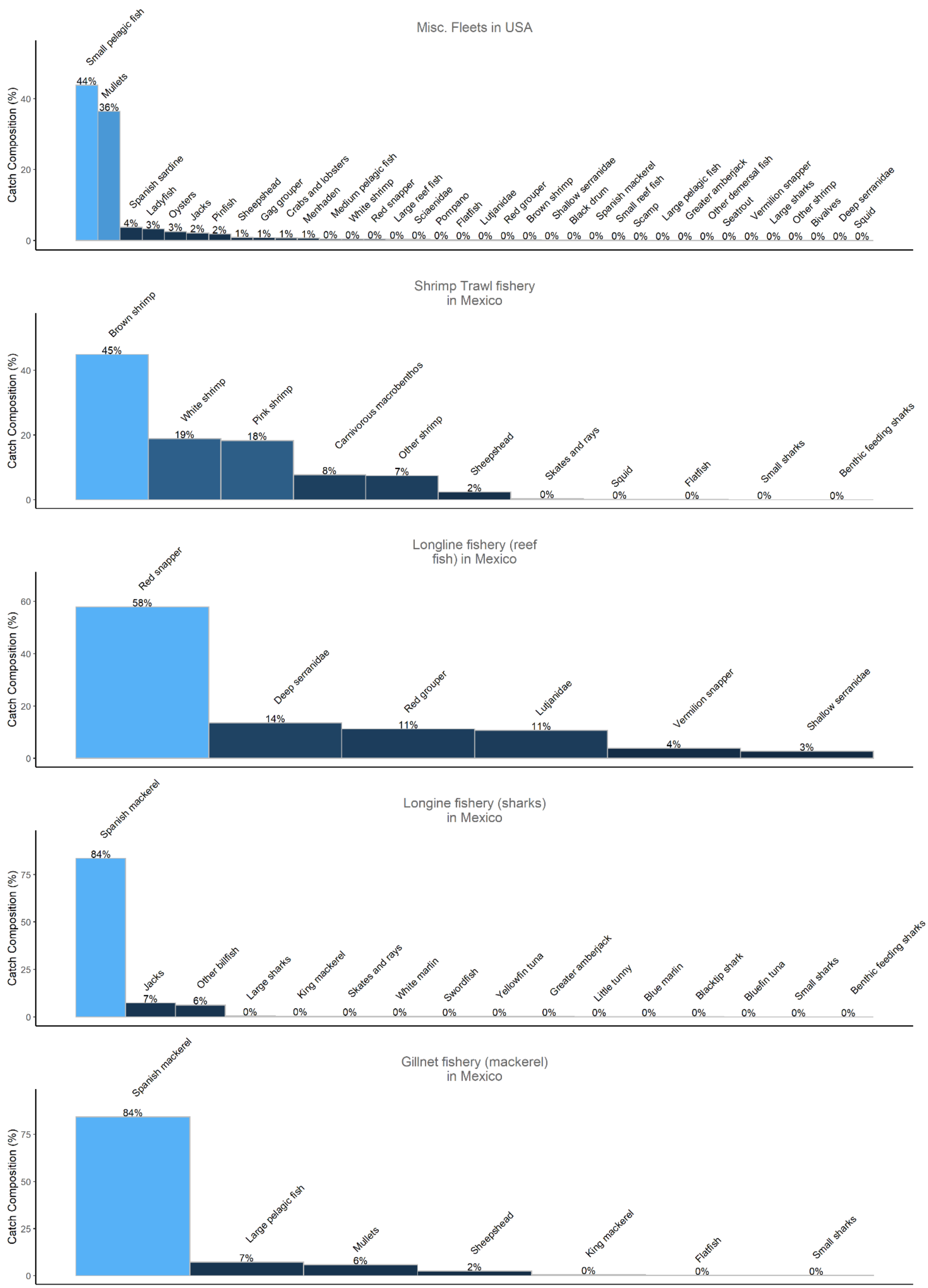


Figure A.6. (continued).

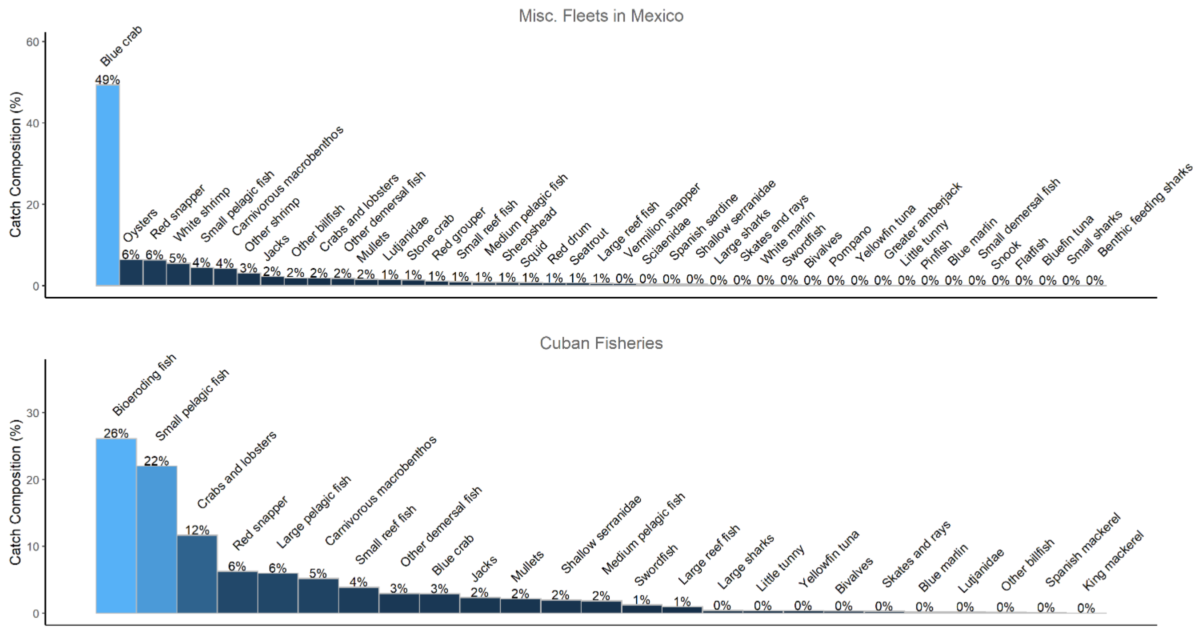


Figure A.6. (continued).

Appendix B – Model performance

Figure B.1. Time series displaying biomass, relative density, relative reserve nitrogen, and relative structural nitrogen. Diagnostics for relative density and nitrogens, which are only available for age-structured groups, are plotted for individual age classes. For relative density, sexually immature age classes are plotted using a heat scale (with the red line being the youngest class and the orange line being the oldest class), while sexually mature age classes are plotted using a gray scale (with the lightest color being the youngest class and the darkest color being the oldest class). For relative nitrogens, age classes are plotted using a rainbow scale, with the red line representing the youngest class and the blue line representing the oldest class. The following images are presented relative to simulation year-20, dropping the burn-in period. Labels show functional group names and short code.

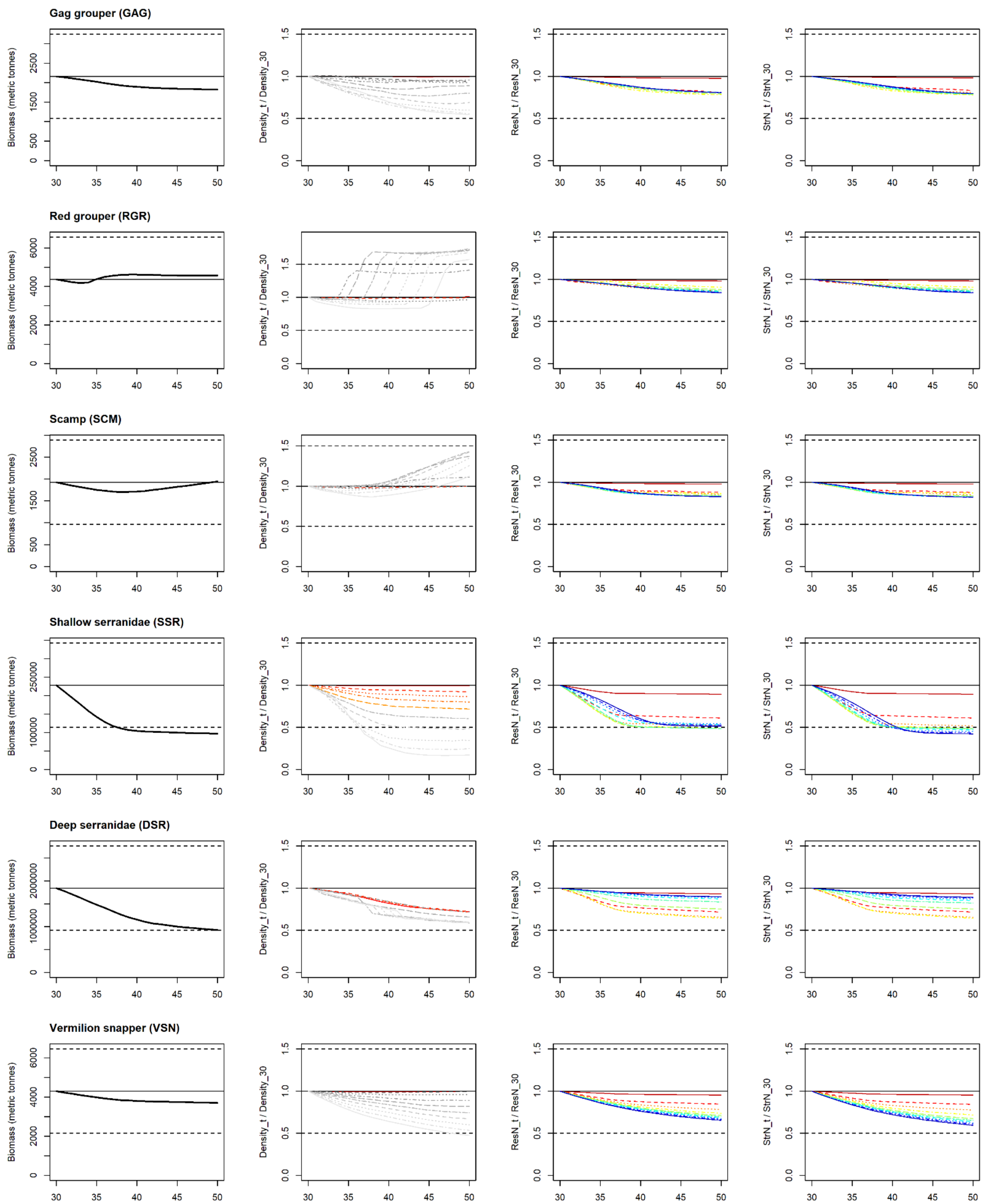


Figure B.1. (continued).

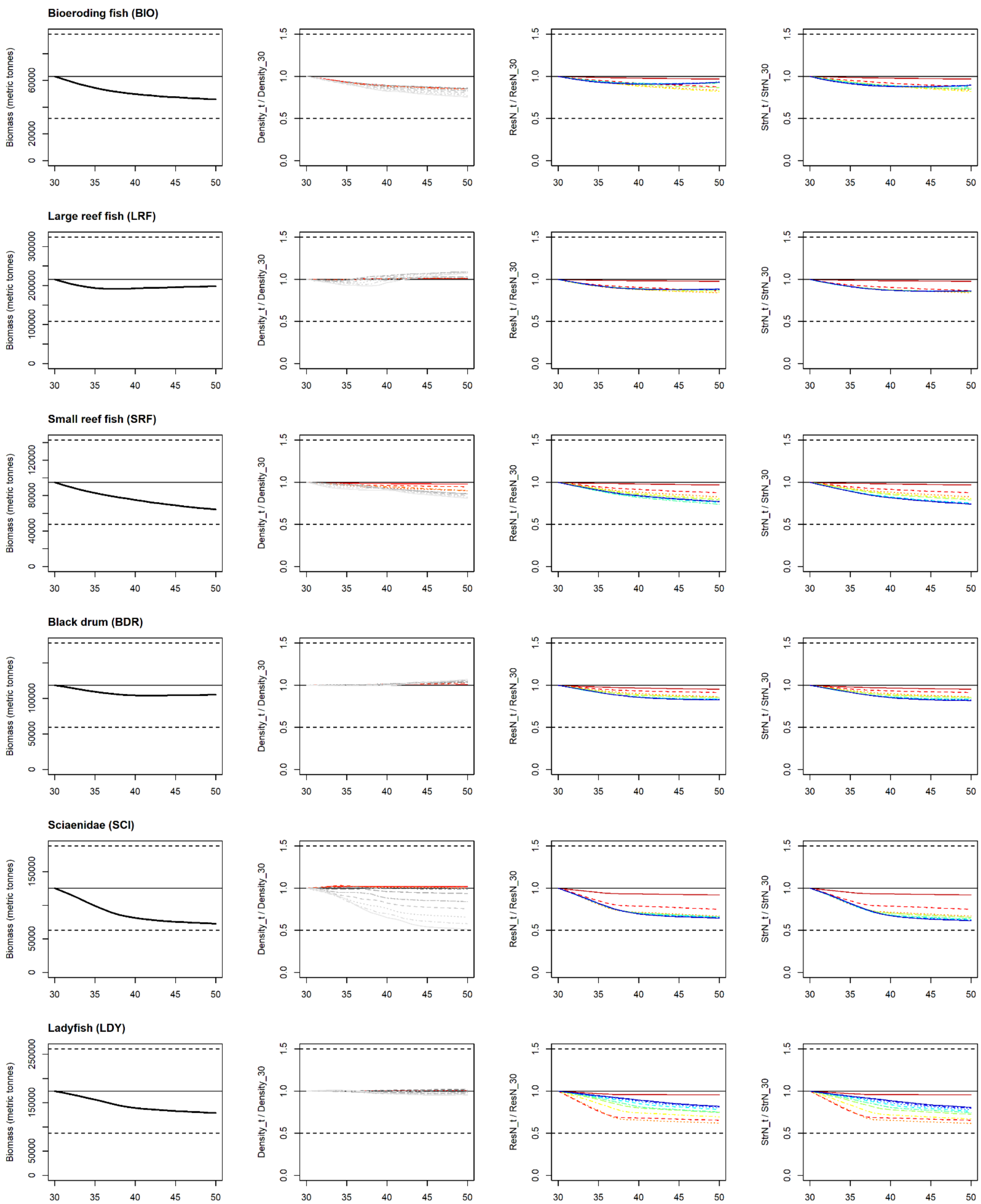


Figure B.1. (continued).

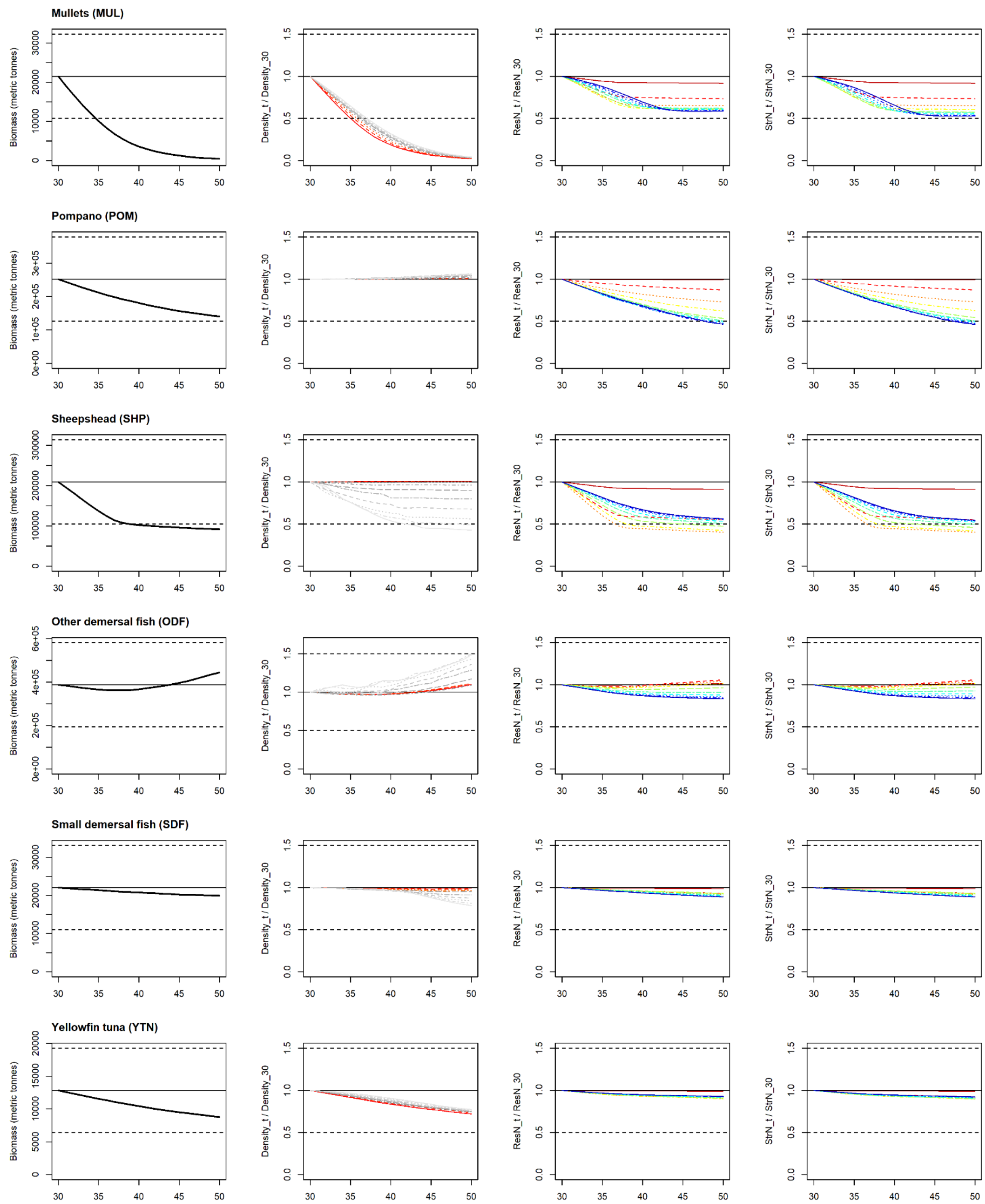


Figure B.1. (continued).

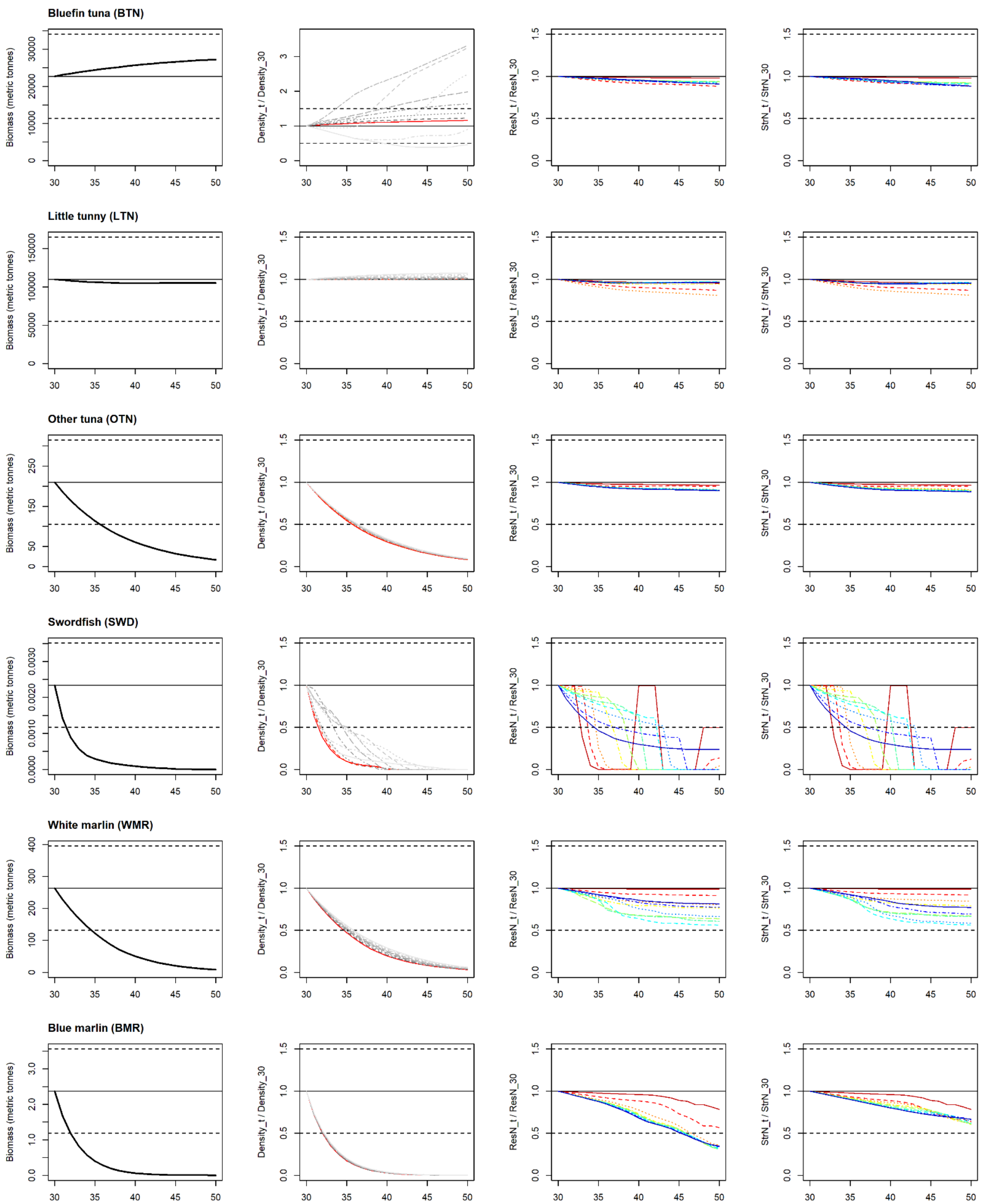


Figure B.1. (continued).

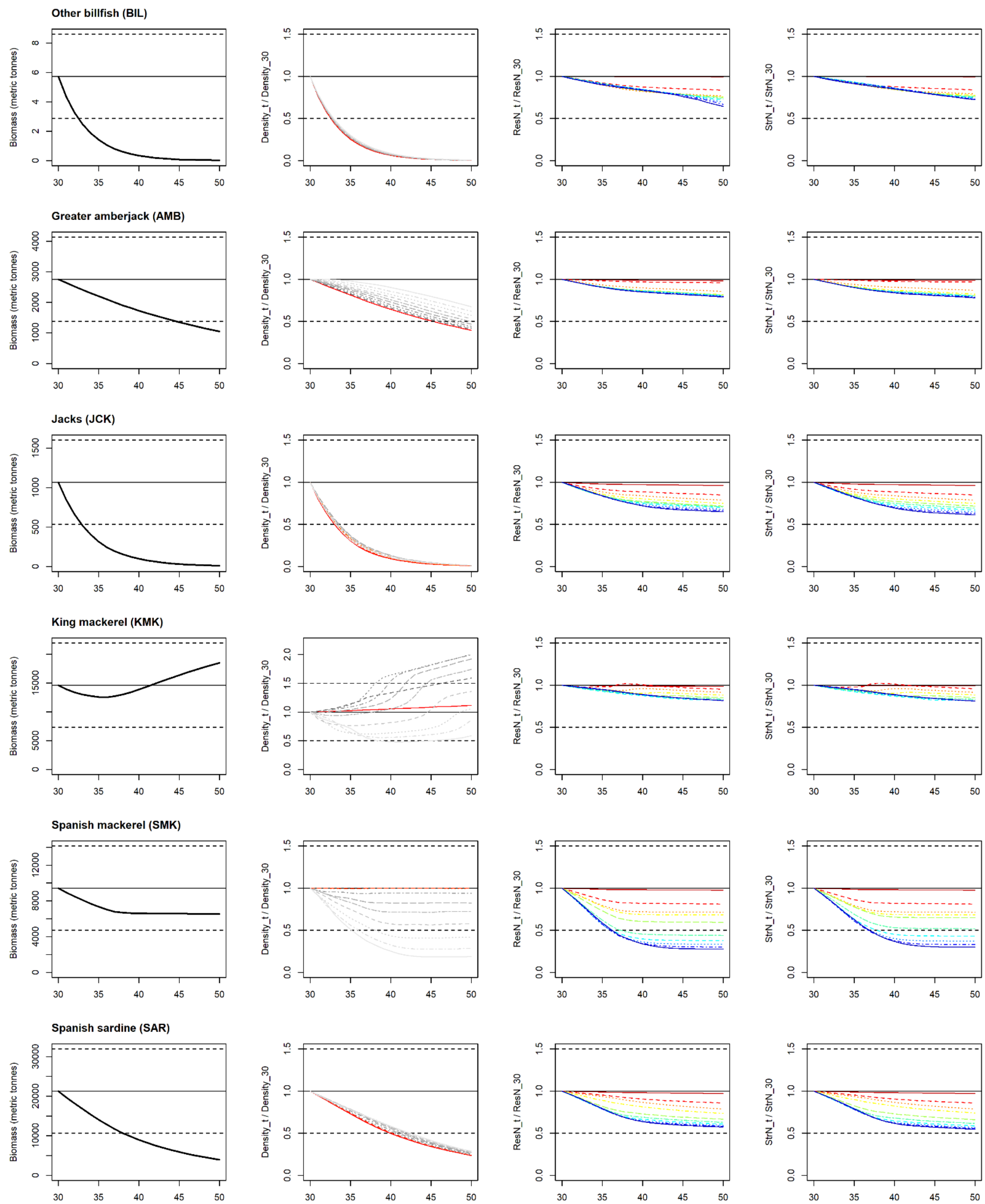


Figure B.1. (continued).

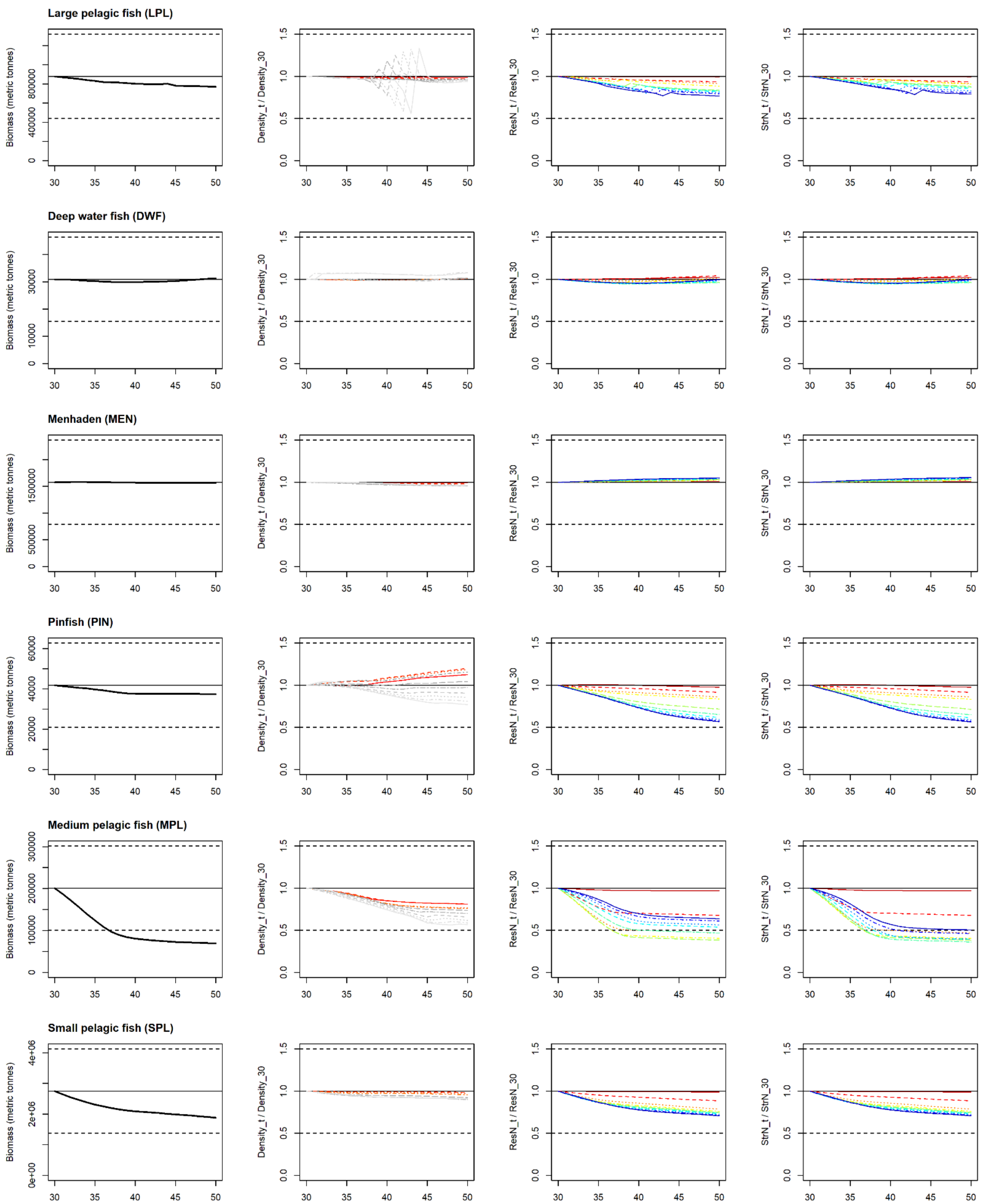


Figure B.1. (continued).

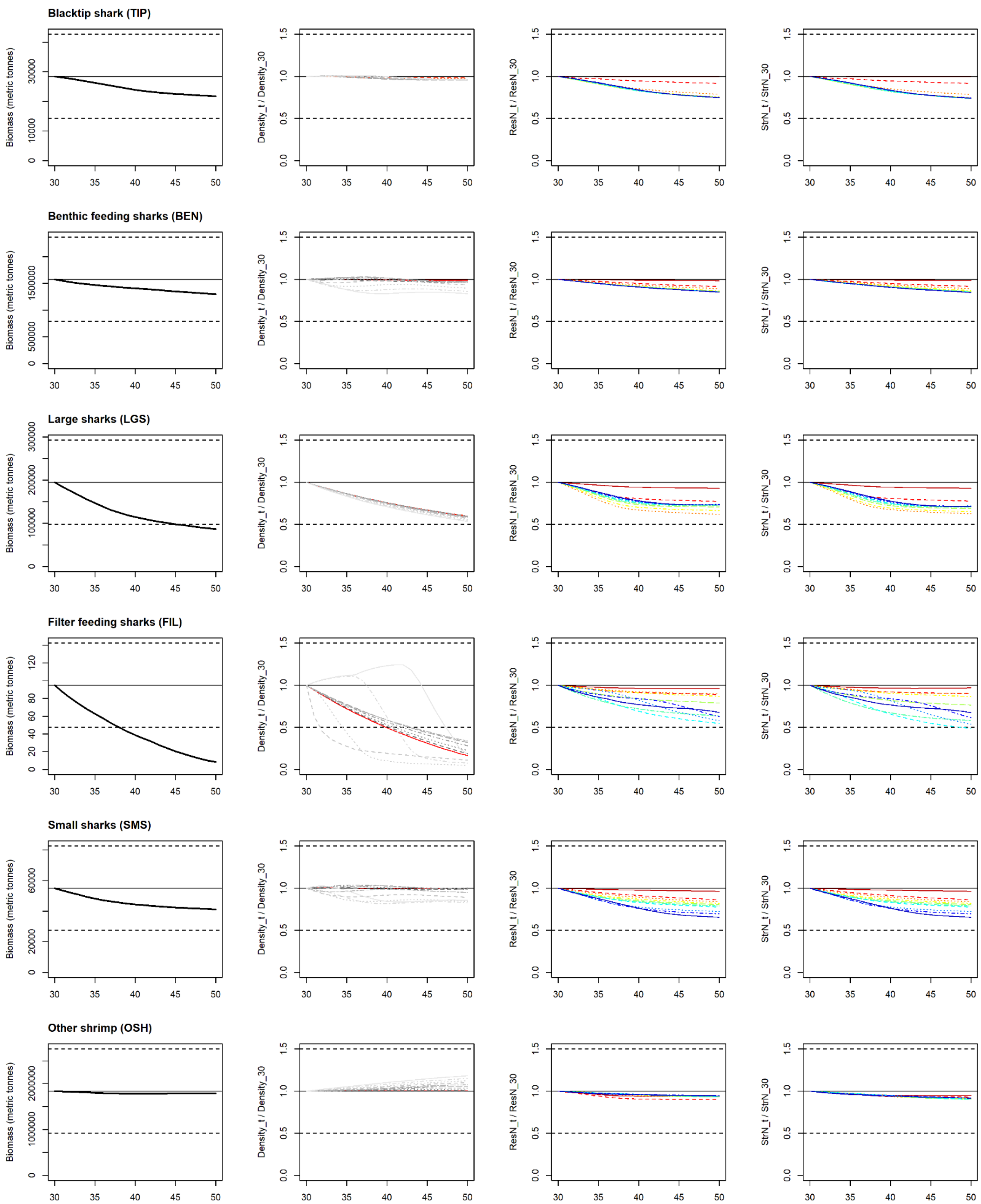


Figure B.1. (continued).

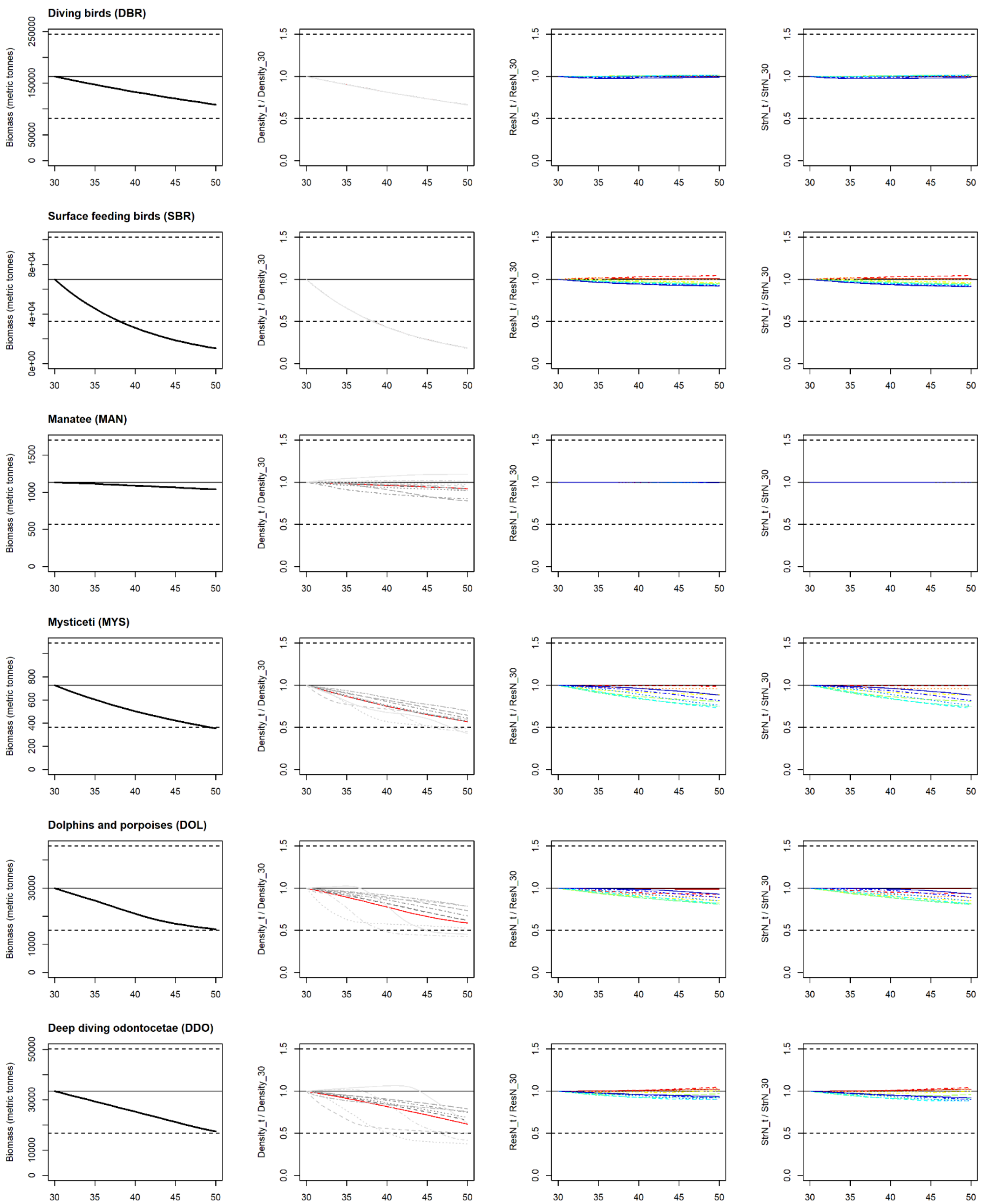


Figure B.1. (continued).

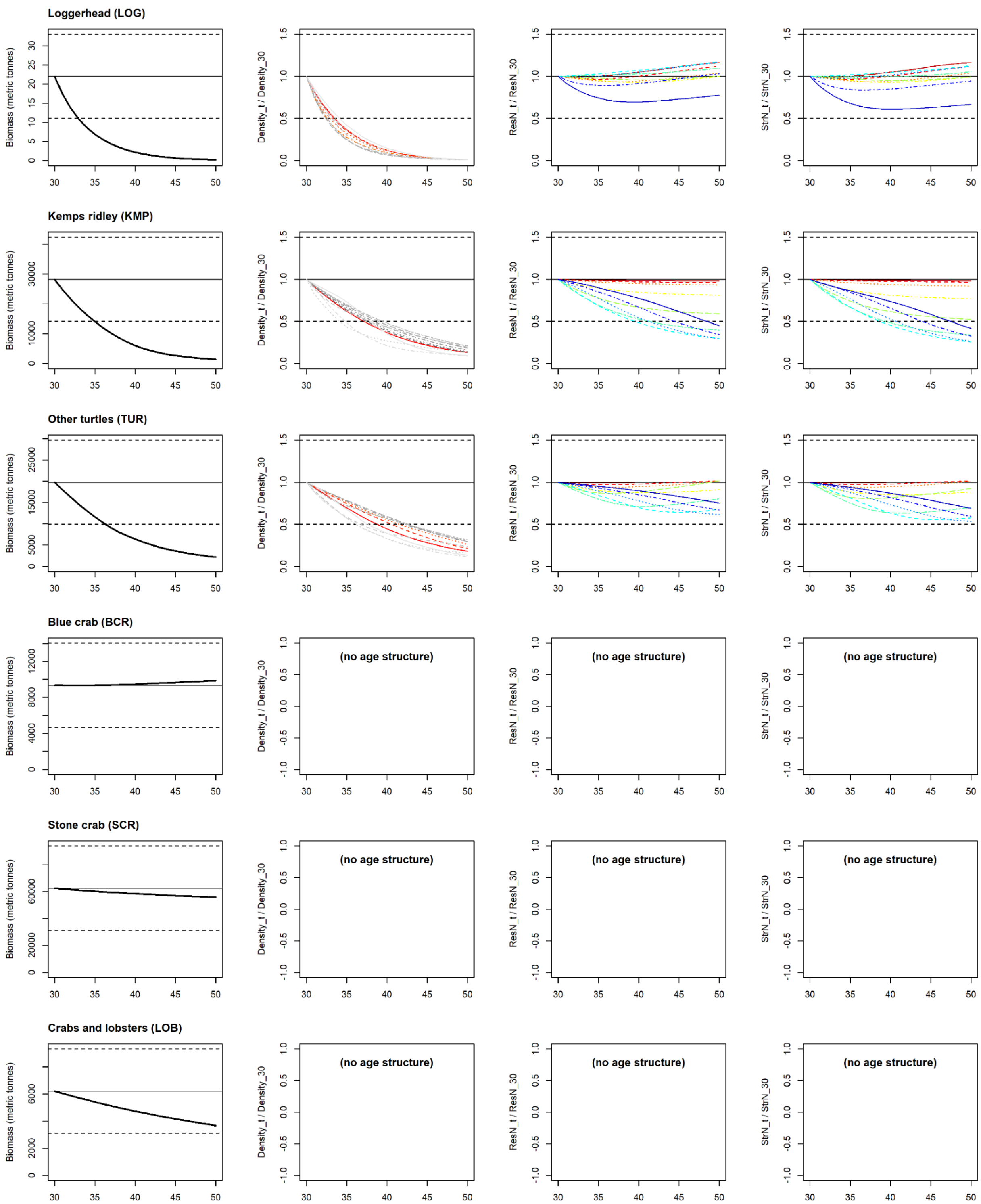


Figure B.1. (continued).

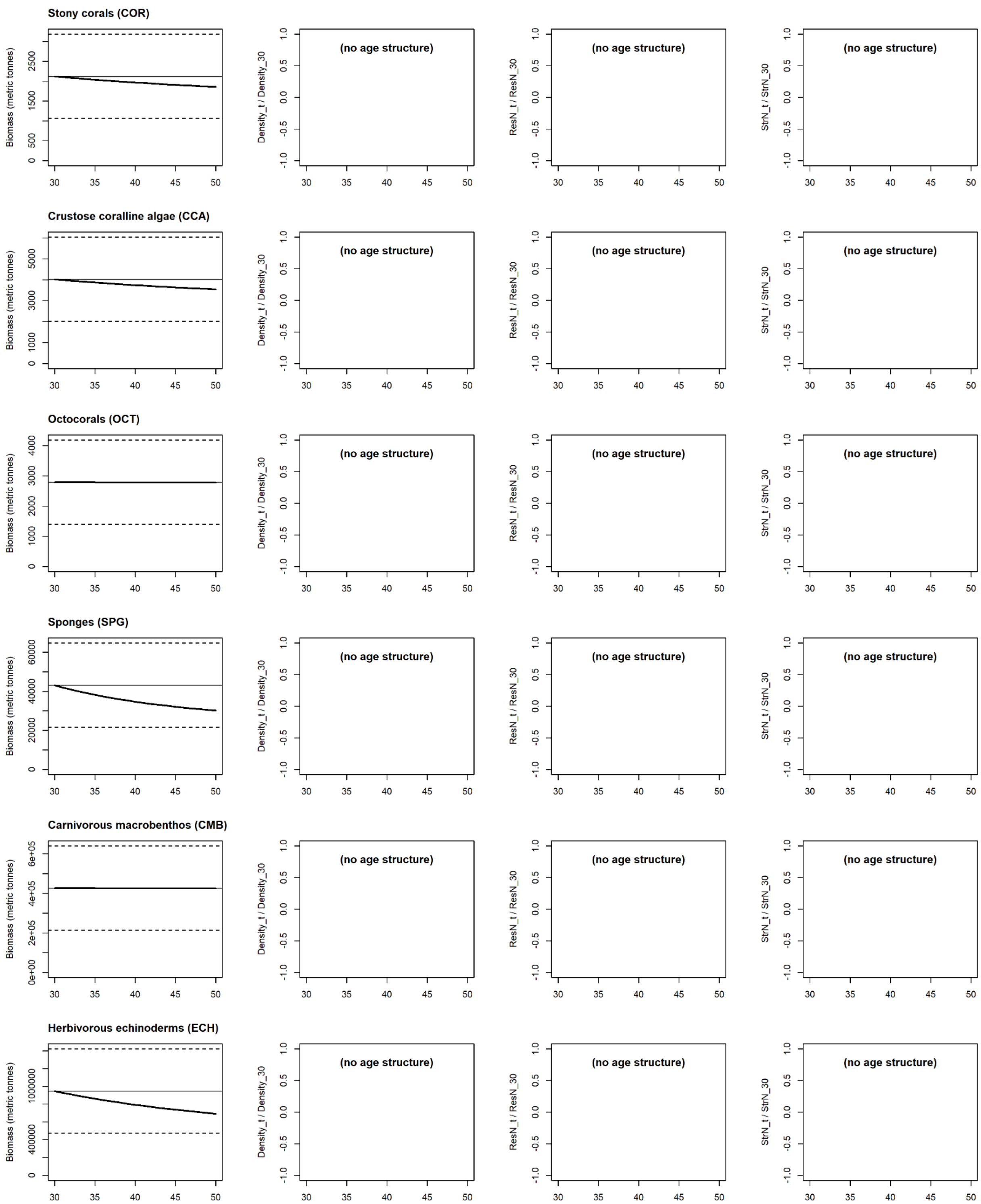


Figure B.1. (continued).

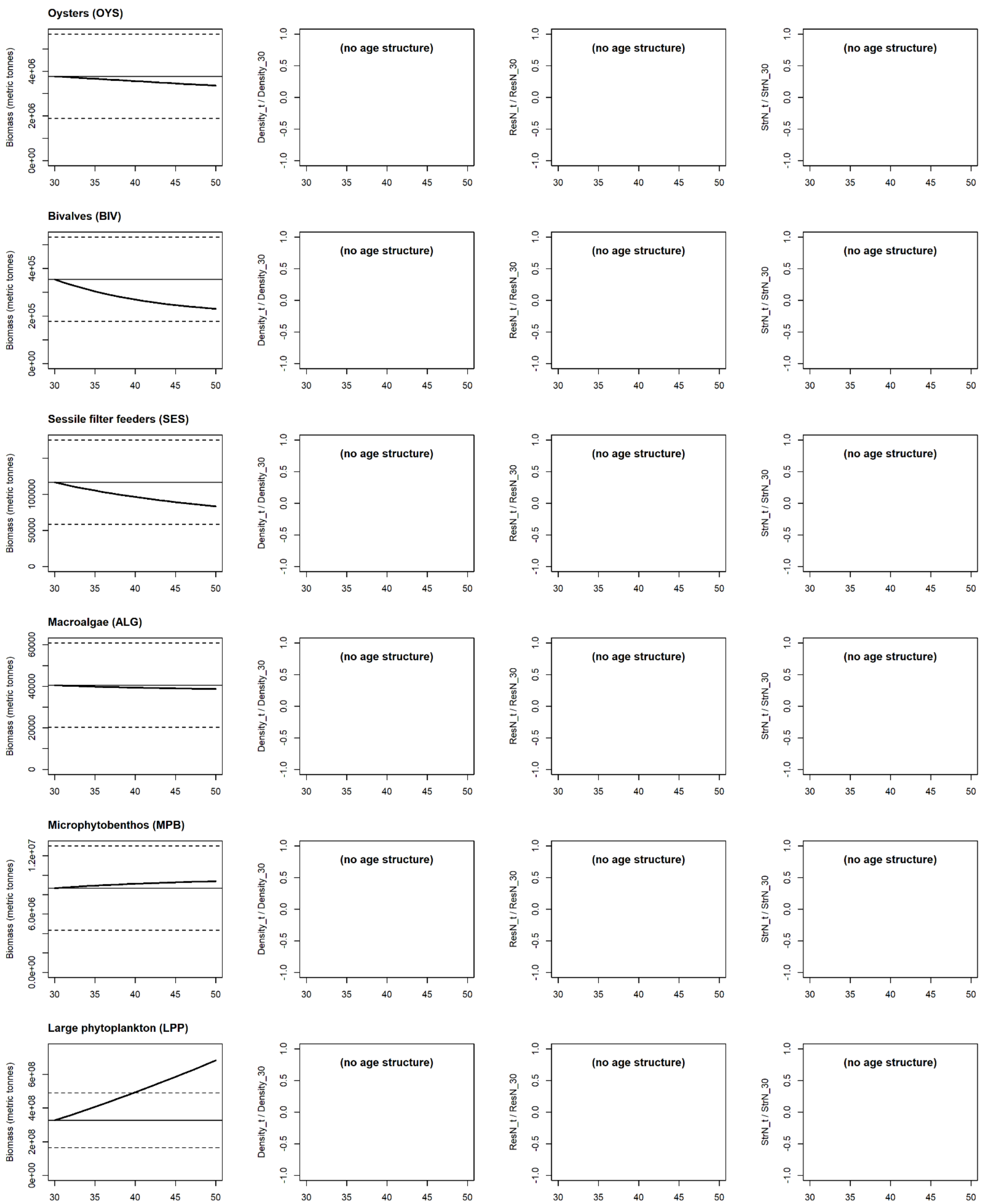


Figure B.1. (continued).

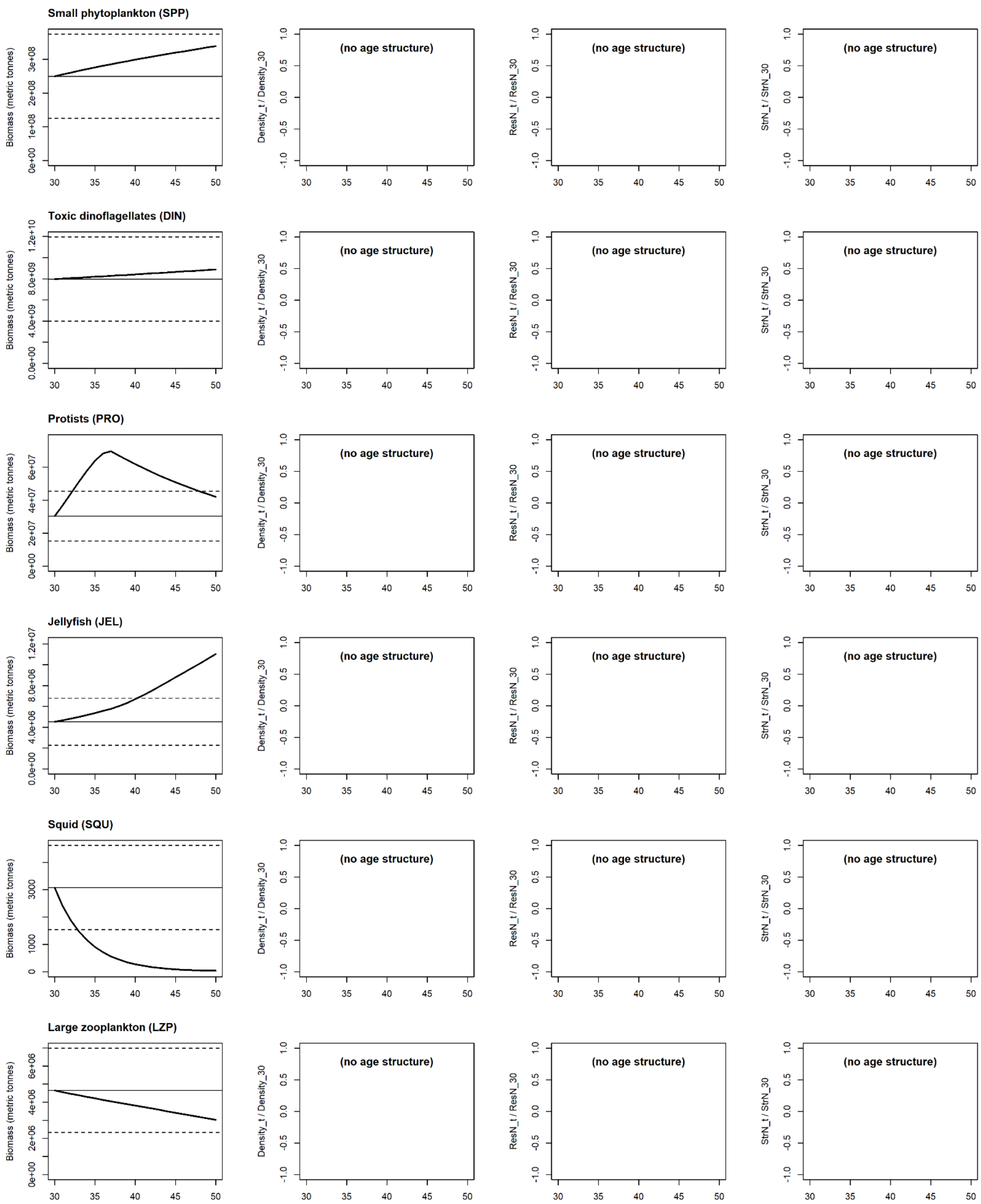


Figure B.1. (continued).

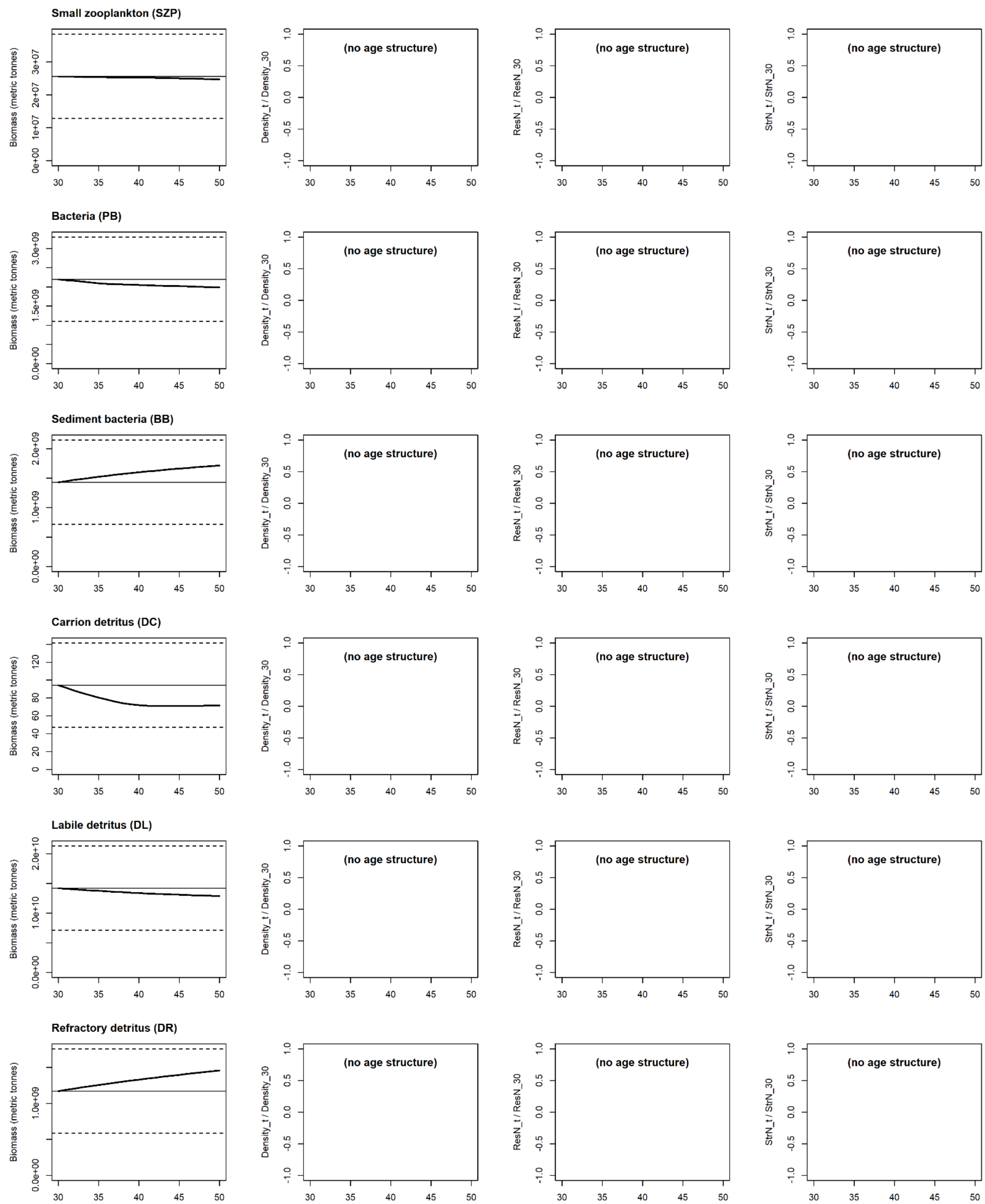


Figure B.1. (continued).

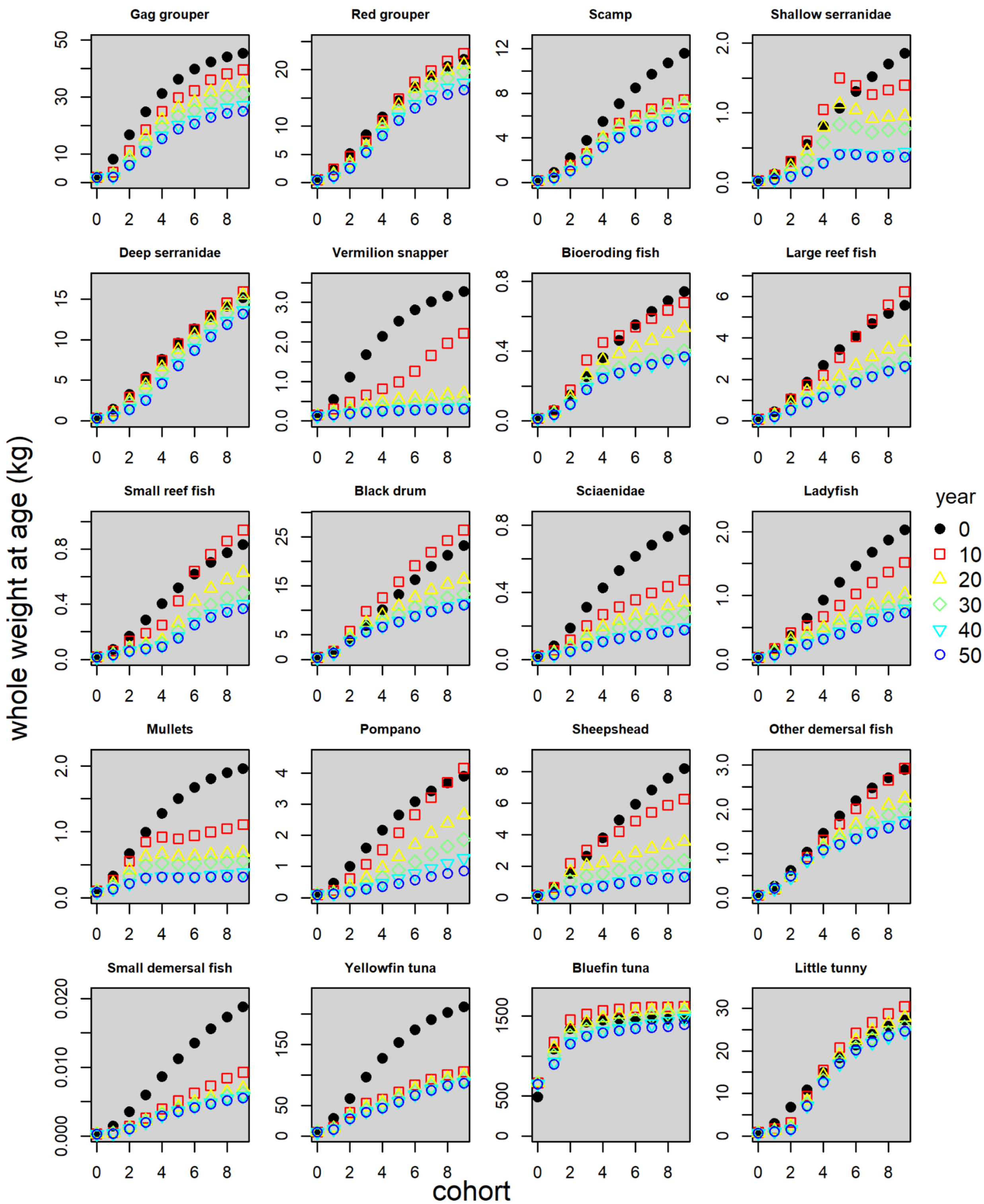


Figure B.2. Weight-at-age over time using GOM Atlantis model outputs.

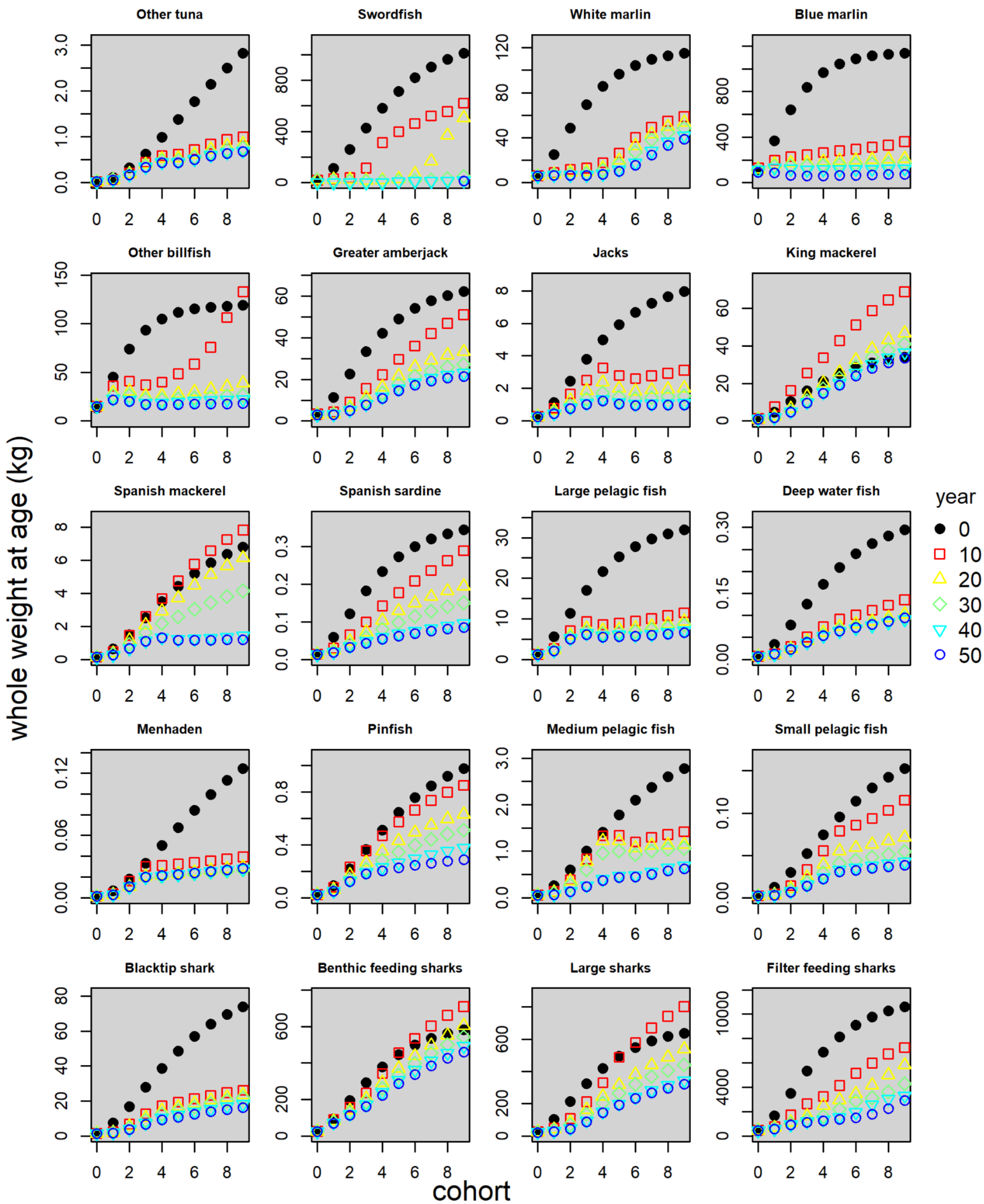


Figure B.2. (continued).

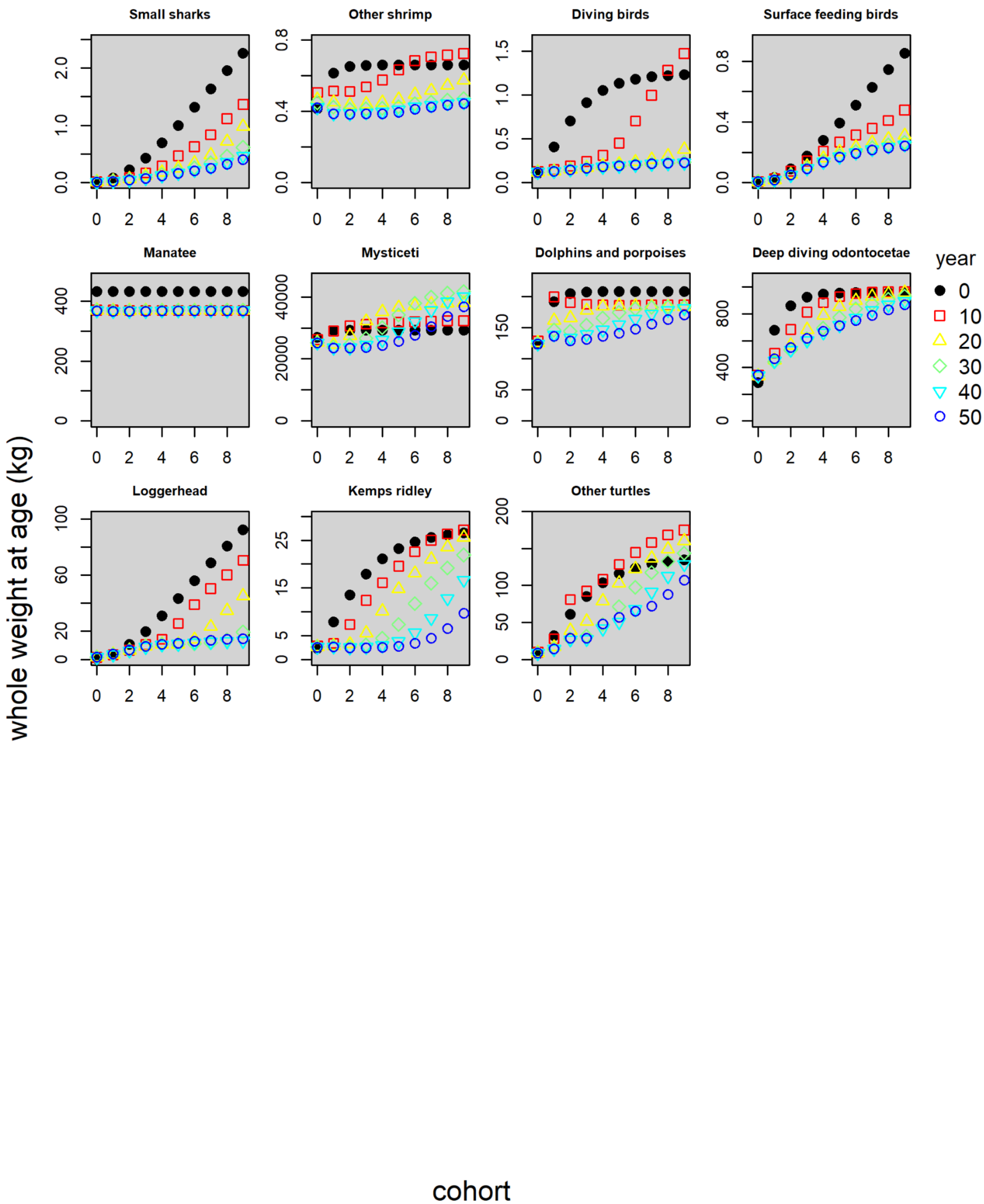


Figure B.2. (continued).

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