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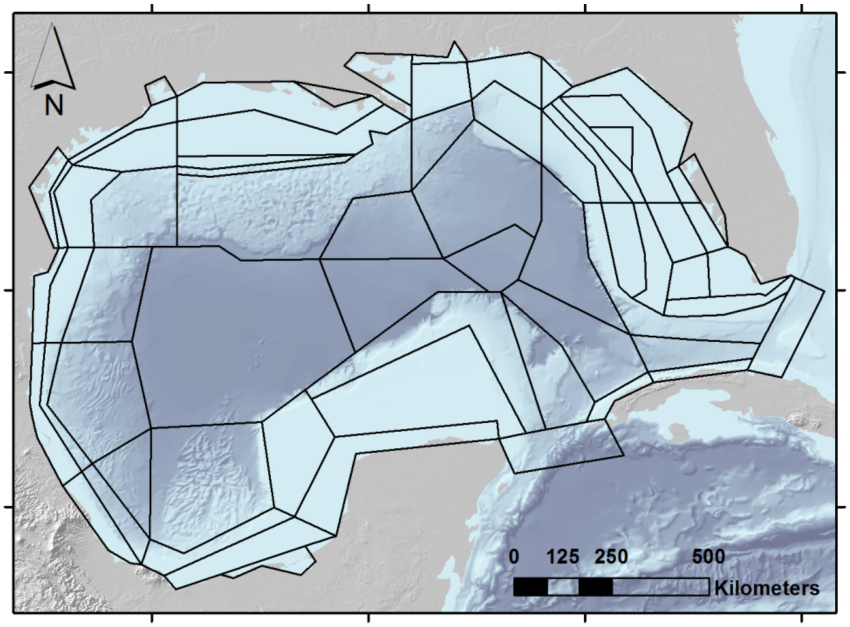
AN ATLANTIS ECOSYSTEM MODEL FOR THE GULF OF MEXICO SUPPORTING INTEGRATED ECOSYSTEM ASSESSMENT

Edited by Cameron H. Ainsworth, Michael J. Schirripa, and Hem Nalini Morzaria Luna



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NOTICE

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Executive summary

The Gulf of Mexico supports a high biological diversity and biomass of fish, seabirds, and mammals; in this region, multiple commercial and recreational fishing fleets operate providing economic resources for local populations. The Gulf is also the site of important oil and gas production and tourism. As a result of intensive human use, the Gulf is subject to various impacts, including oil spills, habitat degradation, and anoxia. Management of this Large Marine Ecosystem requires an ecosystem-based management approach that provides a holistic approach to resource management. The Gulf of Mexico is managed as part of NOAA's Integrated Ecosystem Assessment Program (IEA). This program considers the development of ecosystem models as a tool for ecosystem-based fisheries management (EBFM) and to support the different stages in the IEA process, particularly testing the effects of alternative management scenarios. As part of this program, we have parametrized an Atlantis ecosystem model for the Gulf of Mexico, including major functional groups, physiographic dynamics, and fishing fleets. The Gulf of Mexico (GOM) Atlantis model represents a collaboration between the University of South Florida, the University of Miami, the Southeast Fisheries Science Center, the National Coastal Data Development Center, and other contributors.

The Atlantis ecosystem model framework has been previously used to evaluate management scenarios and assess the effects of climate change in North America and Australia. Atlantis is an 'end-to-end' model which represents trophic dynamics from apex predators to primary producers, fisheries, nutrient dynamics, microbial cycles, habitat, and physical oceanography in a three-dimensional, spatially-explicit domain using a modular structure. In this technical memorandum we describe the structure of the Atlantis GOM model, our assumptions on ecosystem structure and function, data sources, and tuning of the model to historical data. Our final goal was to produce a robust simulation of ecological processes in the Gulf of Mexico that will allow future exploration of the potential effects of alternate management scenarios and human disturbances over various temporal and spatial scales.

The Atlantis GOM model represents present-day conditions (c. 2012). The model extent is divided into 66 three-dimensional polygons, each containing up to 7 depth strata. We linked the Atlantis GOM model to the Navy Coastal Ocean Model (NCOM) – American Seas model (AMSEAS) to force temperature and salinity fluxes. We simulate food web dynamics using 91 functional groups, including reef fish (11 groups), demersal fish (12), pelagic fish (15), forage fish (4), elasmobranchs (6), shrimp (4), seabirds (2), mammals (4), sea turtles (3), commercial benthos (3), structural species (4), macrobenthos (3), filter feeders (3), primary producers (8), pelagic invertebrates (4), and nutrient cyclers (4). We recreated biomass, catch, and effort trends in the Gulf of Mexico from 1980 to 2010 based on historical catch and biomass data. The model also includes fisheries fleet dynamics representing the main fishing fleets in the US, Mexico, and Cuba.

We evaluated the ability of the model to represent historical fishing pressure from 1980 to 2010. Our preliminary assessment shows that the Atlantis GOM can reasonably approximate historical catch time series and spatial distributions for most functional groups and fisheries in the Gulf of Mexico. We believe that the Atlantis GOM will allow addressing ecological hypotheses, test ecosystem indicators, assess the effects of climate change, and evaluate the trade-offs of alternate management scenarios.

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Table of contents

List of figures

List of tables

Abbreviations and acronyms

CPUE	catch-per-unit of effort
CSIRO	Commonwealth Scientific and Industrial Research Organization
EEZ	Exclusive Economic Zone
EBFM	ecosystem-based fisheries management
FL	fork length
GAM	generalized additive model
GOM	Gulf of Mexico
IEA	Integrated Ecosystem Assessment
MLE	maximum likelihood estimate
MSY	maximum sustained yield
mt	metric tons
NH	ammonia
NMFS	National Marine Fisheries Service
NO	nitrate
SEAMAP	Southeast Area Monitoring and Assessment Program
SEFSC	Southeast Fisheries Science Center
TL	total length
USF	University of South Florida
UM	University of Miami
FWC	Florida Wildlife Commission

Introduction

By Cameron H. Ainsworth and Michael J. Schirripa

Ecosystem simulations supporting an Integrated Ecosystem Assessment

There is now solid consensus among the world's marine resource managers that fisheries management in the 21st century must do more to consider the linkages between marine life, the environment, and human beings to ensure continued delivery of ecosystem goods and services (Garcia et al. 2003, Hall and Mainprize 2004, Pikitch et al. 2004, McLeod et al. 2005). This sentiment is reflected in policy guidance documents internationally such as the 1982 UN Convention on the Law of the Sea (United Nations 1982), and in the United States by high profile studies from the Pew Oceans Commission and the U.S. Commission on Ocean Policy (Pew Oceans Comission 2003, U.S. Commission on Ocean Policy 2004). EBFM is further mandated in the United States by the Fishery Conservation and Management Reauthorization Act of 2006 (NMFS 2007) and by various Executive Orders. In response, NOAA has initiated the Integrated Ecosystem Assessment (IEA) Program. Although the IEA framework is not yet firmly established and is likely to vary between regions (Levin et al. 2013), the basic outline provided in Levin et al. (2009), which is the de facto guidance document, calls for five steps: scoping, indicator development, risk analysis, assessment of ecosystem status relative to goals, and management strategy evaluation. This process repeats in an iterative manner based on the concept of adaptive management (Walters 1986, Sainsbury et al. 2000, Levin et al. 2009). Ecosystem modelling can assist in several steps of the IEA process: in development of ecosystem indicators and thresholds (Fulton et al. 2004c, 2005, Samhouri et al. 2010), in risk analysis (Ainsworth et al. 2008b, Ainsworth and Mumby 2015), in assessment of ecosystem status (Shin et al. 2010), and in Management Strategy Evaluation (Fulton et al. 2005).

Although most of the work done under the umbrella of the IEA has thus far focused on the West Coast (see publication list at http://www.noaa.gov/iea/regions/), effort is shifting towards the other large marine ecosystems of the United States: Alaska complex, Pacific Islands, Northeast Shelf, and the Gulf of Mexico. The Gulf of Mexico LME is especially complex in that it borders three countries, the United States, Mexico, and Cuba. Furthermore, it provides an extremely varied set of ecosystem services including tourism, energy production, hurricane protection, navigation and trade, a large and varied recreational fishery, as well as providing spawning grounds for Atlantic bluefin tuna. All of these ecosystem services are intertwined and create a situation where managing for the maximum benefit of one service can easily come at the cost of another service. For these reasons the GOM IEA effort has employed the strategy of creating an across NOAA line office and an interdisciplinary steering committee consisting of scientists with expertise in a wide variety of marine and estuarine fields. Along with NOAA academic and state partners, this approach has ensured that the various services provided by the GOM LME are represented. It is becoming increasingly obvious that traditional single sector management is insufficient to ensure that all of the services provided by the LME are simultaneously managed in a unified manner. Making clear the tradeoffs between managing between the entire suites of services can only be accomplished through a management strategy evaluation (MSE). An effective MSE requires the use of a simulation model in which all services of interest are linked to each other. In response to this need, the GOM IEA steering committee has created several subcommittees to address the various aspects of the IEA and MSE procedure (i.e. data, indicators, modeling, management & outreach, and economics/social aspects) through the use of models such as Atlantis.

Tool development for EBFM has lagged behind the requirements of management mandates (Smith et al. 2007) but is an active area of work in the ecosystem science community. In the Gulf of Mexico, data repositories such as the Data Atlas (NMFS 2014), the Trophic Interactions Database (Simons et al. 2013), the Geospatial Assessment of Marine Ecosystems (GAME) database (Carollo et al. 2009) and the IOOS Biological Observations Data Project (http://www.ioos.noaa.gov/biological_observations/welcome.html), as well as new quantitative tools like Ocean Slicer (see methods section), are facilitating the type of synoptic modelling and evaluation required by EBFM. This technical memorandum introduces a new modelling tool, a GOM Atlantis model, which we hope will serve as a long-term resource to support EBFM and the IEA program in the Gulf of Mexico. It is the product of a four-year collaboration between the University of South Florida, the University of Miami, the Southeast Fisheries Science Center, the National Coastal Data Development Center and other state, federal, academic and non-governmental partners.

Atlantis model

Atlantis (Fulton 2001, Fulton et al. 2004a) is a biogeochemical marine ecosystem model developed by scientists at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. The model summarizes biological players in an ecosystem through use of functional groups, which are groups of species aggregated by trophic, life history, or niche similarities. Atlantis integrates physical, chemical, ecological, and fisheries dynamics in a three-dimensional, spatially explicit domain. Numerous sub-models simulate features and processes crucial to a functioning ecosystem including hydrographic processes, chemical and biochemical processes (e.g., nutrient cycling, salinity, oxygen availability), food-web interactions, fisheries, dependence of functional groups on biogenic and physical habitat, and physical and biophysical features (e.g., light penetration, temperature, stratification). Atlantis therefore bridges low and high trophic level drivers and processes. Although this versatility has a cost in terms of model development and run time, it allows us to simulate important physical processes and their impacts on fish and fisheries in a way inaccessible to simpler modelling frameworks. In ecosystems like the Gulf of Mexico, where the influence of exogenous nutrient and freshwater inputs and oceanographic processes have a major structuring influence on species distribution and productivity, this comprehensive physical-chemical-biological modelling approach pays dividends.

We have developed an Atlantis model of the Gulf of Mexico representing the ecosystem as it appears in the present day (c. 2012). Initially, we assembled catch and relative biomass time series extending back to the 1980s, and from these trends we inferred the historical state of the ecosystem in 1980, creating an ecosystem model for this historical period. The 1980 model was then driven forward to 2012 with the objective of re-creating observed ecosystem changes. The tuned dynamic parameters of the 1980 model are transferred to the present-day 2012 model (*sensu* Ainsworth et al. 2008a, 2011) assuming stationarity in biological rates and conditions (e.g., recruitment parameters, feeding preferences, animal behavior and movement). This approach allows us to develop the 2012 model from which forward-looking simulations, based on the best and most up-to-date information and using dynamic parameters that have been tuned to recent historical data.

Objective of this technical memorandum

The purpose of this technical memorandum is to provide the background on model development and parameterization of the Atlantis model. In this document we describe the structure of the model, our assumptions on ecosystem structure and function, data sources, and tuning of the model to historical data (1980 to 2010). We also present basic diagnostic tests of model function, including test scenarios with and without fishing, and equilibrium relationships of catch and biomass. This document should serve as a supplemental resource for forthcoming peer reviewed publications investigating ecological hypotheses, indicator robustness, management strategy evaluation, and other applications useful to the Gulf of Mexico IEA.

Gulf of Mexico

By Michael Drexler, Michelle Masi, and Holly Perryman

Physical environment

The Gulf of Mexico Large Marine Ecosystem is a semi enclosed basin situated between the countries of Mexico, the United States, and Cuba which spans a subtropical and tropical climate. It is considered the eleventh largest body of water in the world (NOAA 2013). It is somewhat isolated, connected to the Caribbean Sea through the Yucatan Strait, and to the Atlantic Ocean through the Straits of Florida. According to the environmental overview of the Gulf of Mexico (Darnell and Defenbaugh 1990), the Gulf has a maximum depth of 3,850 m at Sigsbee Deep and occupies an area of 564, 200 km^2. The Gulf of Mexico encompasses a marine shoreline of 3,840 miles and is 1,000 miles across longitudinally and 500 miles across latitudinally (Cato 2009). Nearly 38% of Gulf area is made up of shallow zones, 42% is continental shelf and slope, and 20% is deep (Gore 1992).

Circulation within the Gulf of Mexico is driven primarily by the Loop Current which enters the Gulf through the Yucatan Strait, heads towards the north-western center of the Gulf and loops back towards Cuba to the east, exiting through the Florida Straits; the exact position and orientation of the Loop Current is variable (Vukovich 2007). The shallow depths of both the Straits of Yucatan (1900m) and Florida (800m) limit the movement of deep water in and out of the system. The Loop Current intrudes on to the northern shelf off Mississippi and on to the West Florida Shelf and it can form eddies which move large parcels of water westward. The influence of the Loop Current and associated features plays an important role in the advection of nutrients, larvae and plankton determining the distribution of primary and secondary production in the system (Biggs and Müller-Karger 1994, Bakun 1996, Zimmerman and Biggs 1999), and the related distribution of higher trophic levels (Drexler and Ainsworth 2013).

The Mississippi River contributes 64% of the freshwater stream flow to the Gulf of Mexico and is the main driver of the high productivity seen in the area from the Florida-Mississippi border extending west to Texas (Darnell and Defenbaugh 1990); this area has been referred to as the fertile fisheries crescent (Gunter 1963). Over this same region, the nutrient rich Mississippi River water causes a seasonal phytoplankton bloom which results in a hypoxic zone of variable size occurring west of the Mississippi Delta to Texas (Turner et al. 2006). In addition to the Mississippi river, there are 20 river systems; 85% of the total water flow into the Gulf comes from the United States (Moretzsohn et al. 2014).

The Gulf of Mexico can be divided latitudinally into a warm-temperate north and a tropical south with the break occurring near Tampa Bay in the east and Cape Rojo Mexico in the west (Felder and Camp 2009). The Gulf can be further divided into five broad bioregions: the West Florida Shelf, the Campeche Bank, the Northern Gulf, the narrow shelf along the western Gulf, and the deep central region. Roughly 35% of the total area is occupied by the West Florida Shelf and the Campeche Bank, two large, mainly sandy shelves derived from biogenic carbonates in less than 200 m of water. Both shelves are covered by expansive sea grass beds, sparse coral, and hard bottom. Unlike these sandy regions, the narrow shelves in the northern and eastern gulf are covered by river borne deposits transported by the Mississippi River. The western Gulf has a very narrow shelf with a steep slope that drops away quickly to over 4000 m. The deep central region is comprised mostly of muddy sediment, and little information is available on this depauperate abyssal zone (MacDonald et al. 1990). However, diverse chemosynthetic communities associated with hydrocarbon seeps and stands of deep water coral communities located along the shelf edge have been identified (CSA International et al. 2007) although the extent to which these habitats occur is unknown.

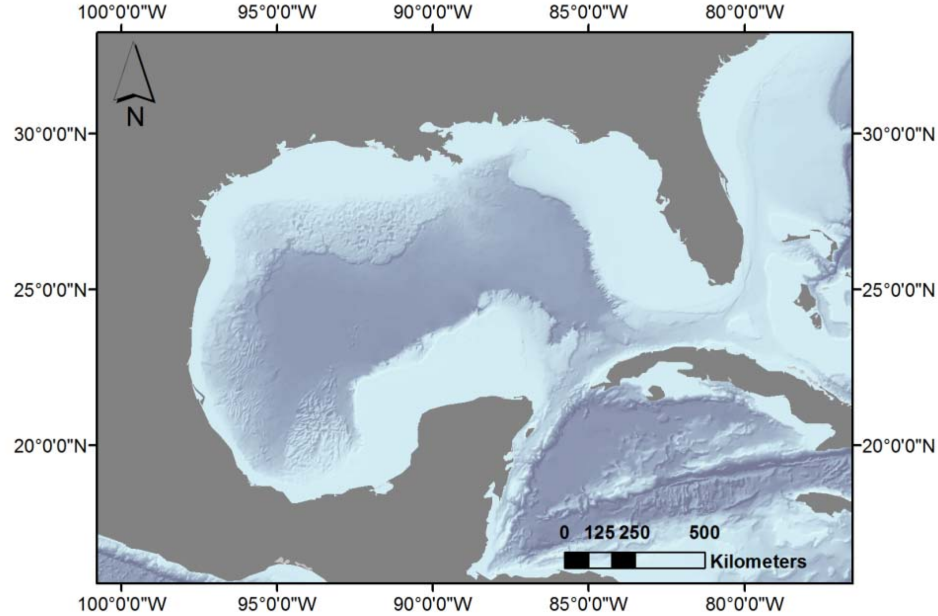

Figure 1. Shaded relief map of the Gulf of Mexico

Biology

Biodiversity

The Gulf of Mexico (Figure 1) is home to a high diversity of organisms. For monitoring purposes, species tend to be grouped according to the water depths where they most frequently occur. Many species are known to migrate in and out of these areas seasonally or at other times throughout their life cycle due to reproduction, prey availability, or environmental factors such as water temperatures, currents, etc. They can be described as either nearshore or offshore species. The nearshore habitat consists of the estuarine waters all the way to the edge of the continental shelf (0 m − 200 m). The offshore habitat is beyond the continental shelf edge (>200 m) (NMFS 2012). Tunnell et al. (2007) has assembled the most comprehensive description of biodiversity in the Gulf of Mexico. A total of 15,419 species occur, including 1,541 fish, 9 reptiles, 395 birds, 30 mammals, 2579 crustaceans, 2455 mollusks, and 522 echinoderm species.

Conservation

The National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) is responsible for protecting our nation's living marine resources as well as their habitats. Species under their jurisdiction can be protected by either the Endangered Species Act (ESA) or the Marine Mammal Protection Act (MMPA) and include all marine mammals, endangered and threatened species, as well as candidate species. A species of concern is any species that NOAA carefully monitors regarding their status or threats in order to identify species potentially at risk (NMFS 2012). The Sand tiger shark, Dusky shark, Nassau grouper, Warsaw grouper, Speckled hind, Alabama shad, Key silverside, Opossum pipefish, and Mangrove rivulus are all listed as species of concern (NMFS 2013). Threatened species inhabiting the Gulf of Mexico include Elkhorn and Staghorn corals, the Gulf Sturgeon, as well as the Loggerhead and Green sea turtle. There are 14 marine species listed as endangered under the ESA, including the Smalltooth sawfish, the Sperm whale, and Kemps Ridley, Hawksbill, and Leatherback sea turtles (NMFS 2012). The Scalloped hammerhead is currently the only species listed as a candidate species in the Gulf of Mexico (Miller et al. 2013). In addition to the species identified by U.S. law, the

International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species identifies 39 species in the Gulf as critically endangered, endangered, or vulnerable (IUCN 2014).

There are currently 295 Marine Protected Areas (MPAs) in the Gulf of Mexico which cover ~40% of U.S. marine waters (NOAA 2011). These vary widely in purpose, legal authorities, managing agencies and restrictions. MPAs classified as "no take" only occupy ~0.5% of all gulf waters. Florida waters are home to the majority of these MPAs containing 217 out of 295 (NOAA 2011). Grand Bay National Estuarine Research Reserve, Florida Keys National Marine Sanctuary, Breton National Wildlife Refuge, and Flower Garden Banks National Marine Sanctuary are just a few examples of MPAs (NOAA 2011).

Oil impacts

The petroleum industry is a key player in the Gulf. Total offshore oil and natural gas production totaled $42 billion dollars in 2003 (Adams et al. 2004). Since 1992, most of the petroleum and natural gas production in the Gulf has occurred off the coasts of Louisiana, Mississippi, and Alabama from over 5,000 offshore oil and gas platforms. Natural seepage and human-related oil releases, both chronic and catastrophic, are common. Oil has a toxic effect on almost all organisms, and the intensity of the effect depends on the species or life stages involved, along with the concentration and composition of the oil spilled (Mosbech 2002). Each effect is further modified by the weathering of the oil components, habitat, currents, and response efforts (Moore and Dwyer 1974). Thus, long-term impacts of large oil spills may be unintuitive and difficult to generalize yet carry major consequences.

In April 2010, eleven lives were lost when the Deepwater Horizon oil rig, owned by BP, exploded and sank in the Gulf of Mexico. Following the explosion, oil continued to spill into the Gulf for 87 days from a depth of 1500m. During this time frame, a federally estimated 4.9 million barrels of crude oil were released into the water column, with the dispersant Corexit applied both on the surface and at depth in an attempt to mitigate the impacts of the oil (Unified Command Deepwater Horizon 2010). This was the second largest oil spill in history, and was unique for the depth at which the oil was entering the ecosystem. Large underwater plumes of oil were reported that never reached the surface, however the anomalous Loop current of 2010 reduced the transport of oil southward (Camilli et al. 2010). Though it is clear that this oil spill in the Gulf of Mexico impacted the surrounding marine community, the cumulative and long-term impacts of all the stressors from the spill (including oil, dispersants, and other mitigation efforts) are currently unknown.

In an effort to gather as much data relating to the spill as possible, by the end of 2014 the Gulf of Mexico Research Initiative had released five requests for proposals (RFPs) for funding scientific research relating to the spill. The RFPs include quick response studies, consortia grants for 15 or more institutions, individual research grants, renewal of consortia grants, and renewals of individual research grants (Colwell et al. 2014). The Atlantis model described in this technical memorandum was developed partly by contributions of the Gulf of Mexico Research Initiative (GOMRI), and efforts are underway to use the Atlantis GOM model to forecast long-range impacts and recovery following the Deepwater Horizon oil spill.

Fisheries

United States

The northern Gulf of Mexico is a highly productive area. Commercial and recreational fishing occurs all across the coast. Fisheries regulations are determined by both state (in state territorial waters 3 nautical miles off Alabama, Mississippi and Lousiana and 9 nautical miles off Texas and the west coast of Florida) and federal (in waters up to 200 nautical miles from shore) agencies. For species not managed by federal regulations, states have the authority to extend state rules into federal waters. Although the magnitude differs, many of the commercial fleets report landings in all five Gulf States: Florida, Alabama, Mississippi, Louisiana, and Texas. Thus, when discussing general U.S. Gulf of Mexico fisheries, it is easier to breakdown operations by gear rather than location. NOAA commercial landings statistics highlight the wide variety of gear-types utilized in Gulf of Mexico waters (e.g., cast nets, diving outfits, spears), but here we focus on the dominant gear-types.

Some of most profitable large-scale fisheries within the northern Gulf of Mexico are supported by benthic species. Although various gears are utilized to exploit bottom-dwelling stocks, the most important gear-types include trawls, dredges, and traps. Trap fishing primarily focuses on crustaceans; the most profitable fishery is the one targeting blue crab, *Callinectes sapidus*. Regional management plans developed by the Gulf States Marine Fisheries Commission (e.g. Guillory et al. 2001) provide an overview of the stock and fishery. Fisheries management is left to the states, and although landings are made across the Gulf, Louisiana is the largest producer followed by Florida and Texas (NMFS 2011a). Traditionally, the fishery targeted hard-shell (post-molt) crabs, but the soft-shell fishery has expanded over time. Traps used in the blue crab fishery have been scrutinized primarily for lacking terrapin excluder devices to reduce diamondback terrapin drowning (Guillory et al. 2001), as well as escape vents and biodegradable panels to limit crab mortality due to ghost fishing by abandoned or lost traps (Guillory 1993). Other trap operations are focused off of the southwest Florida shelf and target stone crabs, *Menippe mercenaria* (Muller and Bert 2001) and spiny lobster, *Panulirus argus* (Muller et al. 2000); both of which are locally important. Various finfishes, including groupers, snappers, and grunts, are also harvested with traps (NMFS 2011a).

While traps retain various species, dredges and tongs are used to harvest one specific stock: oysters, *Crassostrea virginica*. This oyster stock is one of the top commercial fisheries in the northern Gulf of Mexico (Upton 2011) and is now the primary source of oysters to the U.S. (NMFS 2011a). Schlesselman (1955) provides a historical description of the Gulf oyster industry, while Mackenzie (2005) and NOAA Fisheries Eastern Oyster Biological Review Team (2007) describe the present-day industry. Although oyster fisheries are managed by the states, NOAA periodically releases status reports reviewing key characteristics of the stock (e.g., biology, ecology, fisheries). Oysters are harvested across all Gulf States, but a majority of the landings originate from Louisiana and Texas (Eastern Oyster Biological Review Team 2007, NMFS 2011a). Louisiana has a leasing program where numerous areas of open water throughout the marshes are designated as private leases that oyster farmers can purchase. Oyster farmers plant on their leases by dredging seed oyster from the large public oyster reefs that the state of Louisiana maintains (Mackenzie 2005). Besides an important source of sustenance, oyster reefs are considered a keystone species that provide various goods and services (Raj 2008). Although restoration and enhancement efforts are not necessary to sustain biologically viable populations, these efforts are important for maintaining the fishery as well as the ecosystem services (Eastern Oyster Biological Review Team 2007). Studies focusing on the restoration and enhancement of Gulf of Mexico oyster reefs have amplified since the Deepwater Horizon oil spill (e.g., Apeti et al. 2012, Brown et al. 2014).

Similar to dredging, trawl gears extract benthic organisms. Gulf of Mexico trawl fisheries target three species of shrimp: white shrimp (*Penaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), and pink shrimp (*Farfantepenaeus duorarum*); there are also deep sea fleets that target rock shrimp (*Sicyonia brevirostris*), royal red shrimp (*Pleoticus robustus*), and calico scallop (*Argopecten gibbus)* stocks (Stiles et al. 2007). The shrimp stocks provide the largest revenue out of all of the major commercial species harvested within Gulf of Mexico waters (e.g., Upton 2011). Shrimp landings are reported in all of the Gulf States, but white and brown shrimp are primarily caught off of Texas and Louisiana, and pink shrimp are mostly harvested on the Florida shelf (GMFMC 1981, NMFS 2011a). The type of trawl used typically depends on the bottom depth. Otter trawls are essentially the sole gear utilized in federal waters, while other trawls (e.g., beam, butterfly, and skimmer) are commonly utilized in shallower waters (GMFMC 1981, SFP 2013). In general, bycatch management is a major problem for tropical shrimp trawlers operating in the Gulf of Mexico since the gear is not species-selective. Scott-Denton et al. (2011a) found that majority of catch from Gulf of Mexico shrimp trawlers were non-shrimp organisms (e.g., porgies, croakers, and flounders). There has been substantial work in gear technology to incorporate bycatch reduction devices like turtle excluder devices (TEDs) and fisheyes, a metal frame fitted to the codend through which fish can escape (Gillett 2008). However, significant concerns remain with undesirable levels of bycatch, primarily red snapper juveniles (Gallaway and Cole 1999, GMFMC 2007).

There are many other net-based gears utilized in the Gulf of Mexico (e.g., gillnets, trammels, and beach seines). The fishery that produces the largest landings in the Gulf uses purse seine nets– the Gulf menhaden (*Brevoortia patronus*) fishery. Smith (1991) discusses the development and evolution of this fishery, and Vaughan et al. (2007) describe the current state of the fishery. While historically the purse seine fishery was considered laborious and inefficient, Nicholson (1978) documents the major innovations which improved the fleet's productivity. Purse seine fleets originate out of ports in Mississippi and Louisiana (Smith 1991), and a majority of the landings are retained within 16 km for the shoreline (Smith et al. 2002). The Gulf of Mexico purse seine fleet is unique in how it is deployed (Ruttan and Tyedmers 2007). First, spotter planes are typically used to locate fish aggregations. Then, rather than having the main fishing vessel participate in setting the net, two purse boats encircle the school with the seine. The pilot of the spotter plane may communicate with the crew to help set the net. The purse seiners tend to be designed specifically for harvesting menhaden and, generally are not used to target other stocks (Smith 1991). However, various organisms are caught as bycatch, including Atlantic croaker, Spanish mackerel, sand seatrout, and various sharks (de Silva et al. 1997, 2001). Between the mid 1950's and 1987 the number of vessels in the fishery remained stable with 60 – 80 vessels (Smith 1991), but since 1990 the number of vessels has decreased gradually, to approximately 42 vessels (Vaughan et al. 2007). This reflects the corporate downsizing instigated in 1985.

Hooks and lines are other major gear-types utilized by the Gulf of Mexico commercial fleet. There are two different configurations for hook-line operations: 1) a vertical line consisting of no more than two hooks (handlines), and 2) a horizontal mainline with many hooks attached (longlines). Handline fleets harvest all across the Gulf shelf with a majority of the landings being reported in Florida (NMFS 2011a). Finfish retained can consist of reef fish (e.g., groupers and snappers) and pelagic fish (e.g., tuna and jacks). Longline operations are partitioned into two groups: bottom longliners which set hooks on/near the sea bottom, and pelagic longliners, which set hooks within the water column. Commercial bottom longliners target benthic organisms in the shelf and beginning of the slope, which tend to be reef-based species and sharks. In an effort to rebuild declining reef stocks, the Reef Fish Fishery Management Plan was implemented and over the years there have been restrictions set on catch size and quantity, as well as area closures and gear restrictions (Scott-Denton et al. 2011b). Restrictions on longline fleets are focused around Florida – where a majority of catches are landed (NMFS 2011a). Pelagic longliners target highly migratory species (e.g., tuna, swordfish and dolphinfish), and a majority of these catches are landed in Louisiana (NMFS 2011a). Longline gear, in general, is scrutinized because of the incidental mortality of sea turtles (Watson et al. 2005), sea birds (Anderson et al. 2011), billfish, and various elasmobranch species (Mandelman et al. 2008). Gear restrictions have been enforced aiming to reduce the post-release mortality of incidentally caught organisms (e.g., like the utilization of circle hooks instead of J-hooks).

Recreational landings and Total Allowable Catches of various stocks within the Gulf of Mexico match or even surpass landings made by commercial fleets, and landings are increasing (Table 1) (NMFS 2011b). Thus recreational (sport) fishing plays an important role in the biological dynamics and coastal economy (Adams et al. 2004). Sport fisheries include tournaments, for-hire charters, and various individual activities (e.g., personal vessel and scuba). Many different organisms are retained by recreational fishing within Gulf of Mexico waters (NMFS 2011b) but, in general, the most sought after targets include reef and pelagic stocks (e.g., snappers, groupers and billfish, respectively). Recreational fishing practices have changed as concerns for ecological sustainability have grown. Billfish tournaments, which draw in much tourism for local economies, have well established catch-and-release protocols (Prince et al. 1990), and support for catch-and-release is expanding (Fisher and Ditton 1992). Vithin the scientific community, there is a growing focus on the concerns for ecosystem sustainability given recreational fishing activities (Ditton 2008), which has been reflected in some management strategies. Since 2008, the Gulf of Mexico Fishery Management Council requires recreational vessels fishing in federal waters within the Gulf of Mexico to use circle hooks when catching reef fish. This policy aims to reduce cases of lethal injuries and bycatch of undersized fish; circle hooks appear to have been effective in reducing potentially lethal injuries for some stocks (Sauls and Ayala 2012).

Table 1. Percent of total allowable catch reserved for recreational fishermen for selected reef fish caught in the Gulf of Mexico.

Species	Red snapper *Lutjanus campechanus*	Red grouper *Epinephelus morio*	Gag grouper *Mycteroperca microlepis*	Black grouper *Mycteroperca bonaci*	Greater amberjack *Seriola dumerili*
% recreational	49	24	61	27	73
Source	GMFMC 2013	GMFMC 2011	GMFMC 2012a	GMFMC 2012a	GMFMC 2012b

Mexico

Landings of marine commercial fisheries retained by Mexican states bordering Gulf of Mexico waters are important contributions to local livelihoods, as well as the region's economy. Typically, annual total landings (kg) are the largest in Veracruz while Tamaulipas, Tabasco, and Campeche are comparable, and Yucatán retains the least (although the state borders highly important fishing grounds in the Campeche Bank). Catch composition of landings from these areas is dominated by ostión (oyster), pulpo (octopus), mojarra, camarón (shrimp), jaiba (crab), jurel (blue runner), mero (grouper), robalo (snook), and sierra (mackerel). Recreational fisheries in these states retain many of the same species.

The Mexican states bordering the western Gulf of Mexico basin include Tamaulipas, Veracruz, and Tabasco. Fleets operating within this area primarily harvest crustaceans. The shrimp trawl fishery operating off Tamaulipas is considered one of the largest in the Gulf of Mexico (Wakida-Kusunoki et al. 2006). Brown shrimp, *Penaeus aztecus*, is of particular importance – it represents approximately 95% of catch from vessels operating off of the Tamaulipas and northern Veracruz coast (Castro and Arreguín-Sánchez 1991). The whole area from Tamaulipas to Tabasco has very stable catch mean trophic level over time, reflecting the dominance of the shrimp fishery (Arreguin-Sánchez and Arcos-Huitrón 2011). This region also supports the *Callinectes* spp. fishery (Ramos et al. 1998). Finfish like mojarra, mackerel, and lisa (mullet) are landed due to trawl bycatch (Wakida-Kusunoki et al. 2013) and also caught by commercial fleets utilizing different gears. Commercial hook-line operations – which consist of longlines, rather than handlines – operate all across the Gulf of Mexico, but most of the landings are retained from Veracruz waters. For example, the shark bottom longline / gillnet fishery (Castillo-Géniz et al. 1998) retains most of its landings off of Tamaulipas, Veracruz, and Tabasco (Oviedo et al. 2009). In addition, the pelagic longline fleets target tuna species, like yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*), which are primarily distributed off Veracruz, in addition to a smaller fleet off Yucatán (Solana-Sansores and Ramírez-López 2006, Xollaltenco-Coyotl et al. 2010). This fleet is known to incidentally catch other species like marlins and sharks, and utilizes other gears: pole-and-line and purse seine nets (Xollaltenco-Coyotl et al. 2010). It is also worth noting that these Mexican states produce a significant quantity of oysters in aquaculture operations (Avilés-Quevedo and Vázquez-Hurtado 2006).

Fishers from Campeche and Yucatán harvest on the Gulf of Mexico's southern shelf, including the Campeche Sound. Historically, the sound has been an important source of fisheries exploitation, especially for shrimp. The pink shrimp makes up approximately 90% of shrimp catch. However, currently the shrimp fishery is collapsed, as a result of declining recruitment and adverse environmental factors such as salinity and temperature (Arreguín Sánchez 2002). As the shrimp stock has decreased, targeting of other fish has increased. The *Centropomus* spp. gillnet fishery is another important coastal fisheries, especially in areas closer to the Términos Lagoon (Caballero-Chávez 2012); this lagoon is considered to be one of the most productive in the Gulf of Mexico, and supports various fisheries (Day et al. 1982, Yáñez-Arancibia et al. 1983, 1988, Gracia and Soto 1990). Unfortunately, the environmental goods and services provided by the Lagoon are deteriorating due to various anthropogenic activities – like the competing oil industry (Cruz-Orozco et al. 1989).

The Campeche Sound connects to the Campeche Bank - an area of great importance for fishes operating out of Campeche, Yucatán, and Cuba (Valdés and Padrón 1980). The Campeche Bank contains a great diversity of species, and many of them are of high commercial value (Leonce-Valencia 1996). The behavior of commercial landings has varied more so in this area than in any other region in Mexico. This variation is driven by a shift towards capturing higher trophic level organisms (Arreguin-Sánchez and Arcos-Huitrón 2011). Trawling activities are limited since various portions of Campeche Bank cannot be trawled (Valdés and Padrón 1980); they also tend to retain few organisms of commercial importance (De León 1980). As a result, hook-line fleets targeting demersal and pelagic stocks have expanded across the area. Bottom longline operations tend to target various sharks species (Oviedo et al. 2009), *Lutjanus* spp., and *Epinephelus* spp. (Valdés and Padrón 1980). *Epinephelus morio* is the most abundant species and has the highest commercial importance in the Campeche Bank groundfish complex. The stock is closer to the continental shelf of Yucatan, so both Mexico and Cuba participate in the fishery (e.g., Moreno et al. 1992, Brulé and Déniel 1996, Zetina-Moguel et al. 1996). The previously mentioned pelagic longline fleets targeting tuna also operates in the Campeche bank (Solana-Sansores and Ramírez-López 2006, Xollaltenco-Coyotl et al. 2010), but landings are a fraction of what is produced off of Veracruz. A rod-line fleet operates almost entirely out of Campeche and Yucatán from artisanal shallow water boats and mid-sized boats fishing in deeper waters (Arreguín-Sánchez et al. 2000). The waters of the Campeche Bank also contain the octopus fishery – another stock of great commercial importance. Catch retained from the pot/trap fleets can be quite diverse in this area, but one of the main targets is spiny lobster (*Panulirus argus*); the stock harvested from the Gulf of Mexico primarily comes from the Yucatán coast (Briones-Fourzán and Lozano-Álvarez 2000).

Sport fishing in the Mexican Gulf of Mexico coastline has been practiced for the past several decades, but there is poor documentation of the various activities. However, growing concerns for sustainable fisheries is bringing more attention to recreational fishing activities in the Gulf. Recreational fishing activities are substantial off Veracruz, exclusively with handlines (Tunnell et al. 2007). At the Proceedings of the third international Tarpon Forum, Arenas-Fuentes and Utrera-López (2005) discussed tarpon sport fishing tournaments off of Veracruz, which began in 1953. Although several groups participated, only one organization preserved all of the records allowing the authors to analyze catch statistics. The impact of Mexican sport fishing on the Gulf of Mexico stocks remains largely uncertain due to the limited amount of data available.

Cuba

Overall, there is limited available information for quantifying artisanal and recreational fishing in the Northern coast of Cuba, with the exception of some recent information on shark landings and some species composition data on the recreational fishery (Aguilar et al. 2014). The official fishing zones in Cuba are based on the natural division established by the fishermen working different ports. These zones coincide with the four shelves surrounding the country: Northeast, Southeast, Southwest, and Northwest (Hernandez 2006). Fisheries within Gulf of Mexico waters are covered by the Northwest fishing zone. The fleets that operated within the Northwest zone include the Flota Atunera de Cuba (FAC) and Flota del Golfo (FG). Prior to the Cuban Revolution, commercial fisheries were largely small vessels operating near-shore. This includes the FG fleet, which contains bottom-longliners and other hook and line vessels. Historically known as Flota del Alto (deep water fishing fleet), the vessels comprising the FG consisted of viveros (vessels with live-wells) until approximately 1946 when viveros were gradually converted to neveros (vessels icing catch). The FG was officially organized in 1963 by the Instituto Nacional de la Pesca (INP). Initially, the fleet more than doubled in size, however, gradually declined as the INP shifted focus to distant water fisheries. Historically, the FG operated within the western Florida shelf and eastern Campeche shelf in addition to the northwest Cuba shelf (Tashiro and Coleman 1977). However, Cuban fleets ceased operations within the west Florida shelf in 1977, after the U.S. expanded its EEZ (Saul 2006). The FG fleet primarily targets groupers and snappers, but vessels retain other organisms including jacks, mackerels, grunts, and sharks (Tashiro and Coleman 1977, Claro et al. 2001, Gonzalez-Sanson et al. 2009). Starting in the 1960s, a modernization program prompted the expansion of the Cuban fishing fleet. This stimulated the build-up of the FAC fleet, which includes longliners targeting high-value pelagics like tuna and mackerels (Adams et al. 2000). The fleet did not prove to be significantly profitable; then the combination of the expansion of the U.S. EEZ and termination of the Soviet fuel subsidy encouraged the gradual shrinkage of the FAC fleet (Adams et al. 2000). In 1996, the FAC fleet was closed. Although commercial longlining has ceased, there are some artisanal longliners operating out of the Northwest zone (Weidner et al. 2001).

Atlantis ecosystem model

By Cameron H. Ainsworth and Elizabeth Fulton

Summary

Atlantis is a deterministic numerical biogeochemical and biophysical modeling system that simulates the structure and function of marine ecosystems. Ecosystems are resolved spatially in three dimensions using an irregular polygon structure that saves computation time. The polygons are generally designed to capture important climatic, biophysical or jurisdictional features. Biotic ecosystem components are represented in functional groups: groups of species aggregated according to life history, feeding, or niche similarities. Important species (e.g., managed species, species of conservation interest, or functionally important species) are often assigned a dedicated functional group. Vertebrate consumers are normally age structured while body weight and numbers are explicitly tracked for each age class; invertebrates are normally handled as homogenous biomass pools and may be treated either as volumetric (occupying three dimensions) or epifaunal (occupying two dimensions). These simpler group structure options are available to save computation time. Subroutines represent nutrient nitrogen flows throughout groups, consumption, production, waste production, migration, recruitment, habitat dependency and mortality including predation, senescence, and fishery removals. Simulation dynamics follow a 12-hour time step.

The Atlantis ecosystem modeling framework is based on Bay Model 2 (Fulton 2001, Fulton et al. 2004a), which was itself inspired by two other ecosystem models and incorporates some of their successful elements: the Integrated Generic Bay Ecosystem Model (Fulton et al. 2004b) and the Port Phillip Bay Integrated Model (Murray and Parslow 1999). Socioeconomic submodels in Atlantis are described by Fulton et al. (2007). Link et al. (2010) also provide an excellent review of model structure. Therefore, in the following section we provide a summary of critical formulae and refer interested readers to the aforementioned documentation. Reviews of Atlantis and similar marine ecosystem modeling approaches are provided by Plagányi (2007), Cury et al. (2008), and Jørgensen (2008). Discussion on the effects of ecosystem model structure and variable aggregation is available in Metcalf et al. (2008), Pinnegar et al. (2005) and Fulton et al. (2003).

In 2011, Atlantis underwent a substantial rewrite of the base code that now allows users more control over the functional group structure. Whereas previous models were constrained to operate within a hard-coded group structure (which put strict limits on the number and type of functional groups), Atlantis Version 2 (V2) allows any number of groups and is only limited by computer performance. Similarly, age structure for vertebrate groups was previously hard-coded to have 10 age classes whereas Atlantis V2 can use a flexible number of age classes.

Model dynamics

Primary producer dynamics

Growth of primary producer groups is driven by Michaelis-Menten dynamics in which maximum growth rate asymptotes in accordance with nutrient, light, and space limitations. Biomass is lost to predation, lysis, linear and quadratic mortality, and harvesting. The rate of change in biomass *B* for a primary producer group is

$$dB/dt = G - M - \sum_{j=1}^{n} M_j - F$$

(1)

In which, G = growth rate of autotroph, M = natural mortality not explicitly captured in the model (see below), M_j = predation mortality due to grazer j, n = number of grazers, and F = mortality due to harvesting. The rate of growth is defined as

$$G = \mu \cdot \delta_{irr} \cdot \delta_N \cdot \delta_{space} \cdot A$$

(2)

where μ is maximum growth rate, δ_{irr} is light limitation factor, δ_N is nutrient limitation factor, δ_{space} is space limitation factor, and A is rate of catabolism. For formulation of the limitation factors, δ_{irr}, δ_N, and δ_{space}, see Fulton et al. (2004a), as it varies between producers.

Nutrients

Nutrient concentrations affect the growth rate of primary producers through the δ_N term. Rates of change for ammonia (NH) and nitrate (NO) are given as

$$\frac{d(NH)}{dt} = -\sum_{i=1}^{P} A_{NH,i} + \sum_{j=1}^{C} E_{NH,j} - S + R$$

(3)

$$\frac{d(NO)}{dt} = -\sum_{i=1}^{P} A_{NO,i} + S$$

(4)

where, A is rate of uptake of NH or NO from the water column by autotroph i, P is the set of all autotrophs, E is excretion of NH by consumer j, C is the set of all consumers, S is the amount of NH converted to NO by bacteria (nitrification), and R is the amount of NH produced by denitrification.

Consumer biomass dynamics

Vertebrate functional groups are divided into age classes and Atlantis tracks abundance and weight for each age class. Abundance is described for vertebrates in terms of the number of individuals per polygon, the structural nitrogen weight per individual (mg sN/individual), and the reserve nitrogen weight per individual (mg rN/individual). Structural nitrogen represents hard body parts such as bones and teeth, while reserve nitrogen represents somatic and gonadal soft body tissue. These soft tissue types respond differently in body growth and starvation; the ratio between them serves as an indicator of animal condition factor. 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 invertebrates (mg N/m^2). Simplifying, changes in biomass for vertebrate or invertebrate consumers are tracked according to equation 5, where biomass (*B*) is substituted by abundance-per-age class in the case of vertebrate consumers.

$$dB/dt = G - \sum_{i=1}^{n} M_i - M + I - F \tag{5}$$

where M*i* is mortality due to predator *i*, n is number of predators, M is mortality not captured by predator-prey dynamics (see below), *I* is immigration into model domain, and *F* is fishing mortality.

Note that the units for growth (*G*) are biomass per unit time; *G* is defined as

$$G = \sum_{i=1}^{n} P_i \cdot \varepsilon_i \cdot \delta_{O_2} \cdot \delta_{space} \tag{6}$$

Where P_i is predation by consumer on prey *i,* ε_i is assimilation efficiency on prey *i,* δ_{02} is oxygen limitation factor, and δ_{space} is space limitation factor.

For vertebrates, growth is allocated further into structural and reserve nitrogen pools using relationships in Fulton et al. (2004a). Calculation of predation (*P*) on prey *i* by predator *j* (in biomass per unit time) may take on a variety of forms in Atlantis, such as the modified version of the Holling Type II functional response (Holling 1959):

$$P_{ij} = \frac{B_i \cdot a_{ij} \cdot B_j \cdot C_j}{1 + \frac{C_j}{G_j}\left(\sum_{i=1}^{n} B_i \cdot a_{i,j} \cdot E_{ij}\right)} \tag{7}$$

Where B_i is biomass of prey *I,* B_j is biomass of predator *j,* C_j is clearance rate of predator *j,* G_j is growth rate of predator *j,* E_{ij} is growth efficiency of predator *j* eating prey *I,* and a_{ij} is availability of prey *i* to predator *j.*

The availability parameters establish the rates of flow of material between functional groups. The parameters can be calculated from a diet matrix that describes the diet composition of each predator group for a time point, such as the model's initial conditions. The functional response allows these diet compositions to vary through time, thus considering density dependent effects relating to varying abundance of prey items. Predation rate will be affected by spatiotemporal segregation of predator and prey. Thus, predation refuges can be captured in the map design, while rates of feeding respond to seasonal and diel movement patterns. Feeding rates also vary dynamically according to gape limitation. The gape-limited feeding routine directs predation mortality to prey groups and age classes that fall within an accessible size range determined as a fraction of predator body weight. Further explanation of feeding dynamics is available in Fulton et al. (2004a).

Natural mortality

Natural mortality (M) not captured in Atlantis through predator-prey dynamics is calculated for group (i) as

$$M_i = M_{lin,i} \cdot B_i + M_{quad,i} \cdot B_i^2 + M_{special} \tag{8}$$

In the case of vertebrates, the biomass term, B, is replaced by abundance. Natural mortality for group i is composed of density-independent linear mortality (M_{lin}), density-dependent quadratic mortality (M_{quad}), and special mortality terms specific to certain groups (e.g., to represent mechanical stress on macroalgae, fouling by epiphytes on sea grass, oxygen limitation on benthic consumers, and starvation for vertebrate consumers).

Other dynamics

Other processes described in Fulton (2001) and Fulton et al. (2004a) include waste production and removal, population dynamics of dinoflagellates and bacteria, sediment chemistry, animal movement, and vertebrate reproduction.

Map design

By Michael Drexler, Cameron Ainsworth, Michael Schirripa, Scott Cross, Charles Carleton

The Atlantis box geometry was designed to incorporate large-scale regional physical processes, habitat characterization, climatology, and exploitation patterns across the Gulf of Mexico. The spatial distribution of polygons consists of 66 polygons and 171 faces (Figure 2). The physical features that were taken into consideration include depth, bathymetry, and major estuaries. Polygons are subdivided in their vertical dimension into 7 depth strata: 0 – 10 m, 10 – 20 m, 20 – 50 m, 50 – 200 m, 200 – 2000 m, 2000 – 4000 m, and sediment. These depth contours were chosen to best capture the nearshore effects of the oceanographic forcing, to divide the nearshore environment into discrete shallow depths, and to capture the range of the euphotic zone and approximate depth of the continental shelf. The 200 m isobath is significant on the West Florida Shelf as it reflects the approximate extent of the Loop Current in intrusion events (B. Weisberg, University of South Florida, pers. comm.). Major features such as high rugosity and sediment types are also represented. Presence of hard bottom substrates, coral reefs, and marine protected areas such as the Florida Keys Marine Sanctuary (polygon 28), Texas Flower Garden (polygons 43 and 56), Florida Middle Grounds (polygon 42), and stands of coral around Mexico and Cuba were designated as their own respective polygons (polygons 44, 48 and 49). Estuarine polygons were established for those estuaries with existing National Estuary Programs (polygons 19, 52, 53, 54, and 55).

Exploitation patterns were also considered in the polygon design. The economic exclusive zones of the United States, Mexico, and Cuba are closely delineated, as well as the unresolved eastern ‘donut hole’ represented by polygon 3. Distance from the major fishing ports was also considered in polygon construction. The depth contours chosen to delineate polygons coincide with several commercial fishing regulations and recreational boundaries. For example, polygon 7 was included as a significant pink shrimp fishing location. Fisheries considered in the polygon design include stone crab, shrimp (pink, brown, and white), menhaden, Atlantic bay scallop (*Argopecten iradians*), and oysters. Once the polygons were delineated, the total percent cover of sediment type (sand, mud, and hard bottom) and biogenic habitats (corals, oysters, sea grass, and epiphytes) were estimated for every polygon based on FWC substrate maps (FWC 2005, MRGIS 2014). Polygons located westward of the Mississippi plume are representative of the “fertile fisheries crescent” (Gunter 1963; polygons 21, 20, 43 and 56) and the hypoxic zone. Boxes 0 and 65 represent the boundary boxes. Boundary boxes in Atlantis are not dynamic and do not interact with the rest of the model; they provide an inert place to store migrants when ‘outside’ of the ecosystem.

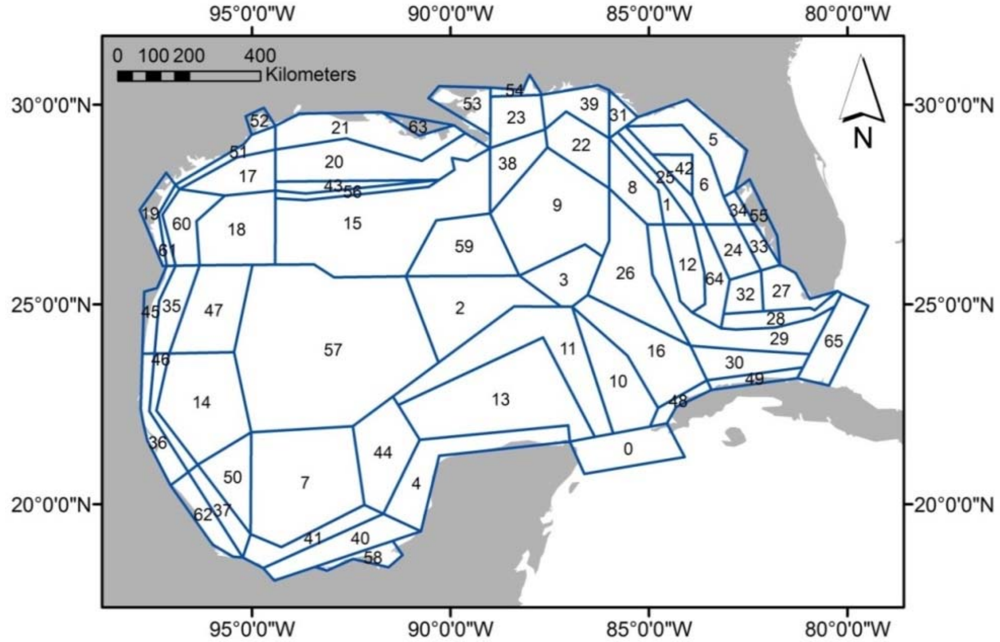

Figure 2. Gulf of Mexico Atlantis model polygon geometry

Oceanographic forcing

Initially, a test set of oceanographic input data was developed using the Intra-American Seas Ocean Nowcast/Forecast System (IASNFS; Ko et al. 2003) from the Naval Research Laboratory (NRL). These data were then replaced with outputs from the Navy Coastal Ocean Model (NCOM) – American Seas model (AMSEAS). AMSEAS is based on the NRL-developed NCOM, and has a resolution of 1/36 degree (~3 km) horizontal and 40 levels in the vertical. AMSEAS is operated by the Naval Oceanographic Office and produces a daily nowcast and 96-hr forecast. The output fields are on a regular lat/lon grid with 3-hour time steps, and 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 COAMPS model. AMSEAS assimilates all quality controlled observations in the region including satellite sea surface temperature and altimetry as well as surface and profile temperature and salinity data using the Navy Coupled Ocean Data Assimilation (NCODA) system. Boundary conditions are applied from the NAVOCEANO operational 1/8 degree global NCOM. A main advantage of AMSEAS over IASNFS is the improved spatial resolution (1/36 degree relative to 1/24 degree). This resolution is sufficient to capture fronts, eddies, Loop Current intrusion onto the WFS and other regional features and thus provides accurate seasonal concentration and retention forcing patterns affecting Atlantis' nutrient concentrations and primary production distributions. Additionally, AMSEAS provides ready availability of longer time series that can be used to force seasonality in Atlantis. At present, we are looping 1 year of oceanographic data in Atlantis; future work will expand this to a longer time series to capture interannual variation, employ specific historical periods, or utilize climate change models for forward projections, such as those developed by NOAA's Geophysics Fluid Dynamics Laboratory.

The Gulf of Mexico IEA program provided in-kind support to this Atlantis modelling effort by funding NOAA's National Coastal Data Development Center to produce the Ocean Model Slicer tool (C. Carleton, unpublished data). This is an automated tool that can integrate current, temperature, and salinity fields over any arbitrary polygon boundaries and thus greatly simplifies the process of hydrodynamics file preparation for Atlantis. It computes average temperature, salinity, and net water flux for each polygon and depth layer at the 12- or 24-hr time step required by Atlantis. Ocean Model Slicer has so far been used with Global NCOM, NCOM AMSEAS, and NCOM USEAST, and can work natively with any regularly gridded ocean model output that conforms to COARDS Climate and Forecast metadata conventions. A follow-up project is underway to make a version of Ocean Model Slicer that can handle Regional Ocean Modeling System (ROMS) and other ocean models that are on a curvilinear grid. Components of the Ocean Model Slicer could also be adapted to models that are on an amorphous triangulated grid. The Ocean Model Slicer was also applied in the development of hydrodynamics files for the Chesapeake Bay Atlantis model (I. Kaplan, NWFSC-NOAA, pers. comm.).

Initial conditions in Atlantis for temperature, salinity, and oxygen were collated from the National Oceanographic Data Center online resources (http://www.nodc.noaa.gov/). Nitrates, dissolved oxygen and silicate concentrations were taken from the NOAA's Gulf of Mexico Data Atlas (http://gulfatlas.noaa.gov/catalog/). These represent climatological means at the surface in winter (January – March) as the model initialization state represents January 1.

Functional group design

By Cameron H. Ainsworth, Michelle Masi, Michael Drexler, Matthew Nuttall, and Michael Schirripa

Species composition

We define 91 functional groups (Table A.1) in the Atlantis model, including reef fish (11 groups), demersal fish (12), pelagic fish (15), forage fish (4), elasmobranchs (6), shrimp (4), seabirds (2), mammals (4), sea turtles (3), commercial benthos (3), structural species (4), macrobenthos (3), filter feeders (3), primary producers (8), pelagic invertebrates (4), and nutrient cyclers (4). Functional groups are both single-species groups and multi-species aggregated groups. Single species groups represent highly-exploited species and species of conservation interest. Aggregated functional groups represent species within similar trophic guilds and ecological niches; species aggregation does not necessarily correspond to taxonomic clades. Species composition of all functional groups is provided in Table A.2. All fish species correspond to species identified in Fishbase (Froese and Pauly 2014) as belonging to the Gulf of Mexico Large Marine Ecosystem.

Reef fish represented in the model correspond to the following functional groups: gag grouper, red grouper, scamp, shallow serranidae, deep-water serranidae, red snapper, vermilion snapper, lutjanidae, bioeroding fish, large reef fish and small reef fish. The gag grouper, red grouper, scamp and vermilion snapper groups are single-species groups. Shallow serranidae and deep serranidae include serranids not included elsewhere; representative species of shallow serranidae include Nassau, yellowfin and yellowmouth groupers, and rock hind, red hind and black sea bass. Deep serranidae includes misty, snowy, yellowedge, warsaw, speckled hind and also other species occurring at 500 m or deeper according to the Fishbase species table (Froese and Pauly 2014). Lutjanidae includes lutjanids not included elsewhere. Bioeroding fish includes parrotfish and surgeon fish. Representative species for large reef fish include barracuda and cobia, Small reef fish includes all species located on reefs (from Fishbase habitat fields) with a length at infinity less than the 50th percentile of all reef fish species.

Demersal fish include the following functional groups: black drum, red drum, sea trout, sciaenidae, ladyfish, mullets, pompano, sheepshead, snook, flatfish, other demersal fish, and small demersal fish. The groups black drum, red drum, and sheepshead represent single species. Sea trout includes three species of genus *Cynoscion*, sciaenidae includes 16 species of drums and croakers not included elsewhere, ladyfish includes two species of genus *Elops*. Mullets include four species of the genus *Mugil*, pompano includes three species of the genus *Trachinotus*, and pompano includes three species of the genus *Centropomus*. Flatfish includes all species of the order Pleuronectiformes. Other demersal fish and small demersal fish include species identified in the Fishbase 'DemersPelag' field as demersal, or identified with the keywords "benthic" or "demersal" in the Gulfbase habitat field. This group includes representatives from 17 orders.

Pelagic fish include the groups yellowfin tuna, bluefin tuna, little tunny, other tuna, swordfish, white marlin, blue marlin, other billfish, greater amberjack, jacks, king mackerel, Spanish mackerel, Spanish sardine, large pelagic fish, and deepwater fish. Single-species groups include yellowfin tuna, bluefin tuna, little tunny, swordfish, white marlin, blue marlin, greater amberjack, king mackerel, and Spanish sardine. The group other tuna includes 2 species of the genus *Auxis* not included elsewhere. The group other billfish includes two species of the genus *Istiophorus* and one of *Tetrapturus*. Jacks include 22 species of the family Carangidae. Spanish mackerel includes Atlantic Spanish mackerel and 9 species of the family Gempylidae. Large pelagic fish includes 33 species from the orders Aulopiformes, Perciformes, Beloniformes, Lampridiformes, Perciformes, and Tetraodontiformes. This group is distinguished from group SPL by including species whose length at infinity are in the top 50 percentile of groups identified as pelagic (including benthopelagic, mesopelagic, bathypelagic, or epipelagic) from the Gulfbase habitat field. Deepwater fish includes all species not included elsewhere whose maximum depth is at least 500 m in the 'DepthRangeDeep' field in the Fishbase species table.

Forage fish include the menhaden, pinfish, medium pelagic fish, and small pelagic fish groups.

Life history parameters

Life history data sources

To create the initial condition file, groups of species were aggregated by life history parameters into functional groups. The life history data (natural mortality M, Von Bertalanffy growth rate k, length at infinity L_∞, length-weight parameters a and b, and age at maturity a_{mat}) used to create the initial conditions file were collated from Fishbase (Froese and Pauly 2014). Life history data for mammals, birds, and turtles were collated from SeaLifeBase (Palomares and Pauly 2014) and the Animal Diversity Database (Myers et al. 2015). Average life history parameter values by functional group are provided in Table A.3.

Length and weight

Length-length conversions

To standardize information in FishBase and other sources, a generic set of conversions were used to obtain total length (TL) for fish. This was necessary for length-weight calculations and to develop an average fish length for adult classes, in order to utilize empirical formulae described below, develop a maturation schedule, and for other purposes. To convert fork length (FL) to TL, we used the linear empirical relationships of Booth and Isted (1997); the relationship employed is based on panga (*Pterogymnus laniarus*), as

$$TL = (FL - 0.6848) / 0.901 \qquad (9)$$

For fish with emarginated tails, the relationship is based on the lesser gurnard (*Chelidonichthys quekerri*) as

$$TL = (FL - 3.6166) / 0.9454 \qquad (10)$$

All pelagic, benthopelagic, and bathypelagic fish were assumed to have forked tails, while all reef fish, demersal, and bathydemersal fish were assumed to have emarginated tails. Each species is demarked into one of these six habitat classifications according to data indicated in the habitat field of the FishBase species table. Vhere standard length (SL) was provided, the conversion factor to TL was applied from Christensen and Pauly (1992) as

$$TL = 1.1757 \cdot SL - 0.1215 \qquad (11)$$

Asymptotic Weight

W_∞ is the asymptotic fish body weight in grams. The parameter is used in calculations of fish natural mortality (below) and in determination of average body weights through use of a dynamic pool model, which converts fish abundance data from transects into biomass densities. W_∞ was taken directly from FishBase, if it was available in the “aveWinf” field of the PopGrowth table or the “Winf” field of the QB table. Vhere no value was available from FishBase, the parameter was calculated from a length-weight (L/W) relationship (Equation 12), using a and b growth parameters found respectively in the “a” and “b” fields of the FishBase PopGrowth table, and length at infinity ($L\infty$). $L\infty$ is taken preferentially from the “aveLinf (TL)” field of the PopGrowth table.

$$W = a \cdot L^b \qquad (12)$$

If any length-weight parameters were unavailable, then $W\infty$ was instead estimated from the maximum weight (W_{MAX}), which occurs in the “Max weight” field of the FishBase Species table, according to the rule-of-thumb equation (Ainsworth et al. 2007).

$$W_{MAX} = W_\infty \cdot 0.95 \qquad (13)$$

Age stanza calculations

Atlantis uses nitrogen as a currency for all biological groups. In setting up the initial conditions for the simulation, we assume the following for all living groups after Ainsworth et al. (2011):

- Wet weight(mg)/20 = Carbon weight
- Carbon weight/5.7 = Ash Free Dry Weight (AFDW)
- AFDW/3.65 = Structural Weight (SW)
- SW·(2.65) = Reserve Weight

In addition to the assumptions listed above, the ratio of N to all other elements (0.175) was based on the Redfield Ratio (Redfield 1934). The ratio of dry to wet weight (1:20) is based on the ratios in Cushing et al. (1958). The ratios of structural and reserve nitrogen to total nitrogen were adopted from Ainsworth et al. (2011) who cited unpublished data from K. Marshall (NWFSC-NOAA, Unpublished data).

The initial conditions file requires biomass by age and polygon for each functional group. The vertebrate and invertebrate concentrations per polygon were based on the generalized additive models (GAMs) and other methods described in the **Biomass distributions** section. Survivorship-at-age for mammals, birds, and turtles was estimated using Siler's competing risk model modified by Barlow and Boveng (1991). Mammals used parameters for cetaceans provided by the same authors. For mammals and turtles, we assumed that the "b" growth parameter was equal to 3, which assumes allometric volume. Using solver, we optimized a in the length-weight equation to solve for weight-at-age. To obtain weight-at-age for fish functional groups, the length at infinity ($L\infty$) for each group was calculated using the "a" and "b" growth parameters; then, a Von Bertalanffy model, using the Von Bertalanffy growth rate (k) and $L\infty$ parameters, was used to calculate the weight-at-age. Mortality rate (M) was calculated using the empirical formula of Pauly (1980) and inflated to account for fishing mortality using a simple guideline of M=F for heavily exploited species and M=2F for lightly exploited species. Total mortality (Z) was then used in an exponential decay model to get numbers-at-age. The derived weight-at-age and numbers-at-age were multiplied to get the biomass-at-age. The resulting biomass is in $t \cdot km^2$. Biomass was converted into mg $N \cdot m^3$ using the conversion ratios stated earlier.

Reproduction

All groups in the model use a Beverton-Holt recruitment relationship to determine the number of offspring except for sea birds, marine mammals, and sea turtles. These groups assume a fixed number of offspring per female per year: diving birds (1 recruit), surface feeding birds (0.6), manatee (0.022), mysticeti (0.034), dolphins, and porpoises (0.018), deep diving odontocetae (0.034), loggerhead (0.25), Kemps ridley (0.07) and other turtles (0.07). Figure 3 shows the spawning windows for fish functional groups and indicates spawn date and larval duration. The weight of new recruits was calculated using the Von Bertalanffy equation and assuming a standard age for new recruits of 30 days. Table 2 includes recruitment parameters for all groups that use Beverton-Holt recruitment; these parameters were adjusted iteratively in tuning.

Table 2. Beverton-Holt recruitment parameters (BHalpha, α and BHbeta, β) for Atlantis functional groups (FG).

Group	Code	a	b	Group	Code	a	b
Gag grouper	GAG	2.60E+06	2.00E+08	Seatrout	SEA	6.60E+07	8.80E+06
Red grouper	RGR	4.10E+06	2.00E+08	Sciaenidae	SCI	1.30E+09	8.80E+06
Scamp	SCM	2.10E+05	8.80E+06	Ladyfish	LDY	1.40E+07	8.80E+06
Shallow serranidae	SSR	6.50E+08	8.80E+06	Mullets	MUL	4.10E+08	2.20E+13
Deep serranidae	DSR	5.10E+07	8.40E+12	Pompano	POM	6.70E+06	8.80E+06
Red snapper	RSN	1.40E+06	2.00E+10	Sheepshead	SHP	1.00E+07	8.80E+06
Vermilion snapper	VSN	4.40E+07	2.00E+08	Snook	SNK	2.30E+07	8.80E+06
Lutjanidae	LUT	3.40E+08	2.00E+08	Flatfish	FLT	2.30E+09	7.20E+10
Bioeroding fish	BIO	2.10E+08	4.30E+11	Other demersal fish	ODF	3.20E+09	7.40E+12
Large reef fish	LRF	6.00E+08	2.00E+08	Small demersal fish	SDF	3.90E+11	9.80E+06
Small reef fish	SRF	4.20E+09	8.80E+06	Yellowfin tuna	YTN	1.50E+05	4.90E+11
Black drum	BDR	1.40E+06	8.80E+06	Bluefin tuna	BTN	1.30E+03	4.90E+11
Red drum	RDR	4.20E+05	8.80E+08	Little tunny	LTN	2.50E+06	4.90E+09
Group	**Code**	**a**	**b**	**Group**	**Code**	**a**	**b**
Other tuna	OTN	2.50E+07	4.90E+11	Pinfish	PIN	1.20E+09	5.90E+10
Swordfish	SWD	3.80E+05	4.90E+11	Medium pelagic fish	MPL	1.10E+09	2.20E+11
White marlin	WMR	4.10E+05	4.90E+11	Small pelagic fish	SPL	2.20E+10	5.90E+09
Blue marlin	BMR	2.00E+04	2.50E+11	Blacktip shark	TIP	4.80E+05	2.70E+05
Other billfish	BIL	5.20E+04	4.90E+11	Benthic feeding sharks	BEN	1.20E+05	2.70E+06
Greater amberjack	AMB	9.00E+05	7.50E+11	Large sharks	LGS	9.20E+05	4.80E+07
Jacks	JCK	1.90E+07	4.90E+11	Filter feeding sharks	FIL	2.60E+03	5.00E+12
King mackerel	KMK	1.90E+06	8.80E+06	Small sharks	SMS	2.60E+07	2.70E+08
Spanish mackerel	SMK	1.60E+07	8.80E+06	Skates and rays	RAY	6.00E+06	5.90E+10
Spanish sardine	SAR	9.00E+08	5.90E+11	Brown shrimp	BSH	3.50E+09	2.00E+11
Large pelagic fish	LPL	1.90E+07	4.90E+11	White shrimp	WSH	2.60E+08	2.00E+11
Deep water fish	DWF	5.60E+09	8.40E+10	Pink shrimp	PSH	2.20E+08	2.00E+11
Menhaden	MEN	1.90E+11	5.90E+11	Other shrimp	OSH	7.50E+08	2.00E+09

Migration and movement

Atlantis considers the seasonal distributions of functional groups in winter, spring, summer, and fall. The seasonal 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 **Biomass distributions** section or survey data when available. When no data were available, we assumed one of five standard movement patterns (Table 3). Pattern 1 reflects temperature-dependent migration where individuals migrate inshore in winter and to deeper water in the summer. Pattern 2 represents spring spawners where individuals migrate inshore in spring and offshore in the summer. Pattern 3 represents summer spawners where individuals migrate inshore in the summer and offshore in the fall. Pattern 4 represents fall spawners where individuals migrate inshore in the fall and offshore in the winter. Pattern 5 represents a uniform distribution year-round. Standard movement patterns were selected based on each group's spawning date (Figure 3). Adult spring and fall distributions were set as the average of winter and spring. Initial winter functional group distributions are shown in Figure A.1.

Table 3. Standard seasonal movement pattern distribution.

Table shows percent biomass allocated to each habitat per season

		Season			
Pattern	**Habitat**	**Winter**	**Spring**	**Summer**	**Fall**
1. Temperature-dependent: migrate inshore in winter, deep in summer					
	Estuary	100%	0%	-100%	0%
	Inshore	100%	0%	-100%	0%
	Shelf	-100%	0%	100%	0%
	Deep	-100%	0%	100%	0%
2. Spring spawner: migrate inshore in spring, offshore in summer					
	Estuary	0%	100%	0%	-100%
	Inshore	0%	100%	0%	-100%
	Shelf	-100%	0%	100%	0%
	Deep	-100%	0%	100%	0%
3. Summer spawner: migrate inshore in summer, offshore in fall					
	Estuary	0%	0%	100%	-100%
	Inshore	0%	0%	100%	-100%
	Shelf	0%	0%	-100%	100%
	Deep	0%	0%	-100%	100%
4. Fall spawner: migrate inshore in fall, offshore in winter					
	Estuary	-100%	0%	0%	100%
	Inshore	-100%	0%	0%	100%
	Shelf	100%	0%	0%	-100%
	Deep	100%	0%	0%	-100%
5. Uniform distribution year-round					
	Estuary	0%	0%	0%	0%
	Inshore	0%	0%	0%	0%
	Shelf	0%	0%	0%	0%
	Deep	0%	0%	0%	0%

Highly migratory pelagics

In addition to seasonal movement patterns within the Gulf of Mexico, highly migratory pelagics (HMPs) travel outside of the model domain seasonally. Adult stanzas of the following functional groups were assumed to undergo these seasonal migrations: yellowfin tuna (*Thunnus albacares*), bluefin tuna (*Thunnus thynnus*), swordfish (*Xiphias gladius*), white marlin (*Tetrapturus albidus*), blue marlin (*Makaira nigricans*), king mackerel (*Scomberomorus cavalla*), Spanish mackerel (*Scomberomorus maculatus*) and other billfish. With the exception of yellowfin and bluefin tunas, we assumed that juveniles will also migrate outside of the model domain seasonally. However, most juveniles likely do not migrate until they have reached maturity. Therefore, to more accurately represent juvenile migration patterns, a larger fraction of the juvenile population was assumed to remain inside the model domain annually (representing younger individuals). Because these HMPs migrate widely, are harvested over broad ocean areas both nationally and internationally, and are widely studied (Turner 1999), their migration patterns are detailed in the following subsections. A summary of the migration assumptions is shown in Table 4. General movement patterns were confirmed by expert opinion (E. Orbesen, SFSC-NOAA, pers. comm.). Details regarding diet and biomass estimates for these groups are listed in the appropriate subsections, in the following section.

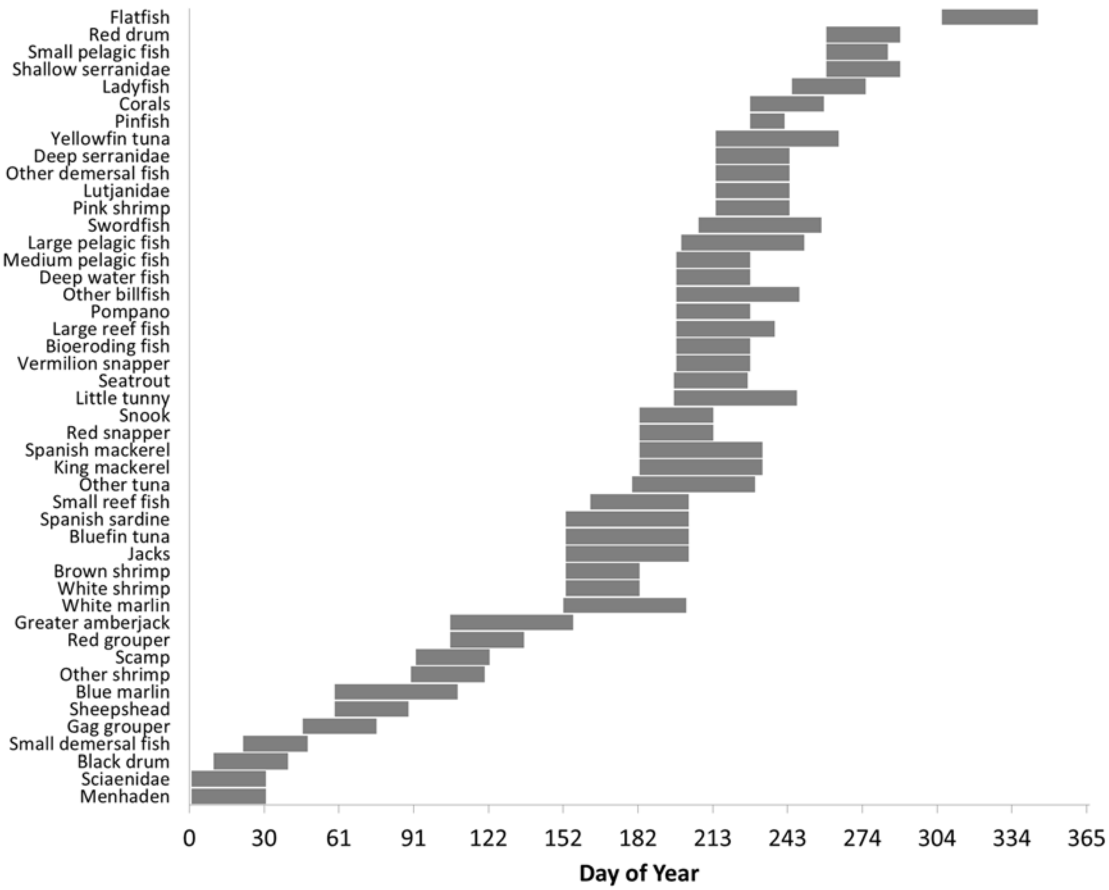

Figure 3. Spawning windows

Yellowfin tuna (YTN)

According to Arocha et al. (2000, 2001) a group of yellowfin tunas migrates into the Gulf of Mexico from May to August to spawn. More recently, Teo and Block (2010) looked at the relative distribution of yellowfin tuna in the Gulf of Mexico, by comparing the spatiotemporal variability and environmental influences on the catch per unit effort (CPUE). Their results confirm that yellowfin tuna are being caught in the Gulf from May to August, with the highest CPUEs occurring in July, and the lowest in March. We assumed a 60-day seasonal migration period, where 40% of the yellowfin tuna stock is assumed to leave the model domain at the end of February, and then return the end of June. Juveniles were assumed to be resident year-round.

Bluefin tuna (BTN)

The International Commission for the Conservation of Atlantic Tunas (ICCAT, http://www.iccat.es) currently manages the Atlantic bluefin tuna as two individual stocks, the western Atlantic spawners and the eastern Atlantic spawners. For migration purposes, we assumed both stocks have the same seasonal migration patterns into and out of the model domain. The Atlantic bluefin tuna is known to spawn in the Gulf of Mexico from March to June (Mather et al. 1995). Tagging data show similar migration patterns, with mature bluefins being present in the Gulf from February to June (Teo et al. 2007). Based on expert opinion, we assumed a 60-day seasonal migration period, where 100% of the bluefin tuna stock leaves the

Gulf in the middle of May. The stock is then assumed to return to the model on December 1st. Juveniles were assumed to be resident year-round.

Swordfish (SWD)

The Atlantic swordfish is primarily a warm-water species that spawns throughout the year in the Caribbean, the Gulf of Mexico, and in the waters off Florida (Nakamura 1985). Neilson et al. (2006) suggests that the peak of the spawning season occurs in the Gulf from April through July. Govoni et al. (2003) inferred the age of larval swordfish from three areas; in the northeast Caribbean near the Lesser Antilles, off the southeast United States and in the Straits of Florida. Their results suggest spawning in the Gulf of Mexico persists near the Gulf Loop Current, with larval transport likely moving in a northward direction. Based on expert opinion, we assumed a 90-day seasonal migration period, where 70% of the swordfish stock leaves the first day of October, and then returns to the Gulf just before April.

White marlin (WMR)

The most recent information on habitat preferences of white marlin is from modern electronic tag technology; though data in general are still very limited (ICCAT 2006-2009). White marlin tagging data show significant movement between the United States east coast, the Gulf of Mexico, and Venezuelan waters (Ortiz et al. 2003). However, migration routes are still uncertain (ICCAT 2006-2009). Based on expert opinion, we assumed a 90-day seasonal migration period, where 70% of the swordfish stock leaves the model domain the in June, and then returns at the end of the summer (in August).

Blue marlin (BMR)

According to the Pelagic Fisheries Conservation Program (Rooker 2006), a small fraction of the adult blue marlin stock leaves the Gulf of Mexico from May to June, and again from August to October, but return to the Gulf in winter. Tagging data, available through NOAA, indicate a similar migration pattern, showing blue marlin being present in the Gulf from May through (E. Orbesen, SFSC-NOAA, pers. comm.). Tag/recapture data from the Cooperative Game Fish Tagging Program, 1954-88, suggest that some blue marlin spend a considerable amount of time inside the Gulf of Mexico (Witzell and Scott 1990). Based on expert opinion, we assumed a 90-day seasonal migration period, where 50% of the blue marlin stock leaves the model at the end of October, and then returns the 1st day of May.

King mackerel (KMK)

According to Johnson et al. (1994) there are two distinct stocks of King mackerel in the Gulf of Mexico, an eastern stock and a western stock. Both stocks exhibit cyclical movements (ICCAT 2006-2009), with the central convergence of both stocks occurring in the northern Gulf during the summer months (Johnson et al. 1994). Sutter et al. (1991) suggests that some king mackerel may be residents to the Gulf, with the proportion of mixing stocks along Florida’s east coast varying annually (Fable et al. 1987, Schaefer and Fable 1994). Therefore, we assumed a 90-day seasonal migration period, where only 10% of the king mackerel stock migrates out of the model domain at the end of October, and returns to the Gulf the 1st day of May.

Spanish mackerel (SMK)

Results from Sutherland and Fable (1980) suggested that there may be a resident stock of Spanish mackerel in the Gulf of Mexico, which migrates from its wintering grounds off southern Florida and the

Yucatan to the northern Gulf in the summer (ICCAT 2006-2009). Like the king mackerel, we assumed a large portion of the stock will remain in the Gulf annually. Based on expert opinion, we assumed a 90-day seasonal migration period, where only 10% of the Spanish mackerel stock leaves the model at the end of October, and then returns the 1st day of May.

Other billfish (BIL)

This group includes three species of billfish; the Indo-Pacific sailfish (*Istiophorus platypterus*), the Atlantic sailfish (*Istiophorus albicans*) and the Longbill spearfish (*Tetrapturus pfluegeri*). Migration patterns for these billfish species are poorly known (ICCAT 2006-2009). It is likely billfish have similar migration patterns as blue marlin (E. Orbesen, SFSC-NOAA, pers. comm.). Therefore, based on expert opinion, we assumed a 90-day seasonal migration period, where 50% of the other billfish stock leaves the Gulf at the end of October, and then returns the 1st day of May.

Table 4. Summary of the migration assumptions for highly migratory pelagics.

Group	Code	Migration period (days)	Percent of stock leaving GOM	Day leaving domain	Day returning to domain
Yellowfin tuna	YTN	60	40%	59 (Feb)	181 (Jun)
Bluefin tuna	BTN	60	100%	135 (May)	340 (Dec)
Swordfish	SWD	90	70%	274 (Oct)	80 (April)
White marlin	WMR	90	70%	152 (June)	243 (Aug)
Blue marlin	BMR	90	50%	304 (Oct)	121 (May)
King mackerel	KMK	90	10%	274 (Oct)	121 (May)
Spanish mackerel	SMK	90	10%	274 (Oct)	121 (May)
Other billfish	BIL	90	50%	304 (Oct)	121 (May)

Biomass distributions

By Michael Drexler, Matthew Nuttall, Elizabeth Babcock and Cameron Ainsworth

Group biomass

Absolute biomass was determined for the 2010 model from sources listed in Table 5. Biomass densities of commercially important species were taken directly from stock assessment reports and literature and extrapolated to represent the entire Gulf of Mexico shelf. Most groups were distributed spatially according the relative results of the Drexler and Ainsworth (2013) generalized additive modeling (GAM) model (see next section). Total biomass estimates for groups without stock assessments were estimated directly from the GAM model. Biomass was scaled by relative CPUE to provide an estimate of biomass for the 1980 model; some unexploited groups were assumed similar in biomass to 2010.

Table 5. Initial biomass for Atlantis GOM functional groups.

Biomass estimates of commercially important species were taken directly from SEDAR stock assessment reports (available at http://www.sefsc.noaa.gov/sedar/) and ICCAT reports (available at http://www.iccat.int/en/assess.htm) and extrapolated by area for the entire Gulf of Mexico shelf. 'Model estimated' indicates groups whose biomass was taken directly from the Drexler and Ainsworth (2013) GAM model.

Group	Code	1980 (mt)	2010 (mt)	Source
Reef Fish				
Gag grouper	GAG	15556	18489	SEDAR 2014
Red grouper	RGR	46902	74447	Saul 2006
Scamp	SCM	1810	1862	Model estimated
Shallow serranidae	SSR	506864	521199	Okey and Mahmoudi 2002
Deep serranidae	DSR	209586	83169	Okey and Mahmoudi 2002; SEDAR 2011
Red snapper	RSN	46631	150154	SEDAR 2013a
Vermilion snapper	VSN	143050	78169	Relative to red snapper; Patterson et al. 2010
Lutjanidae	LUT	2666764	1501540	Relative to red snapper
Bioeroding fish	BIO	139467	41445	Patterson et al. 2010
Large reef fish	LRF	104226	78959	Relative to small reef fish; Patterson et al. 2010
Small reef fish	SRF	220098	98699	Relative to red grouper
Demersal Fish				
Black drum	BDR	16018	16465	Model estimated
Red drum	RDR	35255	39517	Model estimated
Seatrout	SEA	34296	42870	Drexler and Ainsworth 2013
Sciaenidae	SCI	520748	233310	Drexler and Ainsworth 2013
Ladyfish	LDY	20149	75736	Walters et al. 2008
Mullets	MUL	134898	235606	Okey and Mahmoudi 2002
Pompano	POM	20313	146330	Walters et al. 2008
Sheepshead	SHP	38778	321927	Walters et al. 2008
Snook	SNK	185121	191803	Muller and Taylor 2013
Flatfish	FLT	146785	152083	Drexler and Ainsworth 2013
Other demersal fish	ODF	1846005	511033	Drexler and Ainsworth 2013
Small demersal fish	SDF	120442	124789	Drexler and Ainsworth 2013
Pelagic Fish				
Yellowfin tuna	YTN	30702	15246	ICCAT 2006-2009
Bluefin tuna	BTN	18298	7012	Teo and Block 2010
Little tunny	LTN	63603	130422	Teo and Block 2010
Other tuna	OTN	25650	9271	Relative to red grouper from logbook data
Swordfish	SWD	165189	80558	ICCAT 2006-2009
White marlin	WMR	15640	7627	NMFS 2011a, 2011b
Blue marlin	BMR	8895	4338	ICCAT 2006-2009
Other billfish	BIL	3992	1947	ICCAT 2006-2009

Group	Code	1980 (mt)	2010 (mt)	Source
Greater amberjack	AMB	15093	8311	SEDAR 2014
Jacks	JCK	180249	77549	
King mackerel	KMK	33606	100389	SEDAR 2009a
Spanish mackerel	SMK	34027	48590	SEDAR 2013b
Spanish sardine	SAR	174817	119460	
Large pelagic fish	LPL	378082	80558	Equal to swordfish
Deep water fish	DWF	115884	120067	
Forage Fish				
Menhaden	MEN	10266490	10390133	SEDAR 2013c
Pinfish	PIN	194294	194166	Drexler and Ainsworth 2013
Medium pelagic fish	MPL	1092657	232812	Relative to large pelagic fish
Small pelagic fish	SPL	1618004	2013946	Relative to large pelagic fish
Elasmobranchs				
Blacktip shark	TIP	27048	21196	SEDAR 2012
Benthic feeding sharks	BEN	4413769	3427106	Relative to large sharks
Large sharks	LGS	1961675	1523158	
Filter feeding sharks	FIL	879	879	
Small sharks	SMS	455109	353373	Relative to large sharks
Skates and rays	RAY	465229	609521	Drexler and Ainsworth 2013
Shrimp				
Brown shrimp	BSH	277689	1172622	Hart 2012
White shrimp	WSH	19724	109956	Hart 2012
Pink shrimp	PSH	10484	20969	Hart 2012
Other shrimp	OSH	643352	835028	
Seabirds				
Diving birds	DBR	819121	1068625	
Surface feeding birds	SBR	1677514	2188485	
Mammals				
Manatee	MAN	1710	1380	USFWS 2013
Mysticeti	MYS	2196	2196	Waring et al. 2011
Dolphins and porpoises	DOL	73592	48707	Waring et al. 2011
Deep diving Odontocetae	DDO	49730	49730	Palomares and Pauly 2014
Turtles				
Loggerhead	LOG	22071	71358	Ainsworth et al. 2011
Kemps ridley	KMP	216591	700256	Ainsworth et al. 2011
Other turtles	TUR	112606	364063	Ainsworth et al. 2011
Commercial Benthos				
Blue crab	BCR	302250	242532	Drexler and Ainsworth 2013
Stone crab	SCR	191972	191972	
Crabs and lobsters	LOB	77339	77339	Drexler and Ainsworth 2013
Structural Species				
Stony corals	COR	9985	4992	ReefBase 2014
Crustose coralline algae	CCA	22823	11412	ReefBase 2014
Octocorals	OCT	6523	4892	ReefBase 2014
Sponges	SPG	40174	40174	
Macrobenthos				
Carnivorous macrobenthos	CMB	980808	980808	Drexler and Ainsworth 2013
Infaunal meiobenthos	INF	33863935	33863935	Drexler and Ainsworth 2013
Herbivorous echinoderms	ECH	12558729	12558729	Drexler and Ainsworth 2013
Filter Feeders				
Oysters	OYS	13230748	13230748	Drexler et al. 2014
Bivalves	BIV	6641352	6641352	Drexler and Ainsworth 2013
Sessile filter feeders	SES	806741	806741	Drexler and Ainsworth 2013
Primary Producers				
Epiphytes	EPI	70252	35126	Relative to sea grass
Sea grass	GRS	228000	114000	Relative to sea grass
Macroalgae	ALG	114194	57097	Relative to sea grass
Microphytobenthos	MPB	38725	19363	Relative to sea grass

Group	Code	1980 (mt)	2010 (mt)	Source
Large phytoplankton	LPP	13484083	13484083	Model estimated; MODIS
Small phytoplankton	SPP	26967923	26967923	Model estimated; MODIS
Toxic dinoflagellates	DIN	15254	26968	Model estimated; MODIS
Protists	PRO	269679	269679	Model estimated; MODIS
Pelagic Invertebrates				
Jellyfish	JEL	42879	42879	Drexler and Ainsworth 2013
Squid	SQU	74755	54889	Drexler and Ainsworth 2013
Large zooplankton	LZP	1348408	1348408	Model estimated; MODIS
Small zooplankton	SZP	2696792	2696792	Model estimated; MODIS
Nutrient Cycle				
Bacteria	PB	80904578	80904578	Model estimated
Sediment bacteria	BB	80904578	80904578	Model estimated
Carrion detritus	DC	80904578	80904578	Model estimated
Labile detritus	DL	652537	652537	Model estimated
Refractory detritus	DR	652537	652537	Model estimated

Shallow water fauna

A GAM approach (Hastie and Tibshirani 1986) was used to predict the biomass of functional groups across shelf areas of the entire Gulf of Mexico, including Mexican and Cuban waters and areas where fisheries independent surveys do not exist. Generalized additive models are a nonparametric approach to predicting non-linear responses to a suite of predictor variables; in this case the GAM was based on environmental and habitat predictors using the methods outlined in Drexler and Ainsworth (2013). This approach was applied to a large-scale fisheries independent data set (Southeast Area Monitoring and Assessment Program) and regional climatological-scale environmental conditions (National Oceanographic Data Center; http://www.nodc.noaa.gov/) to estimate the biomass of 40 of the 90 Atlantis-GOM functional groups.

The Southeast Area Monitoring and Assessment Program (SEAMAP) is a multiagency fisheries independent data collection program coordinated by the Gulf States Marine Fisheries Commission (GSMFC 2011). Survey data were extracted from the public SEAMAP database (Rester 2011) and aggregated by Atlantis-GOM functional groups. Catch-per-unit effort (abundance) was standardized to the number of individuals per square kilometer based on the total area swept of each SEAMAP tow using the Euclidean distance between start and end points and assumed a 40-ft trawling width.

Predictor variables included in the model were surface chlorophyll a (Chl *a*), sediment type, bottom dissolved oxygen (DO), bottom temperature, and depth (Table 6). These variables were chosen due to the wide spatial coverage of data available throughout the entire Gulf of Mexico. Sediment type was divided into the following categories: mud, sand, gravel, and rock. A 0.1 degree gridded map of seasonal environmental parameters was made for each season (Winter: Jan-Mar, Spring: Apr-Jun, Summer: Jul-Aug, Fall: Sep-Dec). A nearest neighbor function was employed for those grid points lacking any sediment data. Incomplete and low resolution environmental data were subjected to a spline interpolation using GIS v10.0 software [30] across a 0.1 degree grid in order to provide a contiguous surface from which to make model predictions. The seasonal environmental conditions grid was then overlaid with the SEAMAP starting locations for a given season. This environmental grid was used both in fitting the GAM and in predicting biomass distributions for unsampled areas.

Due to the large number of zero observations and the need for a single parsimonious model to make predictions for a large number of functional groups, a GAM was developed using a negative binomial distribution with an offset for effort This model was then used to predict abundance from the environmental conditions within each 0.1 degree grid cell for depths up to 200 m following the equation:

$$g(\eta) \sim s(\text{depth}) + s(\text{Chl } a) + s(\text{temp}) + s(\text{oxygen}) + \text{factor}(\text{sediment type}) + \text{offset}(g(\text{effort})) \qquad (14)$$

where η represents the expected abundance resulting from the generalization of the predictor terms according to the link function *g*. All models were fit using the 'mgcv' package in the R statistical environment (R Development Core Team 2011). The abundance data were modeled using a negative binomial distribution with a log link function, including an offset, with equivalent link function, to allow for variations in effort. Function *s* is a thin-plate regression spline fit to a given environmental parameter. The smoothness selection was fit using a spline-based penalized likelihood estimation. Theta parameters and weighted penalties were determined by Un-Biased Risk Estimator (UBRE) which is similar to an AIC re-scaled (Wood 2006). Estimation of the theta parameter was limited to a range of 1-10. An extra penalty was applied to each parameter as the smoothing parameter approached zero, allowing the complete removal of a term from the model when the smoothing parameter is equal to zero. This extra penalty allows for partially automated model selection and is especially useful given the model's broad application to numerous functional groups.

Deep water fauna

A GAM approach was used to predict biomass for a number of deep-sea, benthic taxa in the Gulf of Mexico. The underlying mechanism(s) responsible for the dynamics of deep-sea communities is still open to conjecture, with potential drivers including food availability, seafloor topography, and various environmental conditions (Carney 2005). Therefore, GAMs were used to apply smoothing functions to variables representing these drivers, providing insight into the relative influence of these factors on the Gulf of Mexico benthos without having to determine, *a priori*, the appropriate model structure to represent cause-effect mechanisms.

The Northern Gulf of Mexico Continental Slope Habitats and Benthic Ecology Study (DGoMB) (Rowe and Kennicutt II 2009), conducted by the Mineral Management Service, was chosen to parameterize these models. This survey was chosen because it used CTD (conductivity-temperature-depth) rosettes, benthic grabs, a semi-balloon otter trawl, and sea floor photography to produce a relatively extensive dataset for the deep benthic communities of the Gulf of Mexico, including data for sediment bacteria, small protists and metazoans, large bottom-dwelling invertebrates, demersal fish, and a variety of environmental variables. Data from other deep-sea surveys were used in calculating estimates of average size (mgC/individual) (Faubel 1982, Pequegnat 1983, Rowe 1983, Gallaway et al. 1988, Mahaut et al. 1995) for taxa with standing stock reported in units of numbers. To further inform average size estimates for macrobenthos, the estimates were used as initial values and optimized using the solver algorithm (in Excel) by minimizing the sum of squared residuals between observations of station-specific total biomass (Wei et al. 2012) and predicted biomass, which is the product of taxa-specific abundance (individuals m^{-2}) and average size (in mgC/individual) summed across all taxa at each station.

GAMs were designed to predict spatial biomass patterns for Atlantis functional groups that occupy the deep benthos based on potential predictor variables that include environmental conditions (depth, temperature, dissolved oxygen, sediment type) and food availability (meiobenthic biomass for macrobenthos and macrobenthic biomass for demersal invertebrate and fish groups):

$$g(\eta) \sim s(\text{depth}) + s(\text{temp}) + s(\text{oxygen}) + \text{factor}(\text{sediment type}) + s(\text{food}) \qquad (15)$$

Table 6. Data sources for the generalized additive modeling (GAM) approach.

A GAM was used to predict the biomass of functional groups. The list of data sources used in the model includes the data resolution and any manipulations that were required to attain a contiguous surface with which to make model predictions.

Environmental Parameter	Data Source	Resolution	Manipulations
Abundance	Southeast Area Monitoring and Assessment Program (SEAMAP)	Varies	Standardized to area swept centered around each starting point
Surface chlorophyll *a* (Chl *a*)	MODIS-Terra 4km Satellite -NASA Giovanni Portal	4km	NA
Sediment	dbSEABED - GOM Data Atlas	Low	Nearest neighbor interpolation
Bottom Temperature	NODC / GOM regional Climatology	0.1^0	Spline interpolation
Bottom Dissolved Oxygen	NODC / GOM regional Climatology	1.0^0	Spline interpolation
Depth	DOC/NOAA/NESDIS/NGDC - GOM Data Atlas	1.85 km	NA

These variables were all sampled in the DGoMB study and available for GAM fitting. GAMs were fit within the 'mgcv' package using a Gaussian distribution and thin plate regression splines. An additional penalty for smoothing was applied in these models to allow partial automation of parameter selection (Wood 2006). Additional datasets were needed to obtain observations of predictor variables in areas not sampled by this survey and to extrapolate predicted biomass trends. Environmental variables were obtained from the databases used in Drexler and Ainsworth (2013) while deep-sea meio- and macrobenthic standing stock were represented by predictions from Wei et al. (2010) and (2012), respectively. As these models were parameterized from samples obtained from depth, predictions were only provided for polygons at depths greater than 200 m. As an example, the predicted biomass for infaunal meiobenthos is provided in Figure 4.

Other fauna

Most of the species distributions were set using the shallow and deep-water GAM models. The remainder was set using a simpler method based on habitat affinities. We scored each of our polygons with a value to indicate the relative amount of habitat in each of the following categories: deep water, shelf water, inshore water, estuaries, hard bottom, mud bottom, sand bottom, oysters, mangroves, and sea grass. Percent cover for each of these categories was normalized. Total percent cover of sediment type (sand, mud, and hard bottom) and biogenic habitats (corals, oysters, sea grass, epiphytes) was estimated based on FWC substrate maps (FWC 2005, MRGIS 2014); other habitat types were estimated subjectively. We then scored habitat affinities for each functional group using the affinities provided in FishBase (Froese and Pauly 2014). The cross product between the habitat affinities and the percent cover by polygon provided an initial estimate of biomass distributions, assuming that functional groups tend to occupy polygons that had high coverage of their preferred habitats.

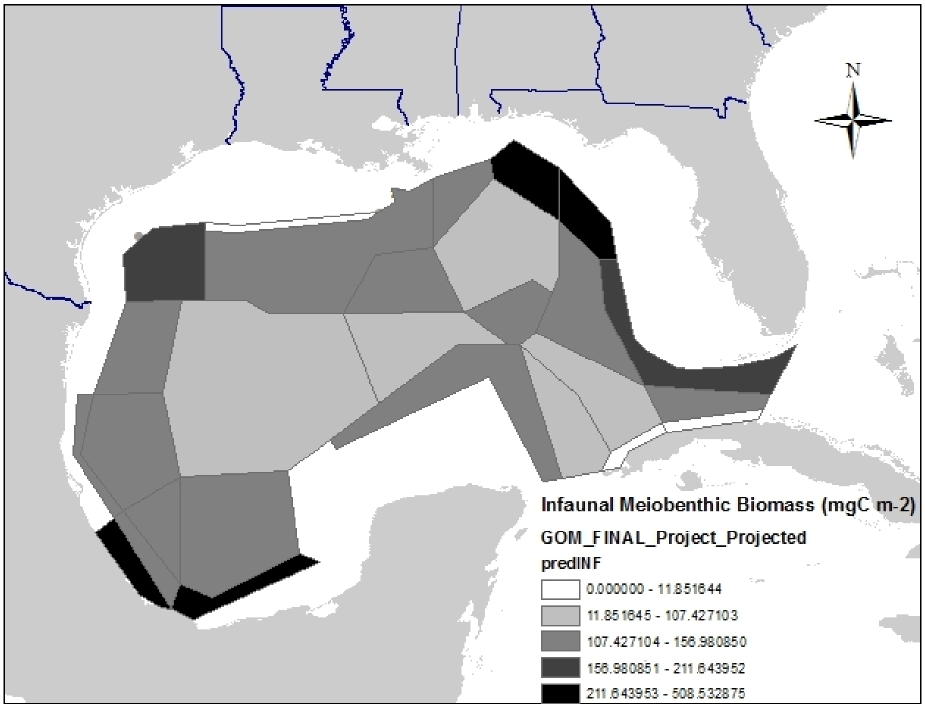

Figure 4. Predictions of infaunal meiobenthic biomass (in mg C·m^{-2}).

Vertical distribution

The polygons have varying numbers of depth layers representing the water column, from a single layer in inshore boxes to a maximum of six layers in the central Gulf. The layer depths are 10 m, 20 m, 50 m, 200 m, 2000 m and 4000 m; in addition, each polygon has a sediment layer. In order to vertically partition the biomass or abundance of species in the water column, we developed a system in which we specified concentrations at each of six reference layers. For polygons that had all six water column layers, the relative distribution of biomass matched the input directly. For polygons that had fewer than six layers, the concentrations were linearly interpolated based on the six reference layers. Thus, a species concentrated in the bottom layers, for example, would show that gross pattern in all polygons regardless of the number of depth layers present. This allowed us to parameterize the vertical distributions using only a simple matrix for each group; these distributions are shown in Table A.4. Concentrations in the sediment layer (generally only applicable to invertebrates) were not part of the interpolation; these concentrations were represented directly by a seventh reference layer.

Gulf of Mexico feeding relationships

By Michelle Masi and Cameron Ainsworth

Defining predator-prey interactions

To characterize the trophic interactions occurring between groups of species in our Atlantis-GOM model, we first performed a laboratory analysis of stomach samples to better understand the trophic interactions of data-deficient fish species within the Gulf of Mexico study area. We then expound on our laboratory results through the assimilation of available diet data sets. Following the methodology of Ainsworth et al. (2010), we used a maximum likelihood estimate (MLE), to aggregate these data sets and provide a probabilistic representation of major predator-prey linkages for the Gulf of Mexico ecosystem. The methodology and results are presented in Masi et al. (2014). A summary follows.

Sampling

In an effort to define trophic interactions for our non-commercial consumer functional groups in the Atlantis-GOM model, we acquired 101 fish stomachs collected in 2011 from sampling locations throughout the Gulf by local, state, and federal agencies. These agencies include the National Marine Fisheries Service (NMFS), Florida Fish and Wildlife Conservation Commission (FWC) and the University of South Florida (USF). Collecting fish stomachs from these various agencies allowed for analysis across a broad range of gear types (trawls, longline fishing and inshore seine netting), thus reducing the intra-haul correlation as a source of error and thus avoiding the resulting bias (Ainsworth et al. 2010). Species sampled are provided in Table 7.

Table 7. Species sampled in gut content analysis.

All species had identifiable gut content except for scamp and gag grouper.

Scientific name	Common name	Functional group	Code
Epinephelus morio	Red grouper	Red grouper	RGR
Mycteroperca microlepis	Gag grouper	Gag grouper	GAG
Seriola dumerili	Greater amberjack	Greater amberjack	AMB
Epinephelus flavolimbatus	Yellowedge grouper	Deep serranidae	DSR
Epinephelus itajara	Goliath grouper	Shallow serranidae	SSR
Scomberomorus cavalla	King mackerel	King mackerel	KMK
Lutjanus campechanus	Red snapper	Red snapper	RSN
Rachycentron canadum	Cobia	Small reef fish	SRF
Rhomboplites aurorubens	Vermilion snapper	Vermilion snapper	VSN
Eucinostomus spp.	Mojarras	Medium pelagic fish	MPL
Mycteroperca phenax	Scamp	Scamp	SCM
Epinephelus niveatus	Snowy grouper	Deep serranidae	DSR

Expansion of the laboratory data

The sampling effort was intended to fill data gaps for the less common consumer functional groups (e.g. deep serranidae) in the Atlantis-GOM model. However, acquiring samples for the generic aggregated functional groups proved challenging, so several common species were also sampled (Table 7). Note that a follow-up study is underway to expand this data set that will include additional under-sampled species. In order to get a more comprehensive representation of the trophic interactions occurring between our 91 modeled functional groups, we combined the gut content analysis with a diet database provided by the Fisheries Independent Monitoring (FIM) group at the FWC in St. Petersburg, FL (B. McMichael, FIM-FWC, pers. comm.). FWC's diet database is comprised of 17,610 stomach samples that have been collected since 2005 from 213 different predator species. The prey content in each stomach sample is measured in volume (mm^3). The majority of these samples were collected in Tampa Bay with fewer samples from Charlotte Harbor, Cedar Key, Apalachicol Bay, and nearshore areas adjacent to these estuaries. Samples that had been recorded in this database as 'unidentified' or 'discarded' were not used for this analysis; thus, we were able to use of 13,084 of the stomach samples. We then aggregated these predator species into our model functional groups.

In addition to the gut-content analysis data and the diet database data from FWC, we collated 868 studies from FishBase (Froese and Pauly 2014), adding an additional 50 fish species to our aggregated diet dataset (e.g. Bluefin tuna). Furthermore, the FWC diet data samples were mostly acquired in the western Gulf of Mexico and within Tampa Bay; by incorporating FishBase data we could provide a more robust representation of the diets of our functional groups across the model area. The three combined data sets, gut-content analysis, FWC diet database and the FishBase data, together describe 14,063 predator-prey interactions relating to 35 of the 47 fish functional groups in the Atlantis-GOM model. Any diet data that did not have at least 10 records for a given predator functional group were not used in the statistical procedure.

Probabilistic analysis of fish diets

The methods and justification for using a probabilistic analysis of fish diets are provided in detail in Masi et al. (2014), and are only summarized here. When we used the combined data set the mode of the contribution of a prey group to the diet of a predator was usually zero because there was always a large number of observations that did not contain any of a given prey group. To deal with this issue, we randomly selected a percentage of the total diet records for each predator functional group, averaged those diet compositions and then re-normalize the data to create diet proportions. This process creates an 'average predator' whose diet composition contains fewer zero-value prey items.

Rather than using the mean of the distribution (which would be heavily influenced by unusual feeding events in small samples), we used the mode while averaging over a number of stomachs (following (Ainsworth et al. 2010). Then, we bootstraped 10,000 samples with replacement, resulting in a distribution of diet proportions. Next, we fit these bootstrapped diet compositions to a Dirichlet distribution, which is a generalized multivariate beta distribution (Gelman et al. 2004). The beta distribution works well for fitting diet composition data as it is constrained from zero to one and can assume an assortment of different shapes (Ainsworth et al. 2010).

The advantage of the MLE method over simple averaging is that it allowed us to produce error ranges (i.e., upper and lower confidence intervals), which better account for the uncertainty surrounding rare feeding events. These rare predator-prey interactions are important in Atlantis and in ecosystem modelling in general, because even a very small diet contribution for a prey can be important when predator biomass and consumption rates are very large or prey biomass is very small (Walters et al. 2008) Also, weak diet linkages can become more important in a predator's diet if prey biomass or availability changes.

Diet matrix

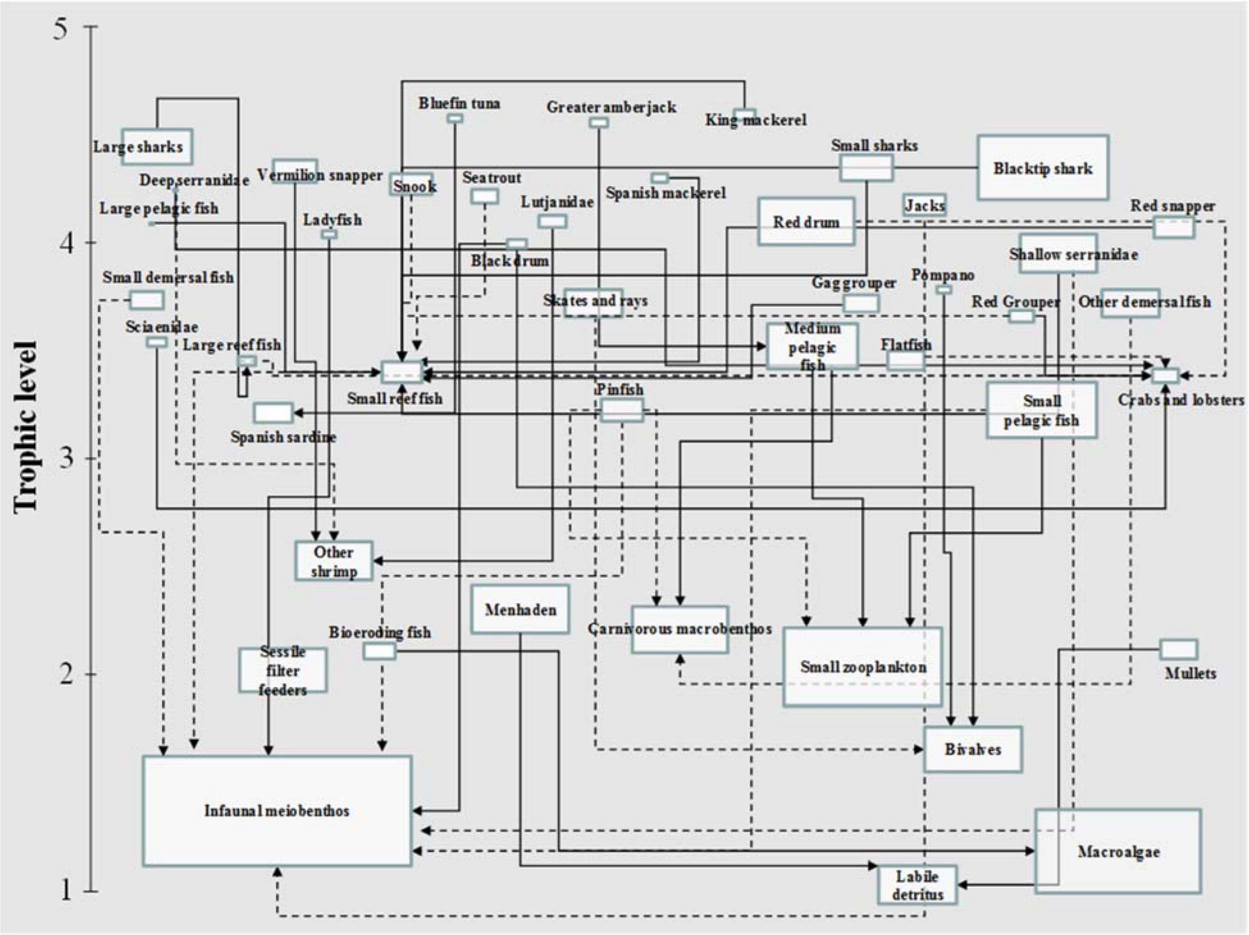

Figure 5. Gulf of Mexico food web diagram

Food web diagram showing the predator-prey interactions The area of each box is directly proportional to the log biomass concentration averaged over all areas in the Gulf of Mexico; solid lines show prey contributions > 40%; dashed lines show 23-40% connectance; linkages <23% not shown. Carnivorous macrobenthos, infaunal meiobenthos, and bivalves are not to scale. From Masi et al. 2014.

Using the normalized mode values obtained from the MLE distribution, we were able to construct a food web diagram, linking the 35 functional groups analyzed in the Gulf of Mexico study area. Figure 5 depicts the predator-prey interactions (modes >23.0%) for the consumer functional groups analyzed using our MLE method, where the size of the box represents the Atlantis model biomass estimates (Drexler and Ainsworth 2013), on a logarithmic scale. However, the carnivorous macrobenthos, infaunal meiobenthos and bivalves groups are not to scale because their biomass is too large to show the actual log biomass. The solid lines represent interactions between groups with modes greater than 40.0%, whereas the dashed lines represent linkages of 23.0 to 40.0% between predators and their prey. The predator groups flatfish, jacks, large reef fish, other demersal fish, pinfish, red drum, seatrout, skates and rays, small demersal fish, small reef fish and snook only show dashed linkages, which probably indicates generalist feeding habits.

Table 8. Growth (MUM) and clearance (c) for vertebrates.

Parameters for Juveniles (Juv) and Adults (Adu).

		Clearance		Growth				Clearance		Growth	
Group	Code	Juv	Adu	Juv	Adu	Group	Code	Juv	Adu	Juv	Adu
Gag grouper	GAG	121.5	168.7	25.1	271.2	Greater amberjack	AMB	879.2	18849.3	87.9	628.3
Red grouper	RGR	108.8	396.4	52.8	295	Jacks	JCK	739.1	1814.7	113.1	335.6
Scamp	SCM	280.3	1806.6	28	180.7	King mackerel	KMK	140.5	284.1	44.6	395.1
Shallow serranidae	SSR	234.4	599.8	26	60	Spanish mackerel	SMK	176.4	310.4	34.9	138.3
Deep serranidae	DSR	142.9	173	61.2	239.8	Spanish sardine	SAR	240.3	532.2	4.2	17.7
Red snapper	RSN	182.3	253	75.7	308	Large pelagic fish	LPL	507.9	2118	101.6	423.6
Vermilion snapper	VSN	182.3	253	25.1	271.2	Deep water fish	DWF	29.9	84.4	6	16.9
Lutjanidae	LUT	158.8	721.9	83	316.7	Menhaden	MEN	25	48.8	5.6	33.3
Bioeroding fish	BIO	76.1	288.1	6.9	28.8	Pinfish	PIN	112.3	448.1	9	35.8
Large reef fish	LRF	324.1	807.6	83	316.7	Medium pelagic fish	MPL	281.2	780.6	725.7	1717.2
Small reef fish	SRF	23	39	10.4	33.3	Small pelagic fish	SPL	161.6	457.4	3.6	10.2
Black drum	BDR	823.8	5710.3	56.2	288	Blacktip shark	TIP	366	1247.6	1102.9	3372.8
Red drum	RDR	1861.8	4273.2	28.9	265.3	Benthic feeding sharks	BEN	123.6	1078.6	382.2	2948.5
Seatrout	SEA	272.6	1661.8	30.6	161	Large sharks	LGS	722.8	2679.9	774.8	4367.6
Sciaenidae	SCI	38.5	54.9	90.6	284.4	Filter feeding sharks	FIL	13640.5	112275	2728.1	22455
Ladyfish	LDY	106.8	310.5	21	62.6	Small sharks	SMS	8.1	179.3	2	44.8
Mullets	MUL	36.6	482.7	6.7	85.5	Skates and rays	RAY	74.5	283.4	37.7	220
Pompano	POM	355.5	1792.1	28	180.7	Brown shrimp	BSH	12	13.6	83	316.7
Sheepshead	SHP	216.9	1411.2	21.7	141.1	White shrimp	WSH	12	13.6	83	316.7
Snook	SNK	78.5	272.8	39.3	136.4	Pink shrimp	PSH	12	13.6	83	316.7
Flatfish	FLT	29	34.1	5.8	14.5	Other shrimp	OSH	49.3	67.8	25.1	271.2
Other demersal fish	ODF	8.6	33	35	152.5	Diving birds	DBR	27.9	28.1	9.6	45.4
Small demersal fish	SDF	90	100	11.2	55.6	Surface feeding birds	SBR	27.9	28.1	1.2	23.1
Yellowfin tuna	YTN	1602.9	7588.1	3291.3	5973	Manatee	MAN	31847.3	31852.4	3184.7	3185.2
Bluefin tuna	BTN	10468.7	26929	3493.7	7275	Mysticeti	MYS	577247	608832	57724.7	60883
Little tunny	LTN	163.3	869.3	65.3	347.7	Dolphins and porpoises	DOL	23973.3	53779.6	2397.3	5378
Other tuna	OTN	293.5	931.7	1833.9	2972	Deep diving odontocetae	DDO	13254	18987.6	1325.4	1898.8
Swordfish	SWD	1475.4	5398.2	800	4444	Loggerhead	LOG	3888.6	10430.4	190.2	810.3
White marlin	WMR	774.2	5040.2	154.8	1008	Kemps ridley	KMP	2485.4	5605.2	82.8	376.7
Blue marlin	BMR	774.2	5040.2	1107.9	5381	Other turtles	TUR	10715.6	17958.5	504.5	1282
Other billfish	BIL	1475.4	5398.2	470.6	1195						

Consumption

Atlantis parameter MUM (or g in Equation 7) is the maximum absolute daily production in units $\text{mgN}\cdot\text{d}^{-1}\cdot\text{individual}^{-1}$ that a predator realizes when the encounter rate with prey is high. It represents the maximum consumption rate (i.e., G_{MAX}, the asymptote of the Holling type 2 function response) multiplied by an assimilation efficiency (E in Equation 7) as follows,

$$g = G_{MAX} \cdot E \qquad (16)$$

We estimate G_{MAX}, applying the weight-consumption relationship from Hanson et al. (1997),

$$G_{MAX} = CA \cdot \text{Weight}^{CB} \qquad (17)$$

We used weight estimates from Von Bertalanffy curves (structural + reserve Nitrogen) to obtain maximum consumption for an average individual, and we generalized the constants across functional groups, setting CA = 0.3 and CB = 0.7 after Horne et al. (2010). We considered growth efficiency to be 10% (Pauly and Christensen 1995).

Clearance (C in equation 7) is a measure of feeding efficiency when prey is scarce; it reflects the slope of the predator-prey functional response near the origin. As programmed in Atlantis, clearance is analogous conceptually to the volume of water filtered by filter feeders, although this may be generalized to swept-volume for other predators; its units are therefore $m^3 \cdot mgN^{-1} \cdot d^{-1}$. Initial values were set at 1/10 of MUM after Horne et al. (2010).

MUM and Clearance are provided in Table 8 for vertebrates and Table 9 for invertebrates.

Table 9. Growth (MUM) and clearance (c) for invertebrates.

Group	Code	Clearance	Growth
Bacteria	PB	0.05	0.5
Bivalves	BIV	0.05	0.01
Blue crab	BCR	0.02	0.0015
Carnivorous macrobenthos	CMB	0.2	0.015
Crabs and lobsters	LOB	0.02	0.0015
Crustose coralline algae	CCA	-	0.0001
Epiphytes	EPI	-	2
Herbivorous echinoderms	ECH	0.2	0.0015
Infaunal meiobenthos	INF	0.2	0.06
Jellyfish	JEL	0.02	0.35
Large phytoplankton	LPP	-	1.5
Large zooplankton	LZP	0.2	0.2
Macroalgae	ALG	-	0.1
Microphytobenthos	MPB	-	0.2
Octocorals	OCT	-	0.0001
Oysters	OYS	0.05	0.01
Protists	PRO	0.05	1.5
Sea grass	GRS	-	0.07
Sediment bacteria	BB	0.05	2
Sessile filter feeders	SES	0.05	0.01
Small phytoplankton	SPP	-	1.5
Small zooplankton	SZP	0.2	1.5
Sponges	SPG	0.05	0.01
Squid	SQU	0.1	0.35
Stone crab	SCR	0.02	0.0015
Stony corals	COR	-	0.0001
Toxic dinoflagellates	DIN	0.08	2.5

Catch reconstruction

Historical landings

By Holly Perryman, David Die and Elizabeth Babcock

We use catch time series files within Atlantis to construct the historical model. The catch time series describe the landings of each functional group (in mg sec^{-1}) from 1980 to 2011 within that polygon, thus there is a catch time series file for each polygon in the modeling space (Figure 1). To construct the catch time series files, we collected species-specific landings across the entire Gulf of Mexico; the time series were collated by functional group and then distributed across time and space. The reconstruction of the historical catch was restricted to marine, wild-caught landings. Thus, landings associated with aquaculture or fresh-water species were not considered.

United States

First, commercial and recreational landings time series were collected from Southeast Data, Assessment, and Review (SEDAR) Stock Assessments for single-species, finfish functional groups that had a SEDAR assessment. This includes functional groups: Gag grouper (SEDAR 2006a, 2009b), red grouper (SEDAR 2009c), red snapper (Matter 2009, SEDAR 2013a), vermilion snapper (SEDAR 2006b), greater amberjack (SEDAR 2014), king mackerel (SEDAR 2009a), and blacktip shark (SEDAR 2012). Often, SEDAR landings time series did not span the entire 1980-2011 time frame. To complete the time series for these functional groups, and to develop commercial and recreational time series for the other functional groups, we obtained data from NOAA's Office of Science and Technology Commercial Fisheries Statistics database (NMFS 2011a), NOAA's Office of Science and Technology Recreational Fisheries Statistics database – MRFSS/MRIP (NMFS 2011b), and NOAA's Recreational Billfish Survey (Venizelos 2013). Data gathered from MRFSS/MRIP were supplemented with data from NOAA's Southeast Fisheries Science Center (SEFSC), which provided recreational landings estimates reported from the Texas State Park and Wildlife Department that were adjusted to match the MRFSS/MRIP format.

Commercial landings data provided by NOAA itemize time series by common name. The Integrated Taxonomic Information System (ITIS 2012), FishBase (Froese and Pauly 2014), and SeaLifeBase (Palomares and Pauly 2014) were used to associate species names to the common names. The species-specific time series were grouped based on the Atlantis functional group definitions (Table A.2). Some landing data could not be assigned to a single functional group because it was either associated to a higher taxonomic level than species (e.g., genus *Epinephelus*), or to miscellaneous fish categories (i.e., "finfishes, unc general", "finfishes, unc for food", "finfishes, unc bait and animal food", and "finfishes, marine, ornamental"); these time series data were split across multiple functional groups. For time series identified by a taxonomic level higher than species, landings proportions for the appropriate functional groups were calculated using species-specific landings time series provided by the NOAA dataset. First, species-specific landings corresponding to organisms under the higher taxonomic level were grouped by functional group. In some cases, all of the species-specific time series under the taxonomic level in question happen to be assigned to a single functional group. For example, the landings time series for "puffers" was identified as *Tetraodontidae*. Although *Tetraodontidae* species are in the other demersal fish and small demersal fish functional groups, NOAA only has landings time series for the species categorized to other demersal fish. Thus, the entire "puffers" time series was assigned to the other demersal fish functional group time series. When the species-specific time series corresponded to multiple functional groups, proportions were calculated to split the landings across the functional groups.

Annual proportions of each functional group were calculated across the time domain that spanned each functional group's time series, and from this an average proportion of each functional group was calculated. For example, the landings time series for "groupers" (identified as *Epinephelus*) was partitioned between the functional groups gag grouper, red grouper, shallow serranidae and deep serranidae groups. The time series length differed between each functional group, thus annual proportions were calculated from 1986-2011, corresponding to the time frame encompassed by all of the functional group's time series. From this, average proportions between each of the functional groups were calculated and utilized to distribute the landings data.

Time series identified for miscellaneous fish categories were handled individually. The "finfishes, marine, ornamental" file was assigned to the small reef fish functional group based on information from Larkin et al. (2001). The remaining categories of unidentified landings (i.e., "finfishes, unc general", "finfishes, unc for food", and "finfishes, unc bait and animal food"), were divided amongst the appropriate functional groups using the shrimp trawl species composition provided by Scott-Denton (2011a) adjusted to only consider finfish, because the dominant gear type was shrimp otter trawls.

Recreational landings time series were compiled with estimates from MRFSS/MRIP, SEFSC, and RBS. Vhile the SEFSC and RBS datasets recorded landings time series by numbers, MRFSS/MRIP provided landings time series by weight and by numbers. Data collected from MRFSS/MRIP were primarily landings by weight; however there are some cases where the landings by numbers records provided more detailed than the landings by weight records (e.g., *Strongylura marina*). Thus, when collecting data from MRFSS/MRIP, when the landings by numbers provided more information that the landings by weight we used the landings by numbers. Time series provided by these datasets were itemized by species which allowed for direct allocation into the appropriate functional group. Both MRFSS/MRIP and SEFSC had miscellaneous catch records for unidentified finfish and unidentified sharks. Considering that unidentified finfish categories made up less than 2% of the annual total catch, for both MRFSS/MRIP and SEFSC, we omitted these data from the catch reconstruction. Unidentified sharks catch estimates were incorporated into the LGS functional group. The MRFSS/MRIP and SEFSC datasets started at 1981 and 1983, respectively, but catch reconstruction files begin on 1980. Thus, landings records from the first year of each dataset were used to impute landings for the previous years. Once landings records were compiled into functional groups, landings units needed to be standardized. Time series describing landings by numbers were converted to landings by weight using the length-weight relationship ($W = aL^b$). Parameter estimates of a and b for individual species were collected from FishBase. When FishBase did not provide such estimates, then we used averages across functional groups. If length estimates were not provided by the datasets, then length was estimated using information from either Marancik and Hare (2005), FishBase, or averaging across the functional group (in that order of preference). Table A.5 and Table A.6 display the catch reconstruction for U.S. commercial and recreational landings from the Gulf of Mexico, respectively.

Mexico

Colleagues connected to Mexican fisheries indicated that no data on recreational landings are collected, so they could not be incorporated into the catch reconstruction. Commercial landings data from 1980 to 2011 were obtained from the Comision Nacional de Acuacultura y Pesca - Secretaría de Agricultura Ganadería, Desarrollo Rural Pesca y Alimentación annual assessments (CONAPESCA 1980-2011). The assessments combined landings data for the Gulf of Mexico and the Caribbean Sea, so to ensure that the catch reconstruction is not biased by landings from the Caribbean we used landing records from the states of Tamaulipas, Veracruz, Tabasco, Campeche, and Yucatán. Although some fleets from the state of Quintana Roo harvest in the Gulf of Mexico, the literature does not provide any quantification of spatial use patterns. Thus, landings from Quintana Roo were excluded from the catch reconstruction.

Landings records collected from CONAPESCA were broken down by Mexican common names. In general, FishBase (Froese and Pauly 2014), Salas et al. (2011), and uBio (Norton et al. 2013) were used to discern the species encompassed by the common names, but some groups required additional sources: Sánchez-Ramírez and Ocaña-Luna (2002) for anchoveta, Wakida-Kusunoki and Mackenzie Jr. (2004) for almeja, Bonfil and Babcock (2006) for tiburón and cazón, Williams et al. (Williams et al. 1989) for charal, Sanchez et al. (2000) for cintilla, and García-Carreño and Haard (1993) for langostilla. For Mexican common names associated to multiple functional groups catch compositions were estimated by species descriptions provided by Ginsburg (1930) (pargo), Bonfil and Babcock (2006) (cazón), Carranza (1957) (mero and tortuga), Gracia (1997) (camarón), and FAO (2012) (jaiba). Some records were uniformly distributed across the appropriate functional groups since approximate catch compositions were not found in the literature (i.e., bonito, charal, coronado, corvina, peto, sargo, and sierra).

Miscellaneous landings records from the CONAPESCA time series were compiled into three individual categories: "otras", "otras sin registro official", and "indirecto". Information concerning the species composition for the "otras sin registro official" and "indirecto" categories could not be located, but CONAPESCA (1980-2011) provided a list of Mexican common names making up the "otras" category. Assigning functional groups to these common names using the methods described above showed that, beside turtle groups, the "otras" category consists of all the functional groups currently in the Mexican catch reconstruction as well as billfish functional groups. Before distributing the Miscellaneous landings records across the appropriate functional groups, landings time series for billfish functional groups were incorporated into the Mexican catch reconstruction by gathering landing time series from the Food and Agriculture Organization of the United Nations Fisheries and Aquaculture Department databases (FAO 2012) and subtracting these data from the "otras" category. Then, the remaining "otras" time series, as well as the "otras sin registro official" and "indirecto" time series, were evenly distributed across the functional groups currently in the Mexican catch reconstruction, excluding turtle groups. Table A.7 highlights the final catch reconstruction for Mexican landings from the Gulf of Mexico.

Cuba

Data concerning the recreational landings are lacking in the literature, thus recreational landings were not incorporated into the catch reconstruction. Commercial landings data were collected from the Food and Agriculture Organization of the United Nations Fisheries and Aquaculture Department databases (FAO 2012) and Claro et al. (2001). Both datasets categorized catch by common name, so the Integrated Taxonomic Information System (ITIS 2012), FishBase (Froese and Pauly 2014), and SeaLifeBase (www.sealifebase.org) were used to associate species names to common names.

The data provided by FAO (2012) summarized landings across the entire country, so we extracted data representing landings from the Gulf of Mexico. Claro et al. (2001) partitioned Cuban commercial landings into four regional zones: SE, SW, NW and NE. Ve assumed that the NW region referred to landings extracted from the Gulf of Mexico. The authors did not provide species-specific catch data by region for all of the species highlighted in the FAO catch data, but they did provide regional breakdowns for major categories of finfish: blackfin and skipjack tuna (1980-1994), swordfishes and billfishes (1980-1989), grunts (1980-1994), jacks (1980-1994), lane snapper (1980-1993), mojarras (1980-1994), Nassau grouper (1980-1994), seerfishes (i.e., mackerels) (1980-1994), and sharks (1980-1994). These regional breakdowns were utilized to begin the catch reconstruction for the highlighted species. The category "swordfishes and billfishes" encompasses two functional groups, so this time series was divided between the swordfish and blue marlin functional groups using the average annual catch percentages between swordfish and blue marlin in the FAO data. These time series were completed (i.e., extended to 2011) with FAO data. To extract data representing landings from Gulf of Mexico waters, we used the average

NW regional catch proportion of each species, which were calculated based off of the last 4 years of Claro et al.'s regional breakdowns.

To develop Gulf of Mexico catch time series for the remaining organisms highlighted in the FAO dataset, average catch composition percentages described by Claro et al. (2001) were utilized. The remaining FAO time series were categorized according to the groups of identified by the authors: mollusks, turtles, lobsters, and other finfish. The "lobster" category was treated as a crustacean group. FAO time series for shrimps and sponges were ignored since these landings do not stem from the NW sector of Cuba (Claro et al. 2001, Baisre-Hernandez 2006). The FAO time series for squids was also ignored since there was only one record early in the time series. Data provided by Claro et al. (2001) highlight that, on average, the NW region encompasses 35% of other finfish catch, 14.6% of lobster catch, 36.9% of mollusk catch, and 62.6% of turtle catch. These percentages were utilized to extract time series from the FAO dataset that represent time series of landings from the Gulf of Mexico for the remaining organisms.

The FAO dataset consisted of two records which encompasses multiple functional groups: "seerfishes nei", and "marine fishes nei". According to Claro et al. (2001) seerfish (i.e., mackerels) landings in Cuba are made up of three species: *Scomberomorus regalis*, *Scomberomorus maculatus*, and *Scomberomorus cavalla* (all of which are in individual functional groups). Since we could not find information discussing the catch proportions within the NW sector of Cuba between these three species, the time series for seerfishes was evenly distributed across the three functional groups corresponding to these species. We assumed that landings reported as "marine fishes nei" do not include any of the organisms identified in the FAO dataset. To determine appropriate functional groups to distribute "marine fishes nei" across, the "other fishes" species composition discussed by Claro et al. (2001) was utilized. Species encompassed by "other fishes" yet not itemized in the FAO dataset include: *Lachnolaimus maximus*, *Mycteroperca bonaci*, *Epinephelus guttatus*, *Scaridae* spp., and *Rachycentron canadum*. Since information on the catch proportions within the NW sector of Cuba between these species could not be located, the time series for "marine fishes nei" was evenly distributed across these species, then assigned to the corresponding functional group. Table A.8 shows the final catch reconstruction for Cuban landings from the Gulf of Mexico.

Seasonal distribution of landings

Atlantis divides a year into four seasons for the purposes of species movement: winter (Jan. – Mar.), spring (Apr. – Jun.), summer (Jul. – Sep.), and fall (Oct. – Dec.). Input biomass distributions act as waypoints to control seasonal species movements. We built a seasonal catch matrix to reflect the same temporal patterns and avoid mismatches in fish and fishery concentrations. Not all of the datasets used to build the landings time series files (discussed above) can be subdivided by season across all years. To distribute the constructed landings time series across season, average seasonal distributions were constructed for each functional group for U.S. commercial landings, U.S. recreational landings, Mexican commercial landings, and Cuban commercial landings. After the seasonal landings time series were assigned to the appropriate functional groups, we determined the average seasonal distribution across all years in the data set. Tables A.9, A.10 and A.11 show the seasonal distribution of U.S. commercial catch, U.S. recreational catch, and Mexican commercial catch, respectively.

Average seasonal landing distributions for species caught by U.S. commercial fleets were developed from seasonal landings provided by NOAA (NMFS 2011a; covering a temporal range of 1990-2011) and ICCAT (ICCAT 2012; covering a temporal range of 1980-2011). NOAA seasonal landings encompassed all of the harvested Atlantis functional groups, except bluefin tuna, white marlin, blue marlin, and other billfish. ICCAT data were used to develop average seasonal landings distributions for those functional groups. Data from the ICCAT database were associated to U.S. fleets and covered the extension between 75°-100°N and 15°-35°W. GIS software was used to extract seasonal landings time series reported for our modeling domain. Using the methodology described under **U.S. historical catch,** seasonal landings from NOAA were associated to functional groups. ICCAT provided a list of species composition for common names, which was used to associate the data to functional groups. These time series were also categorized according to Atlantis's seasonal structure. MRFSS/MRIP data (NMFS 2011b) catagorize estimates of U.S. recreational landings into waves: wave 1 (Jan. – Feb.), wave 2 (Mar. – Apr.), wave 3 (May – Jun.), wave 4 (Jul. – Aug.), wave 5 (Sep. – Oct.), and wave 6 (Nov. – Dec.). This information was used to calculate average seasonal distributions for the U.S. recreational landings. After the bimonthly landings time series from MRFSS/MRIP were collated into functional groups, following the methods described under **U.S. historical catch**, the time series were then categorized by the seasonal structure in Atlantis. Odd waves were directly assigned to seasons while even waves were uniformly split between the two corresponding seasons. The seasonal distributions of U.S. recreational landings were averaged across the annual span of the dataset (1981-2011).

To generate average seasonal distributions of functional group landings from Mexican fleets, we utilized time series describing the monthly distributions of landings for individual marine organisms; this information was provided by CONAPESCA (Conapesca 1980-2011; using data 2003-2011) and ICCAT (ICCAT 2012; covering a temporal range of 1980-2011). The SAGARPA dataset encompasses all of the harvested functional groups, except for bluefin tuna, other tuna, swordfish, white marlin, blue marlin, and other billfish. ICCAT was utilized to calculate average seasonal distributions for these functional groups. Data pulled from the ICCAT database were associated to Mexican fleets and covered 75°-100°N and 15°-35°W. GIS software was utilized to extract seasonal landings time series reported for our modeling domain. Both SAGARPA and ICCAT data are itemized by common name, so data records were associated to functional groups using species composition described under **Mexican historical catch** and the ICCAT species list, respectively. Time series from both datasets were then categorized by the seasonal structure in Atlantis. Average seasonal distributions of Mexican commercial landings were calculated for each functional group by averaging across the temporal span of the time series.

Sufficient information describing the seasonal distribution of Cuban commercial landings could not be located in the literature, nor in other datasets. Thus, a uniform distribution was utilized across all functional groups.

Spatial distribution of landings

Seasonal landings time series (Tables A.9, A.10 and A.11) were distributed across space (i.e., Atlantis polygons) using the seasonal biomass distributions of the functional groups (distribution for winter is shown in Figure A.1). The construction of the seasonal biomass distributions are described above under **Biomass distributions**. First, the polygons that make up the region where each of the territorial fleets (i.e., U.S. commercial, U.S. recreational, Mexican commercial, and Cuban commercial) operate within were determined. Commercial landings are harvested from polygons that lie within the appropriate EEZ boundaries (note, all commercial fleets can harvest in international waters at the center of the Gulf, in the area called the 'donut hole'). Polygons within the U.S. EEZ that do not exceed 200 m in depth were designated to contain U.S. recreational harvesting. However, U.S. recreational landings for the functional group crabs and lobsters were restricted to polygons 27 and 28 (SEDAR 2010). Since boundary polygons 0 and 65 are reserved for flux characteristics, they were not included in the spatial distribution of landings.

Landings were only partitioned for the polygons described above; since the seasonal biomass distributions of the functional groups consider the entire polygon grid, they were partitioned in the same manner. Then, for each season and each territorial fleet, seasonal biomass distributions of the functional groups for the polygon subsets were adjusted so the distributions summed to 1. We utilized these adjusted seasonal distributions to allocate the corresponding seasonal landings across the appropriate polygons for U.S. commercial, U.S. recreational, Mexican commercial, and Cuban commercial landings.

Creating catch time series files

Atlantis requires a catch time series file for each polygon in the modeling space (Figure 1). The catch time series files describe the biomass removal due to fisheries within the polygon (mg sec^{-1}) of each functional group from 1980 to 2011. These rates are held constant in the simulations until an event occurs that changes the removal rate(s). As described under **Spatial distribution of landings**, we produced annual time series describing the seasonal landings of the functional groups from each polygon. These data were used to create the catch time series files. We developed an Excel VBA macro; for each polygon, the macro cycled through the annual span of the time series, starting at 1980 and concluding at the end of 2011, and calculated the rate of biomass removal (i.e., converted tonnes $season^{-1}$ to mg sec^{-1}) for each functional group being harvested in that polygon. When an event occurs (i.e., the season and/or year changed), new rates of biomass removal were calculated for each functional group and recorded in the catch time series file.

Fleet distribution of landings

The 2011 catch profiles for U.S commercial (Table A.5), U.S. recreational (Table A.6), Mexican (Table A.7), and Cuban (Table A.8) territories were distributed across their respective fleets. This fleet distribution was then used to create a fisheries mortality matrix for the fisheries input file by developing catch-by-fleet proportions for each territory.

We developed proportions for the U.S. commercial fleets using the 2011 species-specific landings-by-gear data provided by NOAA. Records were associated to the appropriate functional group (as described under **Biomass distributions**) and gear types were assigned to a fleet (Table 10). Records associated to royal red shrimp were assigned to the RoyalRed fleet since it was difficult to empirically divide gears between the shrimp fleets. The proportion of each functional group caught by each fleet was then calculated (Table A.13). This table was altered for the small demersal fish and Spanish sardine functional groups because the above methodology failed to calculate catch-by-fleet proportions for these groups, and both have landings time series. The catch-by-fleet distribution for Spanish sardine was calculated using the 2011 species-specific landings-by-gear data provided by NOAA. Species-specific landings-by-catch data from the 1990's highlight that scuplins – the only small demersal fish species identified – were harvested by unspecified gear. Based on the life history of sculpins, we associated this catch to the estuary trawl fleet. There are only two U.S. recreational fleets, so catch-by-fleet proportions for these fleets were are binomially distributed as determined by expert judgment. The estuary fleet is responsible for all recreational catch for the functional groups black drum, red drum, seatrout, sciaenidae, ladyfish, mullets, pompano, sheepshead, snook, and skates and rays. The shelf fleet is responsible for recreational catch for all other functional groups identified in the U.S. recreational catch. Since we lacked data to calculate proportions for the Mexican fleets, we used expert judgment to determine the fleet(s) that retained each functional group, and developed proportions using the uniform distribution (Table A.14). Cuba has one fleet so all Cuban commercial landings are distributed to that fleet.

To compile the fisheries mortality matrix, first, the catch-by-fleet proportions were used to distribute the 2011 catch, for each territory, across fleets. Second, we calculated the harvestable biomass in the system for each functional group based the 2010 at-age biomass in the system and the age-at-first capture indicated for each functional group. The harvestable biomass is the product of the harvestable portion and the total system 2010 biomass. The fisheries mortality matrix is the product of the harvestable biomass matrix and total catch-by-fleet matrix (Table A.15).

Table 10. NOAA gear-types assigned to Atlantis-GOM fleets.

Gear types identified in the NOAA 2011 species-specific commercial landings data were assigned to modeled fleets. Some gear-types were not assigned to a fleet because the gear type was too ambiguous (e.g., “Combined gears”), or catch associated to the gear was insignificant.

		Atlantis fleets		
GillnetEst	**TwlShpEst**	**OytEst**	**PotCrbEst**	**PotCrbShf**
Entangling nets (gill) unspc	Beam trawls, shrimp butterfly nets	Rakes, other	Brush trap	Pots and traps, fish
Gill nets, drift, runaround	Skimmer net	Dredge other	Pots and traps, crab, blue	Pots and traps, other
Trammel nets		Tongs and grabs, oyster	Pots and traps, crab, other	Pots and traps, shrimp
Gill nets, stake		Tongs and grabs, other	Pots and traps, eel	
Gill nets, sink/anchor, other				
PotLbtShf	**TwlShpShf**	**HLReefShf**	**LLReefShf**	**SeineMenShf**
Pots and traps, spiny lobster	Otter trawl bottom, shrimp	Reel, electric or hydraulic	Lines long, reef fish	Encircling nets (purse)
	Otter trawl bottom, fish	Rod and Reel	Lines trot with baits	Purse seines, other
	Otter trawl bottom, scallop	Lines hand, other		Purse seines, menhaden
	Trawls, unspecified	Lines long, vertical		
LLShkShf	**LLPelgc**	**RoyalRed**	**OtherUS**	***Not Assigned***
Lines long, shark	Lines troll, other	Otter trawl bottom, shrimp	By hand, other	Not coded
	Lines long set with hooks	Skimmer net	By hand, oyster	Combined gears
	Lines long drift with hooks		Cast nets	Unspecified gear
			Diving outfits, other	Troll & hand lines cmb
			Dip nets, drop	Pots and traps, crayfsh(frhwa)
			Dip nets, common	Slat traps (Virginia)
			Fyke and hoop nets, fish	Forks
			Haul seines, beach	
			Haul seines, long	
			Hooks, sponge	
			Lampara & ring nets, other	
			Spears	

Fleet development

By Holly Perryman, David Die, and Elizabeth Babcock

Fleet structure

We used the list of fleets developed by Walters et al. (2008) for their Ecopath Gulf of Mexico model as a starting point the fleets in the Atlantis-GOM model. However, this Ecopath model only represented the US Gulf of Mexico coastal areas, so we also had to define fleets for deeper areas in the US shelf, the shelves of Mexico, the northern part of Cuba, and pelagic fleets that operate offshore of the continental shelf. Once we had a list of the main fleets, we defined the areas (horizontal and vertical compartments of the model polygons) where each fleet operated. The third step was to assign which functional groups each fleet harvested or impacted. Ideally this process should be done on the basis of detailed information on the spatial distribution of fishing effort and species composition (including bycatch) of each fleet. Because such data were not always available, we had to make some simplifying assumptions:

- Fleets operate only within each country's EEZ – This assumption is likely to be generally true, because there is no agreement for foreign fishing in the Gulf of Mexico and because the only international waters within the Gulf are constituted by a small triangle where all countries are allowed to fish in the model.
- Fleets with no detailed spatial information on fishing effort operated in all compartments where the known habitat supporting the target species was present (e.g. pelagic longline fleets operated in all areas offshore of the continental shelf and on the shallowest vertical strata; estuarine fleets only within estuarine coastal areas).
- In the absence of detailed information on bycatch, we used gear characteristics to define the functional groups that are harvested, retained, or discarded. Given knowledge on gear characteristics, references from the literature on fisheries using similar gear in areas similar to the Gulf of Mexico were used to define which functional groups are impacted.

The following sections briefly describe each of the fleets in the Atlantis-GOM model:

United States fleets

1. U.S. estuary recreational fleet

Recreational fleet that harvests in estuarine and inshore waters. The primary targets include demersal fish (i.e., Black drum, red drum, seatrout, sciaenidae, ladyfish, mullets, pompano, sheepshead, snook, flatfish, and other demersal fish). This fleet may also retain various shark species (i.e., Blacktip shark, large sharks). This fleet includes all modes/gears of recreational fishing (e.g., charter boats, private boats, diving, etc.). The most common gear is a rod and reel; other types of handlines are also frequently used.

2. U.S. estuary gillnet fleet

Gillnet fleet that targets fish in estuarine and inshore waters along the U.S. coast. Gillnets are not allowed in Florida waters. The primary target species are demersal finfish (i.e., Black drum, red drum, seatrout, sciaenidae, ladyfish, mullets, pompano, sheepshead, snook, flatfish, and other demersal fish groups).

3. U.S. estuary trap and trawl fleet

Fixed trap nets and shrimp trawling within estuarine and inshore waters along the U.S. coast. The primary targets include brown shrimp and white shrimp; however, there are many other functional groups that are caught as bycatch.

4. U.S. estuary oyster fleet

Oyster fishery within estuary and inshore waters along the U.S. coast. The oyster fishery is highly selective (i.e., oyster functional group), thus, the fleet has low bycatch of other functional groups.

5. U.S. estuary pot fleet

Pot fishing within estuary and inshore waters along the U.S. coast. Although there are various functional groups that can be retained as bycatch, the primary target for this fleet is blue crab

6. U.S. shelf recreational fleet

Recreational fleet that operates in offshore waters. The primary targets are a mixture of reef and demersal fish on the shelf (e.g., gag grouper, red grouper, scamp, shallow serranidae, deep serranidae, red snapper, vermilion snapper, lutjanidae, black drum, red drum, and other demersal fish) as well as pelagic and forage fish on the slope (e.g., yellowfin tuna, bluefin tuna, swordfish, white marlin, blue marlin, other billfish, greater amberjack, jacks, king mackerel, Spanish mackerel and large pelagic fish. This fleet may also retain various shark species (i.e., blacktip shark and large sharks). This fleet includes all modes/gears of recreational fishing (e.g., charter boats and private boats). The primary gear used is rod and reel.

7. U.S. shelf trawl fleet

Otter trawls that target shrimp in the shallow and mid-shelf waters along the U.S. coast. The primary target functional groups include brown shrimp west of Florida and pink shrimp in the Dry Tortugas. In addition, there are many other functional groups that are caught as bycatch, including other shrimp and Sciaenidae.

8. U.S. shelf crab pot fleet

Pot fishing within offshore waters along the U.S. coast. Although there are various functional groups that can be retained as bycatch, the primary target for this fleet is the blue crab functional group except for the southwest Florida shelf where the target is stone crab. Pots used are wire traps for blue crab and darker, wooden traps for stone crab.

9. U.S. shelf lobster pot fleet

Pot fishing within offshore waters along the U.S. coast. Although there are various functional groups that can be retained as bycatch, the primary target for this fleet is the crabs and lobsters group. Pots used are a mixture of wire and wooden traps. The majority of the fishery is in the southwest corner of the Florida shelf and the Florida Keys.

10. U.S. handline fleet

Handline operating throughout inshore and shelf waters along the U.S. coast. The primary targets include various reef fish functional groups (gag grouper, red grouper, scamp, shallow serranidae, deep serranidae, red snapper, vermilion snapper, and lutjanidae) as well as some coastal pelagic stocks (jacks and king mackerel). The primary gear is a handline, operated either manually or with an electric reel.

11. U.S. shelf longline fleet (reef fish)

Longline fleet operating throughout inshore and shelf waters along the U.S. coast. The primary targets include various reef fish functional groups (gag grouper, red grouper, scamp, shallow serranidae, deep serranidae, red snapper, vermilion snapper, and lutjanidae). In areas of the Florida shelf, this fleet is restricted to the deeper areas of the shelf to avoid interactions with sea turtles. Many other species are caught as bycatch, including sharks, but most of these are all discarded. The longlines are demersal and weighted to lie on the bottom.

12. U.S. shelf longline fleet (sharks)

Longline fleet that operates throughout shelf and offshore waters along the U.S. coast. The primary targets include various elasmobranch groups (blacktip shark, large sharks, skates and rays) and is somewhat distinct from the reef fish fishery because many of the targeted reef fish have strict quotas as a result of existing regulations. The bycatch also includes reef fish.

13. U.S. seine fleet

Seine fishing within U.S. waters. The primary target for this fleet includes the menhaden functional group and this fleet only operates in a restricted area of the central Gulf off Louisiana. This fishery has very little bycatch. The only gear used is purse seine, and vessels use spotter planes to locate menhaden schools.

14. U.S. pelagic longline fleet

Longline fleet operating throughout offshore waters within the U.S. The primary targets include various pelagic species (yellowfin tuna, bluefin tuna, little tunny, other tuna, swordfish, white marlin, blue marlin, other billfish, greater amberjack, jacks, king mackerel, Spanish mackerel). There are many species caught as bycatch, a large proportion have to be released under existing regulations.

15. U.S. royal red fleet

Fishery targeting royal red shrimp in deep areas of the shelf within U.S. waters. Vessels fish in deep areas of the central Gulf of Mexico shelf and use the same gear and vessels as the fleet targeting white and brown shrimp groups in the shallower areas of the shelf. There are many species caught as bycatch.

Mexican fleets

16. Mexico reef longline fleet

The fleet targets a similar complex of species as those targeted by the equivalent US Fleet (red grouper, shallow serranidae, deep serranidae, red snapper, vermilion snapper, and lutjanidae functional groups) and operates also with demersal longlines.

17. Mexico pelagic longline fleet

The fleet targets a similar complex of species as those targeted by the equivalent US Fleet (yellowfin tuna, bluefin tuna, little tunny, other tuna, swordfish, white marlin, blue marlin, other billfish, greater amberjack, jacks, king mackerel, and Spanish mackerel functional groups) and operates also with surface longlines.

18. Mexico gillnet fleet

Primarily targets pelagic species (king mackerel, Spanish mackerel, and large pelagic fish) and operates drifting gillnets offshore and fixed gillnets inshore.

19. Mexico octopus fleet

Operates mainly in the Gulf of Campeche and north of Yucatan and targets octopus (carnivorous macrobenthos group) with pots and has practically no bycatch.

20. Mexico miscellaneous fleet

There are a number of small artisanal vessels that fish with a variety gear in coastal areas of Mexico. They mostly target a mixture of coastal finfish for the local market.

Cuban fleet

The Cuban fleet is mostly small scale targeting reef fish in the shelf and pelagic fish in the areas next to the coast off the shelf.

Model tuning and diagnostics

By Cameron Ainsworth, Michael Drexler, Michelle Masi, Holly Perryman, Lindsey Dornberger, and Hem Nalini Morzaria-Luna

Historical reconstruction (1980 to 2012)

We developed a historical model of 1980, based on the 2012 model, by changing biomasses in proportion to the observed changes in relative biomass such as CPUE (see Table 5 and Figure B.1). The 1980 model was driven forward to 2010 using time series inputs representing catch trends, seasonal fishing closures, and spatial fishing closures. Dynamics were tuned to correspond to assembled relative abundance time series (Figure B.1). The tuned dynamic life history parameters can be used to force any forward-looking simulations using the 2010 model if we assume stationarity in dynamic rates (after Ainsworth et al. 2008). The main tuning parameters used to modify historical model behavior were availabilities, Beverton-Holt recruitment parameters (Table 2), clearance (consumption rates) and MUM (growth rates) (Table 7).

The effects of spatial closures associated with various marine protected areas within the Gulf of Mexico (Figure 6; Table A.15) were included in the historical reconstruction. Several efforts have been made to synthesize a complete record of marine protected areas in the Gulf of Mexico although a comprehensive document spanning the U.S., Mexico, and Cuba does not currently exist. These efforts include spatially referenced databases (www.mpa.gov, www.unep-wcmc.org, Frick 2011) and several manuscripts (Yáñez-Arancibia et al. 1999, Beck and Odaya 2001, Coleman et al. 2004).

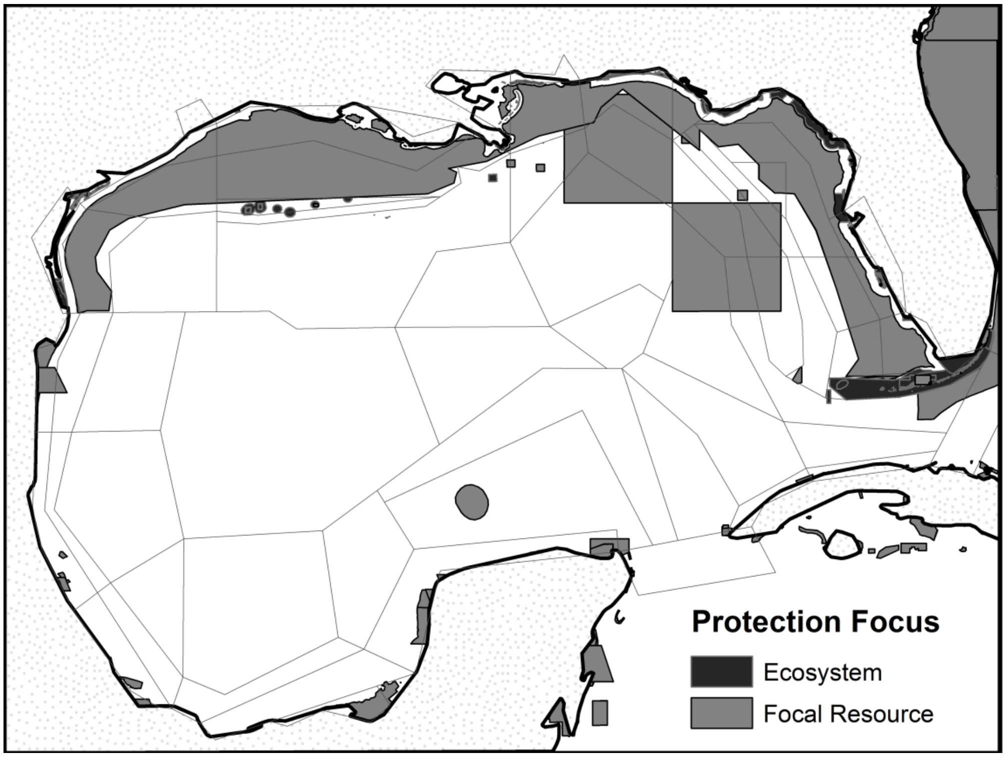

Figure 6. Spatial fishing closures.

See Table A.15 for description.

In addition to these large closures, the MPA spatial databases listed hundreds of additional MPAs within the Gulf of Mexico. The size, scope, and restrictions of each individual MPA varied widely. A merged GIS layer was created from the MPAs listed in each database from Cuba, Mexico, and the USA. The proportion of each Atlantis-GOM polygon affected by each MPA listing was calculated. The year of implementation and any seasonality associated with these restrictions were also included.

When data pertaining to fisheries restrictions were not included in the database, a basic internet search was performed. A typical search for supplemental data included official local, state, and national park websites, fisheries management agency websites, Google scholar searches by MPA name, as well as fishing and travel blogs. Only a small portion of those MPAs included in the previously mentioned databases had specific restrictions on fishing. For example, areas such as national wildlife refuges, and state and local parks did not have any specific restrictions beyond their respective state and national regulations. MPAs with site specific management plans that restrict fishing in a few small localities were not considered due to their scale.

The resulting list of 24 spatial fisheries closures, the date enacted, seasonality, and the boxes affected are listed in Table A.15. These MPAs were thus included in the historical reconstructions in the Atlantis-GOM simulations. For a given MPA, fishing effort was restricted within an effected polygon by reducing fishing effort directly proportional to the total area of each polygon affected by the MPA's spatial footprint. There reductions were toggled on an off during the specific day of year specified by each MPA regulation.

Time series relative abundance

Biomass time series were assembled from stock assessment, from literature, and from an earlier modeling effort (Gray 2014). The historical observations can be seen in Figure B.1. Data sources are provided as follows in Table 11.

Table 11. Source data for historical relative abundance indices used for model fitting.

Group	Code	Source
Gag grouper	GAG	SEDAR 2014
Red grouper	RGR	Saul 2006
Scamp	SCM	Gray 2014
Shallow serranidae	SSR	Gray 2014
Deep serranidae	DSR	SEDAR 2011
Red snapper	RSN	SEDAR 2013a
Vermilion snapper	VSN	SEDAR 2006b
Lutjanidae	LUT	Gray 2014
Bioeroding fish	BIO	Gray 2014
Large reef fish	LRF	Gray 2014
Small reef fish	SRF	Gray 2014
Black drum	BDR	Gray 2014
Red drum	RDR	Porch 2000
Seatrout	SEA	Gray 2014
Sciaenidae	SCI	Gray 2014
Ladyfish	LDY	Gray 2014
Mullets	MUL	Gray 2014
Yellowfin tuna	YTNul	Gray 2014
Bluefin tuna	BTN	Gray 2014
Greater amberjack	AMB	SEDAR 2014
Jacks	JCK	Gray 2014
King mackerel	KMK	SEDAR 2009a
Spanish mackerel	SMK	SEDAR 2013b
Large pelagic fish	LPL	Gray 2014
Menhaden	MEN	SEDAR 2013c
Small pelagic fish	SPL	Gray 2014
Blacktip shark	TIP	SEDAR 2012
Large sharks	LGS	Gray 2014
Skates and rays	RAY	Gray 2014
Brown shrimp	BSH	Hart 2012
White shrimp	WSH	Hart 2012
Diving birds	DBR	Gray 2014
Surface feeding birds	SBR	Gray 2014
Dolphins and porpoises	DOL	Gray 2014
Blue crab	BCR	Gray 2014

Results

Historical reconstruction 1980 to 2010

Reconstruction of the historical ecosystem dynamics from 1980 to 2010 in the Gulf of Mexico is useful both as a diagnostic method for model tuning and as a learning exercise to help us understand what forces have shaped the ecosystem. The historical simulation is presented in Figure B.1. This simulation uses the following drivers: historical catch trends, historical and seasonal/spatial fishing regulations, and seasonal hydrodynamics. Model dynamics from 1990 to 2010 show a reasonable fit to the historical data for most of the major exploited species for which we have time series relative abundance observations available. Since the first 10 years of the historic simulation (1980-1990) show instability, typical for the burn-in period, only dynamics from 1990 to 2010 are presented. Instabilities occur as the model adjusts to a stable spatial and age-structure equilibria at run time.

Most functional groups (68%) fall within one order of magnitude of their 2010 target values (Figure 7). Greater amberjack, carnivorous macrobenthos, blue crab, other turtles and large sharks show steeper declines than expected, while four species, lutjanidae, mullets, pink shrimp and white shrimp go extinct in the historical reconstruction. Carnivorous macrobenthos pink shrimp, white shrimp, and mullets also experience large decreases in the No fishing scenario (below, Figure B.2), suggesting the problem is not related to fishing but to overpredation, reduced productivity or both. In the case of the other declining groups, the problem is limited to the historical reconstruction, probably related to fishery effects or trophic interactions resulting from fishing. Other groups show agreement with observational data to varying degrees but are stable in biomass, numbers, and individual weight. No groups show run-away growth. Variations on input parameters are often able to avert declines to the detriment of other groups. The run we have presented is a good overall compromise where extinctions are minimized. Incongruences tend to be caused by excessive predation mortality, so further efforts to tune the model will focus on availabilities and consumption rates.

Although Figure A.1 shows initial winter biomass distributions for the functional groups, these distributions are expected to change dynamically during simulations as a result of the combination of seasonal migrations, and organism's tendency to occupy suitable habitat, maximize feeding and minimize predation risk. Changes in biomass distribution are a reflection of how well the model simulates local habitat and predator-prey interactions. If the final distribution is very different from initialization, it could indicate that local conditions in each polygon cannot sustain the expected distribution. Figure B.3 shows the ratio between the final and the initial functional group distribution ($t \cdot km^2$) for the historical simulation. The figures show the summed biomass across depth layers. This figure shows that for most functional groups final biomass decreased across polygon cells relative to initial values; final biomass is 25% or less than initial conditions. Basal groups such as sea grass, macroalgae, sessile filter feeders, oysters, and epiphytes maintain a ratio 1-5 times relative to initial values. Significant increases in per polygon biomass are seen in groups including other tuna, red snapper, stone crab, and gag grouper; these increases are often observed in coastal areas.

No fishing scenario 1980-2012

Biomass and abundance

Figure B.2 provides a further test of model behavior for selected exploited species. We present a comparison of biomass dynamics for a 1980-2012 historical reconstruction and an alternative history where fishing is eliminated in 1980. In heavily exploited pelagic groups, such as bluefin tuna, blue marlin, other billfish, greater amberjack, and king mackerel, there is a marked difference between these scenarios, where no fishing results in an increase or maintenance in biomass while the historical trajectories with fisheries show a decrease in biomass. In contrast, species whose harvests have been restricted since the 1980s and whose biomass observations have indicated an increase (like gag grouper, red grouper and red snapper) show a rebuilding of biomass in both scenarios, though typically the rebuilding is faster or more complete in the no-fishing scenario. However, there are also examples of groups where the scenario that includes fishing results in higher overall biomass than the scenario in which there is no fishing, including snook, flatfish, and jacks. This is a result of unintuitive trophic dynamics where predators or competitors of these groups are heavily impacted by fishing, and thus fisheries produce a net decrease in total mortality. Numbers in the adult stanzas of some vertebrate groups (Figure B.4), i.e. jacks, ladyfish, large sharks, red drum, other tuna, decline despite an abundance of juvenile individuals; additional tuning is necessary to reduce the high rates of adult mortality.

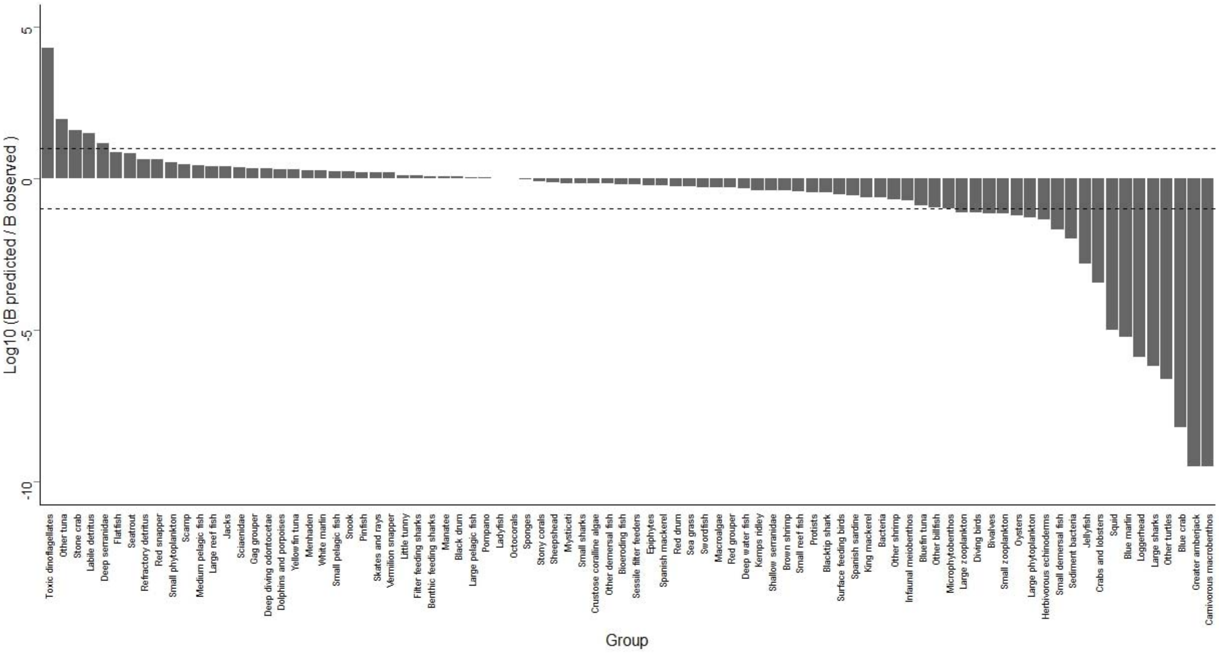

Figure 7. Predicted versus observed biomass in the 1980-2010 historical simulation.

Under the historical simulation the model was driven forward to 2010. The resulting species biomass vector (predicted) is compared to biomass in 2010 derived from historical data. For 68% of functional groups, the predicted biomasses are within one order of magnitude (dashed horizontal lines).

Individual weight-at-age

The ratio of reserve nitrogen (Figure B.5) and structural nitrogen (Figure B.6) per individual are within an acceptable range for most functional groups and age classes. Reserve nitrogen represents muscle, fats, gonads and other soft tissue. For vertebrates, a ratio of 0.5-1.5 relative to initial values is considered optimum and a lower ratio indicates starvation, which can be attributed to a variety of causes such as low prey abundance, low consumption rates defined as clearance and prey availability parameters, and restrictive gape limitation. A reserve nitrogen ratio beyond 1.5 indicates overconsumption. Structural nitrogen, composed of bones and other hard parts, is less sensitive to the effects of starvation. Several vertebrate groups including diving birds, deep serranidae, deep water fish, flatfish, jacks, ladyfish, large reef fish, lutjanidae, menhaden, mullets, pompano, sciaenidae, seatrout, shallow serranidae, surface feeding birds, and vermilion snapper exhibit moderate overconsumption. Meanwhile, greater amberjack, king mackerel, and Spanish sardine show mild starvation. Further tuning of assimilation efficiencies and individual growth rates is needed to solve these problems.

Forward projections 2012 to 2032

Equilibrium scenarios

Figures B.7 and B.8 show the standing biomass and annual catches obtained from the present-day (2010) model after a run-time of 25 years for selected reef associated and pelagic fish, respectively. The plots show the long term near-equilibrium positions, but values are approximate as there was no strict criterion in place for whether equilibrium had been achieved. In all cases, fluctuations in biomass and catch rates were present at least due to the inclusion of seasonal hydrodynamics. Discontinuities in the curves arise from trophic interactions. For convenience, fishing mortalities have been incremented on all exploited groups simultaneously. Thus, the independent variable represents increases in fishing mortalities across many species. This would lead to some divergence from the equilibrium positions predicted from an equivalent single-species model such as a dynamic pool model. Discontinuities in the curves may reflect confounding effects of changing fishing mortalities on all groups, or more generally the presence of trophic interactions.

However, plots are informative as they demonstrate the level of productivity of stocks in relation to a standard sustained exploitation rate, the fishing mortality rate in 2010 (F_{2010}). The left most side of the plots indicates the virgin (unexploited) biomass of the stock. The rightmost side of the plot indicates the standing biomass and catch rate resulting from an increase in fishing mortality to a level twice that of 2010. In many cases, the catch curve takes on a parabolic shape, where the height of the parabola indicates the multispecies maximum sustainable yield (MSY) from the stock and the fishing mortality that produces that yield indicates the multispecies F_{MSY}.

Discussion

By Cameron H. Ainsworth, Michael J. Schirripa and Hem Nalini Morzaria-Luna

Model application in Integrated Ecosystem Assessment

Our objective in this technical report was to describe the development of the Atlantis GOM framework and the parametrization of the biological and fisheries submodels to serve as a resource for future studies. Model-building within the Atlantis framework serves as a way to generate hypotheses about how the ecosystem functions (Brand et al. 2007). The model may be useful for testing management scenarios related to changes in fishing effort, gears, spatial closures, scenarios of the impact of climate change (i.e. warming, acidification), effects of nutrient and sediment inputs, harmful algal blooms, oil spills and other applications. The development of the GOM Atlantis model has helped to compile existing information on the biophysical dynamics in the Gulf of Mexico and to generate additional data to fill existing gaps. The results from the historical and no fishing simulation show that the model can appropriately simulate dynamics for most functional groups. Some deviation from historical estimates derived from stock assessments are expected since these are single-species models that lack the spatial complexity and trophic interactions existing in Atlantis (Horne et al. 2010). While no model will perfectly replicate ecosystem processes observed in natural systems, we believe that the Atlantis GOM model adequately represents ecosystem dynamics. Some groups (i.e. lutjanidae, mullets, pink shrimp, and white shrimp) still require additional tuning such that these groups can persist under historical fishing pressure. Further calibration will be needed to correct issues such as overconsumption in fish groups and to reduce the high rates of adult mortality in other groups.

This Atlantis model of the Gulf of Mexico joins five other North American models, all prepared by NOAA: the California Current (ECCAL: (Brand et al. 2007) and the expanded California Current (I. Kaplan, unpublished), the Northeast U.S. (NEUS: (Link et al. 2010), the Gulf of California (Ainsworth et al. 2010), and Chesapeake Bay (T. Idhe, unpublished); as well as a model for Guam (Weijerman et al. 2014). The development of the Atlantis model for the Gulf of Mexico was driven by the need for tools that help assess the ecological impacts of human actions and the efficacy of alternate management actions within the Integrated Ecosystem Assessment framework. The Gulf of Mexico is a Large Marine Ecosystem that should be used, analyzed, and protected sustainably, while optimizing the environmental and economic returns; thus an integrated perspective that considers the interactions that govern primary productivity, water and habitat quality, and fishery yield in the Gulf of Mexico is needed (Yáñez-Arancibia and Day 2005).

Ecosystem based management is now central in efforts to rebuild and manage marine ecosystems (Levin et al. 2009). Integrated Ecosystem Assessments were designed as a framework for organizing science in order to guide and support the EBFM approach (Levin et al. 2013). Ecosystem models can be used in the different stages of the IEA process, which are scoping, indicator development, risk analysis, management strategy evaluation, and ecosystem assessment (e.g., Marshall et al. 2012). As discussed by (Levin et al. 2009, 2013), in the indicator development stage where indicators of ecosystem state are identified and validated, ecosystem models can serve to evaluate indicator performance, and point to which indicators are more cost-effective and informative to monitor In the risk analysis stage, ecosystem models can help assess changes in indicators in response to changes in athropogenic pressures and to quantify the status of the ecosystem relative to historical conditions and future targets. During the management strategy evaluation phase, ecosystem modelling frameworks may help evaluate how different managemement scenarios and decision rules affect the selected indicators. The GOM Atlantis model is currently being used in a MSE procedure (Masi, M. and Ainsworth, C. unpublished manuscript) to evaluate harvest control rules for pelagic fisheries in the GOM. Use of the GOM Atlantis model in this application has helped spur refinement and updating of the MSE routine which will benefit projects at NMFS and elsewhere. Another project is using the GOM Atlantis model to evaluate oil spill effects (Dornberger, L and Ainsworth, C. in prep).

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Appendix A – Model information

Table A.1. Functional groups in the Atlantis Gulf of Mexico model.

	Category	Functional group		Code	Category	Functional group	Code
1	Reef fish	Gag grouper	46	GAG		Filter feeding sharks	FIL
2		Red grouper	47	RGR		Small sharks	SMS
3		Scamp	48	SCM		Skates and rays	RAY
4		Shallow serranidae	49	SSR	Shrimp	Brown shrimp	BSH
5		Deep serranidae	50	DSR		White shrimp	WSH
6		Red snapper	51	RSN		Pink shrimp	PSH
7		Vermilion snapper	52	VSN		Other shrimp	OSH
8		Lutjanidae	53	LUT	Seabirds	Diving birds	DBR
9		Bioeroding fish	54	BIO		Surface feeding birds	SBR
10		Large reef fish	55	LRF	Mammals	Manatee	MAN
11		Small reef fish	56	SRF		Mysticeti	MYS
12	Demersal fish	Black drum	57	BDR		Dolphins and porpoises	DOL
13		Red drum	58	RDR		Deep diving odontocetae	DDO
14		Seatrout	59	SEA	Turtles	Loggerhead	LOG
15		Sciaenidae	60	SCI		Kemps ridley	KMP
16		Ladyfish	61	LDY		Other turtles	TUR
17		Mullets	62	MUL	Structural species	Stony corals	COR
18		Pompano	63	POM		Crustose coralline algae	CCA
19		Sheepshead	64	SHP		Octocorals	OCT
20		Snook	65	SNK		Sponges	SPG
21		Flatfish	66	FLT	Macrobenthos	Blue crab	BCR
22		Other demersal fish	67	ODF		Stone crab	SCR
23		Small demersal fish	68	SDF		Crabs and lobsters	LOB
24	Pelagic fish	Yellowfin tuna	69	YTN		Carnivorous macrobenthos	CMB
25		Bluefin tuna	70	BTN		Infaunal meiobenthos	INF
26		Little tunny	71	LTN		Herbivorous echinoderms	ECH
27		Other tuna	72	OTN	Filter feeders	Oysters	OYS
28		Swordfish	73	SWD		Bivalves	BIV
29		White marlin	74	WMR		Sessile filter feeders	SES
30		Blue marlin	75	BMR	Primary producers	Epiphytes	EPI
31		Other billfish	76	BIL		Sea grass	GRS
32		Greater amberjack	77	AMB		Macroalgae	ALG
33		Jacks	78	JCK		Microphytobenthos	MPB
34		King mackerel	79	KMK		Large phytoplankton	LPP
35		Spanish mackerel	80	SMK		Small phytoplankton	SPP
36		Spanish sardine	81	SAR		Toxic dinoflagellates	DIN
37		Large pelagic fish	82	LPL		Protists	PRO
38		Deep water fish	83	DWF	Pelagic invertebrates	Jellyfish	JEL
39	Forage	Menhaden	84	MEN		Squid	SQU
40		Pinfish	85	PIN		Large zooplankton	LZP
41		Medium pelagic fish	86	MPL		Small zooplankton	SZP
42		Small pelagic fish	87	SPL	Nutrient cycle	Bacteria	PB
43	Elasmobranchs	Blacktip shark	88	TIP		Carrion detritus	DC
44		Benthic feeding sharks	89	BEN		Labile detritus	DL
45		Large sharks	90	LGS		Refractory detritus	DR

Table A.2. Functional group species composition.

- **Gag grouper (GAG) - 1**
  - *Mycteroperca microlepis*
- **Red grouper (RGR) - 1**
  - *Epinephelus morio*
- **Scamp (SCM) - 1**
  - *Mycteroperca phenax*
- **Shallow serranidae (SSR) - 29**
  - *Alphestes afer*
  - *Bathyanthias cubensis*
  - *Centropristis philadelphica*
  - *Cephalopholis cruentata*
  - *Cephalopholis fulva*
  - *Dermatolepis inermis*
  - *Diplectrum bivittatum*
  - *Diplectrum formosum*
  - *Epinephelus adscensionis*
  - *Epinephelus guttatus*
  - *Epinephelus itajara*
  - *Epinephelus striatus*
  - *Gonioplectrus hispanus*
  - *Hypoplectrus puella*
  - *Hypoplectrus unicolor*
  - *Mycteroperca acutirostris*
  - *Mycteroperca bonaci*
  - *Mycteroperca interstitialis*
  - *Mycteroperca tigris*
  - *Mycteroperca venenosa*
  - *Paranthias furcifer*
  - *Pronotogrammus eos*
  - *Pronotogrammus martinicensis*
  - *Schultzea beta*
  - *Serraniculus pumilio*
  - *Serranus atrobranchus*
  - *Serranus notospilus*
  - *Serranus phoebe*
  - *Serranus subligarius*
- **Deep serranidae (DSR) - 15**
  - *Bathyanthias mexicanus*
  - *Hyporthodus flavolimbatus*
  - *Hyporthodus mystacinus*
  - *Hyporthodus nigritus*
  - *Hyporthodus niveatus*
  - *Centropristis ocyurus*
  - *Centropristis striata*
  - *Epinephelus drummondhayi*
  - *Epinephelus flavolimbatus*
  - *Epinephelus mystacinus*
  - *Epinephelus nigritus*
  - *Epinephelus niveatus*
  - *Hemanthias leptus*
  - *Hemanthias vivanus*
  - *Rypticus maculatus*
- **Red snapper (RSN) - 1**
  - *Lutjanus campechanus*
- **Vermilion snapper (VSN) - 1**
  - *Rhomboplites aurorubens*
- **Lutjanidae (LUT) - 12**
  - *Etelis oculatus*
  - *Lutjanus analis*
  - *Lutjanus apodus*
  - *Lutjanus buccanella*
  - *Lutjanus cyanopterus*
  - *Lutjanus griseus*
  - *Lutjanus jocu*
  - *Lutjanus mahogoni*
  - *Lutjanus synagris*
  - *Lutjanus vivanus*
  - *Ocyurus chrysurus*
  - *Pristipomoides aquilonaris*
- **Bioeroding fish (BIO) - 7**
  - *Nicholsina usta usta*
  - *Scarus iseri*
  - *Scarus taeniopterus*
  - *Sparisoma aurofrenatum*
  - *Sparisoma chrysopterum*
  - *Sparisoma radians*
  - *Sparisoma viride*
- **Large reef fish (LRF) - 92**
  - *Acanthurus bahianus*
  - *Acanthurus chirurgus*
  - *Acanthurus coeruleus*
  - *Acanthurus randalli*
  - *Albula vulpes*
  - *Balistes capriscus*
  - *Balistes vetula*
  - *Canthidermis maculata*
  - *Canthidermis sufflamen*
  - *Chlopsis bicolor*
  - *Kaupichthys hyoproroides*
  - *Kaupichthys nuchalis*
  - *Chilorhinus suensonii*
  - *Ariosoma balearicum*
  - *Bathycongrus bullisi*
  - *Bathycongrus dubius*
  - *Bathycongrus vicinalis*
  - *Conger oceanicus*
  - *Gnathophis bathytopos*
  - *Gnathophis bracheatopos*
  - *Paraconger caudilimbatus*
  - *Pseudophichthys splendens*
  - *Rhynchoconger flavus*
  - *Rhynchoconger gracilior*
  - *Uroconger syringinus*
  - *Xenomystax congroides*
  - *Halichoeres burekae*
  - *Bodianus pulchellus*
  - *Bodianus rufus*
  - *Clepticus parrae*
  - *Decodon puellaris*
  - *Halichoeres bathyphilus*
  - *Halichoeres bivittatus*
  - *Halichoeres caudalis*
  - *Halichoeres garnoti*
  - *Halichoeres maculipinna*
  - *Halichoeres poeyi*
  - *Halichoeres radiatus*
  - *Lachnolaimus maximus*
  - *Thalassoma bifasciatum*
  - *Xyrichtys novacula*
  - *Xyrichtys splendens*
  - *Lobotes surinamensis*
  - *Avocettina infans*
  - *Nemichthys scolopaceus*
  - *Ahlia egmontis*
  - *Aplatophis chauliodus*
  - *Aprognathodon platyventris*

Table A.2 (cont.)

Bascanichthys bascanium
Bascanichthys scuticaris
Callechelys guineensis
Callechelys muraena
Callechelys springeri
Echiophis intertinctus
Echiophis punctifer
Ethadophis akkistikos
Gordiichthys irretitus
Letharchus velifer
Myrichthys breviceps
Myrophis punctatus
Ophichthus gomesii
Ophichthus puncticeps
Ophichthus rex
Bassogigas gillii
Brotula barbata
Brotulotaenia brevicauda
Dicrolene kanazawai
Lamprogrammus niger
Lepophidium brevibarbe
Lepophidium jeannae
Lepophidium profundorum
Lepophidium staurophor
Luciobrotula corethromycter
Monomitopus agassizii
Monomitopus magnus
Neobythites elongatus
Neobythites gilli
Neobythites marginatus
Neobythites unicolor
Ophidion beani
Ophidion grayi
Ophidion holbrookii
Ophidion josephi
Ophidion welshi
Porogadus catena
Porogadus miles
Xyelacyba myersi
Regalecus glesne
Trachyscorpia cristulata cristulata
Aphanopus intermedius
Benthodesmus tenuis
Trichiurus lepturus

Small reef fish (SRF) - 156

Apogon affinis
Apogon aurolineatus
Apogon binotatus
Apogon maculatus
Apogon pseudomaculatus
Apogon townsendi
Astrapogon alutus
Phaeoptyx conklini
Phaeoptyx pigmentaria
Phaeoptyx xenus
Atherinomorus stipes
Hypoatherina harringtonensis
Aulostomus maculatus
Platybelone argalus
Ablennes hians
Platybelone argalus argalus
Strongylura marina
Strongylura notata notata
Strongylura timucu
Tylosurus acus acus
Tylosurus crocodilus crocodilus
Ogilbia suarezae
Cataetyx laticeps
Diplacanthopoma brachysoma
Gunterichthys longipenis
Saccogaster staigeri
Acanthemblemaria aspera
Emblemaria atlantica
Emblemaria pandionis
Emblemaria piratula
Chaenopsis roseola
Chaetodon capistratus
Chaetodon ocellatus
Chaetodon sedentarius
Chaetodon striatus
Prognathodes aculeatus
Prognathodes aya
Amblycirrhitus pinos
Chilomycterus atringa
Diodon holocanthus
Diodon hystrix
Chaetodipterus faber
Fistularia petimba
Fistularia tabacaria
Awaous banana
Bathygobius soporator
Bollmannia communis
Ctenogobius boleosoma
Ctenogobius fasciatus
Ctenogobius shufeldti
Ctenogobius stigmaticus
Elacatinus oceanops
Elacatinus pallens
Elacatinus saucrus
Evorthodus lyricus
Gobioides broussonnetii
Gobionellus oceanicus
Gobiosoma bosc
Gobiosoma robustum
Microgobius carri
Microgobius gulosus
Microgobius microlepis
Microgobius thalassinus
Oxyurichthys stigmalophius
Palatogobius paradoxus
Risor ruber
Arisotremus virginicus
Kyphosus incisor
Kyphosus sectator
Labrisomus bucciferus
Labrisomus gobio
Labrisomus guppyi
Labrisomus haitiensis
Labrisomus kalisherae
Labrisomus nigricinctus
Labrisomus nuchipinnis
Malacoctenus aurolineatus
Malacoctenus gilli
Malacoctenus macropus
Malacoctenus triangulatus
Paraclinus marmoratus

Table A.2 (cont.)

- *Starksia fasciata*
- *Starksia ocellata*
- *Caulolatilus chrysops*
- *Caulolatilus cyanops*
- *Caulolatilus intermedius*
- *Caulolatilus microps*
- *Lopholatilus chamaeleonticeps*
- *Malacanthus plumieri*
- *Ptereleotris calliura*
- *Aluterus heudelotii*
- *Aluterus monoceros*
- *Aluterus schoepfii*
- *Aluterus scriptus*
- *Cantherhines macrocerus*
- *Cantherhines pullus*
- *Monacanthus ciliatus*
- *Stephanolepis hispidus*
- *Stephanolepis setifer*
- *Mulloidichthys martinicus*
- *Mullus auratus*
- *Pseudupeneus maculatus*
- *Upeneus parvus*
- *Halieutichthys bispinosus*
- *Rhinesomus bicaudalis*
- *Rhinesomus triqueter*
- *Acanthostracion polygonius*
- *Acanthostracion quadricornis*
- *Lactophrys bicaudalis*
- *Lactophrys trigonus*
- *Centropyge argi*
- *Holacanthus bermudensis*
- *Holacanthus ciliaris*
- *Holacanthus isabelita*
- *Holacanthus tricolor*
- *Pomacanthus arcuatus*
- *Pomacanthus paru*
- *Abudefduf saxatilis*
- *Abudefduf taurus*
- *Chromis cyanea*
- *Chromis enchrysura*
- *Chromis insolata*
- *Chromis multilineata*
- *Chromis scotti*
- *Microspathodon chrysurus*
- *Stegastes adustus*
- *Stegastes diencaeus*
- *Stegastes leucostictus*
- *Stegastes partitus*
- *Stegastes planifrons*
- *Stegastes variabilis*
- *Heteropriacanthus cruentatus*
- *Priacanthus arenatus*
- *Pristigenys alta*
- *Rachycentron canadum*
- *Acentronura dendritica*
- *Anarchopterus criniger*
- *Cosmocampus albirostris*
- *Hippocampus erectus*
- *Hippocampus zosterae*
- *Microphis brachyurus lineatus*
- *Syngnathus floridae*
- *Syngnathus fuscus*
- *Syngnathus louisianae*
- *Syngnathus pelagicus*
- *Syngnathus scovelli*
- *Saurida brasiliensis*
- *Saurida caribbaea*
- *Saurida normani*
- *Synodus foetens*
- *Synodus intermedius*
- *Synodus poeyi*
- *Synodus synodus*
- *Trachinocephalus myops*
- *Enneanectes boehlkei*
- *Enneanectes pectoralis*

- **Black drum (BDR) - 1**
  - *Pogonias cromis*
- **Red drum (RDR) - 1**
  - *Sciaenops ocellatus*
- **Seatrout (SEA) - 3**
  - *Cynoscion arenarius*
  - *Cynoscion nebulosus*
  - *Cynoscion nothus*
- **Sciaenidae (SCI) - 16**
  - *Bairdiella chrysoura*
  - *Bairdiella sanctaeluciae*
  - *Equetus lanceolatus*
  - *Larimus fasciatus*
  - *Leiostomus xanthurus*
  - *Menticirrhus americanus*
  - *Menticirrhus littoralis*
  - *Menticirrhus saxatilis*
  - *Micropogonias furnieri*
  - *Micropogonias undulatus*
  - *Pareques acuminatus*
  - *Pareques umbrosus*
  - *Stellifer lanceolatus*
  - *Umbrina coroides*
  - *Corvula batabana*
  - *Pareques iwamoto*
- **Ladyfish (LDY) - 2**
  - *Elops smithi*
  - *Elops saurus*
- **Mullets (MUL) - 4**
  - *Mugil cephalus*
  - *Mugil curema*
  - *Mugil hospes*
  - *Mugil trichodon*
- **Pompano (POM) - 3**
  - *Trachinotus carolinus*
  - *Trachinotus falcatus*
  - *Trachinotus goodei*
- **Sheepshead (SHP) - 1**
  - *Archosargus probatocephalus*
- **Snook (SNK) - 3**
  - *Centropomus parallelus*
  - *Centropomus pectinatus*
  - *Centropomus undecimalis*
- **Flatfish (FLT) - 38**
  - *Achirus lineatus*
  - *Gymnachirus melas*
  - *Gymnachirus texae*
  - *Trinectes maculatus*
  - *Bothus ocellatus*
  - *Bothus robinsi*
  - *Chascanopsetta lugubris*

Table A.2 (cont.)

Engyophrys senta
Monolene antillarum
Trichopsetta ventralis
Symphurus civitatium
Symphurus diomedeanus
Symphurus parvus
Symphurus pelicanus
Symphurus piger
Symphurus plagiusa
Symphurus stigmosus
Symphurus urospilus
Ancylopsetta dilecta
Ancylopsetta ommata
Citharichthys arctifrons
Citharichthys cornutus
Citharichthys macrops
Citharichthys spilopterus
Cyclopsetta chittendeni
Cyclopsetta fimbriata
Etropus crossotus
Etropus microstomus
Etropus rimosus
Gastropsetta frontalis
Paralichthys albigutta
Paralichthys lethostigma
Paralichthys squamilentus
Syacium gunteri
Syacium micrurum
Syacium papillosum
Pseudopleuronectes americanus
Poecilopsetta beanii

Other demersal fish (ODF) - 183

Acipenser oxyrinchus oxyrinchus
Synagrops bellus
Albula nemoptera
Alepocephalus agassizii
Alepocephalus australis
Alepocephalus productus
Asquamiceps caeruleus
Bajacalifornia megalops
Bathytroctes microlepis
Conocara macropterum
Conocara murrayi
Leptoderma macrops
Narcetes stomias
Rouleina attrita
Talismania homoptera
Xenodermichthys copei
Anguilla rostrata
Antennarius ocellatus
Antennarius striatus
Ariopsis felis
Bagre marinus
Galeichthys feliceps
Ariomma bondi
Ariomma melanum
Ariomma regulus
Borostomias elucens
Borostomias mononema
Heterophotus ophistoma
Ijimaia antillarum
Aulopus filamentosus
Bathygadus macrops
Gadomus arcuatus
Gadomus longifilis
Opsanus beta
Opsanus pardus
Porichthys plectrodon
Paradiplogrammus bairdi
Antigonia capros
Snyderidia canina
Chauliodus sloani
Coloconger meadi
Dactylopterus volitans
Chilomycterus schoepfi
Dormitator maculatus
Eleotris pisonis
Gobiomorus dormitor
Anisotremus surinamensis
Anisotremus virginicus
Conodon nobilis
Haemulon album
Haemulon aurolineatum
Haemulon carbonarium
Haemulon flavolineatum
Haemulon macrostomum
Haemulon melanurum
Haemulon parra
Haemulon plumierii
Haemulon sciurus
Haemulon striatum
Orthopristis chrysoptera
Pomadasys crocro
Holocentrus adscensionis
Holocentrus rufus
Myripristis jacobus
Idiacanthus fasciola
Bathytyphlops marionae
Lophiodes monodi
Lophiodes reticulatus
Lophius gastrophysus
Lophotus lacepede
Caelorinchus caribbaeus
Caelorinchus occa
Cetonurus globiceps
Coryphaenoides alateralis
Coryphaenoides mediterraneus
Coryphaenoides mexicanus
Coryphaenoides rudis
Coryphaenoides zaniophorus
Kuronezumia bubonis
Malacocephalus laevis
Malacocephalus occidentalis
Nezumia aequalis
Nezumia atlantica
Trachonurus sulcatus
Trachonurus villosus
Ventrifossa macropogon
Squalogadus modificatus
Malacosteus niger
Echiostoma barbatum
Eustomias obscurus
Flagellostomias boureei
Leptostomias gladiator
Melanostomias biseriatus
Photonectes dinema

Table A.2 (cont.)

Photonectes margarita
Microdesmus longipinnis
Neoconger mucronatus
Morone saxatilis
Enchelycore carychroa
Enchelycore nigricans
Gymnothorax conspersus
Gymnothorax funebris
Gymnothorax kolpos
Gymnothorax miliaris
Gymnothorax moringa
Gymnothorax nigromarginatus
Gymnothorax ocellatus
Gymnothorax saxicola
Gymnothorax vicinus
Muraena retifera
Uropterygius macularius
Eptatretus minor
Eptatretus springeri
Nettastoma melanura
Hoplunnis macrura
Hoplunnis tenuis
Nettastoma melanurum
Nettastoma syntresis
Saurenchelys cognita
Psenes pellucidus
Notacanthus chemnitzii
Dibranchus atlanticus
Ogcocephalus cubifrons
Ogcocephalus nasutus
Ogcocephalus pantostictus
Ogcocephalus radiatus
Bembrops anatirostris
Bembrops gobioides
Urophycis cirrata
Urophycis floridana
Urophycis regia
Polydactylus octonemus
Neomerinthe hemingwayi
Pontinus castor
Pontinus longispinis
Scorpaena brasiliensis
Scorpaena plumieri
Helicolenus dactylopterus
Serrivomer beanii
Diplodus holbrookii
Archosargus rhomboidalis
Calamus arctifrons
Calamus bajonado
Calamus calamus
Calamus leucosteus
Calamus nodosus
Calamus penna
Calamus pennatula
Calamus proridens
Pagrus pagrus
Stenotomus caprinus
Eustomias arborifer
Eustomias filifer
Eustomias macrurus
Leptostomias bermudensis
Leptostomias haplocaulus
Melanostomias macrophotus
Melanostomias melanops
Melanostomias tentaculatus
Melanostomias valdiviae
Photonectes braueri
Photonectes parvimanus
Stomias longibarbatus
Synaphobranchus oregonii
Dysomma anguillare
Haptenchelys texis
Ilyophis brunneus
Synaphobranchus affinis
Synaphobranchus brevidorsalis
Lagocephalus laevigatus
Sphoeroides nephelus
Sphoeroides pachygaster
Sphoeroides spengleri
Sphoeroides testudineus
Prionotus longispinosus
Prionotus ophryas
Prionotus rubio
Prionotus scitulus
Prionotus tribulus
Astroscopus y-graecum
Gnathagnus egregius
Kathetostoma albigutta
Zenopsis conchifer

Small demersal fish (SDF) - 194

Synagrops spinosus
Synagrops trispinosus
Rinoctes nasutus
Talismania antillarum
Antennarius multiocellatus
Antennarius radiosus
Histrio histrio
Astronesthes gemmifer
Astronesthes macropogon
Astronesthes richardsoni
Astronesthes similus
Opsanus dichrostomus
Chasmodes bosquianus
Chasmodes longimaxilla
Entomacrodus nigricans
Hypsoblennius invemar
Lupinoblennius dispar
Lupinoblennius nicholsi
Ophioblennius macclurei
Parablennius marmoreus
Scartella cristata
Bregmaceros cayorum
Bregmaceros atlanticus
Bregmaceros cantori
Bregmaceros houdei
Bregmaceros nectabanus
Antigonia combatia
Carapus bermudensis
Echiodon dawsoni
Macroramphosus scolopax
Chauliodus danae
Chaunax suttkusi
Cyprinodon variegatus variegatus
Floridichthys carpio
Dactyloscopus moorei
Dactyloscopus tridigitatus

Table A.2 (cont.)

Gillellus healae
Eleotris amblyopsis
Erotelis smaragdus
Epigonus macrops
Epigonus pandionis
Epigonus pectinifer
Fundulus grandis
Adinia xenica
Fundulus confluentus
Fundulus jenkinsi
Fundulus majalis
Fundulus pulvereus
Lucania parva
Gobiesox strumosus
Evermannichthys spongicola
Lipogramma trilineata
Xenolepidichthys dalgleishi
Haemulon chrysargyreum
Ostichthys trachypoma
Plectrypops retrospinis
Sargocentron bullisi
Sargocentron coruscum
Sargocentron poco
Sargocentron vexillarium
Paraliparis calidus
Hymenocephalus aterrimus
Hymenocephalus billsam
Hymenocephalus italicus
Aristostomias grimaldii
Aristostomias grimaldii
Aristostomias polydactylus
Aristostomias tittmanni
Aristostomias xenostoma
Photostomias guernei
Melamphaes eulepis
Melamphaes pumilus
Melamphaes simus
Melamphaes typhlops
Poromitra capito
Poromitra crassiceps
Poromitra megalops
Bathophilus digitatus
Bathophilus longipinnis
Bathophilus nigerrimus
Bathophilus pawneei
Eustomias brevibarbatus
Eustomias macrophthalmus
Eustomias schmidti
Leptostomias bilobatus
Microdesmus lanceolatus
Xenophthalmichthys danae
Benthosema suborbitale
Bolinichthys photothorax
Bolinichthys supralateralis
Centrobranchus nigroocellatus
Ceratoscopelus warmingii
Diaphus dumerilii
Diaphus fragilis
Diaphus garmani
Diaphus lucidus
Diaphus luetkeni
Diaphus mollis
Diaphus perspicillatus
Diaphus problematicus
Diaphus rafinesquii
Diaphus splendidus
Diaphus subtilis
Diaphus taaningi
Diaphus termophilus
Diogenichthys atlanticus
Gonichthys cocco
Hygophum hygomii
Hygophum macrochir
Hygophum reinhardtii
Lampadena luminosa
Lampanyctus alatus
Lampanyctus nobilis
Lampanyctus tenuiformis
Lepidophanes guentheri
Lobianchia gemellarii
Myctophum affine
Myctophum asperum
Myctophum nitidulum
Myctophum obtusirostre
Nannobrachium atrum
Nannobrachium cuprarium
Nannobrachium lineatum
Notolychnus valdiviae
Notoscopelus caudispinosus
Notoscopelus resplendens
Taaningichthys bathyphilus
Nettenchelys pygmaea
Dibranchus tremendus
Halieutichthys aculeatus
Ogcocephalus corniger
Ogcocephalus declivirostris
Zalieutes mcgintyi
Ophidion antipholus
Ophidion dromio
Otophidium omostigma
Lonchopisthus micrognathus
Opistognathus lonchurus
Opistognathus macrognathus
Opistognathus nothus
Stemonosudis bullisi
Stemonosudis gracilis
Stemonosudis intermedia
Mentodus facilis
Platytroctes apus
Kryptolebias marmoratus
Phenacoscorpius nebris
Scorpaena agassizii
Scorpaena bergii
Scorpaena calcarata
Scorpaena dispar
Scorpaena inermis
Scorpaena isthmensis
Aristostomias lunifer
Astronesthes indicus
Astronesthes micropogon
Astronesthes niger
Eustomias achirus
Eustomias acinosus
Eustomias bibulbosus
Eustomias bigelowi
Eustomias binghami

Table A.2 (cont.)

Eustomias braueri
Eustomias dendriticus
Eustomias fissibarbis
Eustomias hypopsilus
Eustomias longibarba
Eustomias monoclonus
Eustomias polyaster
Eustomias variabilis
Grammatostomias circularis
Leptostomias leptobolus
Melanostomias margaritifer
Melanostomias melanopogon
Neonesthes capensis
Photonectes achirus
Photonectes leucospilus
Photonectes phyllopogon
Stomias affinis
Stomias brevibarbatus
Symphysanodon berryi
Canthigaster jamestyleri
Canthigaster rostrata
Sphoeroides dorsalis
Sphoeroides parvus
Bellator brachychir
Bellator egretta
Bellator militaris
Prionotus alatus
Prionotus martis
Prionotus paralatus
Prionotus roseus
Prionotus stearnsi
Lycenchelys bullisi

Yellowfin tuna (YTN) - 1
Thunnus albacares

Bluefin tuna (BTN) - 1
Thunnus thynnus

Little tunny (LTN) - 1
Euthynnus alletteratus

Other tuna (OTN) - 2
Auxis rochei
Auxis thazard

Swordfish (SWD) - 1
Xiphias gladius

White marlin (WMR) - 1
Tetrapturus albidus

Blue marlin (BMR) - 1
Makaira nigricans

Other billfish (BIL) - 3
Istiophorus platypterus
Istiophorus albicans
Tetrapturus pfluegeri

Greater amberjack (AMB) - 1
Seriola dumerili

Jacks (JCK) - 22
Caranx bartholomaei
Caranx ruber
Alectis ciliaris
Carangoides bartholomaei
Caranx crysos
Caranx hippos
Caranx latus
Caranx lugubris
Chloroscombrus chrysurus
Decapterus macarellus
Decapterus punctatus
Elagatis bipinnulata
Hemicaranx amblyrhynchus
Naucrates ductor
Oligoplites saurus
Selar crumenophthalmus
Selene setapinnis
Selene vomer
Seriola fasciata
Seriola rivoliana
Seriola zonata
Trachurus lathami

King mackerel (KMK) - 1
Scomberomorus cavalla

Spanish mackerel (SMK) - 10
Diplospinus multistriatus
Gempylus serpens
Lepidocybium flavobrunneum
Nealotus tripes
Neoepinnula americana
Neoepinnula orientalis
Nesiarchus nasutus
Promethichthys prometheus
Ruvettus pretiosus
Scomberomorus maculatus

Spanish sardine (SAR) - 1
Sardinella aurita

Large pelagic fish (LPL) - 33
Alepisaurus ferox
Coryphaena equiselis
Coryphaena hippurus
Remora albescens
Echeneis naucrates
Echeneis neucratoides
Phtheirichthys lineatus
Remora australis
Remora brachyptera
Remora osteochir
Remora remora
Remorina albescens
Cheilopogon exsiliens
Lampris guttatus
Luvarus imperialis
Masturus lanceolatus
Mola mola
Gadella imberbis
Pomatomus saltatrix
Acanthocybium solandri
Auxis rochei rochei
Auxis thazard thazard
Katsuwonus pelamis
Sarda sarda
Scomberomorus regalis
Thunnus atlanticus
Thunnus obesus
Sphyraena barracuda
Sphyraena borealis
Sphyraena guachancho
Peprilus burti
Peprilus paru
Peprilus triacanthus

Deep water fish (DWF) - 141

Table A.2 (cont.)

Bathytroctes macrolepis
Anoplogaster brachycera
Anoplogaster cornuta
Aphyonus gelatinosus
Barathronus bicolor
Bathyclupea argentea
Bathygadus favosus
Bathygadus melanobranchus
Bathylagichthys greyae
Bathysaurus mollis
Foetorepus agassizii
Cryptopsaras couesii
Cetomimus teevani
Ditropichthys storeri
Gyrinomimus myersi
Chiasmodon niger
Kali macrodon
Pseudoscopelus altipinnis
Pseudoscopelus scriptus
Chlorophthalmus agassizi
Parasudis truculenta
Bufoceratias wedli
Diretmichthys parini
Diretmoides pauciradiatus
Diretmus argenteus
Coccorella atlantica
Evermannella indica
Odontostomops normalops
Gibberichthys pumilus
Gigantura chuni
Gigantura indica
Bonapartia pedaliota
Aldrovandia affinis
Aldrovandia gracilis
Halosaurus guentheri
Halosaurus ovenii
Himantolophus cornifer
Himantolophus groenlandicus
Howella brodiei
Bathypterois bigelowi
Bathypterois grallator
Bathypterois phenax
Bathypterois quadrifilis
Bathypterois viridensis
Ipnops murrayi
Kogia breviceps
Kogia simus
Haplophryne mollis
Linophryne brevibarbata
Linophryne densiramus
Caelorinchus caelorhincus
Coelorinchus caribbaeus
Coelorinchus carminatus
Hymenocephalus billsamorum
Nezumia cyrano
Nezumia longebarbata
Nezumia suilla
Sphagemacrurus grenadae
Scopelogadus mizolepis
Scopeloberyx opisthopterus
Scopeloberyx robustus
Scopelogadus beanii
Melanocetus johnsonii
Melanocetus murrayi
Melanonus zugmayeri
Microstoma microstoma
Nansenia groenlandica
Venefica procera
Cubiceps pauciradiatus
Nomeus gronovii
Psenes cyanophrys
Polyacanthonotus africanus
Polyacanthonotus merretti
Ahliesaurus berryi
Omosudis lowei
Dicrolene intronigra
Acanthonus armatus
Bassozetus compressus
Bassozetus robustus
Bathyonus pectoralis
Dolichopteryx binocularis
Dolichopteryx longipes
Lestidiops affinis
Lestidium atlanticum
Lestrolepis intermedia
Magnisudis atlantica
Sudis atrox
Sudis hyalina
Cyttopsis rosea
Peristedion gracile
Peristedion greyae
Peristedion imberbe
Peristedion longispatha
Peristedion miniatum
Peristedion thompsoni
Peristedion truncatum
Ichthyococcus ovatus
Pollichthys mauli
Polymetme corythaeola
Polymetme thaeocoryla
Vinciguerria attenuata
Vinciguerria nimbaria
Vinciguerria poweriae
Yarrella blackfordi
Polymixia lowei
Rondeletia bicolor
Scombrolabrax heterolepis
Rosenblattichthys hubbsi
Scopelarchoides danae
Scopelarchus analis
Scopelarchus guentheri
Scopelarchus michaelsarsi
Ectreposebastes imus
Setarches guentheri
Stephanoberyx monae
Argyropelecus aculeatus
Argyropelecus affinis
Argyropelecus gigas
Argyropelecus hemigymnus
Argyropelecus hemigymnus
Argyropelecus sladeni
Maurolicus muelleri
Maurolicus weitzmani
Polyipnus asteroides
Polyipnus clarus
Polyipnus laternatus

Table A.2 (cont.)

- *Sonoda megalophthalma*
- *Sternoptyx diaphana*
- *Sternoptyx pseudobscura*
- *Valenciennellus tripunctulatus*
- *Astronesthes cyaneus*
- *Stylephorus chordatus*
- *Oostethus brachyurus*
- *Gephyroberyx darwinii*
- *Hoplostethus mediterraneus*
- *Hoplostethus occidentalis*
- *Trachipterus arcticus*
- *Zu cristatus*
- *Hollardia hollardi*
- *Parahollardia lineata*
- *Xenocephalus egregius*

Menhaden (MEN) - 3

- *Brevoortia gunteri*
- *Brevoortia patronus*
- *Brevoortia smithi*

Pinfish (PIN) - 1

- *Lagodon rhomboides*

Medium pelagic fish (MPL) - 20

- *Brama caribbea*
- *Brama dussumieri*
- *Eumegistus brevorti*
- *Pterycombus brama*
- *Taractichthys longipinnis*
- *Hyperoglyphe bythites*
- *Hyperoglyphe perciformis*
- *Diapterus auratus*
- *Eucinostomus argenteus*
- *Eucinostomus gula*
- *Eucinostomus harengulus*
- *Eucinostomus jonesii*
- *Eucinostomus lefroyi*
- *Eucinostomus melanopterus*
- *Eugerres brasilianus*
- *Eugerres plumieri*
- *Gerres cinereus*
- *Oxyporhamphus micropterus*
- *Megalops atlanticus*
- *Scomberesox saurus saurus*

Small pelagic fish (SPL) - 59

- *Argentina georgei*
- *Argentina striata*
- *Glossanodon pygmaeus*
- *Membras martinica*
- *Menidia beryllina*
- *Menidia peninsulae*
- *Dolicholagus longirostris*
- *Melanolagus bericoides*
- *Alosa alabamae*
- *Alosa chrysochloris*
- *Dorosoma petenense*
- *Etrumeus teres*
- *Harengula clupeola*
- *Harengula humeralis*
- *Harengula jaguana*
- *Jenkinsia lamprotaenia*
- *Opisthonema oglinum*
- *Sardinella janeiro*
- *Anchoa cayorum*
- *Anchoa cubana*
- *Anchoa hepsetus*
- *Anchoa lyolepis*
- *Anchoa mitchilli*
- *Anchoviella perfasciata*
- *Engraulis eurystole*
- *Cheilopogon cyanopterus*
- *Cheilopogon furcatus*
- *Cheilopogon heterurus*
- *Cheilopogon melanurus*
- *Cypselurus comatus*
- *Exocoetus obtusirostris*
- *Exocoetus volitans*
- *Hirundichthys affinis*
- *Hirundichthys rondeletii*
- *Parexocoetus brachypterus*
- *Prognichthys occidentalis*
- *Cyclothone acclinidens*
- *Cyclothone alba*
- *Cyclothone braueri*
- *Cyclothone microdon*
- *Cyclothone obscura*
- *Cyclothone pallida*
- *Cyclothone pseudopallida*
- *Diplophos taenia*
- *Gonostoma atlanticum*
- *Gonostoma elongatum*
- *Manducus maderensis*
- *Margrethia obtusirostra*
- *Chriodorus atherinoides*
- *Euleptorhamphus velox*
- *Hemiramphus balao*
- *Hemiramphus brasiliensis*
- *Hyporhamphus meeki*
- *Hyporhamphus unifasciatus*
- *Oxyporhamphus micropterus*
- *Merluccius albidus*
- *Uncisudis advena*
- *Uncisudis quadrimaculata*
- *Steindachneria argentea*

Blacktip shark (TIP) - 1

- *Carcharhinus limbatus*

Benthic feeding sharks (BEN) - 8

- *Heptranchias perlo*
- *Hexanchus griseus*
- *Mitsukurina owstoni*
- *Pristis pectinata*
- *Pristis perotteti*
- *Pristis pristis*
- *Squatina heteroptera*
- *Squatina dumeril*

Large sharks (LGS) - 26

- *Alopias superciliosus*
- *Alopias vulpinus*
- *Carcharhinus perezii*
- *Carcharhinus acronotus*
- *Carcharhinus altimus*
- *Carcharhinus brevipinna*
- *Carcharhinus falciformis*
- *Carcharhinus isodon*
- *Carcharhinus leucas*
- *Carcharhinus longimanus*
- *Carcharhinus obscurus*
- *Carcharhinus plumbeus*

Table A.2 (cont.)

  - *Carcharhinus porosus*
  - *Carcharhinus signatus*
  - *Galeocerdo cuvier*
  - *Negaprion brevirostris*
  - *Prionace glauca*
  - *Rhizoprionodon terraenovae*
  - *Ginglymostoma cirratum*
  - *Carcharodon carcharias*
  - *Isurus oxyrinchus*
  - *Isurus paucus*
  - *Carcharias taurus*
  - *Sphyrna lewini*
  - *Sphyrna mokarran*
  - *Sphyrna tiburo*
- **Filter feeding sharks (FIL) - 3**
  - *Cetorhinus maximus*
  - *Manta birostris*
  - *Rhincodon typus*
- **Small sharks (SMS) - 13**
  - *Centrophorus acus*
  - *Centrophorus granulosus*
  - *Dalatias licha*
  - *Isistius brasiliensis*
  - *Etmopterus bigelowi*
  - *Etmopterus hillianus*
  - *Etmopterus schultzi*
  - *Etmopterus virens*
  - *Zameus squamulosus*
  - *Squalus uyato*
  - *Cirrhigaleus asper*
  - *Squalus cubensis*
  - *Squalus mitsukurii*
- **Skates and rays (RAY) - 36**
  - *Anacanthobatis folirostris*
  - *Hydrolagus alberti*
  - *Hydrolagus mirabilis*
  - *Dasyatis americana*
  - *Dasyatis centroura*
  - *Dasyatis guttata*
  - *Dasyatis sabina*
  - *Dasyatis say*
  - *Gymnura altavela*
  - *Gymnura micrura*
  - *Myliobatis freminvillei*
  - *Aetobatus narinari*
  - *Narcine brasiliensis*
  - *Breviraja spinosa*
  - *Dactylobatus armatus*
  - *Dipturus garricki*
  - *Dipturus olseni*
  - *Fenestraja sinusmexicanus*
  - *Leucoraja lentiginosa*
  - *Raja ackleyi*
  - *Raja eglanteria*
  - *Raja texana*
  - *Rajella bigelowi*
  - *Rajella purpuriventralis*
  - *Rhinobatos lentiginosus*
  - *Rhinoptera bonasus*
  - *Apristurus laurussonii*
  - *Apristurus parvipinnis*
  - *Apristurus riveri*
  - *Galeus arae*
  - *Scyliorhinus retifer*
  - *Torpedo nobiliana*
  - *Mustelus canis*
  - *Mustelus norrisi*
  - *Mustelus sinusmexicanus*
  - *Urobatis jamaicensis*

- **Brown shrimp (BSH) - 1**
  - *Farfantepenaeus aztecus*
- **White shrimp (WSH) - 1**
  - *Litopenaeus setiferus*
- **Pink shrimp (PSH) - 1**
  - *Farfantepenaeus duorarum*
- **Other shrimp (OSH) - 69**
  - *Alpheus armillatus*
  - *Alpheus floridanus*
  - *Alpheus packardii*
  - *Alpheus paracrinitus*
  - *Hippolyte coerulescens*
  - *Hippolyte zostericola*
  - *Latreutes fucorum*
  - *Latreutes parvulus*
  - *Synalpheus fritzmuelleri*
  - *Synalpheus townsendi*
  - *Tozeuma carolinense*
  - *Discias atlanticus*
  - *Glyphocrangon aculeata*
  - *Glyphocrangon alispina*
  - *Glyphocrangon longleyi*
  - *Glyphocrangon nobilis*
  - *Pontophilus gracilis*
  - *Cinetorhynchus rigens*
  - *Nematocarcinus rotundus*
  - *Acanthephyra acanthitelsonis*
  - *Acanthephyra acutifrons*
  - *Acanthephyra armata*
  - *Acanthephyra curtirostris*
  - *Acanthephyra exima*
  - *Acanthephyra pelagica*
  - *Acanthephyra purpurea*
  - *Acanthephyra stylorostratis*
  - *Heterogenys microphthalma*
  - *Janicella spinicauda*
  - *Meningodora mollis*
  - *Notostomus gibbosus*
  - *Oplophorus gracilirostris*
  - *Systellaspis debilis*
  - *Systellaspis pellucida*
  - *Kemponia americanus*
  - *Leander tenuicornis*
  - *Macrobrachium acanthurus*
  - *Macrobrachium carcinus*
  - *Heterocarpus ensifer*
  - *Heterocarpus oryx*
  - *Leptochela carinata*
  - *Parapasiphae sulcatifrons*
  - *Pasiphaea merriami*
  - *Psathyrocaris infirma*
  - *Aristaeomorpha foliacea*
  - *Bentheogennema intermedia*
  - *Benthesicymus bartletti*
  - *Benthesicymus brasiliensis*

Table A.2 (cont.)

Gennadas capensis
Gennadas valens
Hemipenaeus carpenteri
Hymenopenaeus aphoticus
Parapenaeus politus
Penaeopsis serrata
Pleoticus robustus
Plesiopenaeus armatus
Rimapenaeus similis
Sicyonia brevirostris
Sicyonia burkenroadi
Sicyonia dorsalis
Sicyonia parri
Sicyonia typica
Solenocera atlantidis
Solenocera necopina
Xiphopenaeus kroyeri
Processa bermudensis
Psalidopus barbouri
Acetes americanus carolinae
Lucifer faxoni

Diving birds (DBR) - 35

Ceryle alcyon
Aix sponsa
Anas acuta
Anas americana
Anas crecca
Anas discors
Anas platyrhynchos
Aythya affinis
Aythya collaris
Dendrocygna bicolor
Nomonyx dominicus
Anhinga anhinga
Mycteria americana
Oceanites oceanicus
Chlidonias niger
Larus argentatus
Larus atricilla
Larus delawarensis
Larus fuscus
Larus pipixcan
Rynchops niger
Stercorarius parasiticus
Stercorarius pomarinus
Sterna antillarum
Sterna caspia
Sterna forsteri
Sterna hirundo
Sterna maxima
Sterna nilotica
Sterna sandvicensis
Pelecanus erythrorhynchos
Pelecanus occidentalis
Phalacrocorax auritus
Sula dactylatra
Sula leucogaster

Surface feeding birds (SBR) - 54

Pandion haliaetus
Branta canadensis
Ardea alba
Ardea herodias
Egretta caerulea
Egretta rufescens
Egretta thula
Egretta tricolor
Ixobrychus exilis
Nyctanassa violacea
Nycticorax nycticorax
Charadrius alexandrinus
Charadrius melodus
Charadrius semipalmatus
Charadrius vociferus
Charadrius wilsonia
Pluvialis dominica
Pluvialis squatarola
Fregata magnificens
Haematopus palliatus
Podilymbus podiceps
Fulica americana
Gallinula chloropus
Laterallus jamaicensis
Porzana carolina
Rallus elegans
Rallus longirostris
Himantopus mexicanus
Recurvirostra americana
Actitis macularius
Arenaria interpres
Calidris alba
Calidris alpina
Calidris canutus
Calidris fuscicolis
Calidris himantopus
Calidris mauri
Calidris melanotos
Calidris minutilla
Calidris pusilla
Catoptrophorus semipalmatus
Gallinago delicata
Limnodromus griseus
Limosa fedoa
Numenius americanus
Numenius phaeopus
Phalaropus tricolor
Tringa flavipes
Tringa melanoleuca
Tringa solitaria
Tryngites subruficollis
Eudocimus albus
Platalea ajaja
Plegadis falcinellus

Manatee (MAN) - 1

Trichechus manatus

Mysticeti (MYS) - 2

Megaptera novaeangliae
Balaenoptera edeni

Dolphins and porpoises (DOL) - 11

Feresa attenuata
Globicephala macrorhynchus
Grampus griseus
Orcinus orca
Pseudorca crassidens
Stenella attenuata
Stenella frontalis
Steno bredanensis

Table A.2 (cont.)

  - *Tursiops truncatus*
  - *Mesoplodon europaeus*
  - *Peponocephala electra*
- **Deep diving odontocetae (DDO) - 3**
  - *Kogia breviceps*
  - *Kogia simus*
  - *Physeter macrocephalus*
- **Loggerhead (LOG) - 1**
  - *Caretta caretta*
- **Kemps ridley (KMP) - 1**
  - *Lepidochelys kempii*
- **Other turtles (TUR) - 3**
  - *Eretmochelys imbricata*
  - *Dermochelys coriacea*
  - *Chelonia mydas*
- **Blue crab (BCR) - 2**
  - *Callinectes sapidus*
  - *Callinectes similis*
- **Stone crab (SCR) - 1**
  - *Menippe mercenaria*
- **Crabs and lobsters (LOB) - 51**
  - *Coralaxius nodulosus*
  - *Acanthocarpus alexandri*
  - *Calappa flammea*
  - *Hepatus epheliticus*
  - *Chlidonophora incerta*
  - *Ethusa microphthalma*
  - *Polycheles sculptus*
  - *Agononida longipes*
  - *Munida angulata*
  - *Munida flinti*
  - *Munida forceps*
  - *Munida iris*
  - *Munida microphthalma*
  - *Munida pusilla*
  - *Munida valida*
  - *Munidopsis erinaceus*
  - *Munidopsis robusta*
  - *Munidopsis sigsbei*
  - *Munidopsis simplex*
  - *Pachycheles monilifer*
  - *Pachycheles rugimanus*
  - *Petrolisthes armatus*
  - *Petrolisthes galathinus*
  - *Porcellana sayana*
  - *Uroptychus nitidus*
  - *Pachygrapsus transversus*
  - *Celleporaria albirostris*
  - *Myropsis quinquespinosa*
  - *Persephona mediterranea*
  - *Anasimus latus*
  - *Macrocoeloma trispinosum*
  - *Mithraculus forceps*
  - *Podochela sidneyi*
  - *Stenocionops furcatus*
  - *Stenorhynchus seticornis*
  - *Acanthacaris caeca*
  - *Nephropsis aculeata*
  - *Nephropsis agassizii*
  - *Nephropsis rosea*
  - *Ocypode quadrata*
  - *Uca rapax*
  - *Panulirus argus*
  - *Scyllarides aequinoctialis*
  - *Scyllarides nodifer*
  - *Scyllarus chacei*
  - *Scyllarus depressus*
  - *Arenaeus cribrarius*
  - *Lysirude nitidus*
  - *Symethis variolosa*
  - *Stenopus hispidus*
  - *Stenopus scutellatus*

Table A.3. Life history parameters by group.

Group	M	k	L∞	tmax	Lmax	L-W a	L-W b	Age at maturity	Duration(d)
GAG	0.15	0.132	136.713	23.6	145.0	0.020	2.990	5.3	30
RGR	0.20	0.127	108.394	23.4	125.0	0.022	2.985	5.1	30
SCM	0.20	0.110	101.209	31.3	107.0	0.014	3.000	6.8	30
SSR	0.81	0.413	51.822	13.5	54.4	0.014	3.067	3.1	30
DSR	0.39	0.218	101.974	16.0	102.2	0.046	2.798	3.6	30
RSN	0.10	0.144	98.783	18.0	100.0	0.018	3.006	3.9	30
VSN	0.25	0.199	62.250	14.5	60.0	0.029	2.836	3.2	30
LUT	0.45	0.213	79.083	18.3	87.2	0.030	2.874	4.0	30
BIO	1.01	0.573	35.236	6.4	36.6	0.021	2.997	1.6	30
LRF	0.63	0.346	71.334	10.3	72.0	0.020	2.992	2.4	40
SRF	1.51	0.838	34.076	5.6	33.8	0.033	2.937	1.4	40
BDR	0.33	0.160	137.075	16.9	170.0	0.016	2.949	3.8	30
RDR	0.09	0.210	125.472	6.2	155.0	0.011	3.042	3.1	30
SEA	0.41	0.225	65.187	14.8	66.5	0.025	2.909	2.8	30
SCI	0.94	0.644	35.669	7.4	36.0	0.011	3.166	1.6	30
LDY	0.55	0.290	67.538	4.6	72.0	0.009	2.989	1.0	30
MUL	0.55	0.422	54.313	11.8	65.6	0.040	2.725	2.8	30
POM	0.58	0.361	74.043	7.9	79.7	0.031	2.766	2.0	30
SHP	0.70	0.371	69.788	8.0	91.0	0.037	2.967	1.9	30
SNK	0.54	0.386	85.349	10.7	89.3	0.012	2.983	2.7	30
FLT	1.08	0.604	25.398	6.2	25.3	0.017	3.041	1.6	38.5
ODF	0.52	0.307	52.751	11.4	53.5	0.024	2.999	2.8	30
SDF	1.46	0.749	13.228	4.4	13.3	0.014	2.902	1.3	26
YTN	0.49	0.350	223.789	7.8	266.0	0.040	2.881	2.2	50
BTN	0.08	0.202	416.725	43.5	458.0	0.032	2.925	5.5	50
LTN	0.29	0.184	120.721	15.2	122.0	0.030	2.898	3.2	50
OTN	0.87	0.359	62.350	5.0	57.5	0.008	3.210	2.0	50
SWD	0.20	0.146	384.401	24.2	505.8	0.005	3.248	5.2	50
WMR	0.59	0.580	294.975	5.0	300.0	0.005	3.000	0.9	50
BMR	0.35	0.442	455.363	9.0	500.0	0.010	3.038	1.6	50
BIL	0.28	0.379	283.800	17.3	328.2	0.014	2.828	3.3	50
AMB	0.25	0.210	168.313	11.6	190.0	0.028	2.860	3.3	50
JCK	0.97	0.747	76.394	9.5	80.4	0.022	2.972	2.1	50

Table A.3 (cont.)

Group	M	k	L∞	tmax	Lmax	L-W a	L-W b	Age at maturity	Duration(d)
KMK	0.20	0.152	160.543	22.2	184.0	0.009	2.994	3.3	50
SMK	0.42	0.257	104.596	19.6	113.8	0.007	2.993	4.0	50
SAR	0.48	0.418	32.629	11.1	31.0	0.008	3.072	2.7	50
LPL	0.74	0.636	118.121	6.3	121.7	0.021	2.998	1.3	50
DWF	1.24	0.913	26.573	6.9	26.4	0.009	3.197	1.8	30
MEN	0.85	0.415	21.725	6.9	38.1	0.009	3.234	1.6	30
PIN	0.68	0.432	33.317	9.1	40.0	0.022	3.103	2.3	25
MPL	0.72	0.418	54.121	11.6	56.2	0.029	2.923	2.8	30
SPL	1.59	0.940	22.290	4.6	22.8	0.011	3.155	1.3	25
TIP	0.43	0.264	227.188	10.5	275.0	0.009	2.963	4.1	330
BEN	0.19	0.150	424.802	17.6	449.6	0.018	2.867	3.4	90
LGS	0.19	0.157	356.073	32.1	381.0	0.012	3.033	6.8	90
FIL	0.07	0.059	1185.667	47.6	1220.0	0.007	3.000	7.6	90
SMS	0.25	0.082	92.076	15.5	89.3	0.004	3.084	3.2	60
RAY	0.42	0.261	100.124	13.4	96.2	0.015	3.032	2.6	190
BSH	11.70	1.400	19.400	2.0	18.3	0.569	3.360	1.0	30
WSH	7.02	1.600	19.300	1.5	17.3	0.650	2.998	1.0	30
PSH	7.80	1.200	17.600	1.6	17.0	0.773	3.024	0.9	30
OSH	0.22	0.873	12.380	1.3	12.1	0.934	2.608	0.3	30
DBR	0.22	0.281	62.498	20.1	57.7	0.005	3.000	2.4	21
SBR	0.31	0.106	60.879	14.7	69.0	0.007	3.000	1.7	21
MAN	0.04	0.845	304.800	56.0	304.8	0.015	3.000	4.0	365
MYS	0.08	0.665	1410.600	83.5	1410.6	0.010	3.000	6.0	365
DOL	0.09	0.340	340.973	48.5	398.4	0.008	2.932	10.0	365
DDO	0.08	0.200	593.367	69.0	899.3	0.005	3.000	7.0	365
LOG	0.16	0.056	110.000	61.5	125.0	0.166	2.953	12.0	60
KMP	0.09	0.096	62.700	62.0	74.8	0.892	2.495	9.0	60
TUR	0.08	0.086	111.833	51.7	150.7	0.099	3.000	17.0	60
BCR	1.49	1.424	20.900	3.0	20.9	0.081	2.954	0.8	30
SCR	1.60	1.424	14.500	8.0	14.5	0.202	3.000	1.0	30
LOB	0.36	0.200	17.418	20.0	17.4	0.053	2.910	4.0	30

Table A.4. Vertical distributions.

DAY - ADULT	**Functional group**																				
Depth	GAG	RGR	SCM	SSR	DSR	RSN	VSN	LUT	BIO	LRF	SRF	BDR	RDR	SEA	SCI	LDY	MUL	POM	SHP	SNK	FLT
Shallowest	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.23	0.03	0.00	0.03	0.00
…	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.00	0.03	0.00
…	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.03	0.00
…	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.02	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.00	0.07	0.03
…	0.20	0.20	0.20	0.06	0.21	0.20	0.20	0.05	0.00	0.16	0.05	0.20	0.20	0.20	0.16	0.00	0.13	0.10	0.00	0.17	0.19
Deepest	0.80	0.80	0.80	0.92	0.72	0.80	0.80	0.93	1.00	0.74	0.92	0.80	0.80	0.80	0.84	1.00	0.50	0.73	1.00	0.67	0.77
Sediment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth	ODF	SDF	YTN	BTN	LTN	OTN	SWD	WMR	BMR	BIL	AMB	JCK	KMK	SMK	SAR	LPL	DWF	MEN	PIN	MPL	SPL
Shallowest	0.05	0.16	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.00	0.14	0.00	0.08	0.00	0.49	0.09	0.80	0.00	0.30	0.41
…	0.03	0.07	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.00	0.04	0.00	0.08	0.00	0.11	0.07	0.15	0.00	0.06	0.10
…	0.03	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.03	0.00	0.08	0.00	0.05	0.07	0.05	0.00	0.02	0.05
…	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.14	0.00	0.04	0.12	0.00	0.00	0.01	0.04
…	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.28	0.00	0.07	0.31	0.00	0.20	0.08	0.11
Deepest	0.62	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.68	1.00	0.34	1.00	0.25	0.33	0.00	0.80	0.53	0.28
Sediment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth	TIP	BEN	LGS	FIL	SMS	RAY	BSH	WSH	PSH	OSH	DBR	SBR	MAN	MYS	DOL	DDO	LOG	KMP	TUR	BCR	SCR
Shallowest	0.00	0.01	0.13	0.53	0.01	0.03	0.03	0.03	0.03	0.03	0.40	1.00	0.40	0.00	0.30	0.05	0.25	0.25	0.25	0.05	0.05
…	0.00	0.01	0.03	0.10	0.01	0.01	0.03	0.03	0.03	0.03	0.30	0.00	0.30	0.10	0.20	0.05	0.25	0.25	0.25	0.10	0.10
…	0.00	0.01	0.01	0.03	0.01	0.01	0.03	0.03	0.03	0.03	0.30	0.00	0.30	0.20	0.20	0.10	0.25	0.25	0.25	0.10	0.10
…	0.00	0.09	0.01	0.00	0.15	0.08	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.30	0.10	0.30	0.25	0.25	0.25	0.10	0.10
…	0.00	0.21	0.04	0.00	0.35	0.24	0.30	0.30	0.30	0.30	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00	0.10	0.10
Deepest	1.00	0.66	0.78	0.33	0.46	0.63	0.60	0.60	0.60	0.60	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00	0.15	0.15
Sediment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40
Depth	LOB	COR	CCA	OCT	SPG	CMB	INF	ECH	OYS	BIV	SES	EPI	GRS	ALG	MPB	LPP	SPP	DIN	PRO	JEL	SQU
Shallowest	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.40	0.20	0.20	0.20
…	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.20	0.20	0.20
…	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.20	0.15	0.15	0.15
…	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.15	0.15	0.15
…	0.10	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15
Deepest	0.15	0.40	0.40	0.40	0.40	0.70	0.10	1.00	0.40	0.40	0.40	0.90	0.90	0.90	0.90	0.00	0.00	0.00	0.15	0.15	0.15
Sediment	0.40	0.60	0.60	0.60	0.60	0.20	0.90	0.00	0.60	0.60	0.60	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00

Table A.4 (cont.)

DAY – ADULT	**Functional group**						
Depth	LZP	SZP	PB	BB	DC	DL	DR
Shallowest	0.05	0.05	0.15	0.00	0.00	0.10	0.10
…	0.05	0.05	0.15	0.00	0.00	0.10	0.10
…	0.05	0.05	0.15	0.00	0.00	0.10	0.10
…	0.25	0.25	0.15	0.00	0.00	0.10	0.10
…	0.30	0.30	0.15	0.00	0.00	0.30	0.30
Deepest	0.30	0.30	0.15	0.00	1.00	0.30	0.30
Sediment	0.00	0.00	0.10	1.00	0.00	0.00	0.00

NIGHT - ADULT

Depth	GAG	RGR	SCM	SSR	DSR	RSN	VSN	LUT	BIO	LRF	SRF	BDR	RDR	SEA	SCI	LDY	MUL	POM	SHP	SNK	FLT
Shallowest	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.25	0.03	0.00	0.03	0.00
…	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.03	0.00
…	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.07	0.00	0.07	0.01
…	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.02	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.00	0.07	0.03
…	0.20	0.20	0.20	0.06	0.20	0.20	0.20	0.05	0.00	0.15	0.05	0.20	0.20	0.20	0.16	0.00	0.10	0.07	0.00	0.13	0.18
Deepest	0.80	0.80	0.80	0.92	0.72	0.80	0.80	0.93	1.00	0.73	0.92	0.80	0.80	0.80	0.84	1.00	0.50	0.73	1.00	0.67	0.77
Sediment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Depth	ODF	SDF	YTN	BTN	LTN	OTN	SWD	WMR	BMR	BIL	AMB	JCK	KMK	SMK	SAR	LPL	DWF	MEN	PIN	MPL	SPL
Shallowest	0.06	0.17	0.90	0.90	0.80	0.80	0.90	0.90	0.90	0.90	0.00	0.16	0.00	0.08	0.00	0.55	0.10	0.90	0.00	0.34	0.46
…	0.03	0.06	0.05	0.05	0.15	0.15	0.05	0.05	0.05	0.05	0.00	0.03	0.00	0.08	0.00	0.05	0.07	0.05	0.00	0.02	0.05
…	0.03	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.05	0.00	0.12	0.00	0.06	0.07	0.05	0.00	0.02	0.05
…	0.09	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.18	0.00	0.05	0.19	0.00	0.00	0.01	0.07
…	0.19	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.22	0.00	0.05	0.27	0.00	0.20	0.08	0.10
Deepest	0.61	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.68	1.00	0.32	1.00	0.24	0.30	0.00	0.80	0.53	0.27
Sediment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Depth	TIP	BEN	LGS	FIL	SMS	RAY	BSH	WSH	PSH	OSH	DBR	SBR	MAN	MYS	DOL	DDO	LOG	KMP	TUR	BCR	SCR
Shallowest	0.00	0.01	0.15	0.60	0.01	0.03	0.60	0.60	0.60	0.60	0.40	1.00	0.40	0.00	0.30	0.05	0.25	0.25	0.25	0.05	0.05
…	0.00	0.01	0.01	0.03	0.01	0.01	0.30	0.30	0.30	0.30	0.30	0.00	0.30	0.10	0.20	0.05	0.25	0.25	0.25	0.10	0.10
…	0.00	0.03	0.02	0.03	0.01	0.01	0.03	0.03	0.03	0.03	0.30	0.00	0.30	0.20	0.20	0.10	0.25	0.25	0.25	0.10	0.10
…	0.00	0.09	0.01	0.00	0.16	0.08	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.30	0.10	0.30	0.25	0.25	0.25	0.10	0.10
…	0.00	0.20	0.03	0.00	0.35	0.23	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00	0.10	0.10
Deepest	1.00	0.66	0.78	0.33	0.46	0.63	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00	0.15	0.15
Sediment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40

Table A.4 (cont.)

NIGHT - ADULT **Functional group**

Depth	LOB	COR	CCA	OCT	SPG	CMB	INF	ECH	OYS	BIV	SES	EPI	GRS	ALG	MPB	LPP	SPP	DIN	PRO	JEL	SQU
Shallowest	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.40	0.20	0.30	0.20
…	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.20	0.30	0.20
…	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.20	0.15	0.30	0.15
…	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.15	0.04	0.15
…	0.10	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.03	0.15
Deepest	0.15	0.40	0.40	0.40	0.40	0.70	0.10	1.00	0.40	0.40	0.40	0.90	0.90	0.90	0.90	0.00	0.00	0.00	0.15	0.03	0.15
Sediment	0.40	0.60	0.60	0.60	0.60	0.20	0.90	0.00	0.60	0.60	0.60	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00

Depth	LZP	SZP	PB	BB	DC	DL	DR
Shallowest	0.30	0.30	0.15	0.00	0.00	0.10	0.10
…	0.30	0.30	0.15	0.00	0.00	0.10	0.10
…	0.25	0.25	0.15	0.00	0.00	0.10	0.10
…	0.05	0.05	0.15	0.00	0.00	0.10	0.10
…	0.05	0.05	0.15	0.00	0.00	0.30	0.30
Deepest	0.05	0.05	0.15	0.00	1.00	0.30	0.30
Sediment	0.00	0.00	0.10	1.00	0.00	0.00	0.00

DAY – JUVENILE

Depth	GAG	RGR	SCM	SSR	DSR	RSN	VSN	LUT	BIO	LRF	SRF	BDR	RDR	SEA	SCI	LDY	MUL	POM	SHP	SNK	FLT
Shallowest	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.00	0.02	0.00
…	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.02	0.00
…	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.11	0.02	0.00	0.02	0.00
…	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.02	0.01
…	0.20	0.20	0.20	0.03	0.08	0.20	0.00	0.03	0.00	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.13	0.00	0.13	0.06
Deepest	0.80	0.80	0.80	0.97	0.89	0.80	1.00	0.96	1.00	0.83	0.97	1.00	1.00	1.00	1.00	1.00	0.60	0.80	1.00	0.80	0.92

Depth	ODF	SDF	YTN	BTN	LTN	OTN	SWD	WMR	BMR	BIL	AMB	JCK	KMK	SMK	SAR	LPL	DWF	MEN	PIN	MPL	SPL
Shallowest	0.01	0.03	0.20	0.20	0.80	0.80	0.20	0.20	0.20	0.20	0.00	0.04	0.00	0.02	0.00	0.12	0.01	0.20	0.00	0.07	0.09
…	0.01	0.04	0.30	0.30	0.15	0.15	0.30	0.30	0.30	0.30	0.00	0.06	0.00	0.02	0.00	0.18	0.01	0.30	0.00	0.11	0.14
…	0.03	0.08	0.40	0.40	0.05	0.05	0.40	0.40	0.40	0.40	0.00	0.07	0.00	0.04	0.00	0.24	0.05	0.40	0.00	0.15	0.21
…	0.04	0.05	0.10	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.03	0.00	0.05	0.00	0.07	0.06	0.10	0.00	0.04	0.07
…	0.18	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.36	0.00	0.09	0.37	0.00	0.00	0.02	0.14
Deepest	0.74	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.73	1.00	0.51	1.00	0.29	0.50	0.00	1.00	0.61	0.35

Depth	TIP	BEN	LGS	FIL	SMS	RAY	BSH	WSH	PSH	OSH	DBR	SBR	MAN	MYS	DOL	DDO	LOG	KMP	TUR
Shallowest	0.00	0.01	0.03	0.13	0.00	0.01	0.03	0.03	0.03	0.03	0.40	1.00	0.40	0.00	0.30	0.05	0.25	0.25	0.25
…	0.00	0.01	0.05	0.20	0.00	0.01	0.03	0.03	0.03	0.03	0.30	0.00	0.30	0.10	0.20	0.05	0.25	0.25	0.25
…	0.00	0.01	0.07	0.27	0.00	0.01	0.03	0.03	0.03	0.03	0.30	0.00	0.30	0.20	0.20	0.10	0.25	0.25	0.25
…	0.00	0.04	0.02	0.07	0.08	0.04	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.30	0.10	0.30	0.25	0.25	0.25
…	0.00	0.17	0.02	0.00	0.33	0.16	0.30	0.30	0.30	0.30	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00
Deepest	1.00	0.77	0.82	0.33	0.59	0.77	0.60	0.60	0.60	0.60	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00

Table A.4 (cont.)

DAY – JUVENILE										**Functional group**											
Depth	GAG	RGR	SCM	SSR	DSR	RSN	VSN	LUT	BIO	LRF	SRF	BDR	RDR	SEA	SCI	LDY	MUL	POM	SHP	SNK	FLT
Shallowest	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.33	0.13	0.00	0.13	0.01
…	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.07	0.00	0.07	0.01
…	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.03	0.00
…	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.02	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.03	0.03
…	0.20	0.20	0.20	0.06	0.19	0.20	0.20	0.05	0.00	0.14	0.05	0.20	0.20	0.20	0.16	0.00	0.08	0.03	0.00	0.10	0.18
Deepest	0.80	0.80	0.80	0.92	0.71	0.80	0.80	0.93	1.00	0.72	0.92	0.80	0.80	0.80	0.84	1.00	0.48	0.70	1.00	0.63	0.77

Depth	ODF	SDF	YTN	BTN	LTN	OTN	SWD	WMR	BMR	BIL	AMB	JCK	KMK	SMK	SAR	LPL	DWF	MEN	PIN	MPL	SPL
Shallowest	0.13	0.32	0.90	0.90	0.00	0.90	0.90	0.90	0.90	0.90	0.00	0.22	0.00	0.32	0.00	0.61	0.30	0.90	0.00	0.35	0.55
…	0.05	0.11	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.00	0.06	0.00	0.16	0.00	0.10	0.14	0.10	0.00	0.05	0.11
…	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.08	0.00	0.02	0.07	0.00	0.00	0.01	0.03
…	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.10	0.00	0.02	0.12	0.00	0.00	0.01	0.04
…	0.16	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.12	0.00	0.02	0.17	0.00	0.20	0.07	0.05
Deepest	0.57	0.35	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.66	1.00	0.22	1.00	0.22	0.20	0.00	0.80	0.52	0.22

Depth	TIP	BEN	LGS	FIL	SMS	RAY	BSH	WSH	PSH	OSH	DBR	SBR	MAN	MYS	DOL	DDO	LOG	KMP	TUR
Shallowest	0.00	0.06	0.16	0.60	0.04	0.05	0.60	0.60	0.60	0.60	0.40	1.00	0.40	0.00	0.30	0.05	0.25	0.25	0.25
…	0.00	0.03	0.02	0.07	0.02	0.01	0.30	0.30	0.30	0.30	0.30	0.00	0.30	0.10	0.20	0.05	0.25	0.25	0.25
…	0.00	0.01	0.00	0.00	0.01	0.01	0.03	0.03	0.03	0.03	0.30	0.00	0.30	0.20	0.20	0.10	0.25	0.25	0.25
…	0.00	0.07	0.00	0.00	0.15	0.07	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.30	0.10	0.30	0.25	0.25	0.25
…	0.00	0.19	0.03	0.00	0.34	0.23	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00
Deepest	1.00	0.64	0.78	0.33	0.45	0.63	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.20	0.10	0.25	0.00	0.00	0.00

Table A.5. United States commercial catch reconstruction by functional group (tonnes).

	Year								
Group	1980	1981	1982	1983	1984	1985	1986	1987	1988
GAG	643.7	898.8	1069.9	788.4	703	819.7	771.8	697.7	551.8
RGR	1316.8	1542.5	1792.9	2715	2466.6	2598.3	2863.5	3047.2	2151.2
SCM	0	0	0	0	0	14.4	174	164.4	125.3
SSR	218.9	256.4	259	269.3	340	279.1	993.6	900.7	715.7
DSR	223.2	372.8	406.5	280.7	294.9	403.5	703	711.9	1002.2
RSN	2273.4	2706.1	2907.1	3302.6	2604.5	2013	1798.5	1522.7	1841.6
VSN	139.9	164.1	180.4	258.8	652.4	670.7	793.5	728.2	705.1
LUT	715.8	767.7	1194.2	1002.6	939.3	797.4	960.6	1226.2	1085.6
BIO	0	0	0	0	0	0	0	0	0
LRF	72.6	84.8	76.7	85	142.5	110.8	87.2	152.9	119.5
SRF	267	509.9	490.2	475.7	727.3	593	475.1	818.3	878.1
BDR	2691.9	2954.4	1932.2	2389.5	2691.5	3180.2	3455.5	4828.2	4748.5
RDR	1240.2	1249.7	1103.3	1422.1	1972.6	2881.8	6410.6	2223.9	136.5
SEA	2234.7	2112.4	1847	1921.3	1684.3	1491.8	1862	1878	1599
SCI	3474.5	3612.1	2147.5	1282	1121.7	939.6	844.1	1120.5	827.2
LDY	612.5	1814.4	1494.3	1888	1560.3	1342.9	2032.6	2322.7	1881.5
MUL	13896.6	15270.3	12211.1	11718.3	10292.9	9006.8	11899.1	10758.6	11602.5
POM	300.8	247.4	320.7	274.4	247	213.1	240.2	250.1	263.1
SHP	539.9	474.8	558.5	760.6	683.8	749.5	791.7	1518.3	1439.1
SNK	0	0	0	0	0	0	0	0	0
FLT	697.6	713.2	990.2	931.3	937.2	987	1034.5	1207.7	724.4
ODF	569.9	694.1	728.4	792.3	1292.8	1046.6	740.5	1377.7	1155.4
SDF	42.1	55.7	55.9	62.4	112.1	81.5	45.7	96.4	70
YTN	33	18.2	63.6	100.2	376.7	1505.9	3393.6	4179.4	7815.8
BTN	5.1	12.1	16.4	38.8	70	69.1	108.5	175	138.6
LTN	0.7	0.5	2.9	2.3	1.9	2.3	0.1	1.5	108.7
OTN	0	0	0	0	0	0	0	0	0
SWD	837.8	532.3	587.9	327.7	307.2	511.7	320.9	666.3	970.1
WMR	0	0	0	0	4.1	9.4	39.1	24.6	0.2
BMR	0	0	0	0	0.9	5	16.2	16.4	3.2
BIL	0	0	4.3	1.2	5	10.2	11.2	18.1	0
AMB	81.6	107.5	102.3	127.5	240.9	346.2	506.4	705.7	932.4
JCK	2424.6	2125.5	2335.1	2261.8	1679.1	1499.2	1414.9	2034	2868
KMK	1543.2	2399.6	662.4	1437.7	978.8	826.5	917	1109.1	865
SMK	887.9	1670.2	1524.1	1031.5	1596.8	1375.8	1244.5	1300.6	1054.4
SAR	1348.2	1264.6	1268.3	1217.6	1601.9	2069.4	2774.4	2925.9	1594.2
LPL	1226.1	860	869.7	705.8	641.8	588.2	631.3	684.2	1115
DWF	0	0	0	0	0	0	0	0	0
MEN	702081	553684.4	861426.8	962982	985411.7	884189.2	830743.7	911642.5	639787.1
PIN	34.6	45.9	46	51.4	92.3	67.2	37.6	79.4	57.6
MPL	71.8	91.8	115	125.5	180.5	132	68.5	151.8	128.3
SPL	158.2	334.2	824.5	939.2	415.7	406.2	1417.6	825.8	1678.8
TIP	60.6	60.6	60.6	65.5	89.5	83.1	596.5	825.1	1460
BEN	0	0	0	0	0	0	0	0	0
LGS	155.6	258.3	304.5	352.9	306.7	417.6	855.9	2052.8	3781
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0	0
RAY	0	0	0	0	0	0	40.2	0	77.7
BSH	49861.9	72678.6	56121.7	48553	62929.2	63706	72075.9	67305.6	59535.4
WSH	29835.2	32212.8	27443.7	29559.9	39196.7	41175.1	49417	37339.1	31600.1
PSH	9345.8	13625.5	8454.8	9196.7	10632.4	11526.7	8502.1	7557.5	6583.4
OSH	6276	4700.6	3073.6	3772.8	3546.5	3491.3	8644.1	5572.3	4855.6
TUR	0	0	0	0	0	0	0	0	0
BCR	19444.9	19248.4	16761.2	18362.6	25558	25335.4	24047.6	35592.7	35992.1
SCR	1710.6	1894	2583.3	2173.4	1798.3	1847.2	1834.9	2160.4	2367.2
LOB	2594	2292.7	2594	1708.4	2772.1	2787.6	2010.5	2513.2	2648.5
SPG	0	0	0	0	0	0	0	0	43.8
CMB	0	0	0.2	0.9	0	0	0.6	0.5	1.5
OYS	7039.7	8785.8	11408.8	13229	12520.5	12024.8	10220.3	8515.2	8103.4
BIV	7.9	21.3	5.9	17	44	55.6	8	8.9	33.5
SQU	26.9	43.9	35	32.1	55.4	67.2	80.1	75.3	104.7

Table A.5. (cont.)

				Year				
Group	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
GAG	767.9	814.4	710.1	754.8	847.6	734.4	751.1	712.6	727.4
RGR	3342	2181.5	2310.8	2024.5	2893.8	2223.9	2152.8	2020.4	2199.2
SCM	137.5	131.7	163	146.8	164	112	123	122.5	153.4
SSR	967.2	919.1	715.1	625.5	1049.3	747.5	545.1	646.6	572.8
DSR	548.1	817.3	741.2	813.7	679.9	939.7	698.7	513.4	610.4
RSN	1406.1	1207.5	1016.5	1380.3	1544.5	1475.1	1339.9	1973.6	2187.7
VSN	752.4	1113.1	814.1	1028.7	1233.6	1197.1	987.9	828.8	964.3
LUT	1348	1213.6	1396.2	1324.1	1700.4	1500.9	1267.2	1070.3	1202.3
BIO	0	0	3.6	1.5	0.3	0.5	0.5	0.3	0.4
LRF	170.2	198.6	198.3	202.7	465.3	361.7	250.5	273.5	266.2
SRF	812.9	829.3	812.2	831.5	1846.9	1396.3	1026	1128.4	1200.1
BDR	2490	1722.4	1215.7	1801.4	1890.9	2596.1	2737	2729.9	2569.6
RDR	81.6	9.5	17.3	35.2	58.7	32.6	19.3	25.9	21.7
SEA	1485	1010.3	1312.8	1131.5	1552.5	1446.2	882.3	806.6	686.5
SCI	1071.1	1171.8	1154.2	1258.8	2232.4	1683.1	1765.3	1294	1277.8
LDY	2073.1	2629.7	2058.3	2073	1819	1935.4	1245.1	844	858.1
MUL	12818.3	13307.5	11624.9	11675.4	13804.4	12392.1	9624.6	7023.6	7941.1
POM	245.9	327.6	278.5	253.6	253.1	266.4	179	120.6	261.9
SHP	1927.4	1796.3	1472.6	1880.7	2113	1964.9	1818.6	1558.8	1685.3
SNK	0	0	0	0	0	0	0	0	0
FLT	813.8	831	1062.9	1022.7	1712.5	1399.9	995.8	847.3	841
ODF	1550.8	1765.6	1859.3	1666	3971.5	2841.7	1932.8	2338.9	2254.6
SDF	105.3	121.7	123.7	119.2	338.8	221.4	144	192.2	186.7
YTN	5786.2	3665	2567.7	4229.4	2910.3	2105.4	1588	2125.2	2407.4
BTN	66.4	102.1	120.4	81.4	47	34.2	26.9	22.5	16.9
LTN	49.2	51.6	51	460.7	263.7	28.4	29.5	89.1	171.9
OTN	0	0	0	0	0	0	0	0	0
SWD	957.1	445.8	632.5	590.1	466.9	339	583.6	752.9	593.8
WMR	0	0	0	0	0	0	0	0	0
BMR	0	0	0	0	0	0	0	0	0
BIL	0	0	0	0	0	0	0	0	0
AMB	886.9	555.2	817.3	461.2	729.5	578.2	573.1	576.6	507.4
JCK	3101.6	2981.6	3031.7	3062.6	3497.9	2499.3	1403.1	661.1	766.1
KMK	788.7	912.4	881.4	1045.9	1352.3	1140	1007.7	1363	1367.4
SMK	1448.2	1212.7	1646.6	1816.2	1303.6	1310	769.1	412.6	367.3
SAR	1079.1	974.4	760.8	848.4	772.2	984.2	173	498.6	413.3
LPL	1177.4	1258.3	1881.7	1814.9	1728.6	1958.5	1387.8	1211.4	1287.6
DWF	0	0	0	0	0	0	0	0	0
MEN	583185.8	539421.6	552946.5	432763.4	551534.6	774825.8	472059.7	491689.1	622013.7
PIN	85.8	99.5	106.6	112.9	296.5	221.3	128	166.5	168.3
MPL	234.3	243.7	250.3	290.6	635.3	487.2	354.7	383.7	333.6
SPL	4339.6	2160.8	2475.8	2676	3216.9	3059.7	2082.6	2449.5	2425.9
TIP	1594.7	960.3	388.2	444.6	476.8	1002.3	708.7	489.9	377.6
BEN	0	0	0	0	0	0	0	0	0
LGS	5543.5	4005	3505.5	3237	1757.1	2000.1	1914.3	1827.7	1727
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0	0
RAY	224.9	280.9	132.7	122.9	73.3	33.8	45.3	8.7	0.1
BSH	69213.4	76343.7	64545.4	50898.6	50212.5	49684.1	57209.3	55140.8	49559.2
WSH	25567.2	30912.2	32000.3	33681.8	27581.2	32467.8	34996.8	25561.6	27993.3
PSH	6274.6	5470.3	4921.5	4651.9	6937.8	7313.9	10356.9	13969.2	9227.5
OSH	4362.6	3183.9	3311.3	10745.2	8642.4	5862.2	4241	7716.2	9957
TUR	0	0	0	0	0	0	0	0	0
BCR	25240.2	26467.1	29866.1	31664.8	29781.1	24164.4	24800.9	28331.3	29095.9
SCR	2337.2	2853.7	2843.4	3013.5	3021.5	2976.1	2713	2924.7	2897.2
LOB	3265.1	2467.1	2762.1	1840.7	2066.8	2885.6	3537.6	3386.7	3276.1
SPG	277.5	360.5	381.2	338.9	338.7	387.8	357.4	324.3	236.4
CMB	0	0	0	0.7	1.1	1.3	0	1.7	1.4
OYS	7177.7	5600	5607.1	7414.2	8252.6	9219.5	10016.8	10571	10881.1
BIV	1322.2	28.7	0.4	2.7	2206.9	868.9	23.8	94.2	180.8
SQU	61.4	58.4	38.7	69.2	54.2	64.5	70.6	97.2	68.7

Table A.5. (cont.)

					Year				
Group	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
GAG	1151.8	952.3	1053.9	1470.5	1385.6	1239.8	1369.9	1233.8	661.3
RGR	1799.5	2705.3	2646.6	2697.4	2678.4	2239.5	2605.2	2454.4	2333.2
SCM	115.9	138	104.4	143.3	163.4	168.3	172.6	164.9	117.3
SSR	506.8	530.8	521.9	370.6	343.9	364.9	347.2	221	217.9
DSR	513.8	763.6	899	737.5	756	976.4	767.6	664.1	614.8
RSN	2129.2	2212.2	2197.2	2116.5	2187.7	2016.2	2121.4	1863.7	2103.5
VSN	785.9	899.2	662.2	778	911.1	1095.8	968.1	847.4	800.3
LUT	1056.5	1178.2	1108.9	977.7	996.5	936.3	1009.8	856.1	836.8
BIO	0.2	0.3	0.2	0.1	0.3	1.1	0.4	0.7	0.4
LRF	203	239	246.5	133.2	166.2	142.8	141.4	82.1	87.8
SRF	940.3	950.2	916	602.1	648.6	588.7	614.4	542	437.6
BDR	2066.2	2308.3	2630.1	2560.1	2510.1	2379.4	2526.1	2060.4	1909.5
RDR	24.4	26.2	24.6	13.8	11.4	13.3	11.2	15.5	12.2
SEA	393.2	403	342	239.2	219.3	177	145.3	113.8	107.7
SCI	992.9	972	856.8	477.1	423.3	402.8	378.9	246.4	280.8
LDY	970.4	1917.3	154.8	544.2	760.5	866.2	665.1	870.8	795.8
MUL	7153.1	9092.1	7625.7	7295.6	5742.8	5877.3	6237.1	4092.6	5772.9
POM	305.8	210.5	222.6	166.1	135.9	130.1	108.8	102.8	160.9
SHP	1299.6	1661.8	1433	1186.3	1036.3	1072.1	911.3	681.5	442.5
SNK	0	0	0	0	0	0	0	0	0
FLT	729.4	774.7	695.9	435.2	438.6	385	370.4	281.8	277.5
ODF	1794.4	1778.6	1706.3	1125.4	990.6	968.7	879.4	641.2	577.7
SDF	140.3	136.1	124.1	59.6	56	53	48.5	31.6	36.7
YTN	1721.3	2369.2	1957.1	1329.6	1927.4	1711.6	1584.6	1202.1	1096.2
BTN	13.7	36.1	34.5	16.9	29.5	38.5	66.3	43.5	16
LTN	105.3	232.1	54.1	193.3	207.6	506.2	81.1	110	144
OTN	0	0	0	0	0	0	0	0	0
SWD	510.5	447.8	467.8	347	413.2	375.7	402.4	345.8	267
WMR	0	0	0	0	0	0	0	0	0
BMR	0	0	0	0	0	0	0	0	0
BIL	0	0	0	0	0	0	0	0	0
AMB	317.6	354.2	415.7	332.9	357.2	451.1	442.7	337.4	286.9
JCK	1176.7	891.7	835	878.9	775.8	967.6	1013	956.1	736.8
KMK	1374.7	1363	1135.5	1281.9	1218.1	1098.2	1273.6	1113.9	1515.1
SMK	303.9	552.1	610.3	701.8	533.8	839.6	617.4	819.5	820.3
SAR	371.5	312.4	621.7	626.6	653.4	725.3	964	458	1023.2
LPL	1162.7	947.4	840.7	1018.6	1024.6	982.8	894.7	539.2	623.9
DWF	0	0	0	0	0	0	0	0	0
MEN	495684.2	694272.6	591487.6	528569.9	585341.5	518362.8	464162.4	369914.8	408881.9
PIN	128.9	124.3	116.2	64.4	61.1	62.2	60.4	46.3	52.5
MPL	274.7	280.5	274.5	192.9	175	190.4	199.7	131.1	180.6
SPL	2543.2	2559.8	2453.7	2675.8	2919.6	2311.9	2728.5	2012.7	1327.2
TIP	521.8	436.8	351.8	329	250.9	597.4	368.9	242.2	364.8
BEN	0	0	0	0	0	0	0	0	0
LGS	1924.3	691.7	658	775.9	1053.2	1230.2	1059.9	907.2	1238.4
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0	0
RAY	10.2	0.4	23.4	0	22.1	1.3	6.6	0.6	8.6
BSH	59092.6	60651.8	71592.5	65725.2	55472.7	62187.3	54625.3	43559.1	64925.7
WSH	39036.9	39187.3	49640.8	37874.8	38050.8	43369.7	51317.1	46179.7	60594.6
PSH	12436.6	5912.8	5417.9	7000.7	7760.6	6844.1	7015.1	6508.3	4379
OSH	9517.6	4902.7	4391.8	6020.2	4776.8	4178.2	3086.1	1938.6	1189.7
TUR	0	0	0	0	0	0	0	0	0
BCR	30715.2	31432.3	31283.1	24722.9	29953.2	29088.6	27484.8	22718.3	30612.2
SCR	3171.8	2579.9	3109.9	3031.1	2918.7	2409.1	2708.8	2058.9	2180.5
LOB	2530	3270.3	2557.2	1479.4	1914	1774.6	2099.2	1394.3	1983.5
SPG	280.2	285.1	268.1	235.8	234.2	187.3	202.1	185.5	140.2
CMB	1.2	0.7	0	0	0	0	0	0	0
OYS	9349.9	10946.5	11699.9	11622	10939.2	12291.5	11365.6	9158.7	8925.2
BIV	1293.1	1267.7	250.6	230.9	218.3	257.6	121.1	97.5	43.6
SQU	108	58.5	57.6	85	55.5	55.1	49.1	34.4	45.8

Table A.5. (cont.)

			Year		
Group	**2007**	**2008**	**2009**	**2010**	**2011**
GAG	621.3	678.6	384.6	264.9	161.4
RGR	1670.5	2141.6	1990.8	1582.6	2512
SCM	147.4	149.4	135.9	84.1	69.3
SSR	251	166.2	136.8	126.3	245.2
DSR	673.7	650.7	696.5	422.2	620.9
RSN	1360	1074.2	1135.3	1478.3	1605.7
VSN	1081.3	1273.8	1722.2	956.9	1391.3
LUT	654.7	831.1	1072.7	879.6	1043.4
BIO	1.2	0.7	0.8	0.6	0
LRF	113.3	99.3	99.1	71.5	143.6
SRF	561.9	538.5	482.2	344.5	641.4
BDR	1907.3	1838.2	2254.9	2079.4	2402.6
RDR	14.1	15.6	17.1	18.7	18.2
SEA	175.6	149	146.3	129.8	225.8
SCI	446.2	357.9	320.3	295	597
LDY	547.3	664.5	389.2	660.5	415.3
MUL	4052.1	4799	5126.8	4064	6455.8
POM	156.3	147.3	125.5	39.4	33.2
SHP	631	664.3	690.6	611.3	562.2
SNK	0	0	0	0	0
FLT	347.8	303.9	307	236.9	508.5
ODF	897.1	801.3	884.1	680.7	1416.8
SDF	64.7	49.7	43.3	37.2	91.4
YTN	1348.8	731.3	1114.4	302	658.1
BTN	32.9	25.2	17.4	20.5	3.1
LTN	127.7	34	119.6	266.2	26.7
OTN	0	0	0	0	0
SWD	337.9	301.2	398.4	174.1	320.4
WMR	0	0	0	0	0
BMR	0	0	0	0	0
BIL	0	0	0	0	0
AMB	280.6	228.7	287.1	452.4	386.4
JCK	834.9	647.4	599.3	633.2	681
KMK	694.6	1017.5	1306.6	1042.8	1208.2
SMK	500.6	610.9	890.5	615.7	660.9
SAR	3.8	986	628	909.3	5.4
LPL	731	768.3	1081.5	271.9	1007.6
DWF	0	0	0	0	0
MEN	456034.1	420734.8	528882.8	438650	623408.5
PIN	88.3	61.2	53.8	134.2	102.9
MPL	213.7	185.9	155.3	158.3	165.5
SPL	1395.2	1867.6	2009.5	1496.9	1565.7
TIP	382.2	117.3	121.4	175.4	228.7
BEN	0	0	0	0	0
LGS	477.9	585.6	650.9	652.9	471
FIL	0	0	0	0	0
SMS	0	0	0	0	0
RAY	5.5	15.4	2.8	1	3.2
BSH	52838.1	36466.2	56968.4	33909.1	54333.2
WSH	46157.7	44995	53315.2	42053.1	41705.1
PSH	2449.4	3286.9	3132.5	4539.3	3845.3
OSH	1171.1	894.8	581.4	1006.9	1746.2
TUR	0	0	0	0	0
BCR	26416.7	22346.4	27795.8	18694.7	25464
SCR	2686.7	2777.6	2420.4	2318.8	2512.9
LOB	1558.4	1355.4	1792.4	2398.3	2438.3
SPG	200.8	184.3	91.5	100.9	46.7
CMB	0	0	0	0	0
OYS	10262.4	9369.8	10358	7199	8439.7
BIV	59.4	66.5	68	70.7	76.3
SQU	23	33.2	30.4	39	60.4

Table A.6. United States recreational catch reconstruction by functional group (tonnes).

	Year								
Group	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**
GAG	992.2	829.9	1459.2	2893.6	884.7	2980.5	1631.8	1110.3	1699.8
RGR	446.1	446.1	739.6	1577.6	3218	1533	1088.8	664.4	1123.1
SCM	34.1	34.1	40.6	54.9	5.2	6.9	52.4	10.1	19.4
SSR	1236.6	1236.6	1347.4	4753.9	1678.5	2507.4	4026.8	2311.6	2976.2
DSR	21090.8	21090.8	22237.9	12566.1	12845.7	87930.8	22805.7	10596.5	9651.9
RSN	3669.7	3669.7	3255.4	5683.7	2095.1	2069.7	1816.5	1455.6	1757.4
VSN	52.2	52.2	6.1	34.3	44.9	128.4	482.3	500.2	665.1
LUT	138125.2	138125.2	1535.9	64608	123888.6	7214.3	29803.7	54095.4	46023.9
BIO	19.4	19.4	5.6	139.7	16.8	8	14	15.5	4.7
LRF	941.7	941.7	561.3	1262.1	2526.9	233.8	249.4	2004.8	277.2
SRF	2175.8	2175.8	5854.4	1239.6	860.1	660.8	2089.8	2728.3	1002.6
BDR	685.7	685.7	1349.4	1589.8	800.5	912.8	1350.7	1799.6	1098.9
RDR	2248.2	2248.2	3428.2	3703.3	3577.6	3435.9	2853.5	2675.4	1820.1
SEA	8504.4	8504.4	10298.5	12081.6	11544.1	10475.4	12391.3	1665.1	8085.3
SCI	1327.5	1327.5	1303.7	1112.4	1010	1045.2	1442	120.4	583.6
LDY	528.9	528.9	216.2	128.5	206.8	234	172.2	130.1	152
MUL	979.3	979.3	1064.9	6272.4	10711.2	11478.4	6321.3	2674.9	3190
POM	11.4	11.4	64.6	345.6	98.6	29.1	60.9	62.4	30.4
SHP	875.8	875.8	1104.8	2032.6	1499.7	1575.1	1164.5	985.8	2181.2
SNK	31	31	23.6	35	0	16.8	7.2	18.8	19.8
FLT	312.9	312.9	3096.9	4475.3	774.4	913.4	897.4	448.8	557.8
ODF	40392.9	40392.9	232027.2	57408.7	60719.3	287598.9	245347.4	214242.1	313932.5
SDF	0.9	0.9	9.5	2.5	2.2	0.6	0.9	0.5	6.5
YTN	0	0	71.3	0	109.6	0	115.4	13.7	48.6
BTN	0	0	0	4.1	9.5	0.4	2.8	6.2	0.7
LTN	293.7	293.7	419.7	292.4	190.4	167	743.4	610	568.7
OTN	6	6	5	0.6	0.5	0	1.7	2.7	0
SWD	0	0	0	0	0	0	0	0	0
WMR	87.6	81.3	30.5	12.2	16.1	6.1	5.7	16.9	3.7
BMR	43.1	66.4	3269.1	3754	453.2	11427.4	1203.9	799.3	4995.3
BIL	464.9	464.9	762.6	13	682.8	15	268.8	207.7	71.7
AMB	261	283.7	2094.5	1220.8	592.8	1055.3	2634	2106.8	1024
JCK	1828.7	1828.7	8004.8	30669.1	13265.5	7785.2	9947.4	8595.2	7307.7
KMK	1695.1	4536.1	5949	2360	2521.8	1309.9	1452.2	3493.6	2704.1
SMK	65.7	65.7	65.7	3717.3	1504.7	1619.5	11585.1	143.4	24.3
SAR	3.9	3.9	2	7.9	10.7	22.1	0	1.2	0
LPL	21673.1	21673.1	12376.3	15977.2	8819.5	12481.2	25097.2	15537.4	10401.7
DWF	0	0	0	0	0	0	0	0	0
MEN	210	38	54	24	5	449	258	209	488
PIN	368.7	368.7	423.7	372.1	622.6	217.8	363.2	188.5	375.1
MPL	98	98	117.6	88.6	4.1	9.4	160.9	65.4	11.9
SPL	279.3	279.3	170.5	364.4	254.9	54.5	50.7	239.1	103.5
TIP	45.8	45.8	162.9	29.1	60.3	250	500	184.8	397.2
BEN	0	0	0	0	0	0	0	0	0
LGS	9068.6	9068.6	7832.1	10199.8	12170.8	11404.7	16225.9	7752.1	15590.6
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0	0
RAY	25.1	25.1	109.7	77	379.8	466.7	146.4	77.9	199.6
LOB	640.2	798.9	692.8	717.2	535.7	582.3	564.5	528.1	627.5

Table A.6. (cont.)

	Year								
Group	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
GAG	1049.8	571.5	1246.6	1018.7	1264.6	907.1	1224.8	1067.5	1167.1
RGR	1252.5	511.5	805.2	1205.1	948.5	820.2	844.8	405.4	255.1
SCM	21.5	2.3	8.6	14.8	17.5	31.5	2.2	5.5	30.6
SSR	1846.4	353.6	236	233.9	225.6	243.6	214.5	210.1	269.5
DSR	45938.7	15256	3815	1195.6	3289.8	3629.9	3518.9	732.6	570.3
RSN	1537.4	964	1511.7	2217.9	3002.3	2263.6	1936.4	1674.6	2252.8
VSN	416.1	570	627.4	657	581.2	477.9	594	283.2	300.6
LUT	27297.3	31589.9	37691.2	39300.8	40448.9	19691	24318.1	15058.2	10916.5
BIO	61.5	19.2	2.8	0	3.1	36.3	9	2	0
LRF	106.7	742.2	157.7	516.5	576.6	644.8	432	267.4	267.4
SRF	695.3	645.4	820.2	688.3	762.2	795	768.4	982.1	1156.8
BDR	936.3	463.1	619.9	773.2	775.4	664.3	713.5	651.7	915.7
RDR	3050.1	2201.9	2724.9	4004.6	4736.5	4161.4	6144.5	6016.4	6132.4
SEA	6172.4	3781.7	6523.2	4760.3	4591.2	5466.8	5558.2	5332.6	5209.1
SCI	249.1	262.6	475.9	318.5	194.8	282.7	264.5	310.5	253.1
LDY	65.3	58.3	39.2	105.2	30.7	84	47.5	62.6	40.1
MUL	1072	388.8	1860.5	1067.3	1501.1	908.9	660.2	1023.2	699.9
POM	50.4	4.1	564.4	82.3	18.5	48.6	65.3	54.7	36.2
SHP	2346.3	1216.3	1538.3	2346.5	2201.8	1378	2405.3	1726.1	1959.6
SNK	8.8	0.6	7	12.8	14.8	6.1	10.9	5.8	48.1
FLT	318.7	579.9	676.5	371	348.8	292.9	282	222.9	251.6
ODF	74275	88709.9	82406.3	38978	51599.6	61849.9	76264.3	66112	60576.2
SDF	5.5	0	0.6	0.7	2.1	0.6	1	0.8	2.7
YTN	20.2	0	39.2	76.6	312.5	30.9	0	2.9	34.8
BTN	0	0	1.9	0	0	15.1	0	0	0
LTN	308	655.1	1106.1	679.6	412.1	609.7	369.4	359.6	282.4
OTN	0	0.7	0	0	0	0	0	12.7	2.9
SWD	0	0	0	0	0	0	0	0	0
WMR	0.7	1.1	1	1.1	0.6	1	0.8	0.6	0.8
BMR	18.1	16.5	196.2	16.4	9.4	17.1	18.6	10.7	13.5
BIL	12.5	75.7	144.6	34.6	122.6	56.9	81.9	122.4	5.7
AMB	1588.8	429.8	1345.7	1132.2	1370	732.5	394.2	583.8	538.4
JCK	23103.9	6003.4	9699.6	4751	69465.3	17795.4	6885.5	3614.3	5165.3
KMK	2237	3162.3	4872.4	3236.6	4144.6	4428.8	4059.7	4750.9	4461.1
SMK	1759.7	2140.8	2587.2	3060.5	1931.6	1702.4	1677.1	1265.6	1218
SAR	0.4	26	2.2	0.5	0.2	0	28.7	0.9	0.3
LPL	13981.1	8613.7	12145.9	13422.1	17121.7	11245.4	18779.2	13452.6	20680
DWF	0	0	0	0	0	0	0	0	0
MEN	440	135	51	138	170	189	56	82	20
PIN	309.7	257.5	364.8	402.4	446.7	475.3	547.3	397	604.4
MPL	48	57.7	3.5	14	27.1	28.8	15.9	26.5	229
SPL	85.4	59.2	366.7	136.6	158.9	168.7	387.3	147.1	175.6
TIP	322.1	300.1	302.1	274.9	128.6	88.6	154.6	170.1	236.9
BEN	0	0	0	0	0	0	0	0	0
LGS	8700.2	6216.1	3521.7	1953.5	2903	2462.7	2890	5336.8	3130.8
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0	0
RAY	170.2	113.2	43.8	43.6	22.6	36.3	33.4	30.4	4.8
LOB	841.3	827.3	720.7	963.4	613.4	854.2	830.6	845.3	847.3

Table A.6. (cont.)

Year

Group	1998	1999	2000	2001	2002	2003	2004	2005	2006
GAG	1596.3	1688.2	2255.5	1828.6	2011.9	1711.5	2228.7	1618.1	1087.3
RGR	291.7	522.9	956	602.3	730.8	578.7	1377.6	664.5	420
SCM	36.9	46.7	12.3	26.4	26.1	30.6	55.6	34.9	66.3
SSR	177.2	108.9	105	59.5	88.4	107.9	218.3	123.5	108.3
DSR	1096	1018.4	373.3	635.7	608.4	512.5	895.1	1098.3	621.9
RSN	1769.8	1434.9	1428.4	1537.3	1982.2	1819.9	1866.2	1489.7	1735.3
VSN	152	204.5	161.8	303.7	248.3	288.9	396.4	123.2	161.5
LUT	9706.1	14222.9	3585.5	3317.8	9390.9	16721.9	8973.8	3028.6	25879.3
BIO	0	0	0	2.4	0	1.5	2.9	0	0
LRF	252.3	267.2	156	183.4	240.1	314.7	412.5	278.3	234.6
SRF	497	535.1	411	595.4	460.7	643.8	795.6	606.5	488.5
BDR	1052.7	658.5	1610.9	1224.8	1238.9	1403	1341.9	1106.9	1146
RDR	4492.1	4984.2	7260.7	6771.9	5907.1	6706.5	7321.6	5640.4	6080.8
SEA	3636	5318.4	4501.9	3744.6	3379.4	2848.5	3254.7	2951.2	3508
SCI	322.9	358.3	329	625.4	231.7	271.8	208.1	153.2	193.3
LDY	93.4	46.3	124.3	130.9	77.4	223.1	299.3	156.2	265.7
MUL	642.6	741.1	1102.2	917.9	415.4	442.7	531.3	732	1172.4
POM	383	72.5	47.4	93	75.9	43.5	142	34.5	244.1
SHP	1790.2	1815.2	1698.2	2168.9	1900.6	2440	3147.7	2531.8	1489
SNK	13.7	29.8	10	16.9	10.4	8	35.4	4.9	3.8
FLT	233.2	327.7	189.6	262.7	197.7	189.8	198.6	133.7	104.3
ODF	40935.4	31167.5	29843.4	38494.5	34102.4	40969	67956.9	44269.9	48908.3
SDF	1.7	0	4.3	0.1	2.2	0	0	0.1	0.2
YTN	57.1	115.1	112.8	350.3	141.9	455.6	267	288.1	337
BTN	0	0	0.6	0	0	0	0	3.4	0
LTN	313.3	311.4	259.1	268.9	398.7	269.2	484.7	158.6	292.7
OTN	0	0	0.6	0	0	0	0	0	0
SWD	0	0	0	0	0	0	0	33.4	0
WMR	0.2	0.1	0	0.1	0	0	0	0	0
BMR	5.7	10.3	6.2	6.8	6.4	60.6	3211.9	6.5	8.9
BIL	45	33.6	3.7	0	0	2	0	0	8.5
AMB	295.1	384.7	470.6	571.1	928.8	1206.6	1080.2	655.3	640.5
JCK	8563.5	7714.4	19771.1	13856	8727.9	7732	8953.6	4109.1	8870.1
KMK	3782.1	2971.1	3498.6	3442.4	3573.4	2996.3	2883.3	2537.1	4937.2
SMK	1247.8	1854.7	1781.7	3233	2110.6	1909.6	3230.7	1678.3	2656.6
SAR	3.4	2.6	0.9	4	16.8	13.6	8.5	3.5	28.5
LPL	23391.2	17655.7	17692.6	11270.6	9787.2	9947.1	14615	9106.1	19110.4
DWF	0	0	0	0	0	0	0	0	0
MEN	47	51	207	48	108	118	64	48	55
PIN	788.1	487.7	852	708.7	761.1	789.4	1253.2	587.2	395.9
MPL	44.8	12.3	19.2	11.4	8.2	16.9	61.8	0.1	21.5
SPL	146.7	112.1	90.4	456	266.2	364.8	568	260.5	1234.2
TIP	173.9	132	287.4	163.2	134.1	89.7	125.6	134.2	73.1
BEN	0	0	0	0	0	0	0	0	0
LGS	2062.8	1366.1	1599.6	2325.8	1092.4	950.7	1461.6	908.4	1105.8
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0	0
RAY	0.5	7.9	6.8	5.6	8.8	8.1	1.5	18.6	0.5
LOB	1022.5	568.4	1088.8	870.7	540.1	607.7	572.1	572.1	572.1

Table A.6. (cont.)

			Year		
Group	**2007**	**2008**	**2009**	**2010**	**2011**

GAG	1001.3	1369.5	579.8	604.3	262.8
RGR	435.3	390.5	444.7	338.5	290.2
SCM	32.2	49.6	40.3	22.6	25.2
SSR	138.8	118.3	91.4	10.5	20.9
DSR	390.5	451.9	568.3	348.6	817.3
RSN	1932.8	1249.2	1666.9	799.2	1626.6
VSN	176.8	161.2	167.6	114.3	302.8
LUT	34000.6	30384.9	12403.3	9761.6	5762.6
BIO	0.6	0	0	0	0
LRF	274.5	274.3	205.2	177.1	178.3
SRF	585.1	842.2	434.7	2709.7	592.7
BDR	1285.1	1613.7	1357.1	1310.5	1313.5
RDR	6801.2	7327.1	6141.1	6870.8	7945.6
SEA	3234	3250.7	2887.2	1764.6	3216.5
SCI	122.8	174.3	102.1	127.6	129.4
LDY	145.2	358.1	206.9	151.7	150.7
MUL	500.2	750.1	192.8	521	787.9
POM	61.4	156.7	37.9	36.9	11.1
SHP	1700.7	2106.8	1847.7	1606.1	3289.8
SNK	3.9	1.7	3.1	0	0
FLT	146.6	118.2	133	122.4	184.6
ODF	79342.7	79270.3	48483.9	70510.6	139676.5
SDF	0.4	0.1	0	1.6	0
YTN	204.7	444.4	121.1	18.4	417.4
BTN	0	0	0	0	0
LTN	265.5	200.4	235.7	192.1	198.6
OTN	4.3	0	0	0	0
SWD	0	47.1	308.1	24.3	7.1
WMR	0	0	0	0.1	0
BMR	4.5	3.5	3.4	2.2	4.3
BIL	3.4	0	0	0	0
AMB	489.2	589.8	723.2	675	430.2
JCK	20958.2	13329	15333.2	7257.1	2957.1
KMK	1884.8	881.6	1789.2	869.1	855.8
SMK	1818.6	2614.1	1651.6	1795.1	1944
SAR	3.6	3.8	0.7	0.3	0.4
LPL	16336.7	17906.4	18674.7	8642.5	17294
DWF	0	0	0	0	0
MEN	30	28	61	44	78.7
PIN	632.7	921	364	920.6	680.1
MPL	29.8	36.6	18.6	0.5	0.5
SPL	559.8	735.5	1805.4	476.6	166.1
TIP	102.9	29.8	42.6	57.3	75
BEN	0	0	0	0	0
LGS	825.9	442.7	694.4	3318.4	716
FIL	0	0	0	0	0
SMS	0	0	0	0	0
RAY	0.3	13.4	0.3	1.9	9.5
LOB	572.1	572.1	572.1	572.1	572.1

Table A.7. Mexico catch reconstruction by functional group.

Year

Group	1980	1981	1982	1983	1984	1985	1986	1987	1988
AMB	1242.8	1906.2	1590.4	655.7	883	704.2	294.3	547.3	1062.4
BCR	6282.7	9142.2	10864	6841.4	6784.1	6304.8	4891.7	5569.2	12042.1
BFS	1240.2	1905.8	1624.4	701.5	940.1	753.8	332	587.1	1145.6
BIL	1219.2	1874.4	1590.4	655.7	883	704.2	294.3	547.3	1062.4
BIV	3176	3756.8	3784	2477.4	3148.2	2292.7	1943.6	1635	2200
BMR	1219.2	1874.4	1590.4	655.7	883	704.2	294.3	547.3	1062.4
BSH	22946.2	25402.5	19493.1	18763.3	20866	20304.3	19104.9	18732.5	37423.7
BTN	1219.2	1874.4	1591.7	662	893.8	710	301.1	547.7	1068.2
CMB	3006.4	4316.6	4927	2144.4	4367.5	2714.5	1452.8	1879.1	4550.5
DSR	1619.3	2283.2	1977.8	962.6	1225.3	1097.8	679.3	1042.2	2233
FLT	1263.7	1963.3	1634	655.7	883	704.2	294.3	547.3	1062.4
JCK	2662.5	3829.4	4439	3598.7	4711.3	2610.2	1968.1	2375.3	4322.8
KMK	3186.4	4415.5	4957.4	655.7	883	704.2	294.3	547.3	1062.4
LGS	4310.2	8466.3	8746.8	9013.9	10056.2	8787.6	7958.1	8008.5	17597.7
LOB	1436.7	2073.3	1904.7	889.8	1166.6	904.1	514	884.5	2311
LOG	2.5	3.8	14.8	147.6	101.3	89.7	0.2	0.4	0
LPL	4431.1	6160	7341.3	3315.8	3808.7	3358.6	3090.1	3475.7	5186
LRF	1339.9	2416.9	1884.4	655.7	883	704.2	294.3	547.3	1062.4
LTN	1291.3	2057.7	1763.2	655.7	1220.5	799	294.3	547.3	1062.4
LUT	2590.4	7111.4	3963.6	693.3	916.9	738.6	360.2	589.6	1150.5
MPL	12575.3	23615.1	32905.5	8365.9	7870.1	7051.8	5727.5	7096.3	15792.3
MUL	7930.6	6968.3	7424.5	4695.4	6100.2	4472.6	8948.9	9675.4	19754.9
ODF	4878.8	7587.9	7733	695.7	3369.6	3246.1	2725.6	4192.4	8397.9
OSH	1702	2397.3	1988.3	1058.1	1327	1139.8	712.3	951.4	1870.4
OYS	47763.2	36080.7	29167	31051.9	38086.6	36430	35177.4	42572.7	95458.6
PIN	1472.8	2187.9	1906.6	655.7	883	704.2	294.3	547.3	1062.4
POM	1465	2045	1764.6	655.7	883	704.2	294.3	547.3	1062.4
PSH	2184.8	2920.1	2386.1	1460.5	1771.1	1575.3	1130.4	1355.6	2678.4
RAY	1355.5	1947.6	2077.1	701.5	940.1	753.8	332	587.1	1145.6
RDR	1903.7	2527.6	2225.9	1624.6	1850.9	1507.1	1386.6	1432.3	2873.1
RGR	8420.4	9233.2	8563.9	6178.3	7044.9	7788.7	7223.7	9455	22132.9
RSN	2361	3207	3441	3073.9	4082.9	3763.7	3977.1	4839	7881.3
SAR	1219.2	1986.9	1693.8	3282.1	6184.6	3575.4	1903.7	1348.4	2096.6
SCI	1860.6	2596.5	2372.4	655.7	883	704.2	294.3	547.3	1062.4
SCR	1333.2	2038.1	1799.2	795	1015.9	830.3	397.8	660.4	1309.6
SDF	1219.2	1874.4	1590.4	655.7	883	704.2	294.3	547.3	1062.4
SEA	2808.1	3775.9	3732.7	1624.6	1850.9	1507.1	1386.6	1432.3	2873.1
SHP	1472.8	2187.9	1906.6	655.7	883	704.2	294.3	547.3	1062.4
SMK	3487.6	4655.9	5062.7	3302.5	3457.6	3254.7	3080.7	3475.3	5168.8
SMS	1261.3	1937.2	1658.4	747.3	997.1	803.4	369.8	626.8	1228.9
SNK	3767.5	5234.6	6331.4	4499.5	3876.7	4030.8	3244.5	3474.8	6983.6
SPL	2763.2	3567.2	4500.2	655.7	883	704.2	294.3	547.3	1062.4
SQU	7104.1	8133.1	7449	8406.7	6115.6	6453.9	8752.9	7905.5	14791.7
SRF	1368	2209.2	2174.2	655.7	883	704.2	294.3	547.3	1062.4
SSR	4150.3	4421.5	3955.5	962.6	1225.3	1097.8	679.3	1042.2	2233
SWD	1219.2	1874.4	1590.4	655.7	883	704.2	294.3	547.3	1062.4
TIP	2482	3758.8	3629.4	3403.4	4307.2	3680.5	2557.6	2932.5	6058.1
TUR	22.9	34.3	133.1	1328.4	912	807.5	1.6	3.3	0
VSN	1395.2	2308.1	2083.9	655.7	883	704.2	294.3	547.3	1062.4
WMR	1219.2	1874.4	1590.4	655.7	883	704.2	294.3	547.3	1062.4
WSH	2184.8	2920.1	2386.1	1460.5	1771.1	1575.3	1130.4	1355.6	2678.4
YTN	1219.2	1874.4	1701.8	1195.9	1819.2	1201	876	576.5	1562.8

Table A.7. (cont.)

Year

Group	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
AMB	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	1356.5
BCR	7053.6	8360.9	9591.7	36327.5	11940.7	11888.7	11531.8	14014.8	14126.5
BFS	1861.2	2339.2	2468.1	10688.9	2319.9	2353.9	2134.9	1886.6	1390.4
BIL	1809.3	2285.2	2422.2	10456.8	2264.8	2309	2092.5	1840.3	1358.1
BIV	2225	2832.7	4119.3	19048.5	2344.8	2821.1	2782.8	2444.7	1852.9
BMR	1809.3	2285.2	2422.2	10456.8	2264.8	2308.9	2092.5	1840.3	1363.3
BSH	20640.3	20478.5	23350.7	101445.4	19778.6	19285	19879.2	18265.1	18457.3
BTN	1812.9	2288.2	2427.3	11716.9	2272.7	2317.4	2104.1	1848.6	1367.7
CMB	4551.6	4573.3	4675.9	22640.4	6165.3	6000.5	6071.5	3860.4	5607
DSR	1860.4	2882.9	3060.6	12342.6	2871.4	2883.8	2682	2313.9	1830.2
FLT	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	1537.9
JCK	3190	3325.7	4233	17082.8	4533.6	4719	4886.6	7352.3	10468.2
KMK	1809.3	2285.2	2422.2	10456.8	2262.9	2305	3493.6	3891.4	3714.7
LGS	8322.6	10943.8	8679.2	51992.8	10135.6	9925.1	9579	9920.7	6991.1
LOB	2226.5	2481	2896.8	13241.1	2801.7	2606.9	2511.3	2183.9	1823.1
LOG	0	0	0	0	0	0	0	0	0
LPL	4823	6348.6	7029.9	36502.5	7283.3	6504.1	7484.8	9491.1	7997.1
LRF	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	6399.5
LTN	1909.5	2470.2	2956.6	11539.5	2707	2691.4	2609.1	2431.8	2280.9
LUT	1846.7	2324.9	2482	10713.6	2332.1	2351.1	2137.3	1882.3	2067.4
MPL	5598.3	4303.3	3431	77238.4	6048.6	6414.4	5179.2	5632.6	4429.4
MUL	9703.2	11425.5	9233.6	37457.8	12004.8	12441.8	14258.6	13716.6	14189.7
ODF	6081.8	7052.2	7920.3	30116.2	8182.1	8689.9	8210.9	7911.2	8924.6
OSH	2227.8	2689.5	2887.3	12478.7	2652.2	2682.3	2487.7	2205.3	1736.5
OYS	1809.3	2285.2	2422.2	65833.1	2262.9	3097.8	3353.5	1840.3	5650.2
PIN	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	1356.5
POM	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	1934.3
PSH	2646.2	3093.8	3352.4	14500.7	3041.4	3059.6	2883	2570.3	2116.5
RAY	1861.2	2339.2	2468.1	10688.9	2319.9	2353.9	2134.9	1886.6	6444.3
RDR	2510.5	3078	2931.2	13695	3057.6	2885.1	2723.4	2756.5	2185.6
RGR	2729.5	13045.4	13913.2	44402.2	13215	12723.1	12213.4	9875.1	9884.4
RSN	3773.5	7067	7523.2	33762.9	8871.6	6778.9	6400.2	5998	5241
SAR	3684.4	2912	2913	241379.8	3165.6	4778	2400.9	2357.4	2270.9
SCI	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	2453.2
SCR	1927.4	2422	2583.7	11039.3	2480.9	2520.8	2305	2114.4	1644
SDF	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	5792.6
SEA	2510.5	3078	2931.2	13695	3057.6	2885.1	6006.3	5595.1	5418.2
SHP	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	1356.5
SMK	4703.7	6155.2	6489.1	25003.9	6817.9	6037.6	5552.5	6836.2	4696.7
SMS	1913.2	2393.2	2513.9	10921	2376.9	2402.8	2177.4	1932.9	1424.3
SNK	3709.3	3782.6	4323.3	15784.7	4087.7	4328.1	4193.5	4205.9	3676.8
SPL	1809.3	2285.2	2422.2	13911.8	2262.9	2319.5	2092.5	1840.3	2175.6
SQU	2849.8	16124.3	16202.4	55342.5	16441.3	17405.1	19015.1	27494.6	17379.2
SRF	1809.3	2285.2	2422.2	13911.8	2262.9	2319.5	2092.5	1840.3	1366.4
SSR	1860.4	2882.9	3060.6	12342.6	2871.4	2883.8	2654.7	2286.7	2122.3
SWD	1809.3	2285.2	2422.2	10456.8	2266.9	2310.1	2092.5	1840.3	1363
TIP	4926.6	5527.6	5172.6	24383	5680.1	5239.3	4639.3	4617.9	3393.3
TUR	0	0	0	0	0	0	0	0	0
VSN	1809.3	2285.2	2422.2	10456.8	2262.9	2305	2092.5	1840.3	3282.4
WMR	1809.3	2285.2	2422.2	10456.8	2264.1	2307.1	2092.5	1840.3	1359.6
WSH	2646.2	3093.8	3352.4	14500.7	3041.4	3059.6	2883	2570.3	2116.5
YTN	2121.4	2547.7	2860.7	119129.7	3100.1	3376.4	3091.4	2559.9	2325.4

Table A.7. (cont.)

	Year								
Group	1998	1999	2000	2001	2002	2003	2004	2005	2006
AMB	1216.9	957.3	899.4	7252	636.8	719.5	704.6	701.7	585.2
BCR	12667.3	12079.7	8473.9	818.6	7783.3	10443.3	11117.1	10740.1	10710.6
BFS	1252.6	986.3	927.2	789.8	664.1	744.9	732.7	734.7	606.6
BIL	1217.9	958.8	902.6	1851.2	636.8	721.5	706	702.9	586.3
BIV	1870.1	1578.5	2008.9	789.8	1617.5	1714.1	1702.7	2239.5	2767
BMR	1222.1	961.1	913.7	18178.9	636.8	738.4	726.7	717.8	601.9
BSH	19869.9	16827	17915.4	802.5	15626.8	19686	15392	22584.3	16008.2
BTN	1228.7	977.1	914.4	8099	651.1	736.6	719.9	716	598.2
CMB	3990.3	7025.4	7828.5	1228.1	5927	5725.8	7182.4	6901.5	6689.5
DSR	1701.9	1432.1	1454.3	948.6	1122.1	1095.2	1072	1198.9	1006.8
FLT	1411.1	1134.2	1001	7423.2	875.4	891.9	887	879.8	789.7
JCK	10470.2	5253.8	7688.8	3085	7452	9149.1	8832.1	9227.9	9081.2
KMK	3248.6	3191.2	2926.5	5349.9	3213.6	3099.9	3196.2	2910.1	2803.8
LGS	6387.5	6037	5652.5	1184.7	4342	4042.8	3958.8	4529.9	4007.7
LOB	1476.3	1208.2	1260.1	0	1184.5	1103.2	1048.2	1070.9	813.5
LOG	0	0	0	6273.8	0	0	0	0	0
LPL	7602	7402.6	6334.1	5403.8	6739	7196.1	7230.6	6925.2	5974.6
LRF	6977.5	7056.3	7489.2	1473.4	4149.9	5208.2	6002.6	3087.9	3012.3
LTN	2210.3	1304.5	1678.2	2865.7	1272	1429.4	1405.4	1323.4	1305
LUT	3433.5	2902.1	2504	2669.1	2399.4	2705.4	2356.9	2661.8	2151.1
MPL	3737.6	3105	2715.1	11231.4	1838.7	2274.5	2585.6	2355.1	2686.5
MUL	12389.4	12137.6	13141.5	7734.3	9263.6	8749.4	8387.3	8299.4	6888.3
ODF	9212.9	7679.7	7683	1176.2	6991.5	7361	6670.3	6469.3	7486.4
OSH	1631.4	1310	1277.6	789.8	969.9	1141	1031	1188	927.9
OYS	1216.9	979.1	899.4	789.8	636.8	893.7	788.1	3604.3	2632.5
PIN	1216.9	957.3	899.4	1078.3	636.8	719.5	704.6	701.7	585.2
POM	1713.2	1432.7	1265	1562.7	1166.3	1262.9	1081.1	1223.3	884.3
PSH	2045.9	1662.6	1655.7	3189.1	1303	1562.5	1357.4	1674.2	1270.6
RAY	6977	4697.6	3511.8	1595.4	2841.1	3069.1	3262.8	3711.3	3632.7
RDR	2215.7	1943	1973.1	8679.3	1680.4	2122.9	2039.6	1950.5	1499
RGR	9946.6	9503.6	10887.3	3326.8	9371.2	7481.5	7317.2	9652.5	8175.5
RSN	4355.9	4152.5	3435.3	1128.2	3055.6	3220.2	3419.5	3938.6	3228.1
SAR	4905.5	2201.1	1388.4	1228.9	793.7	945.4	848.9	914.3	734.1
SCI	2857.1	2384.3	1449.2	935.3	1208.2	1114.1	1266.2	1161.7	962.8
SCR	1474.8	1207.8	1070	3460.6	797.7	938.5	939.1	927.7	813.2
SDF	4802.1	4247.7	3285.3	3892.9	3764.3	3664.2	3446.1	3546.5	2790.2
SEA	5473.4	5242.6	4903.1	789.8	4450.8	5158.9	5620.4	4717.1	4086
SHP	1216.9	957.3	899.4	3196.6	636.8	719.5	704.6	701.7	585.2
SMK	4555.8	4750.2	3486.7	847.4	3411.4	3961.8	3876.6	3922.4	2866.1
SMS	1288.3	1015.4	955	3578.5	691.4	770.3	760.7	767.7	628
SNK	3286.9	3286.1	3037.8	1993.7	4156.2	5109.3	4309.4	4794.7	4570.2
SPL	2815.4	2420.6	1953.6	19388.9	1597.9	2215.4	2155.2	2751.4	2132.5
SQU	16001.3	18262.8	21255.7	815.2	15171	14914.2	22549.6	10556.9	26657.6
SRF	1265	1019.9	940.2	1413.2	643.7	757.6	729.1	712.8	597.2
SSR	1980.4	1728.7	1572.2	789.8	1294.3	1273	1322.4	1440	1231.5
SWD	1222.8	964	911.5	2517.5	636.8	728	719.1	713.1	595.1
TIP	3358.8	2699.6	2567.7	0	2275.2	2244.1	2387.6	2681.7	1869
TUR	0	0	0	2743	0	0	0	0	0
VSN	2580.4	2457.8	2308.3	789.8	2166.9	2143.8	2049.1	2445.6	2233.5
WMR	1217.7	958.9	907.8	1562.7	636.8	724.2	712.5	707.3	589.6
WSH	2045.9	1662.6	1655.7	1880.7	1303	1562.5	1357.4	1674.2	1270.6
YTN	2232.7	2668.8	2189.3	0	1869.9	2197.6	2021.9	1940.8	1709.4

Table A.7. (cont.)

	Year				
Group	**2007**	**2008**	**2009**	**2010**	**2011**
AMB	557.5	469.5	411.1	545.2	374.6
BCR	10504.8	9972.3	8151.7	11912.3	9660.8
BFS	576.6	488.4	432.9	571.5	391.3
BIL	559.4	471.2	412.2	547	375.3
BIV	2503.1	2231.7	1756.6	1781.3	1829.4
BMR	576.6	490.2	425.5	570.5	392.9
BSH	17272.9	15870.8	16863.4	20449.7	17503.4
BTN	569.3	482.4	426.9	559.4	392
CMB	6565.2	3332.1	3678.1	7348.4	5041
DSR	1128.4	1018.2	978.1	1097.8	760.5
FLT	701.6	579.7	455	648.8	465.7
JCK	8871.9	8654.3	10438.8	13143	11021.9
KMK	2543.9	2880	2426.5	2755	2208.2
LGS	3606.7	2880.7	2738.3	3657.1	2676.8
LOB	854.9	686.6	604.5	935.6	621.7
LOG	0	0	0	0	0
LPL	5882.2	6878.1	6004.9	7236.1	5375.6
LRF	3786	4540.2	2681.5	2448	2449.2
LTN	1088.6	1000.9	1042.9	1360.3	1069.8
LUT	2452.8	2736.4	2058.4	2400.4	2232.5
MPL	2236.1	1860.6	1319.7	1721.9	1761.5
MUL	7647.8	6976.5	7848.9	8096.1	7063.1
ODF	5417.4	5151	5403.5	5893.2	3894.9
OSH	929	811.8	776.7	987.6	755.3
OYS	2121.5	1683.9	2307.9	2411.2	1903.6
PIN	557.5	469.5	411.1	545.2	374.6
POM	938.9	841.6	887.6	1028.7	749.7
PSH	1300.4	1154	1142.3	1429.9	1135.9
RAY	3558.5	2914.2	2898.9	3382.9	3665.1
RDR	1234.5	1076.9	1055.2	1359.4	1030.5
RGR	10834.3	10345.5	10617	9369.6	7319.5
RSN	3471.7	3094.6	3351.9	4198.2	3145.2
SAR	669	511	479.4	596.2	411.2
SCI	756.6	570	519.9	680.1	480.4
SCR	781.5	683.5	585.4	801.2	583.7
SDF	2285.9	2217.4	2495.2	3401.2	2371.6
SEA	2646.8	3036.1	2954.1	3646.8	3012.5
SHP	557.5	469.5	411.1	545.2	374.6
SMK	3268.6	3903.1	3330.4	4185.9	2815.7
SMS	595.7	507.3	454.7	597.7	407.9
SNK	4712.8	4408.3	4528.1	4946.3	3531
SPL	1334.3	1487.7	601.3	1409.3	1151.4
SQU	19226.2	11681.6	24259.2	22463.5	26057.5
SRF	571.7	472.6	414.4	1074.5	1061.9
SSR	1239.1	1070.8	1020.2	1088	800
SWD	570.8	481.9	416.8	565.3	385.8
TIP	1702.4	1604.3	1719.2	2120	1374.3
TUR	0	0	0	0	0
VSN	2481.7	1441.3	1377.8	1521.2	971.6
WMR	560.3	473.8	415.7	556.2	387.2
WSH	1300.4	1154	1142.3	1429.9	1135.9
YTN	1578.3	1576.6	1772.8	1763.2	1873.4

Table A.8. Cuban catch reconstruction by functional group (tonnes).

	Year								
Group	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**
BCR	0	80.5	104.4	132.1	147.5	153.6	174.8	132.1	216.2
BFT	0	0	0	0	0	0	0	0	0
BIO	1983	1356.9	1715.6	2130.5	2234.8	2327	2419.4	2339.5	2342.7
BIV	0	263.1	682.3	525.8	583.4	653.9	683.4	660.1	649.4
BMR	102.1	155.3	159.4	105.3	44.3	54.9	34.8	4	43.6
CMB	0	0	28.4	281.9	263.5	250.9	93	78.2	80.8
JCK	30	13	28	23	38	44	42	56	24
KMK	5.7	3.3	0.1	0.3	1.3	0.7	0.5	0.1	0.3
LGS	369	702	561	445	422	335	319	470	524
LOB	1551.3	1575.3	1704.6	1596.8	1848.7	1985.3	1728.8	2059	1899.2
LOG	200.3	155.9	162.8	170.9	173.4	201.6	193.4	149.6	115.8
LPL	723.4	556.3	628.6	624	499.8	498.7	433.9	392.1	558.3
LRF	1983	1356.9	1715.6	2130.5	2234.8	2327	2419.4	2339.5	2342.7
LTN	0	0	11.6	2.1	5.3	5.6	8.4	19.3	18.6
LUT	825.5	883.8	900.1	844.2	735.6	693.4	701.7	790.1	715.1
MPL	0	0	0	0	5	8	10	15	17
MUL	214.9	184.8	216.7	204.1	249.6	111.3	132.7	136.9	68.6
OBL	41.7	46.9	63.4	9.8	59.2	45.5	17.5	59.9	27.3
ODF	189.3	233.5	318.9	290.6	308.3	317	339.6	328	372.9
OYS	332.8	514.8	526.6	446.5	629.2	516.2	529.5	330.3	479
RAY	0	0	0	0	0	0	0	0	0
RGR	1025.2	824.6	734.3	578.2	724.5	635.3	669.9	726.6	766.2
RSN	373.5	341.6	367.2	433.7	382.2	505.1	429.1	594.3	491.8
SCR	119.3	12.1	28.5	26.3	25.8	23.2	17.8	15.2	12.6
SMK	5.7	3.3	0.1	0.3	1.3	0.7	0.5	0.1	0.3
SPL	829.9	813.8	833	963.6	799.4	979.7	1058.1	795.2	1001.7
SRF	1983	1356.9	1715.6	2130.5	2234.8	2327	2419.4	2339.5	2342.7
SSR	4038.1	2886.2	3702.8	4504.1	4646.2	4911.2	5090.4	4897	4843.3
SWD	134.9	138.7	53.6	44.7	28.8	33.1	48.3	57.1	47.4
TUR	350.6	416.3	414.4	407.5	338.7	541.5	421.3	373.1	324.3
WMR	74.2	40.6	15.8	39.2	53.6	75.6	67.2	21.7	8.4
YTN	241.2	699	526.1	277.6	888.3	667.1	728.4	371.7	34.3

Table A.8. (cont.)

	Year								
Group	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
BCR	227	0	139.9	166.2	74.9	122.6	108.6	131	102.8
BFT	0	1810.3	0	0	0	0	0	0	0
BIO	2297.8	645	1691.9	1639.4	1139.7	1492.6	1286.9	969.2	1209.5
BIV	698.5	33.5	475.3	475.3	499.6	573.1	703	686.3	638
BMR	18.4	30.6	38	40.4	20.6	11.7	25.4	12.9	15.9
CMB	100.4	96	30.3	19.9	33.6	22.5	28.8	313.3	460.9
JCK	24	3.3	45	36	19	61	36.9	37.4	25.1
KMK	0.3	197	1.3	0.2	1.3	0.1	1.1	1.2	0.9
LGS	471	1242.2	122	142	74	88	120	123.9	167.8
LOB	1744.3	77	1496.8	1412.4	1266	1460.6	1426.3	1423.2	1413.6
LOG	88.9	606.3	52.6	40.1	30.1	14.4	6.9	6.3	4.4
LPL	593.3	1810.3	501.3	514.2	167.3	360	289.4	351.3	462.7
LRF	2297.8	22.1	1832.6	1720.6	1205.2	1564	1356.2	1010.5	1243.4
LTN	29.1	574.7	22.1	11.6	4.6	5.3	9.5	8.1	6
LUT	753.5	8	777.3	494.9	384	475.4	506	767.7	590.4
MPL	22	46.9	8	8	8	8	9.2	7.1	5.6
MUL	78.1	44.1	90.7	50.4	55.3	46.9	37.8	32.6	55.7
OBL	19.3	373.9	29.1	24.5	14.7	16.1	11.6	13	14
ODF	396.5	794.1	361.6	295.4	232.7	318.8	358.5	306.6	264.5
OYS	854.6	0	757.2	564.2	440.6	607.7	695.6	696.7	742.1
RAY	0	407.4	1.1	0	4.2	0	1.8	334.3	475.3
RGR	903	431.2	320.3	150.2	119.4	104.3	73.9	94.2	68.3
RSN	483	0.4	52.2	211.4	166.6	218.1	283.2	350.7	318.2
SCR	5.1	3.3	0.4	1	0.4	0.3	0.7	4.1	1.3
SMK	0.3	1061.6	1.3	0.2	1.3	0.1	1.1	1.2	0.9
SPL	994	1810.3	1151.2	792.4	640.2	873.6	1067.5	1073.8	996.5
SRF	2297.8	3725.9	1691.9	1639.4	1139.7	1492.6	1286.9	969.2	1209.5
SSR	4786.3	20	3478.9	3399.4	2357.1	3027.2	2623.8	2015	2469.5
SWD	23.6	399.4	16.2	7.5	2.4	3	4.5	2.1	3
TUR	343.7	2.1	249.2	289.8	154.6	102	49.5	35.7	23.2
WMR	7.7	18.6	3.5	3.5	0	0	0	0	0
YTN	31.9	0	6.3	3.9	0.4	0	0	0	0

Table A.8. (cont.)

	Year								
Group	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
BCR	155.5	82.6	85.3	77.1	59.9	113.9	62.8	32.9	51
BFT	0	0	0	0	25.9	3.9	6.3	9.5	6.7
BIO	962.5	1426.4	1587.3	773.9	351.5	723.9	576.8	576.5	580.9
BIV	899.6	753.9	956.1	233.6	138.4	107	163.5	148.7	138
BMR	3.6	11.4	16.5	16.8	10.2	0.9	1.2	2.1	2.1
CMB	181.2	305.9	429.2	432.5	367.9	137.3	203.7	237.6	120.3
JCK	53.5	17.9	274.1	229	19.3	17.7	7.9	7.3	5.1
KMK	0.5	0.5	0.4	0.4	0.5	0.4	0.2	0.2	0.3
LGS	270.1	250.3	199.1	210.7	206.1	107.7	50.3	48.4	78.1
LOB	1488.2	1567	1225.1	1115.6	1201.9	792.2	1137.3	891.5	669.7
LOG	3.1	3.1	5.6	4.4	5	5	3.8	4.4	1.9
LPL	397.7	482.5	369.9	310.4	320.5	364.6	373.5	369.5	287
LRF	975.5	1430.9	1593.3	779.8	355.4	725.3	577.9	577.9	581.2
LTN	3.2	1.1	0.7	0.4	1.1	1.8	2.8	2.8	1.1
LUT	543.8	413.9	464.9	518	570.3	458.9	251.7	159.4	192.3
MPL	5	4.2	4.5	4.6	3.6	3.3	3	3.2	2.9
MUL	42.7	37.8	41.7	39.9	43.8	27	16.5	14	20
OBL	9.8	68.6	72.8	23.8	11.2	6.3	17.5	25.2	16.5
ODF	214.4	209.3	219.1	199.9	196.5	265.5	247.6	196.1	189.6
OYS	0	0	0	0	0	0	0	0	0
RAY	466.9	473.2	417.6	391.7	447.3	465.5	497.4	536.6	534.5
RGR	24.2	38.5	59.9	31.9	30.1	36.1	19.6	0	0
RSN	282.5	267.1	241.2	270.6	309.8	345.1	219.5	248.2	223.7
SCR	5.1	7.6	7.9	11.1	7	7.3	19.3	16.6	11.2
SMK	0.5	0.5	0.4	0.4	0.5	0.4	0.2	0.2	0.3
SPL	677.3	882.7	1079.4	1206.1	806.8	860.7	871.9	655.2	944.7
SRF	962.5	1426.4	1587.3	773.9	351.5	723.9	576.8	576.5	580.9
SSR	1970.4	2882.5	3211.1	1566.4	734.9	1476.1	1177.3	1163.2	1176.2
SWD	3	1.5	3.3	0.9	3	0.9	0.9	0.9	0.6
TUR	22.5	12.5	17.5	10	14.4	10	5	8.1	6.9
WMR	0	0	0	0	0	0	0	0	0
YTN	0	11.9	99.4	54.6	22.8	24.9	6.7	6.7	6.7

Table A.8. (cont.)

	Year				
Group	**2007**	**2008**	**2009**	**2010**	**2011**
BCR	48.2	49.6	44.7	50.4	58.3
BFT	0	0	0	0	0
BIO	618	502.2	569.2	280.8	293.7
BIV	142.1	35.1	109.2	112.2	69
BMR	0.6	1.2	1.8	0.9	1.8
CMB	211.8	148	197.1	186.7	181.6
JCK	7.7	6.5	10.8	4.4	6.3
KMK	0.3	0.4	0.4	0.3	0.4
LGS	78.7	79.2	77.6	54.4	53.9
LOB	761	902.1	647.2	712.5	769.1
LOG	1.9	0	0	0	0
LPL	244.5	241.9	305.1	209.8	265.2
LRF	618.4	502.2	569.2	280.8	293.7
LTN	1.4	2.5	1.4	4.9	8.1
LUT	212.2	233.1	227.7	223.5	335.2
MPL	3	3.6	4.5	5.5	5
MUL	18.2	21	37.8	87.2	85.4
OBL	19.6	6.7	6.7	9.1	20.7
ODF	183	137	150.6	155.8	184.9
OYS	0	0	0	0	0
RAY	648.9	674.1	709.5	559.7	614.6
RGR	0	0	0	0	0
RSN	269.5	265.7	322.4	296.8	263.2
SCR	13.9	13.1	0	0	0
SMK	0.3	0.4	0.4	0.3	0.4
SPL	781.6	876.8	984.9	912.5	881.3
SRF	618	502.2	569.2	280.8	293.7
SSR	1245.3	1012.9	1149.4	567.7	595.2
SWD	0.3	0	0	0	0.3
TUR	1.3	0	0	0	0
WMR	0	0	0	0	0
YTN	12.6	0.7	0.7	2.8	0.7

Table A.9. Seasonal distribution of landings retained by U.S. commercial fleets.

Group	Winter (Jan.-Mar.)	Spring (Apr.-Jun.)	Summer (Jul.-Sep.)	Fall (Oct. - Dec.)
GAG	0.2837	0.2954	0.1858	0.2351
RGR	0.2042	0.2799	0.2833	0.2325
SCM	0.2396	0.2900	0.2452	0.2252
SSR	0.2538	0.3272	0.1991	0.2200
DSR	0.3054	0.3329	0.1742	0.1875
RSN	0.4027	0.2362	0.1471	0.2140
VSN	0.1853	0.3173	0.2728	0.2246
LUT	0.1997	0.3384	0.2637	0.1982
BIO	0.5082	0.0880	0.0887	0.3150
LRF	0.1920	0.3119	0.3232	0.1730
SRF	0.2735	0.3429	0.1905	0.1931
BDR	0.3265	0.2044	0.2224	0.2468
RDR	0.3433	0.0972	0.0937	0.4658
SEA	0.3625	0.1934	0.1654	0.2787
SCI	0.1247	0.3797	0.3344	0.1611
LDY	0.2833	0.2301	0.1699	0.3167
MUL	0.1496	0.0993	0.1345	0.6166
POM	0.2145	0.1855	0.3386	0.2614
SHP	0.5021	0.1957	0.0761	0.2261
SNK	0.2500	0.2500	0.2500	0.2500
FLT	0.0793	0.2154	0.2564	0.4489
ODF	0.1954	0.3063	0.2756	0.2227
SDF	0.1309	0.4605	0.2993	0.1093
YTN	0.2107	0.2809	0.3060	0.2024
BTN	0.3786	0.5336	0.0562	0.0317
LTN	0.0867	0.3047	0.4285	0.1801
OTN	0.2500	0.2500	0.2500	0.2500
SWD	0.3654	0.2216	0.1881	0.2249
WMR	0.0515	0.2434	0.5943	0.1108
BMR	0.0662	0.2946	0.5315	0.1077
BIL	0.2209	0.2683	0.3274	0.1834
AMB	0.3093	0.2938	0.2472	0.1497
JCK	0.1049	0.4795	0.2655	0.1501
KMK	0.4039	0.0310	0.3902	0.1749
SMK	0.4086	0.2946	0.1166	0.1802
SAR	0.0042	0.5258	0.3699	0.1000
LPL	0.1249	0.3599	0.4028	0.1124
DWF	0.2500	0.2500	0.2500	0.2500
MEN	0.0002	0.3833	0.5244	0.0920
PIN	0.2709	0.2936	0.2526	0.1829
MPL	0.2789	0.4624	0.1125	0.1463
SPL	0.3551	0.3010	0.1431	0.2008
TIP	0.3479	0.1551	0.3919	0.1051
BEN	0.2500	0.2500	0.2500	0.2500
LGS	0.3661	0.1752	0.3579	0.1008
FIL	0.2500	0.2500	0.2500	0.2500
SMS	0.2500	0.2500	0.2500	0.2500
RAY	0.3947	0.3293	0.2436	0.0324

Table A.9. (cont.)

Group	Winter (Jan.-Mar.)	Spring (Apr.-Jun.)	Summer (Jul.-Sep.)	Fall (Oct. - Dec.)
BSH	0.0414	0.4218	0.3999	0.1369
WSH	0.0701	0.1410	0.3328	0.4561
PSH	0.3107	0.3364	0.1165	0.2364
OSH	0.2156	0.1519	0.1686	0.4639
DBR	0.2500	0.2500	0.2500	0.2500
SBR	0.2500	0.2500	0.2500	0.2500
MAN	0.2500	0.2500	0.2500	0.2500
MYS	0.2500	0.2500	0.2500	0.2500
DOL	0.2500	0.2500	0.2500	0.2500
DDO	0.2500	0.2500	0.2500	0.2500
LOG	0.2500	0.2500	0.2500	0.2500
KMP	0.2500	0.2500	0.2500	0.2500
TUR	0.2500	0.2500	0.2500	0.2500
BCR	0.1369	0.2992	0.3252	0.2387
SCR	0.3436	0.1124	0.0030	0.5410
LOB	0.1283	0.0090	0.4946	0.3680
COR	0.2500	0.2500	0.2500	0.2500
CCA	0.2500	0.2500	0.2500	0.2500
OCT	0.2500	0.2500	0.2500	0.2500
SPG	0.2086	0.3385	0.2719	0.1811
CMB	0.2500	0.2500	0.2500	0.2500
INF	0.2500	0.2500	0.2500	0.2500
ECH	0.2500	0.2500	0.2500	0.2500
OYS	0.2872	0.2405	0.1926	0.2798
BIV	0.2593	0.2247	0.3167	0.1993
SES	0.2500	0.2500	0.2500	0.2500
EPI	0.2500	0.2500	0.2500	0.2500
GRS	0.2500	0.2500	0.2500	0.2500
ALG	0.2500	0.2500	0.2500	0.2500
MPB	0.2500	0.2500	0.2500	0.2500
LPP	0.2500	0.2500	0.2500	0.2500
SPP	0.2500	0.2500	0.2500	0.2500
DIN	0.2500	0.2500	0.2500	0.2500
PRO	0.2500	0.2500	0.2500	0.2500
JEL	0.2500	0.2500	0.2500	0.2500
SQU	0.1666	0.2854	0.3481	0.1998
LZP	0.2500	0.2500	0.2500	0.2500
SZP	0.2500	0.2500	0.2500	0.2500
PB	0.2500	0.2500	0.2500	0.2500
BB	0.2500	0.2500	0.2500	0.2500
DC	0.2500	0.2500	0.2500	0.2500
DL	0.2500	0.2500	0.2500	0.2500
DR	0.2500	0.2500	0.2500	0.2500

Table A.10. Seasonal distribution of landings retained by U.S. recreational fleets.

Group	Winter (Jan.-Mar.)	Spring (Apr.-Jun.)	Summer (Jul.-Sep.)	Fall (Oct. - Dec.)
GAG	0.1878	0.2831	0.2292	0.2999
RGR	0.1290	0.2683	0.3897	0.2131
SCM	0.0815	0.3257	0.3474	0.2454
SSR	0.2875	0.3417	0.1894	0.1814
DSR	0.3065	0.2758	0.1726	0.2452
RSN	0.0891	0.3531	0.3759	0.1819
VSN	0.0978	0.3585	0.3726	0.1711
LUT	0.3385	0.2286	0.2152	0.2177
BIO	0.2721	0.2862	0.2537	0.1881
LRF	0.1094	0.2608	0.3634	0.2664
SRF	0.1050	0.2384	0.3436	0.3131
BDR	0.2306	0.2302	0.2246	0.3147
RDR	0.1071	0.2139	0.3966	0.2824
SEA	0.1292	0.2537	0.3788	0.2383
SCI	0.0546	0.3032	0.4085	0.2337
LDY	0.0927	0.3571	0.3625	0.1876
MUL	0.1629	0.2763	0.2735	0.2873
POM	0.1447	0.2374	0.3026	0.3152
SHP	0.4475	0.2627	0.0827	0.2071
SNK	0.1127	0.2980	0.2614	0.3279
FLT	0.0826	0.3033	0.3940	0.2201
ODF	0.3448	0.3462	0.1342	0.1748
SDF	0.0872	0.3030	0.3761	0.2337
YTN	0.1579	0.2273	0.4593	0.1555
BTN	0.1111	0.4444	0.2222	0.2222
LTN	0.1081	0.3017	0.4262	0.1640
OTN	0.2300	0.2700	0.3500	0.1500
SWD	0.2000	0.0000	0.7000	0.1000
WMR	0.0000	0.2500	0.6664	0.0836
BMR	0.0000	0.5264	0.3500	0.1236
BIL	0.2457	0.2038	0.2114	0.3392
AMB	0.1577	0.3881	0.2762	0.1779
JCK	0.1938	0.2674	0.2741	0.2647
KMK	0.1477	0.2845	0.3661	0.2017
SMK	0.1108	0.3280	0.3567	0.2044
SAR	0.0711	0.3268	0.3104	0.2917
LPL	0.2553	0.3537	0.2119	0.1791
DWF	0.0385	0.2645	0.5021	0.1949
MEN	0.0193	0.3437	0.4506	0.1864
PIN	0.0916	0.2999	0.3846	0.2239
MPL	0.0602	0.4461	0.2833	0.2105
SPL	0.2130	0.2319	0.2276	0.3275
TIP	0.0405	0.3909	0.4526	0.1159
BEN	0.5000	0.5000	0.0000	0.0000
LGS	0.1308	0.2192	0.4067	0.2433
FIL	0.2500	0.2500	0.2500	0.2500
SMS	0.8750	0.1250	0.0000	0.0000
RAY	0.1577	0.2999	0.2839	0.2585

Table A.10. (cont.)

Group	Winter (Jan.-Mar.)	Spring (Apr.-Jun.)	Summer (Jul.-Sep.)	Fall (Oct. - Dec.)
BSH	0.2500	0.2500	0.2500	0.2500
WSH	0.2500	0.2500	0.2500	0.2500
PSH	0.2500	0.2500	0.2500	0.2500
OSH	0.2500	0.2500	0.2500	0.2500
DBR	0.2500	0.2500	0.2500	0.2500
SBR	0.2500	0.2500	0.2500	0.2500
MAN	0.2500	0.2500	0.2500	0.2500
MYS	0.2500	0.2500	0.2500	0.2500
DOL	0.2500	0.2500	0.2500	0.2500
DDO	0.2500	0.2500	0.2500	0.2500
LOG	0.2500	0.2500	0.2500	0.2500
KMP	0.2500	0.2500	0.2500	0.2500
TUR	0.2500	0.2500	0.2500	0.2500
BCR	0.2500	0.2500	0.2500	0.2500
SCR	0.2500	0.2500	0.2500	0.2500
LOB	0.1283	0.0090	0.4946	0.3680
COR	0.2500	0.2500	0.2500	0.2500
CCA	0.2500	0.2500	0.2500	0.2500
OCT	0.2500	0.2500	0.2500	0.2500
SPG	0.2500	0.2500	0.2500	0.2500
CMB	0.2500	0.2500	0.2500	0.2500
INF	0.2500	0.2500	0.2500	0.2500
ECH	0.2500	0.2500	0.2500	0.2500
OYS	0.2500	0.2500	0.2500	0.2500
BIV	0.2500	0.2500	0.2500	0.2500
SES	0.2500	0.2500	0.2500	0.2500
EPI	0.2500	0.2500	0.2500	0.2500
GRS	0.2500	0.2500	0.2500	0.2500
ALG	0.2500	0.2500	0.2500	0.2500
MPB	0.2500	0.2500	0.2500	0.2500
LPP	0.2500	0.2500	0.2500	0.2500
SPP	0.2500	0.2500	0.2500	0.2500
DIN	0.2500	0.2500	0.2500	0.2500
PRO	0.2500	0.2500	0.2500	0.2500
JEL	0.2500	0.2500	0.2500	0.2500
SQU	0.2500	0.2500	0.2500	0.2500
LZP	0.2500	0.2500	0.2500	0.2500
SZP	0.2500	0.2500	0.2500	0.2500
PB	0.2500	0.2500	0.2500	0.2500
BB	0.2500	0.2500	0.2500	0.2500
DC	0.2500	0.2500	0.2500	0.2500
DL	0.2500	0.2500	0.2500	0.2500
DR	0.2500	0.2500	0.2500	0.2500

Table A.11. Seasonal distribution of landings retained by Mexican commercial fleets.

Group	Winter (Jan.-Mar.)	Spring (Apr.-Jun.)	Summer (Jul.-Sep.)	Fall (Oct. - Dec.)
GAG	0.2500	0.2500	0.2500	0.2500
RGR	0.2416	0.3179	0.2554	0.1852
SCM	0.2500	0.2500	0.2500	0.2500
SSR	0.2503	0.3040	0.2499	0.1958
DSR	0.2367	0.3119	0.2687	0.1827
RSN	0.2943	0.2426	0.2109	0.2522
VSN	0.2292	0.2505	0.2831	0.2373
LUT	0.3093	0.2410	0.2438	0.2059
BIO	0.2500	0.2500	0.2500	0.2500
LRF	0.2603	0.2477	0.2665	0.2255
SRF	0.8907	0.0782	0.0292	0.0019
BDR	0.2500	0.2500	0.2500	0.2500
RDR	0.3960	0.2285	0.1357	0.2398
SEA	0.3624	0.2137	0.1756	0.2484
SCI	0.3231	0.2239	0.2150	0.2379
LDY	0.2500	0.2500	0.2500	0.2500
MUL	0.2665	0.1746	0.2319	0.3269
POM	0.3561	0.2697	0.1863	0.1880
SHP	0.2500	0.2500	0.2500	0.2500
SNK	0.2645	0.2580	0.2431	0.2344
FLT	0.2384	0.1983	0.1427	0.4206
ODF	0.2306	0.2558	0.2648	0.2488
SDF	0.3932	0.2937	0.1585	0.1546
YTN	0.1904	0.2750	0.2991	0.2356
BTN	0.7164	0.2027	0.0032	0.0777
LTN	0.2825	0.2657	0.2301	0.2217
OTN	0.1207	0.1706	0.3159	0.3929
SWD	0.2286	0.2019	0.2351	0.3344
WMR	0.2353	0.1759	0.2716	0.3172
BMR	0.1843	0.2385	0.3258	0.2514
BIL	0.0331	0.6081	0.2894	0.0694
AMB	0.2500	0.2500	0.2500	0.2500
JCK	0.2794	0.2916	0.2069	0.2220
KMK	0.3421	0.2728	0.2133	0.1718
SMK	0.3753	0.1318	0.1321	0.3608
SAR	0.2559	0.2359	0.3233	0.1849
LPL	0.3519	0.1992	0.1737	0.2752
DWF	0.2500	0.2500	0.2500	0.2500
MEN	0.2500	0.2500	0.2500	0.2500
PIN	0.2500	0.2500	0.2500	0.2500
MPL	0.2948	0.2832	0.2194	0.2026
SPL	0.6850	0.0956	0.0420	0.1775
TIP	0.2752	0.2823	0.1807	0.2618
BEN	0.2752	0.2823	0.1807	0.2618
LGS	0.2924	0.2735	0.2054	0.2287
FIL	0.2500	0.2500	0.2500	0.2500

Table A.11. (cont.)

Group	**Winter (Jan.-Mar.)**	**Spring (Apr.-Jun.)**	**Summer (Jul.-Sep.)**	**Fall (Oct. - Dec.)**
SMS	0.2752	0.2823	0.1807	0.2618
RAY	0.2855	0.2503	0.2382	0.2260
BSH	0.1893	0.2428	0.2640	0.3040
WSH	0.1893	0.2428	0.2640	0.3040
PSH	0.1893	0.2428	0.2640	0.3040
OSH	0.1893	0.2428	0.2640	0.3040
DOL	0.2500	0.2500	0.2500	0.2500
DDO	0.2500	0.2500	0.2500	0.2500
LOG	0.2500	0.2500	0.2500	0.2500
KMP	0.2500	0.2500	0.2500	0.2500
TUR	0.2500	0.2500	0.2500	0.2500
BCR	0.2568	0.2567	0.2370	0.2496
SCR	0.2568	0.2567	0.2370	0.2496
LOB	0.1958	0.2816	0.3932	0.1294
COR	0.2500	0.2500	0.2500	0.2500
CCA	0.2500	0.2500	0.2500	0.2500
OCT	0.2500	0.2500	0.2500	0.2500
SPG	0.2500	0.2500	0.2500	0.2500
CMB	0.0900	0.5917	0.3020	0.0163
INF	0.2500	0.2500	0.2500	0.2500
ECH	0.2500	0.2500	0.2500	0.2500
OYS	0.1985	0.2176	0.2813	0.3026
BIV	0.2522	0.2380	0.2324	0.2774
SES	0.2500	0.2500	0.2500	0.2500
EPI	0.2500	0.2500	0.2500	0.2500
GRS	0.2500	0.2500	0.2500	0.2500
ALG	0.2500	0.2500	0.2500	0.2500
MPB	0.2500	0.2500	0.2500	0.2500
LPP	0.2500	0.2500	0.2500	0.2500
SPP	0.2500	0.2500	0.2500	0.2500
DIN	0.2500	0.2500	0.2500	0.2500
PRO	0.2500	0.2500	0.2500	0.2500
JEL	0.2500	0.2500	0.2500	0.2500
SQU	0.0281	0.0264	0.3757	0.5698
LZP	0.2500	0.2500	0.2500	0.2500
SZP	0.2500	0.2500	0.2500	0.2500
PB	0.2500	0.2500	0.2500	0.2500
BB	0.2500	0.2500	0.2500	0.2500
DC	0.2500	0.2500	0.2500	0.2500
DL	0.2500	0.2500	0.2500	0.2500
DR	0.2500	0.2500	0.2500	0.2500

Table A.12. Proportion of each functional group caught in each fleet associated to the U.S. commercial landings.

Group	GillnetEst	TwlShpEst	OytEst	PotCrbEst	TwlShpShf	PotCrbShf	PotLbtShf	HLReefShf	LLReefShf	SeineMenShf	LLShkShf	LLPelgc	RoyalRed	OtherUS
GAG								0.672	0.244					0.084
RGR						0.000			0.991					0.009
SCM								0.480	0.507					0.013
SSR						0.010	0.001	0.525	0.281					0.183
DSR				0.013		0.373		0.121	0.493					0.000
RSN								0.961	0.033					0.007
VSN								0.997	0.002					0.001
LUT	0.000					0.003	0.001	0.919	0.065					0.013
BIO														
LRF	0.002	0.015			0.004	0.012	0.007	0.326	0.042					0.591
SRF	0.001							0.282	0.692			0.003		0.021
BDR	0.025	0.019		0.015	0.066			0.059	0.791			0.020		0.004
RDR								1.000						
SEA	0.095	0.003			0.091			0.783						0.028
SCI	0.124	0.068		0.001	0.284			0.371						0.151
LDY	0.688							0.042						0.270
MUL	0.177			0.000	0.000			0.000		0.006				0.816
POM	0.234							0.554						0.212
SHP	0.078	0.134		0.002	0.176			0.405	0.037	0.000				0.168
SNK														
FLT	0.203	0.254		0.017	0.069	0.016		0.041	0.039			0.018		0.343
ODF	0.005			0.007		0.241	0.001	0.711	0.031					0.005
SDF		1												
YTN								0.012				0.988		
BTN												1.000		
LTN	0.087							0.913						
SWD								0.035				0.965		
AMB								0.961	0.014					0.025
JCK	0.048			0.000		0.012		0.645	0.015					0.280
KMK								0.792				0.208		
SMK	0.810	0.000						0.101		0.002		0.061		0.027
SAR								0.088						0.912
LPL	0.190	0.036						0.398	0.015	0.016		0.338		0.008
DWF														
MEN	0.000							0.000		1.000				0.000
PIN						0.588		0.270						0.142

Table A.12. (cont.)

Group	GillnetEst	TwlShpEst	OytEst	PotCrbEst	TwlShpShf	PotCrbShf	PotLbtShf	HLReefShf	LLReefShf	SeineMenShf	LLShkShf	LLPelgc	RoyalRed	OtherUS
MPL				0.001				0.311				0.003		0.685
SPL	0.000													1.000
TIP								0.919			0.081			
LGS	0.340	0.001			0.000			0.258	0.037	0.000	0.290	0.072		0.002
RAY	1.000													
BSH		0.193			0.807									0.000
WSH		0.298			0.701									0.000
PSH		0.002			0.998									
OSH		0.311			0.622	0.000							0.067	0.000
BCR		0.002		0.997	0.000	0.000		0.000	0.000					
SCR				0.984			0.016							
LOB				0.000	0.000		0.966							0.033
SPG														1.000
OYS			0.967											0.033
BIV	0.003	0.003	0.002	0.001	0.937	0.037	0.004	0.000	0.000			0.000		0.013
SQU		0.266		0.115	0.429	0.140		0.049						0.001

Table A.13. Proportion of each functional group caught in each fleet associated to the Mexico commercial landings.

Group	TwlShpMX	LLReefMX	LLShkMX	GillnetMackMX	OctpsMX	MixedMX
RGR		0.5				0.5
SSR		0.5				0.5
DSR		1				
RSN		0.5				0.5
VSN		0.5				0.5
LUT		0.5				0.5
LRF						1
SRF						1
RDR						1
SEA						1
SCI						1
LDY						1
MUL				0.5		0.5
POM						1
SHP	0.333333333			0.333333333		0.33
SNK						1
FLT	0.333333333			0.333333333		0.333333333
ODF						1
SDF						1
YTN			0.5			0.5
BTN			0.5			0.5
LTN			0.5			0.5
OTN			0.5			0.5
SWD			0.5			0.5
WMR			0.5			0.5
BMR			0.5			0.5
BIL			0.5			0.5
AMB			0.5			0.5
JCK			0.5			0.5
KMK			0.5	0.5		
SMK			0.5	0.5		
SAR						1
LPL				1		
PIN						1
MPL						1
SPL						1
TIP			1			
BEN	0.333333333		0.333333333			0.333333333
LGS			0.5			0.5
FIL						1
SMS	0.25		0.25	0.25		0.25
RAY	0.333333333		0.333333333			0.333333333
BSH	1					
WSH	0.5					0.5
PSH	1					
OSH	0.5					0.5
BCR						1
SCR						1
LOB						1
OCT					1	
CMB	0.5					0.5
OYS						1
BIV						1
SQU	0.5					0.5

Table A.14. The mFC matrix utitilized in the at_harvest input file. This describes the portion of system-wide harvestable biomass for each functional group designated to each fleet.

Group	GillnetEst	TwlShpEst	OytEst	PotCrbEst	TwlShpShf	PotCrbShf	PotLbtShf	HLReefShf	LLReefShf
GAG	0	0	0	0	0	0	0	0.006187098	0.002251154
RGR	0	0	0	0	0	5.51908E-06	0	0	0.039503222
SCM	0	0	0	0	0	0	0	0.020651985	0.021796163
SSR	0	0	0	0	0	1.19219E-05	1.28452E-06	0.000624235	0.00033368
DSR	0	0	0	0.00014253	0	0.004091742	0	0.001334551	0.005414366
RSN	0	0	0	0	0	0	0	0.011345548	0.000384824
VSN	0	0	0	0	0	0	0	0.018734756	3.27641E-05
LUT	3.90987E-08	0	0	0	0	9.85287E-06	3.96674E-06	0.003568454	0.000253228
BIO	0	0	0	0	0	0	0	0	0
LRF	5.71812E-06	3.94663E-05	0	0	1.02777E-05	3.10199E-05	1.89109E-05	0.000845983	0.00010913
SRF	1.46558E-05	0	0	0	0	0	0	0.003511606	0.008623781
BDR	0.004231813	0.003148907	0	0.002424769	0.011104226	0	0	0.009927822	0.132153911
RDR	0	0	0	0	0	0	0	0.000554441	0
SEA	0.0003089	8.80607E-06	0	0	0.000295843	0	0	0.002538109	0
SCI	0.000469553	0.000257515	0	2.56873E-06	0.00107303	0	0	0.001400543	0
LDY	0.003885089	0	0	0	0	0	0	0.000238976	0
MUL	0.008002357	0	0	2.5923E-06	8.67336E-06	0	0	1.35149E-05	0
POM	6.40384E-05	0	0	0	0	0	0	0.000151422	0
SHP	0.000157468	0.000269429	0	4.85322E-06	0.000354607	0	0	0.000817503	7.50498E-05
SNK	0	0	0	0	0	0	0	0	0
FLT	0.000962698	0.001206383	0	7.99046E-05	0.000324801	7.46056E-05	0	0.000194107	0.000186933
ODF	1.8188E-05	0	0	2.64282E-05	0	0.000966286	2.62574E-06	0.002852192	0.00012548
SDF	0	0.001373001	0	0	0	0	0	0	0
YTN	0	0	0	0	0	0	0	0.000645082	0
BTN	0	0	0	0	0	0	0	0	0
LTN	2.12321E-05	0	0	0	0	0	0	0.000223051	0
OTN	0	0	0	0	0	0	0	0	0
SWD	0	0	0	0	0	0	0	0.002466633	0
WMR	0	0	0	0	0	0	0	0	0
BMR	0	0	0	0	0	0	0	0	0
BIL	0	0	0	0	0	0	0	0	0
AMB	0	0	0	0	0	0	0	0.047273841	0.000698102
JCK	0.00091971	0	0	4.34132E-06	0	0.000226454	0	0.012466711	0.000297761
KMK	0	0	0	0	0	0	0	0.009967443	0
SMK	0.016067385	8.75564E-06	0	0	0	0	0	0.001997266	0
SAR	0	0	0	0	0	0	0	4.91798E-06	0
LPL	0.001986873	0.000374322	0	0	0	0	0	0.004172328	0.000159289
DWF	0	0	0	0	0	0	0	0	0
MEN	1.50878E-05	0	0	0	0	0	0	8.1051E-09	0
PIN	0	0	0	0	0	0.000452542	0	0.000208191	0

Table A.14.(cont.)

Group	GillnetEst	TwlShpEst	OytEst	PotCrbEst	TwlShpShf	PotCrbShf	PotLbtShf	HLReefShf	LLReefShf
MPL	0	0	0	1.2134E-06	0	0	0	0.000432841	0
SPL	4.40667E-07	0	0	0	0	0	0	0	0
TIP	0	0	0	0	0	0	0	0.014583278	0
BEN	0	0	0	0	0	0	0	0	0
LGS	0.000129811	3.72487E-07	0	0	2.68944E-08	0	0	9.83531E-05	1.41327E-05
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0	0
RAY	6.0577E-06	0	0	0	0	0	0	0	0
BSH	0	0.010104398	0	0	0.042210807	0	0	0	0
WSH	0	0.021416073	0	0	0.050342806	0	0	0	0
PSH	0	8.29309E-05	0	0	0.049439931	0	0	0	0
OSH	0	0.007257947	0	0	0.014520941	3.12854E-07	0	0	0
DBR	0	0	0	0	0	0	0	0	0
SBR	0	0	0	0	0	0	0	0	0
MAN	0	0	0	0	0	0	0	0	0
MYS	0	0	0	0	0	0	0	0	0
DOL	0	0	0	0	0	0	0	0	0
DDO	0	0	0	0	0	0	0	0	0
LOG	0	0	0	0	0	0	0	0	0
KMP	0	0	0	0	0	0	0	0	0
TUR	0	0	0	0	0	0	0	0	0
BCR	0	0.000216748	0	0.104694157	2.19124E-05	3.23873E-05	0	4.92347E-07	2.65808E-05
SCR	0	0	0	0.012881678	0	0	0.000208099	0	0
LOB	0	0	0	8.57368E-06	9.3412E-07	0	0.030465254	0	0
COR	0	0	0	0	0	0	0	0	0
CCA	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0
SPG	0	0	0	0	0	0	0	0	0
CMB	0	0	0	0	0	0	0	0	0
INF	0	0	0	0	0	0	0	0	0
ECH	0	0	0	0	0	0	0	0	0
OYS	0	0	0.000617056	0	0	0	0	0	0
BIV	3.45267E-08	2.98558E-08	2.4168E-08	8.23717E-09	1.07639E-05	4.23887E-07	4.85253E-08	2.81936E-09	4.62179E-09
SES	0	0	0	0	0	0	0	0	0
EPI	0	0	0	0	0	0	0	0	0
GRS	0	0	0	0	0	0	0	0	0
ALG	0	0	0	0	0	0	0	0	0
MPB	0	0	0	0	0	0	0	0	0
LPP	0	0	0	0	0	0	0	0	0
SPP	0	0	0	0	0	0	0	0	0
DIN	0	0	0	0	0	0	0	0	0
PRO	0	0	0	0	0	0	0	0	0

Table A.14.(cont.)

Group	GillnetEst	TwlShpEst	OytEst	PotCrbEst	TwlShpShf	PotCrbShf	PotLbtShf	HLReefShf	LLReefShf
JEL	0	0	0	0	0	0	0	0	0
SQU	0	0.000293034	0	0.000126105	0.000472454	0.000154061	0	5.38999E-05	0
LZP	0	0	0	0	0	0	0	0	0
SZP	0	0	0	0	0	0	0	0	0
PB	0	0	0	0	0	0	0	0	0
BB	0	0	0	0	0	0	0	0	0
DC	0	0	0	0	0	0	0	0	0
DL	0	0	0	0	0	0	0	0	0
DR	0	0	0	0	0	0	0	0	0

Group	SeineMenShf	LLShkShf	LLPelgc	RoyalRed	OtherUS	SprtEst	SprtShf	TwlShpMX	LLReefMX
GAG	0	0	0	0	0.000772411	0	0.014992669	0	0
RGR	0	0	0	0	0.000360106	0	0.004606422	0	0.058084168
SCM	0	0	0	0	0.000578778	0	0.015660394	0	0
SSR	0	0	0	0	0.000217083	0	0.000101141	0	0.001938071
DSR	0	0	0	0	1.12377E-06	0	0.014459221	0	0.013453318
RSN	0	0	0	0	7.85378E-05	0	0.011962657	0	0.014672637
VSN	0	0	0	0	1.46899E-05	0	0.004087626	0	0.006558453
LUT	0	0	0	0	4.87436E-05	0	0.021453141	0	0.004829618
BIO	0	0	0	0	0	0	0	0	0
LRF	0	0	0	0	0.001531149	0	0.003216696	0	0
SRF	0	0	4.27062E-05	0	0.000264413	0	0.011511863	0	0
BDR	0	0	0.00340205	0	0.000739368	0.091369678	0	0	0
RDR	0	0	0	0	0	0.24152899	0	0	0
SEA	0	0	0	0	9.05295E-05	0.046195662	0	0	0
SCI	0	0	0	0	0.000569091	0.00081795	0	0	0
LDY	0	0	0	0	0.001522795	0.002049619	0	0	0
MUL	0.000254541	0	0	0	0.036804568	0.005502539	0	0	0
POM	0	0	0	0	5.79373E-05	9.10773E-05	0	0	0
SHP	4.94294E-07	0	0	0	0.000337972	0.01180452	0	0.000448062	0
SNK	0	0	0	0	0	7.30887E-08	0	0	0
FLT	0	0	8.3445E-05	0	0.001628617	0	0.00172162	0.001447536	0
ODF	0	0	0	0	1.90526E-05	0	0.395364727	0	0
SDF	0	0	0	0	0	0	3.52755E-07	0	0
YTN	0	0	0.051934786	0	0	0	0.033352097	0	0
BTN	0	0	0.000539553	0	0	0	0	0	0
LTN	0	0	0	0	0	0	0.001815951	0	0
OTN	0	0	0	0	0	0	0	0	0
SWD	0	0	0.068221466	0	0	0	0.001562638	0	0
WMR	0	0	0	0	0	0	0	0	0
BMR	0	0	0	0	0	0	0.001064637	0	0

Table A.14.(cont.)

Group	SeineMenShf	LLShkShf	LLPelgc	RoyalRed	OtherUS	SprtEst	SprtShf	TwlShpMX	LLReefMX
BIL	0	0	0	0	0	0	0	0	0
AMB	0	0	0	0	0.001206759	0	0.05474537	0	0
JCK	0	0	0	0	0.005408694	0	0.083902594	0	0
KMK	0	0	0.002613159	0	0	0	0.008911432	0	0
SMK	3.72547E-05	0	0.00120092	0	0.000530393	0	0.05836533	0	0
SAR	0	0	0	0	5.09048E-05	0	4.05215E-06	0	0
LPL	0.000163297	0	0.003539634	0	7.91658E-05	0	0.179785919	0	0
DWF	0	0	0	0	0	0	0	0	0
MEN	0.067073385	0	0	0	1.28575E-05	0	8.46586E-06	0	0
PIN	0	0	0	0	0.000109181	0	0.005088181	0	0
MPL	0	0	3.86081E-06	0	0.000951989	0	3.76994E-06	0	0
SPL	0	0	0	0	0.001458363	0	0.000154778	0	0
TIP	0	0.001288063	0	0	0	0	0.005205005	0	0
BEN	0	0	0	0	0	0	0	4.00832E-05	0
LGS	1.17327E-07	0.000110736	2.72964E-05	0	6.04451E-07	0	0.000579857	0	0
FIL	0	0	0	0	0	0	0	0	0
SMS	0	0	0	0	0	0	0	0.000293504	0
RAY	0	0	0	0	0	1.83249E-05	0	0.002351281	0
BSH	0	0	0	0	1.76809E-05	0	0	0.016858931	0
WSH	0	0	0	0	2.15688E-05	0	0	0.000977511	0
PSH	0	0	0	0	0	0	0	0.014628726	0
OSH	0	0	0	0.001570797	9.78787E-07	0	0	0.005049756	0
DBR	0	0	0	0	0	0	0	0	0
SBR	0	0	0	0	0	0	0	0	0
MAN	0	0	0	0	0	0	0	0	0
MYS	0	0	0	0	0	0	0	0	0
DOL	0	0	0	0	0	0	0	0	0
DDO	0	0	0	0	0	0	0	0	0
LOG	0	0	0	0	0	0	0	0	0
KMP	0	0	0	0	0	0	0	0	0
TUR	0	0	0	0	0	0	0	0	0
BCR	0	0	0	0	0	0	0	0	0
SCR	0	0	0	0	0	0	0	0	0
LOB	0	0	0	0	0.00105292	0	0.007397275	0	0
COR	0	0	0	0	0	0	0	0	0
CCA	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0
SPG	0	0	0	0	0.001161363	0	0	0	0
CMB	0	0	0	0	0	0	0	0.00256983	0
INF	0	0	0	0	0	0	0	0	0
ECH	0	0	0	0	0	0	0	0	0
OYS	0	0	0	0	2.08295E-05	0	0	0	0

Table A.14.(cont.)

Group	SeineMenShf	LLShkShf	LLPelgc	RoyalRed	OtherUS	SprtEst	SprtShf	TwlShpMX	LLReefMX
BIV	0	0	3.37693E-09	0	1.48062E-07	0	0	0	0
SES	0	0	0	0	0	0	0	0	0
EPI	0	0	0	0	0	0	0	0	0
GRS	0	0	0	0	0	0	0	0	0
ALG	0	0	0	0	0	0	0	0	0
MPB	0	0	0	0	0	0	0	0	0
LPP	0	0	0	0	0	0	0	0	0
SPP	0	0	0	0	0	0	0	0	0
DIN	0	0	0	0	0	0	0	0	0
PRO	0	0	0	0	0	0	0	0	0
JEL	0	0	0	0	0	0	0	0	0
SQU	0	0	0	0	1.37631E-06	0	0	0.237363797	0
LZP	0	0	0	0	0	0	0	0	0
SZP	0	0	0	0	0	0	0	0	0
PB	0	0	0	0	0	0	0	0	0
BB	0	0	0	0	0	0	0	0	0
DC	0	0	0	0	0	0	0	0	0
DL	0	0	0	0	0	0	0	0	0
DR	0	0	0	0	0	0	0	0	0

Group	LLShkMX	GillnetMackMX	OctpsMX	MixedMX	MixedCB
GAG	0	0	0	0	0
RGR	0	0	0	0.058084168	0
SCM	0	0	0	0	0
SSR	0	0	0	0.001938071	0.002883985
DSR	0	0	0	0	0
RSN	0	0	0	0.014672637	0.0019357
VSN	0	0	0	0.006558453	0
LUT	0	0	0	0.004829618	0.00124796
BIO	0	0	0	0	0.008239517
LRF	0	0	0	0.04419073	0.005299568
SRF	0	0	0	0.020625604	0.005705031
BDR	0	0	0	0	0
RDR	0	0	0	0.031324677	0
SEA	0	0	0	0.043265352	0
SCI	0	0	0	0.00303586	0
LDY	0	0	0	0	0
MUL	0	0.024663734	0	0.024663734	0.000596416
POM	0	0	0	0.006180515	0
SHP	0	0.000448062	0	0.000448062	0
SNK	0	0	0	0.028226943	0

Table A.14.(cont.)

Group	LLShkMX	GillnetMackMX	OctpsMX	MixedMX	MixedCB
FLT	0	0.001447536	0	0.001447536	0
ODF	0	0	0	0.01102476	0.000523467
SDF	0	0	0	0.035629856	0
YTN	0.074875416	0	0	0.074875416	5.59318E-05
BTN	0.034125225	0	0	0.034125225	0
LTN	0.004890825	0	0	0.004890825	7.36078E-05
OTN	0	0	0	0	0
SWD	0.042554353	0	0	0.042554353	6.59996E-05
WMR	0.026975985	0	0	0.026975985	0
BMR	0.049164316	0	0	0.049164316	0.00044923
BIL	0.138081376	0	0	0.138081376	0.015195588
AMB	0.023838441	0	0	0.023838441	0
JCK	0.156365502	0	0	0.156365502	0.000179334
KMK	0.011496381	0.011496381	0	0	3.98337E-06
SMK	0.042267239	0.042267239	0	0	1.14855E-05
SAR	0	0	0	0.004269545	0
LPL	0	0.055896256	0	0	0.002756752
DWF	0	0	0	0	0
MEN	0	0	0	0	0
PIN	0	0	0	0.002802694	0
MPL	0	0	0	0.014790644	4.2011E-05
SPL	0	0	0	0.001072728	0.000821119
TIP	0.095390343	0	0	0	0
BEN	4.00832E-05	0	0	4.00832E-05	0
LGS	0.00108391	0	0	0.00108391	4.36527E-05
FIL	0	0	0	0	0
SMS	0.000293504	0.000293504	0	0.000293504	0
RAY	0.002351281	0	0	0.002351281	0.001182872
BSH	0	0	0	0	0
WSH	0	0	0	0.000977511	0
PSH	0	0	0	0	0
OSH	0	0	0	0.005049756	0
DBR	0	0	0	0	0
SBR	0	0	0	0	0
MAN	0	0	0	0	0
MYS	0	0	0	0	0
DOL	0	0	0	0	0
DDO	0	0	0	0	0
LOG	0	0	0	0	0
KMP	0	0	0	0	0
TUR	0	0	0	0	0
BCR	0	0	0	0.039832921	0.000240191

Table A.14.(cont.)

Group	LLShkMX	GillnetMackMX	OctpsMX	MixedMX	MixedCB
SCR	0	0	0	0.003040634	0
LOB	0	0	0	0.008038277	0.009944866
COR	0	0	0	0	0
CCA	0	0	0	0	0
OCT	0	0	0	0	0
SPG	0	0	0	0	0
CMB	0	0	0	0.00256983	0.0001851
INF	0	0	0	0	0
ECH	0	0	0	0	0
OYS	0	0	0	0.000143875	0
BIV	0	0	0	0.00027546	1.03899E-05
SES	0	0	0	0	0
EPI	0	0	0	0	0
GRS	0	0	0	0	0
ALG	0	0	0	0	0
MPB	0	0	0	0	0
LPP	0	0	0	0	0
SPP	0	0	0	0	0
DIN	0	0	0	0	0
PRO	0	0	0	0	0
JEL	0	0	0	0	0
SQU	0	0	0	0.237363797	0
LZP	0	0	0	0	0
SZP	0	0	0	0	0
PB	0	0	0	0	0
BB	0	0	0	0	0
DC	0	0	0	0	0
DL	0	0	0	0	0
DR	0	0	0	0	0

Table A.15. Marine protected areas represented in Atlantis

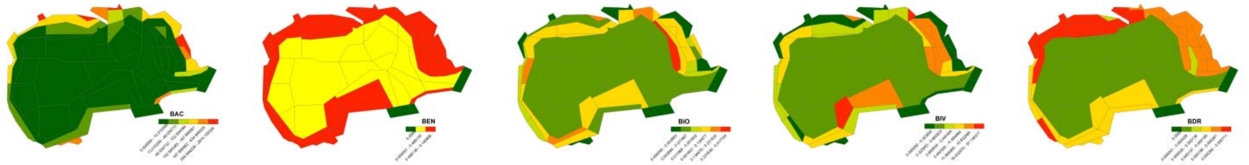
Year enacted	Name	Boxes affected	Restrictions
2005	Madison and Swanson Sites	31	No fishing, Nov 1st to April 30th
2000	Desoto Canyon Closed Area	1,8,9,12,33,23,25,26, 29,38,39,42	No pelagic longline
1980	Dry Tortugas National Park	28	No lobsters, no spearfishing
2000	East Florida Coast Closed Area	28	No pelagic longline
2009	East Hump MPA	29	No commerical (bottom gear)
1990	Florida Keys National Marine Sanctuary -	27,28,29,32	No removal of coral or benthos
1990	Florida Keys National Marine Sanctuary	28	No take
1984	Florida Middle Grounds Habitat Area of Particular Concern	42	No bottom longline, trawl, or dredge, pot, or trap
1992	Flower Garden Banks National Marine Sanctuary	20, 43	Only hook and line, no fishign of any other type allowed
1998	Isla Contoy	0	No fishing, no removing coral
1980	John Pennekamp Coral Reef State Park	27,28	No spearfishing or collection of tropical fish
1989	John Pennekamp Coral Reef State Park, Harvest Prohibited or Restricted Area	27	No lobsters, no spearfishing
1994	Laguna de Terminos	40	92.5% reduction in all fisheries
2006	McGrail Bank Habitat Area of Particular Concern	43	no bottom gear, bouy gear, traps etc
2006	Pulley Ridge Habitat Area of Particular Concern	29, 64	no bottom gear, bouy gear, traps etc
1990	Reef Fish Longline and Buoy Gear Restricted Area	1,5,6,17,20,21,22,23, 24,25,27,28,31,32,33, 34,39,42,43,51,53,60, 61	no bottom gear, bouy gear

Table A.15. (cont.)

Year enacted	Name	Boxes affected	Restrictions
1990	Reef Fish Stressed Area	5,6,17,20,21,23,24,27,28,31,32,33,34,39,51,53,54,60,61	No roller trawls
1980	Rockefeller Wildlife Management Area and Game Preserve	21	No Take
1989	San Pedro Underwater Archaeological Preserve State Park	28	No Take
2010	Steamboat Lumps	1,25	No fishing, Nov1 to April 30th
2006	Stetson Bank Habitat Area of Particular Concern	20	No bottom longline, trawl, or dredge, pot, or trap
2002	Tortugas Marine Reserves	28, 29, 32	No take
2000	Arrecife Alacranes	13	Closed to lobster and grouper
1984	Biscayne Bay-Card Sound Spiny Lobster Sanctuary	27	No lobster fishing

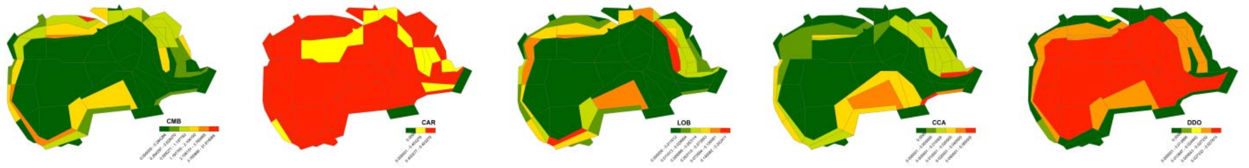
Figure A.1. Seasonal functional group biomass distributions (winter)

Bacteria | Benthic feeding sharks | Bioeroding fish | Bivalves | Black drum

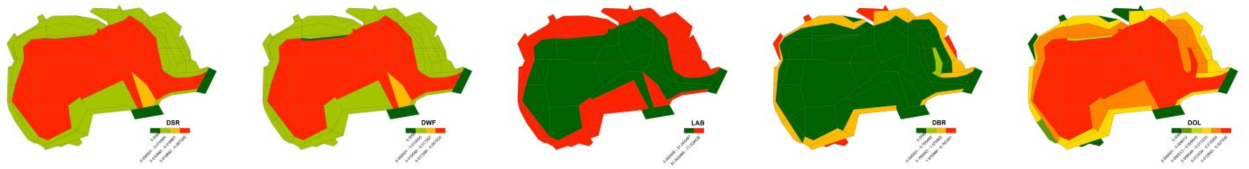


Blacktip shark | Blue crab | Blue Marlin | Bluefin tuna | Brown shrimp

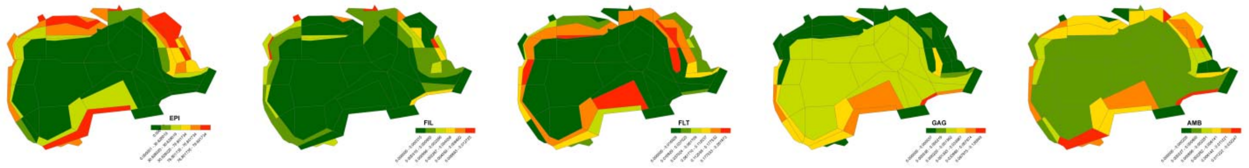
Carn. macrobenthos | Carrion detritus | Crabs and lobsters | Crust. coralline algae | Deep diving odont.



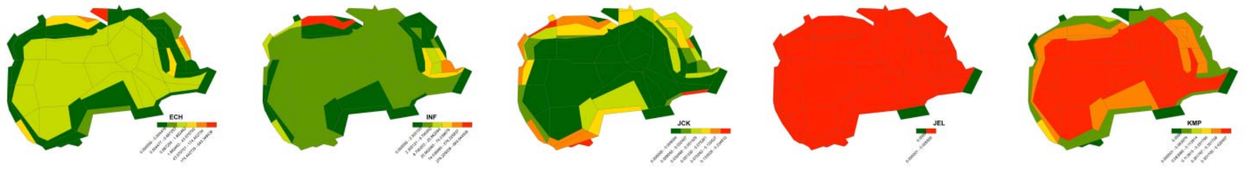
Deep serranidae | Deep water fish | Detritus | Diving birds | Dolphins / porpoises



Epiphytes | Filter feeding sharks | Flatfish | Gag grouper | Greater amberjack



Herb. echinoderms | Infaunal meiobenthos | Jacks | Jellyfish | Kemps ridley turtle



King mackerel | Labile detritus | Ladyfish | Large pelagic fish | L. phytoplankton

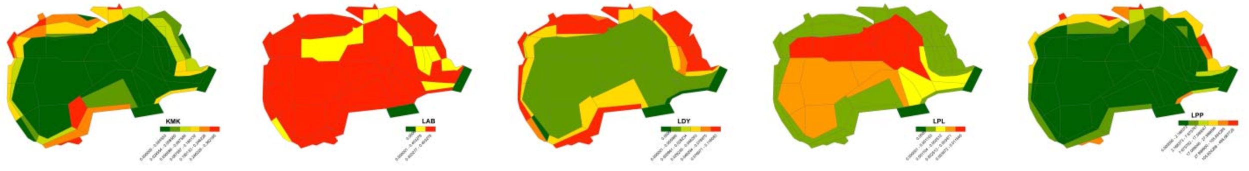
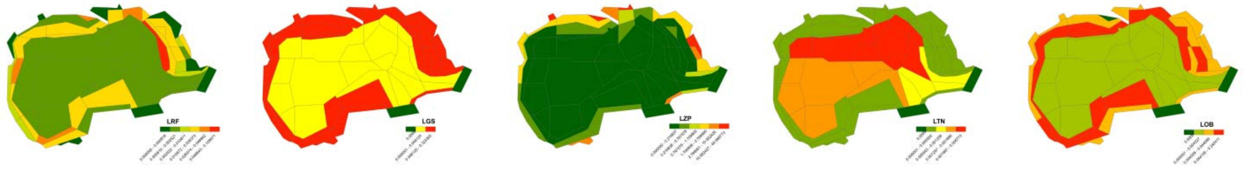
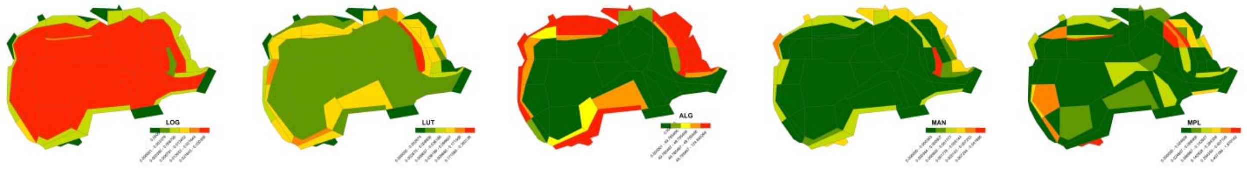


Figure A.1 (cont.)

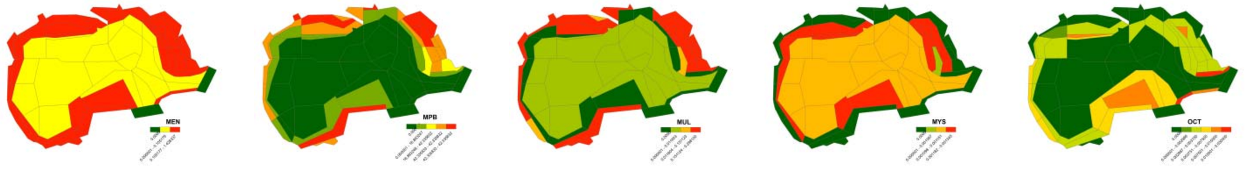
Large reef fish
Large sharks
Large zooplankton
Little tunny
Lobsters and crabs



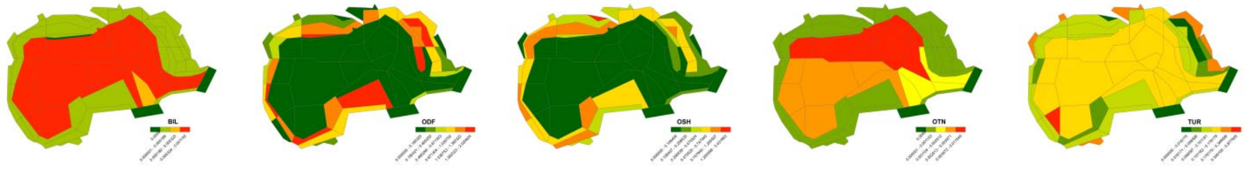
Loggerhead turtle
Lutjanidae
Macroalgae
Manatees
Medium pelagic fish



Menhaden
Microphytobenthos
Mullet
Mysticeti
Octocorals

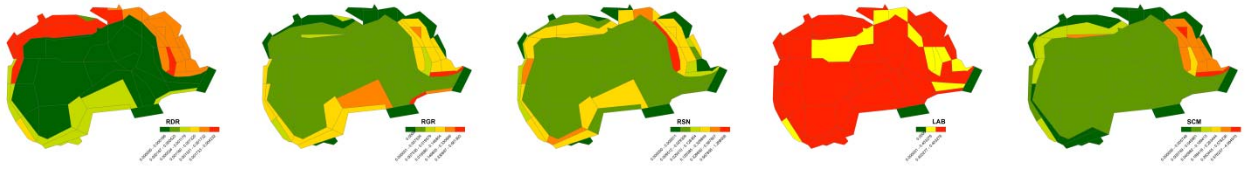


Other billfish
Other demersal fish
Other shrimp
Other tuna
Other turtles



Oysters
Pinfish
Pink shrimp
Pompano
Protists

Red drum
Red grouper
Red snapper
Refractory detritus
Scamp



Scianidae
Seagrass
Sea trout
Shallow serranidae
Sheepshead

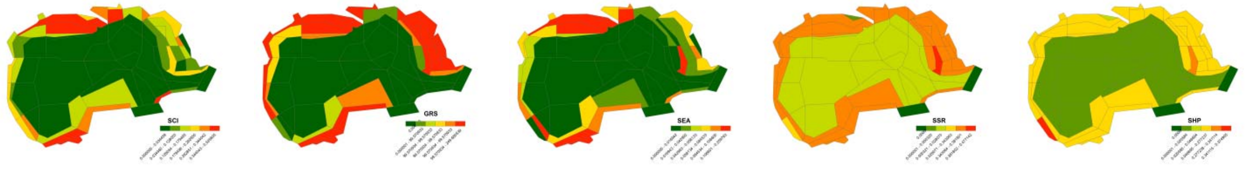
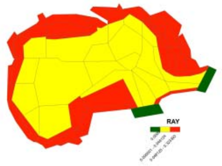
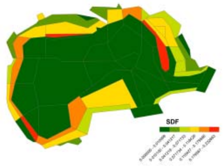


Figure A.1 (cont.)

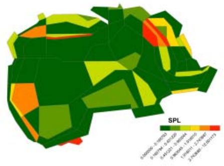
Skates and rays



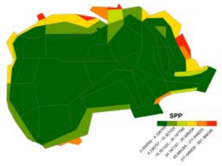
Small demersal fish



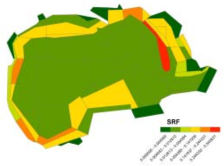
Small pelagic fish



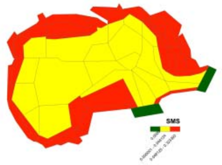
Small phytoplankton



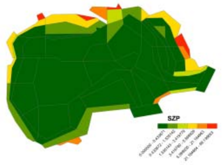
Small reef fish



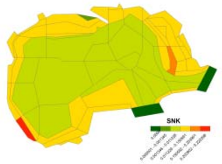
Small sharks



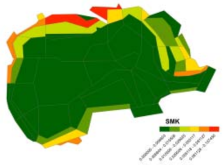
Small zooplankton



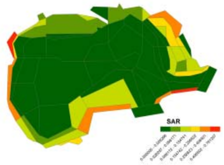
Snook



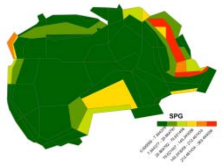
Spanish mackerel



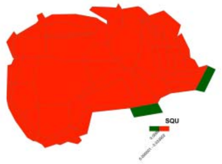
Spanish sardine



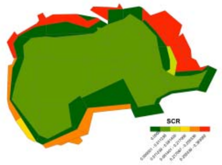
Sponges



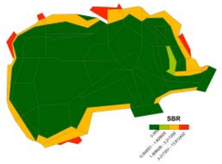
Squid



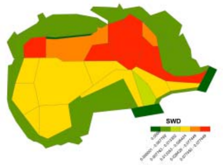
Stone crab



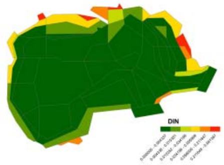
Surface feeding birds



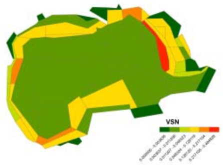
Swordfish



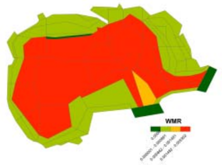
Toxic dinoflagellates



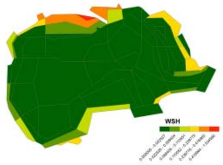
Vermillion snapper



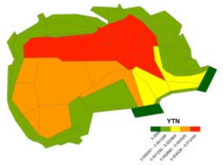
White marlin



White shrimp



Yellowfin tuna



Appendix B – Model performance

Figure B.1. Fit to observational data 1990-2010

Line is model fit; black dots are best fit CPUE; gray dots are CPUE scaled to match model mean.

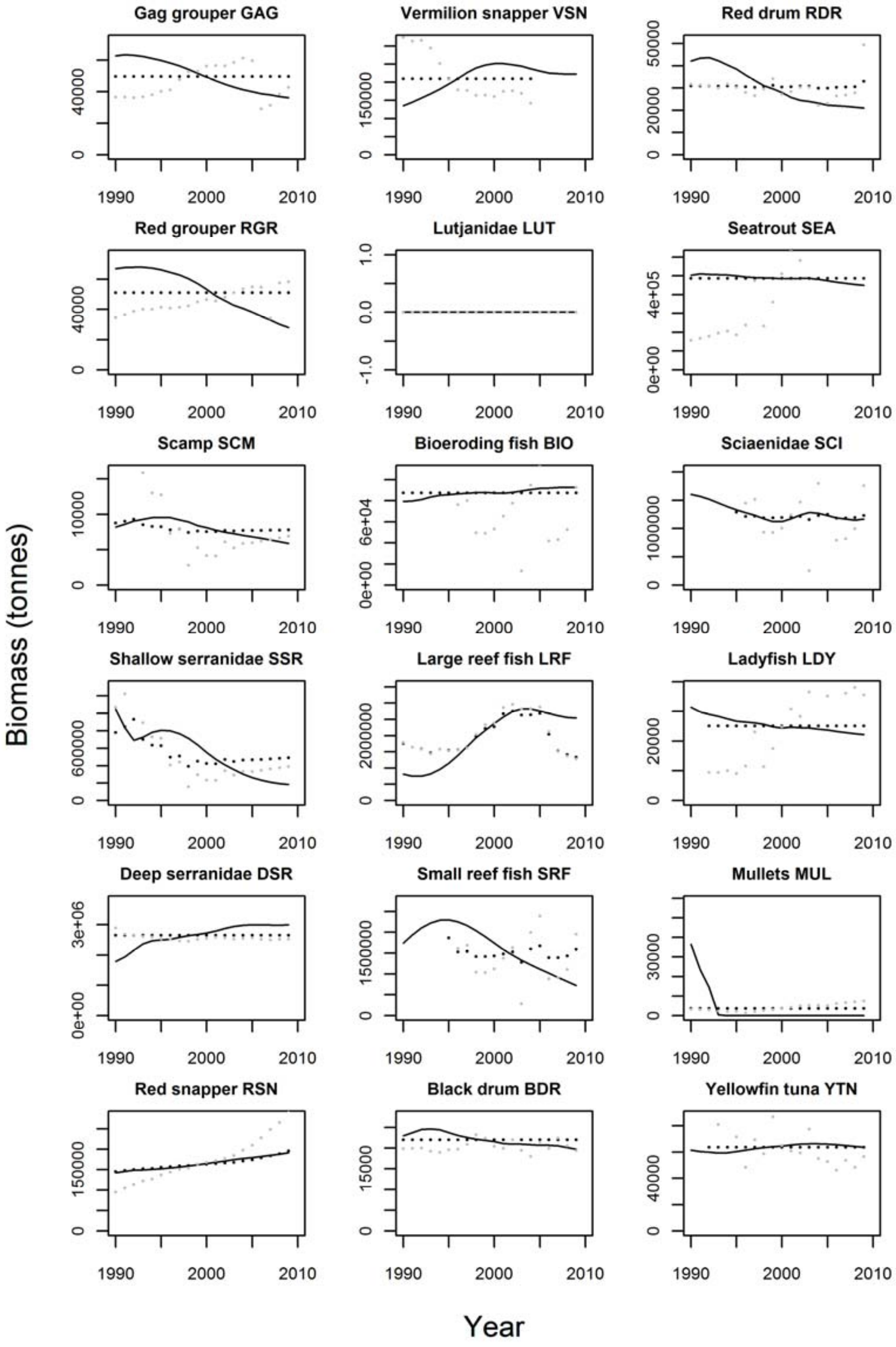


Figure B.1. (cont.)

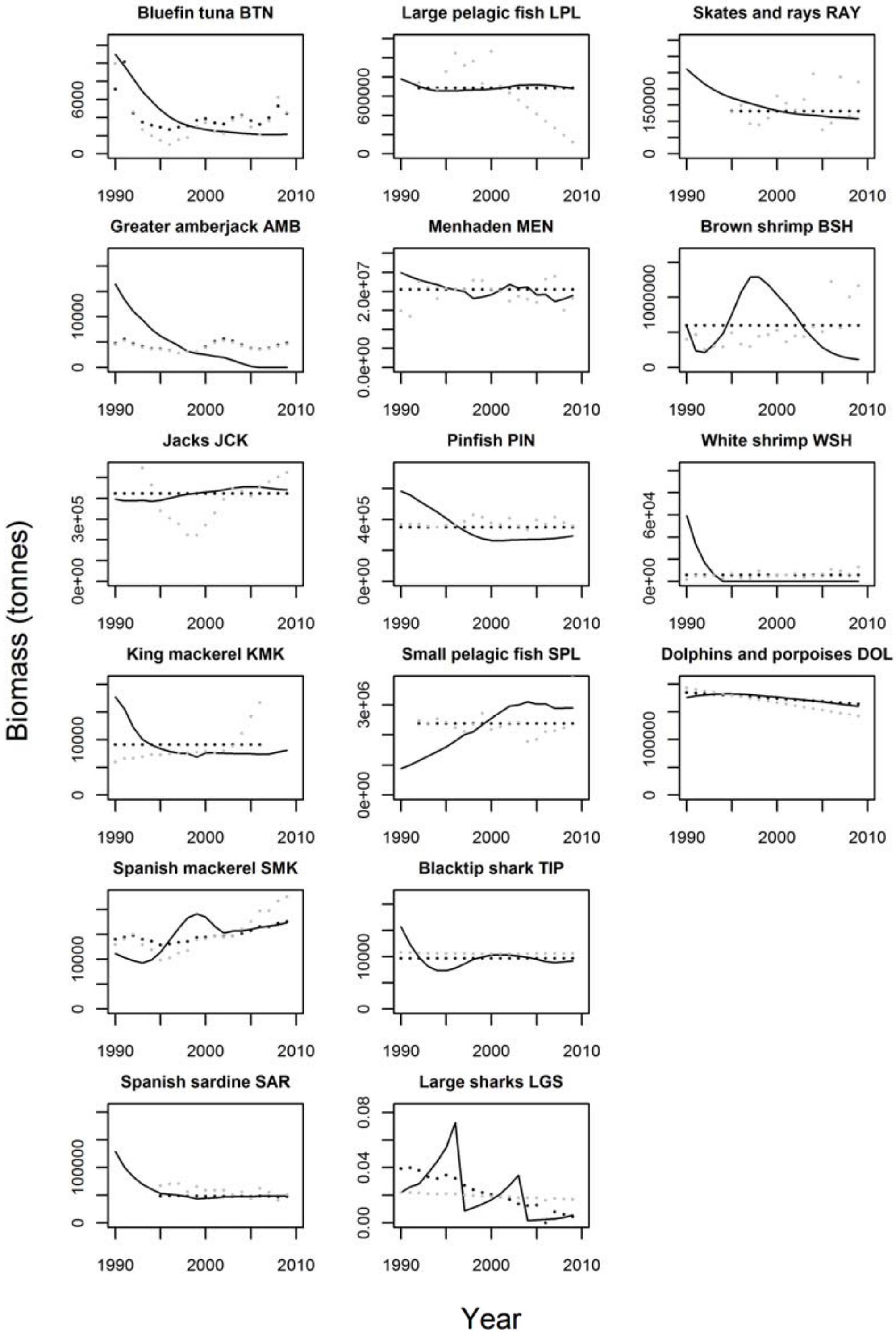


Figure B.2. Simulations (1980-2010) with (red) and without fisheries (black) for selected species

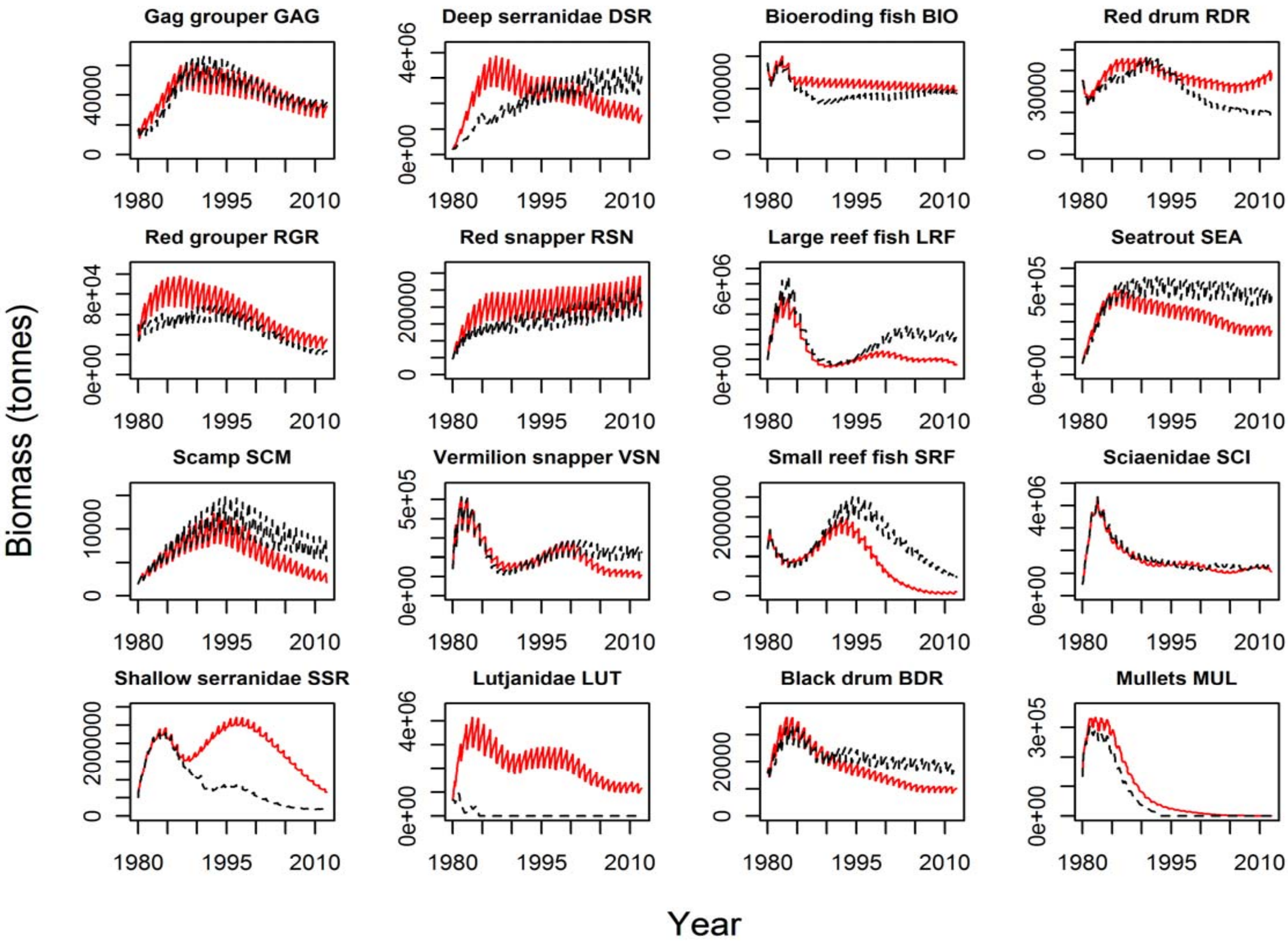


Figure B.2. (cont.)

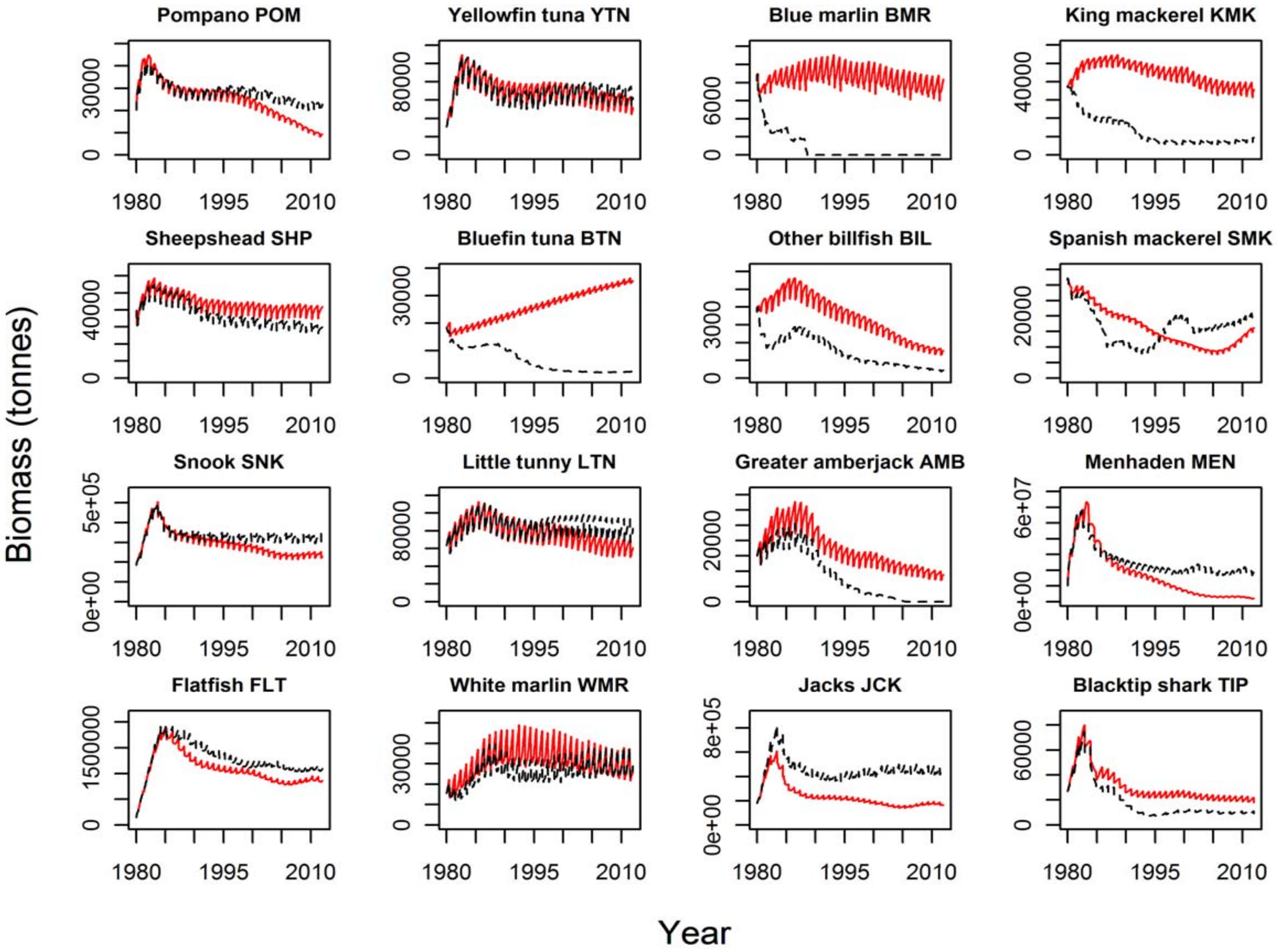


Figure B.3. Ratio between initial and predicted (2012) spatial biomass distribution for the historical run.

Groups that go extinct at the end of the historical run are not shown.

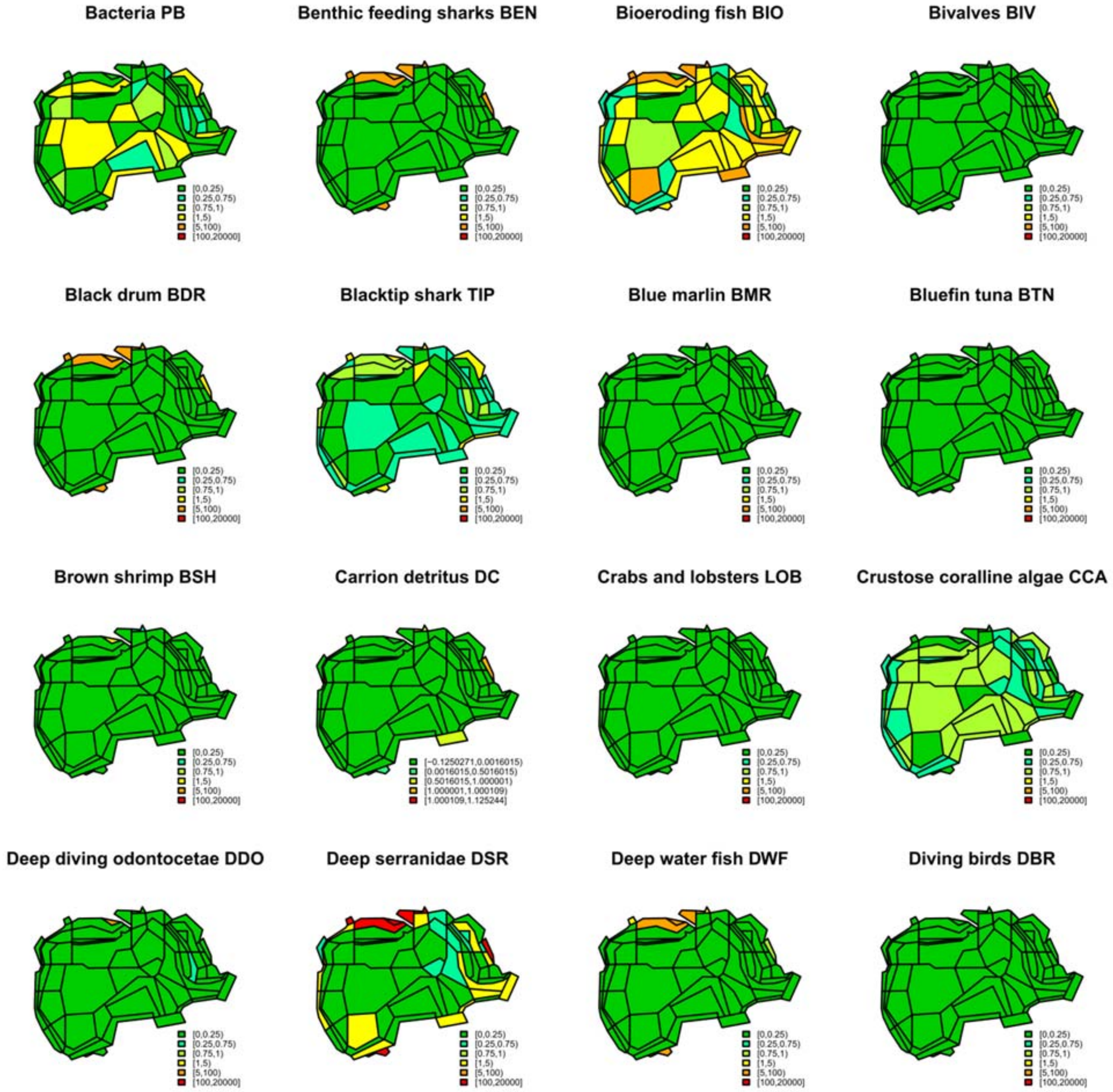


Figure B.3. (cont.)

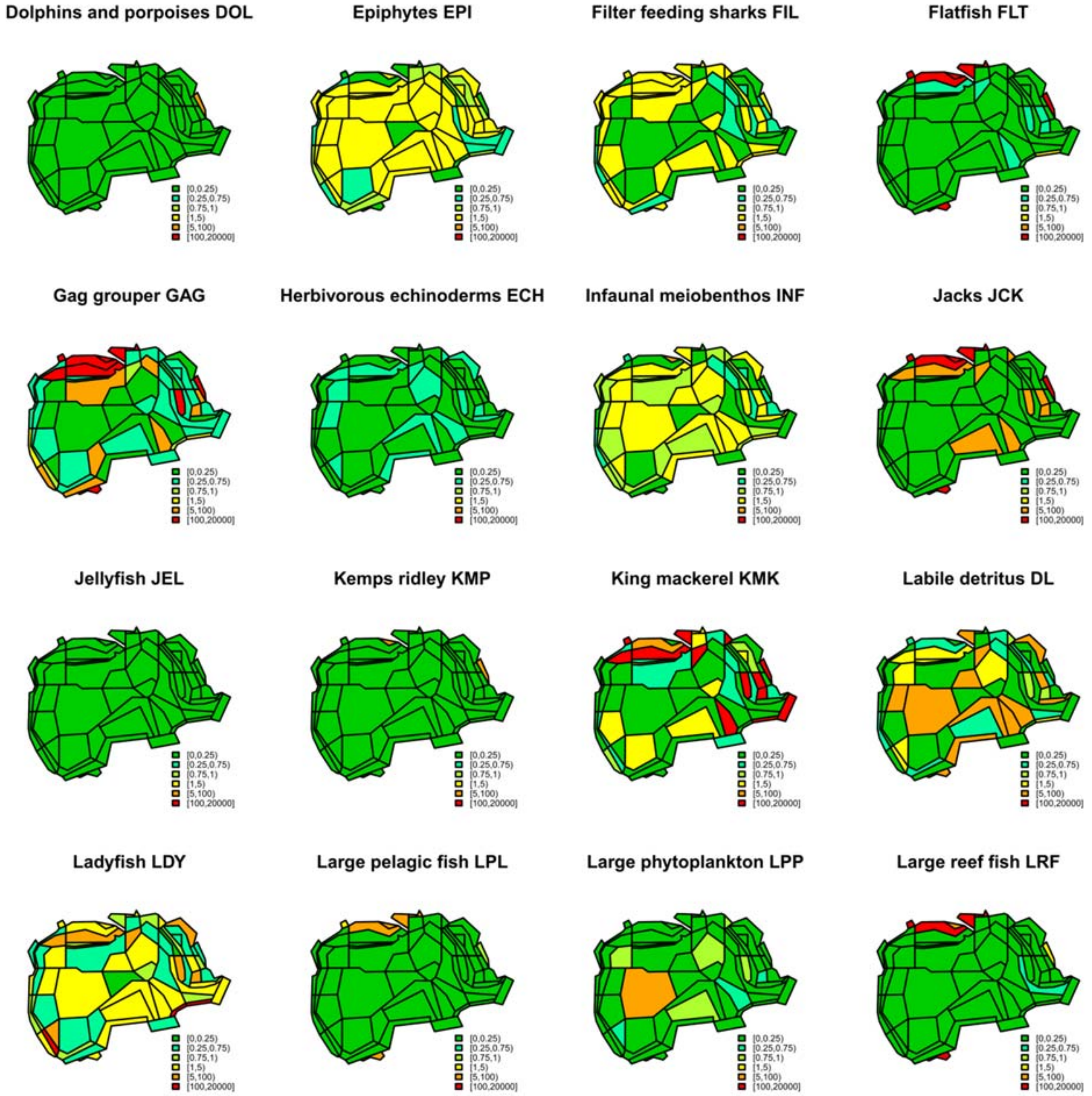


Figure B.3. (cont.)

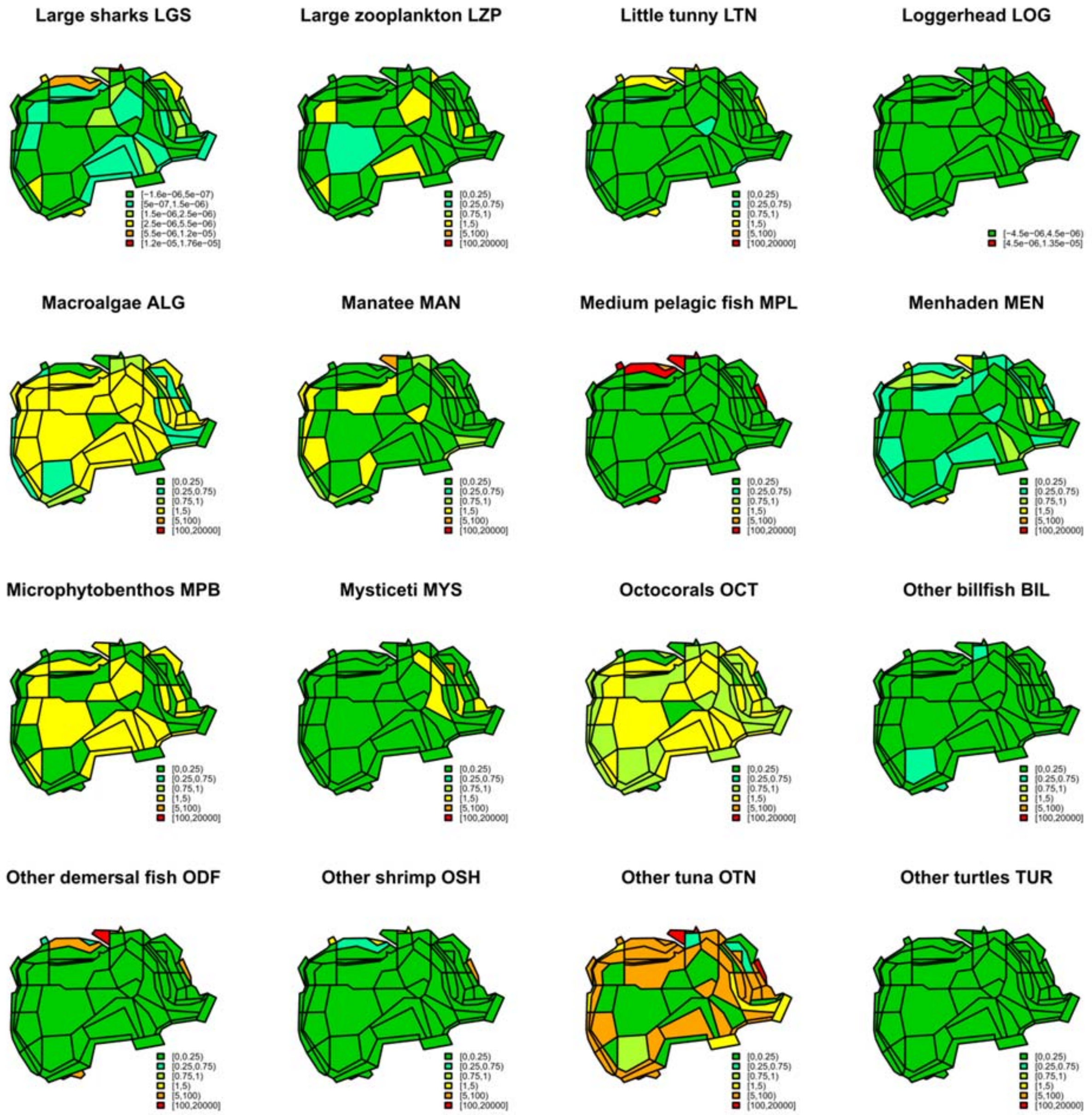
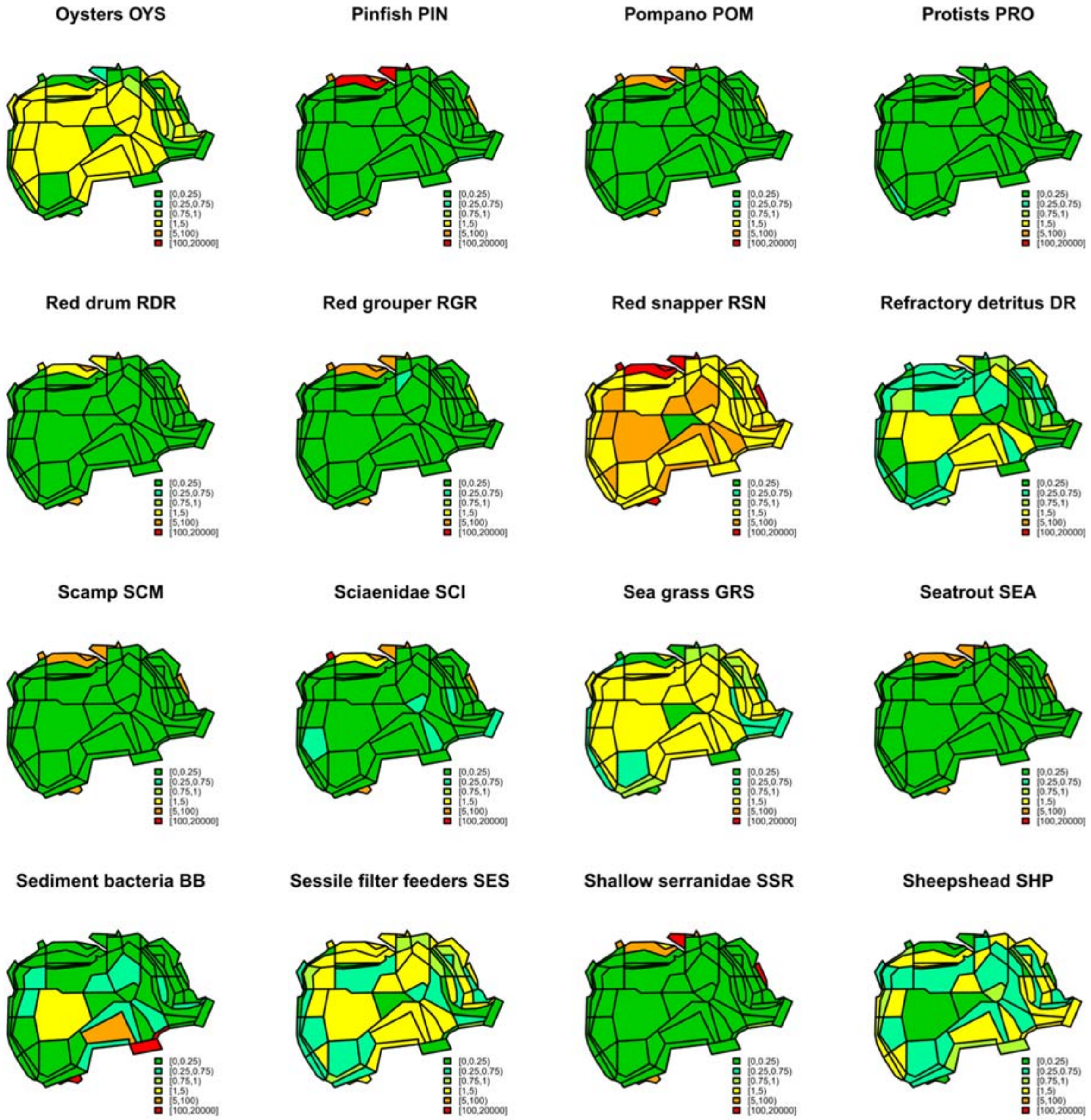


Figure B.3. (cont.)



Oysters OYS

Pinfish PIN

Pompano POM

Protists PRO

Red drum RDR

Red grouper RGR

Red snapper RSN

Refractory detritus DR

Scamp SCM

Sciaenidae SCI

Sea grass GRS

Seatrout SEA

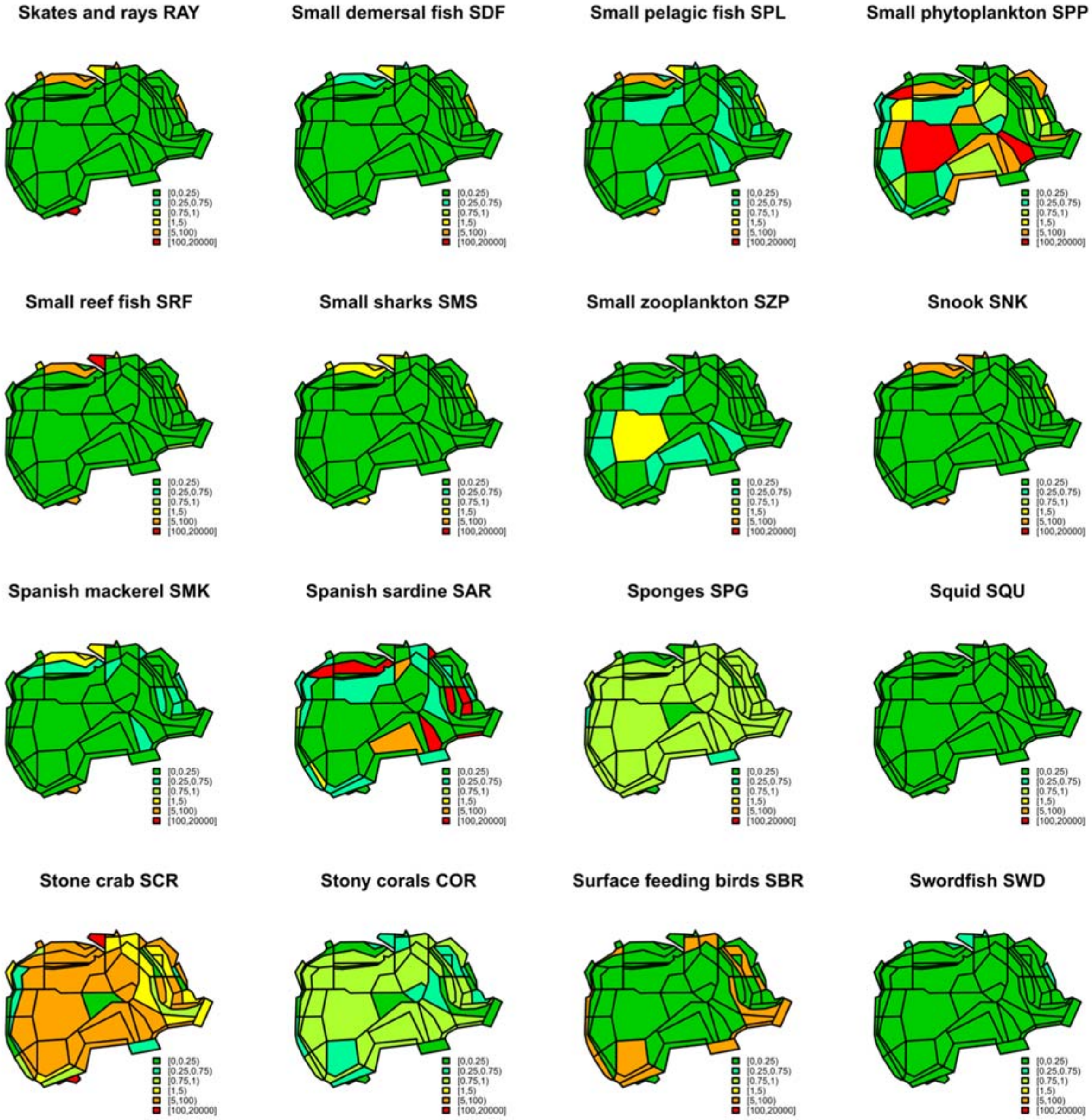
Sediment bacteria BB

Sessile filter feeders SES

Shallow serranidae SSR

Sheepshead SHP

Figure B.3. (cont.)



Skates and rays RAY

Small demersal fish SDF

Small pelagic fish SPL

Small phytoplankton SPP

Small reef fish SRF

Small sharks SMS

Small zooplankton SZP

Snook SNK

Spanish mackerel SMK

Spanish sardine SAR

Sponges SPG

Squid SQU

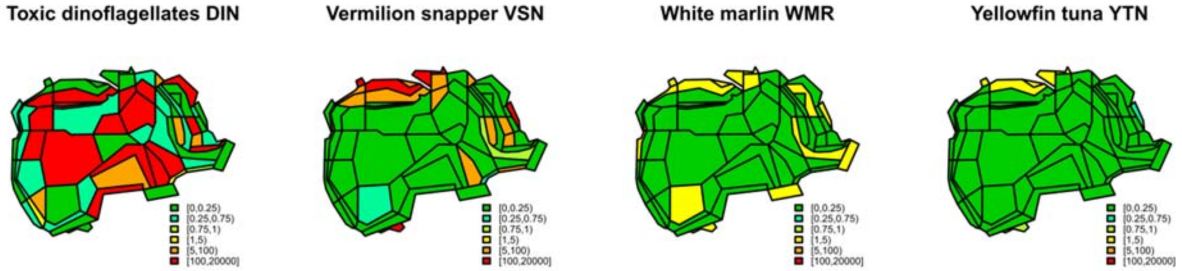
Stone crab SCR

Stony corals COR

Surface feeding birds SBR

Swordfish SWD

Figure B.3. (cont.)



Toxic dinoflagellates DIN

Vermilion snapper VSN

White marlin WMR

Yellowfin tuna YTN

Figure B.4. Numbers dynamics by age class (1980-2012) for age structured functional groups.

No fishing scenario. Age classes are plotted using a rainbow scale, with red representing the youngest class and the purple representing the oldest class. Labels show functional group name and short code.

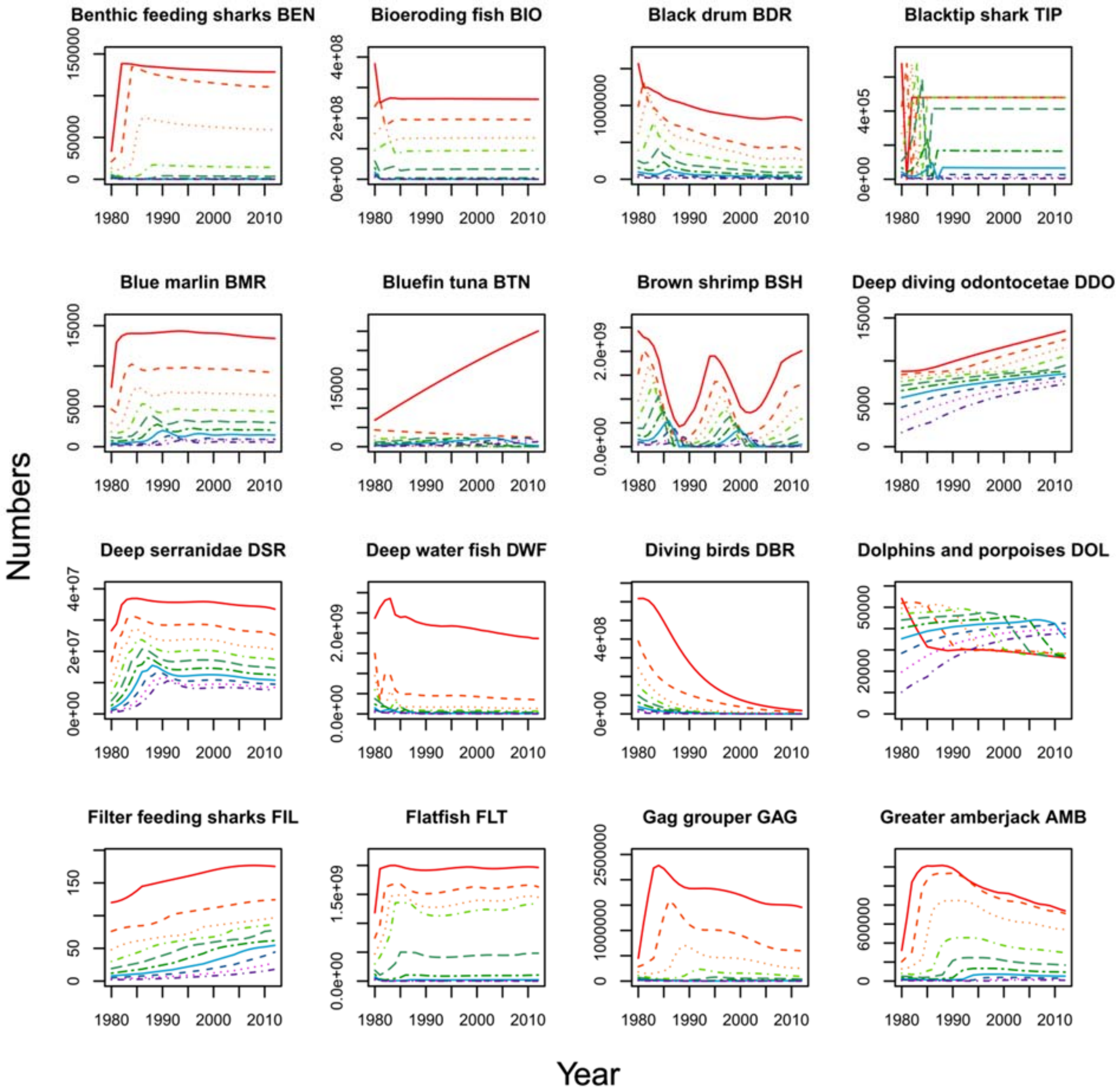


Figure B.4. (cont.)

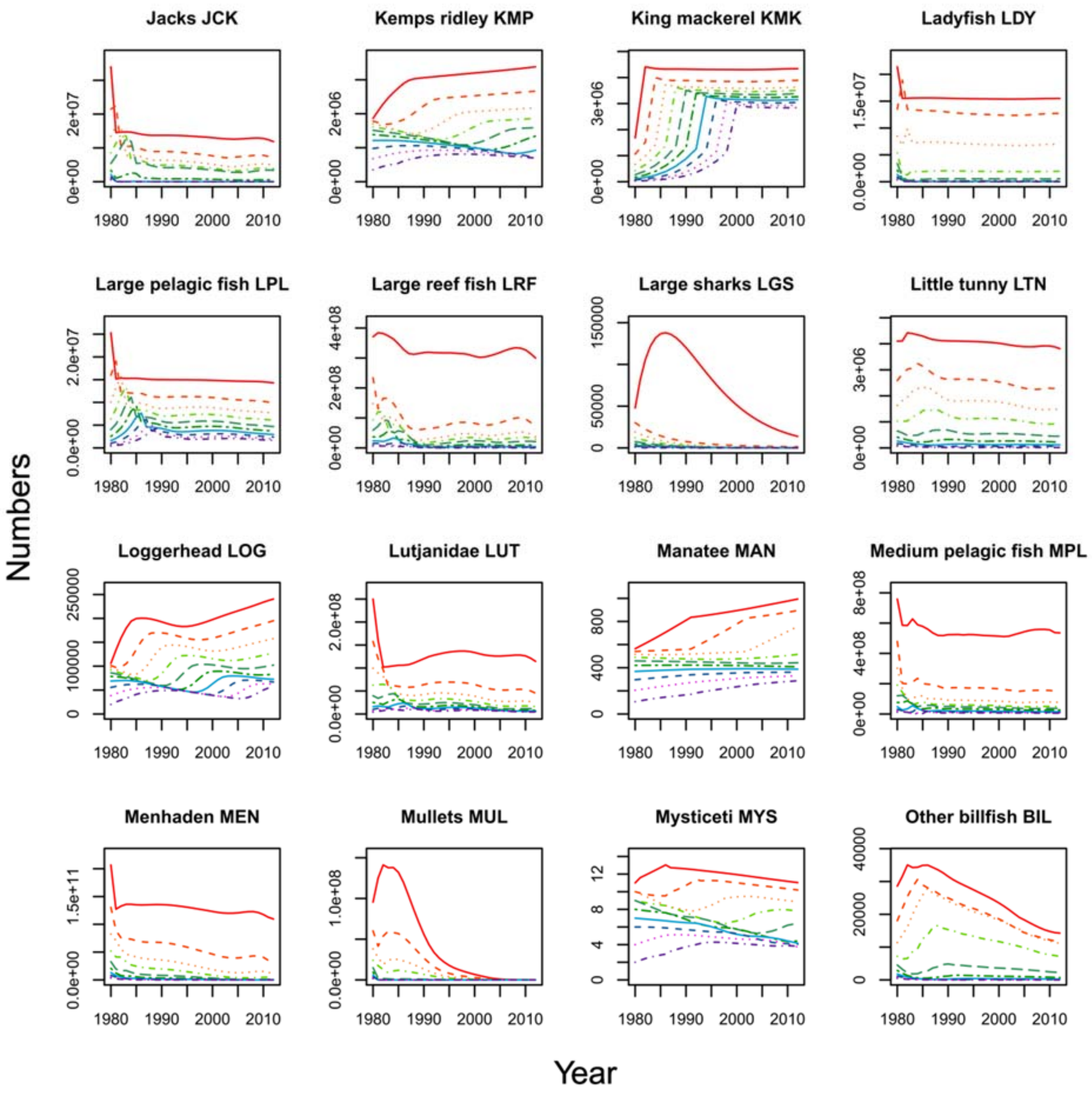


Figure B.4. (cont.)

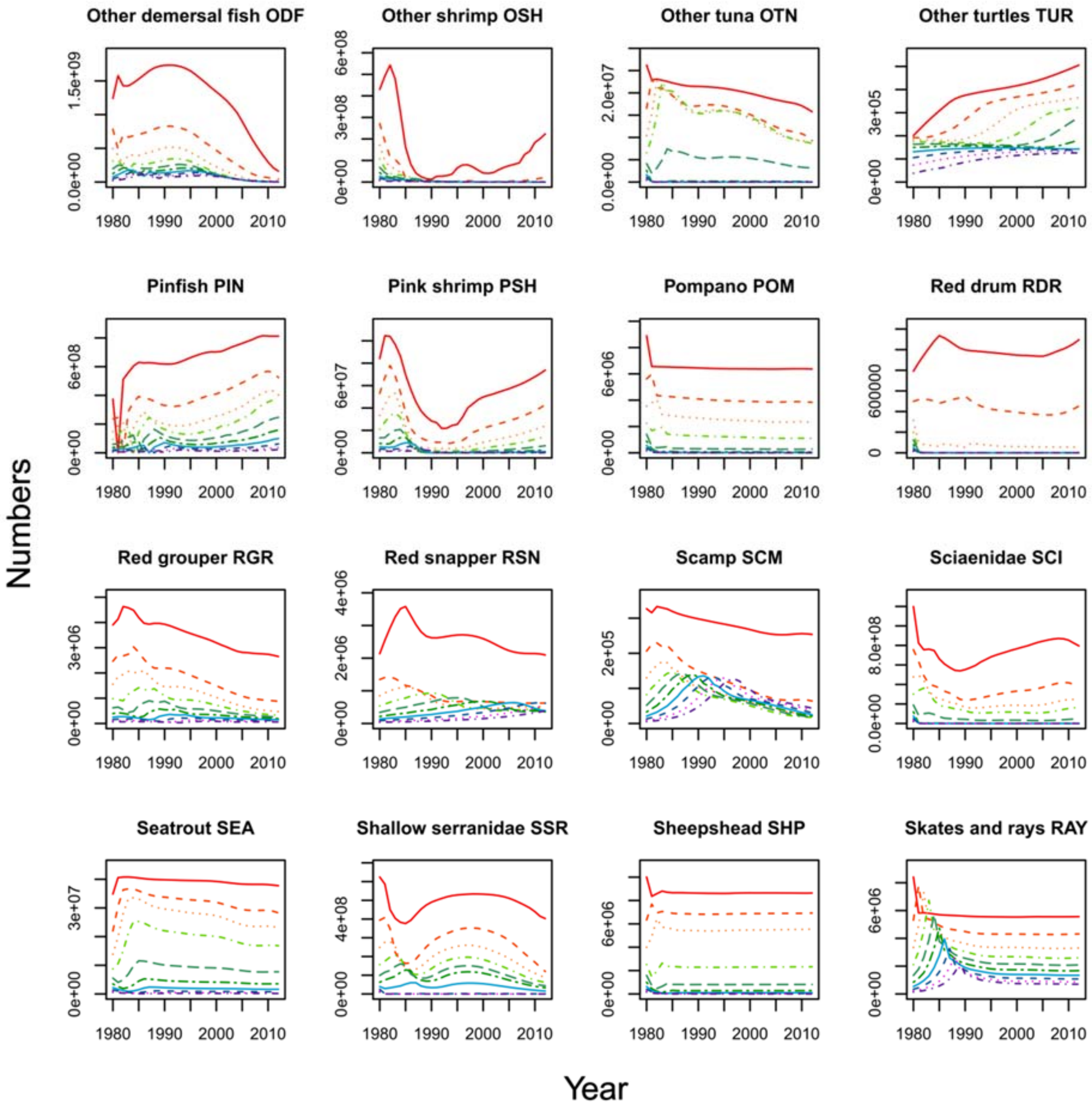


Figure B.4. (cont.)

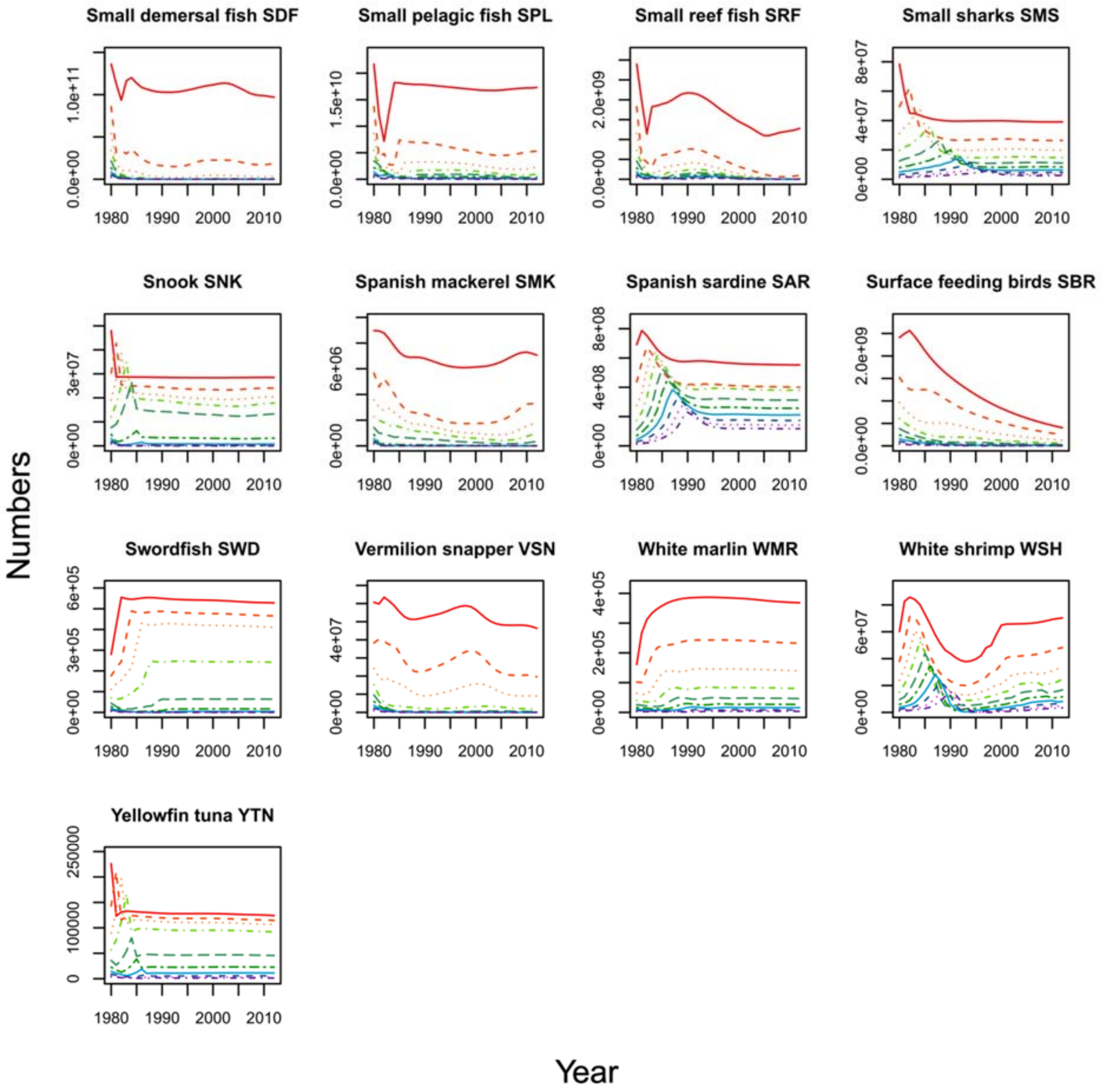


Figure B.5. Reserve nitrogen dynamics by age class (1980-2012) for age structured functional groups.

No fishing scenario. Age classes are plotted using a rainbow scale, with red representing the youngest class and the purple representing the oldest class. Labels show functional group name and short code.

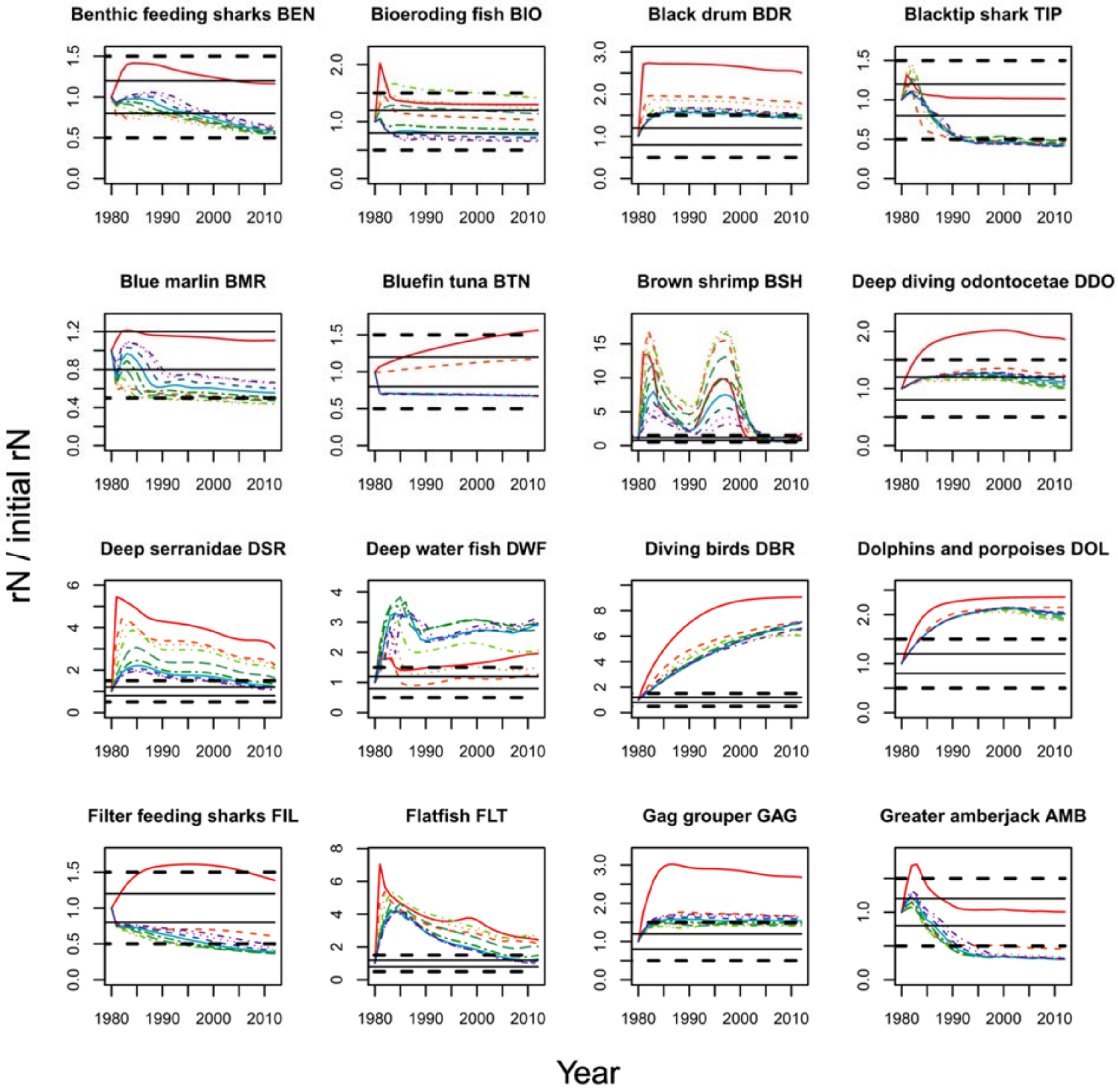


Figure B.5.(cont.)

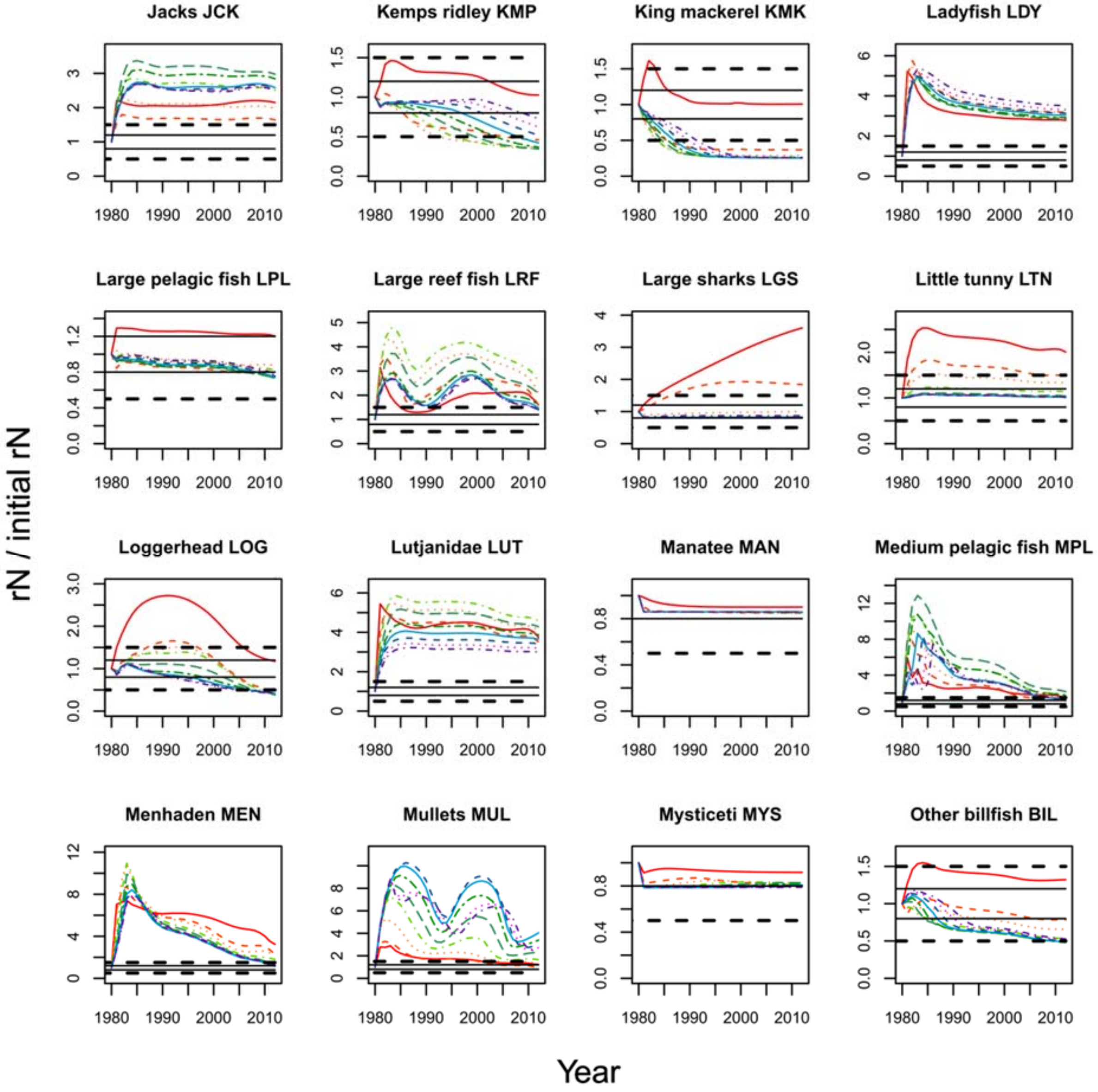


Figure B.5.(cont.)

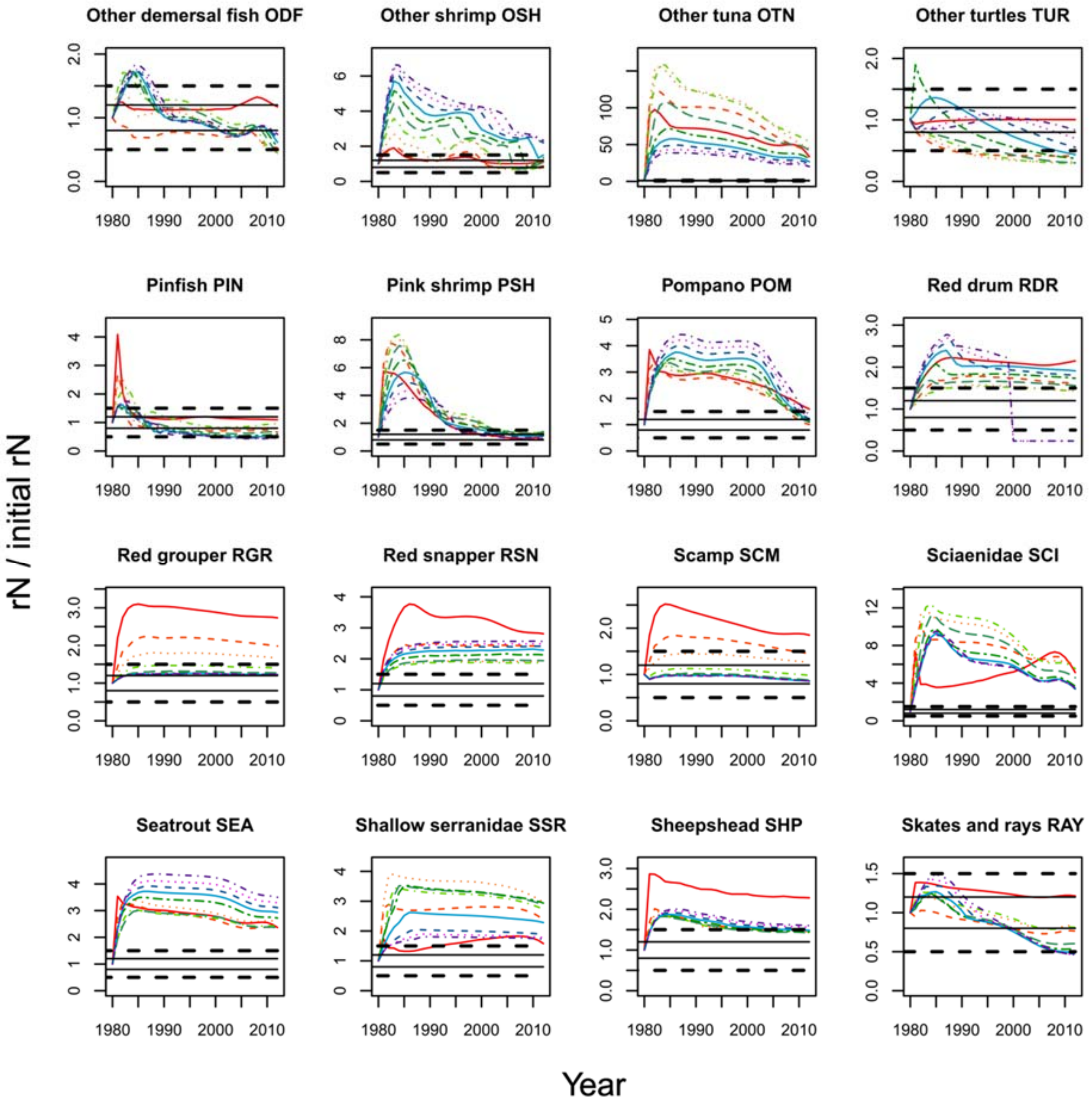


Figure B.5.(cont.)

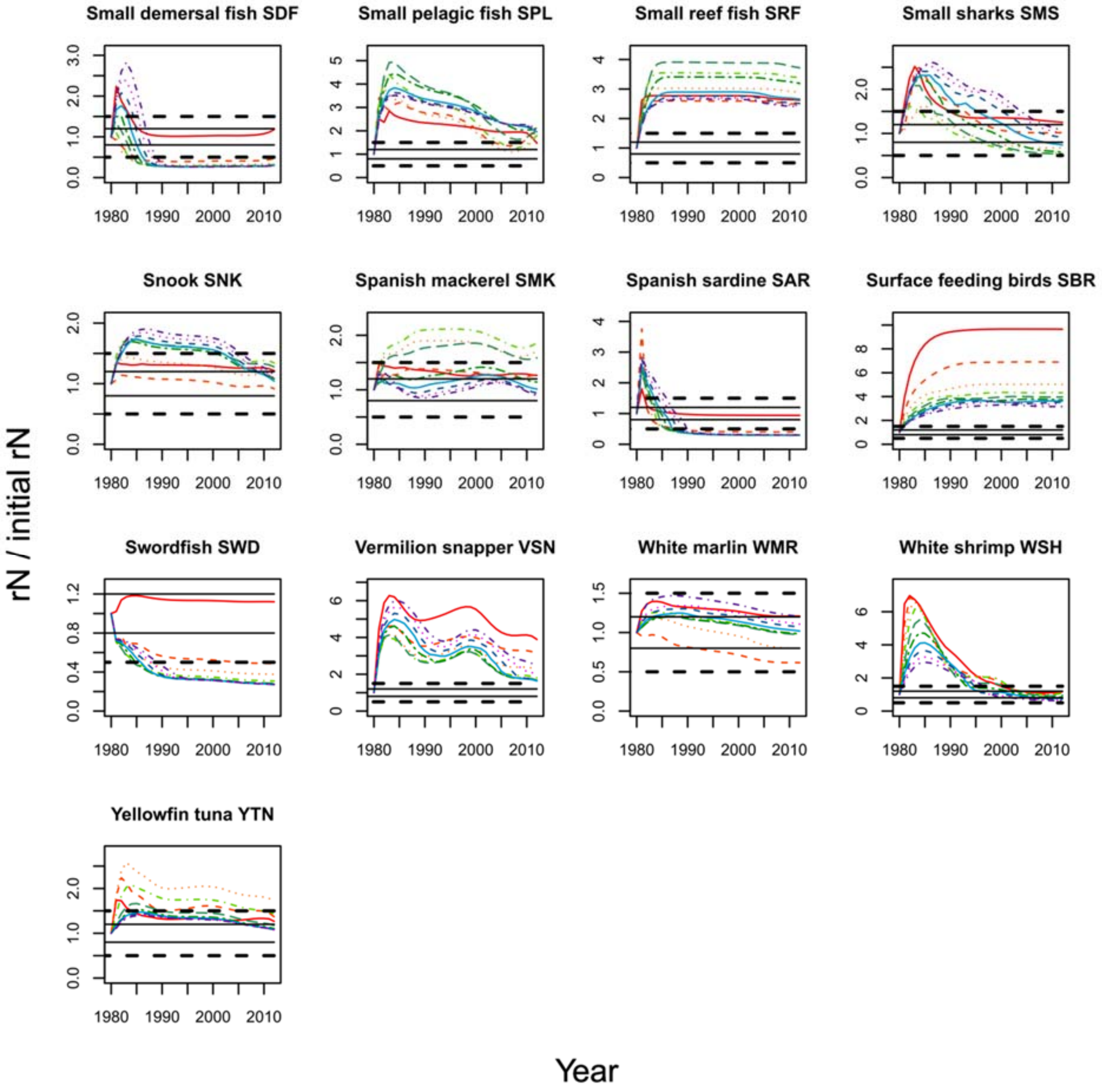


Figure B.6. Structural nitrogen dynamics by age class (1980-2012) for age structured functional groups.

No fishing scenario. Age classes are plotted using a rainbow scale, with red representing the youngest class and the purple representing the oldest class. Labels show functional group name and short code.

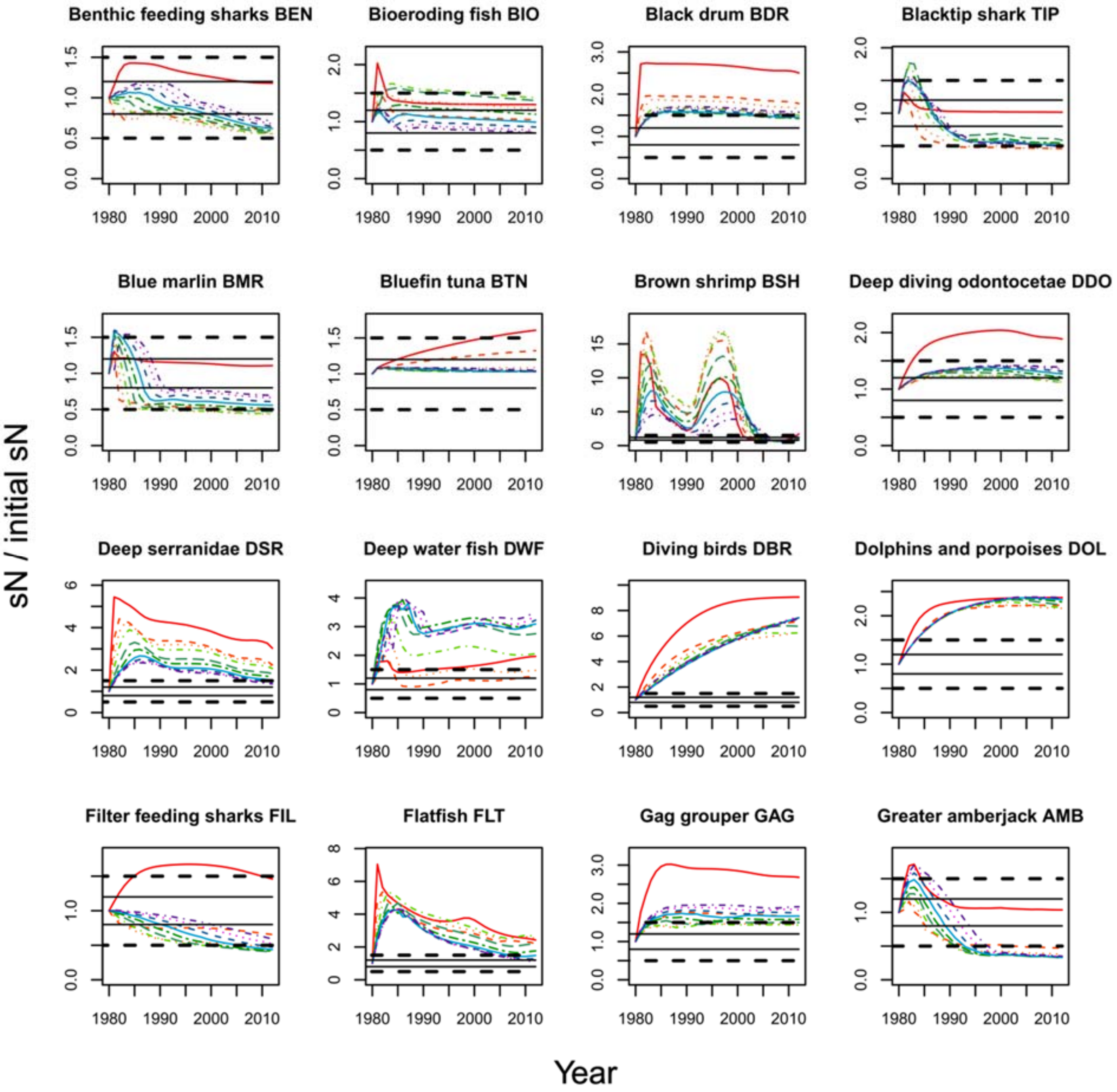


Figure B.6. (cont.)

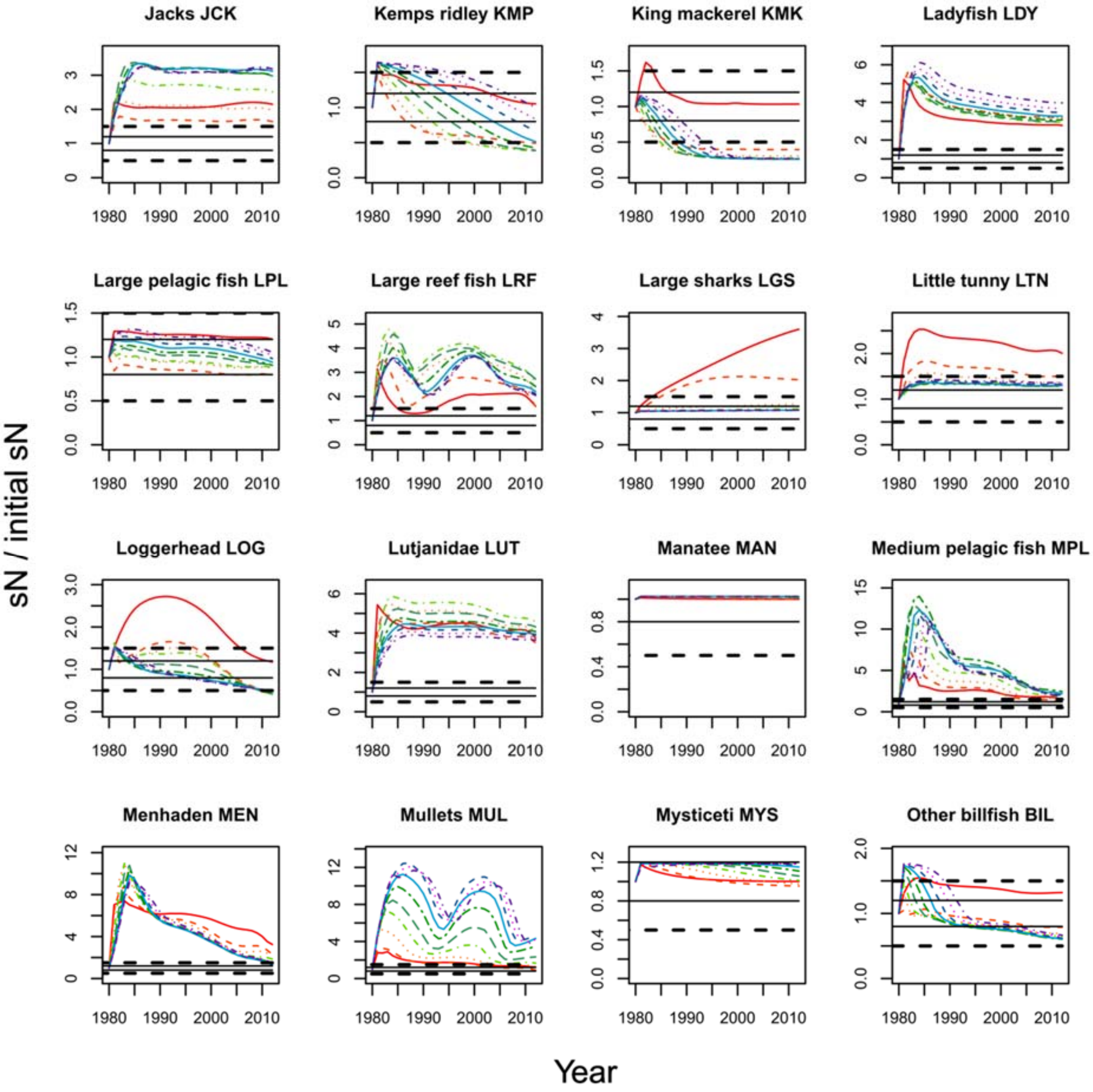


Figure B.6. (cont.)

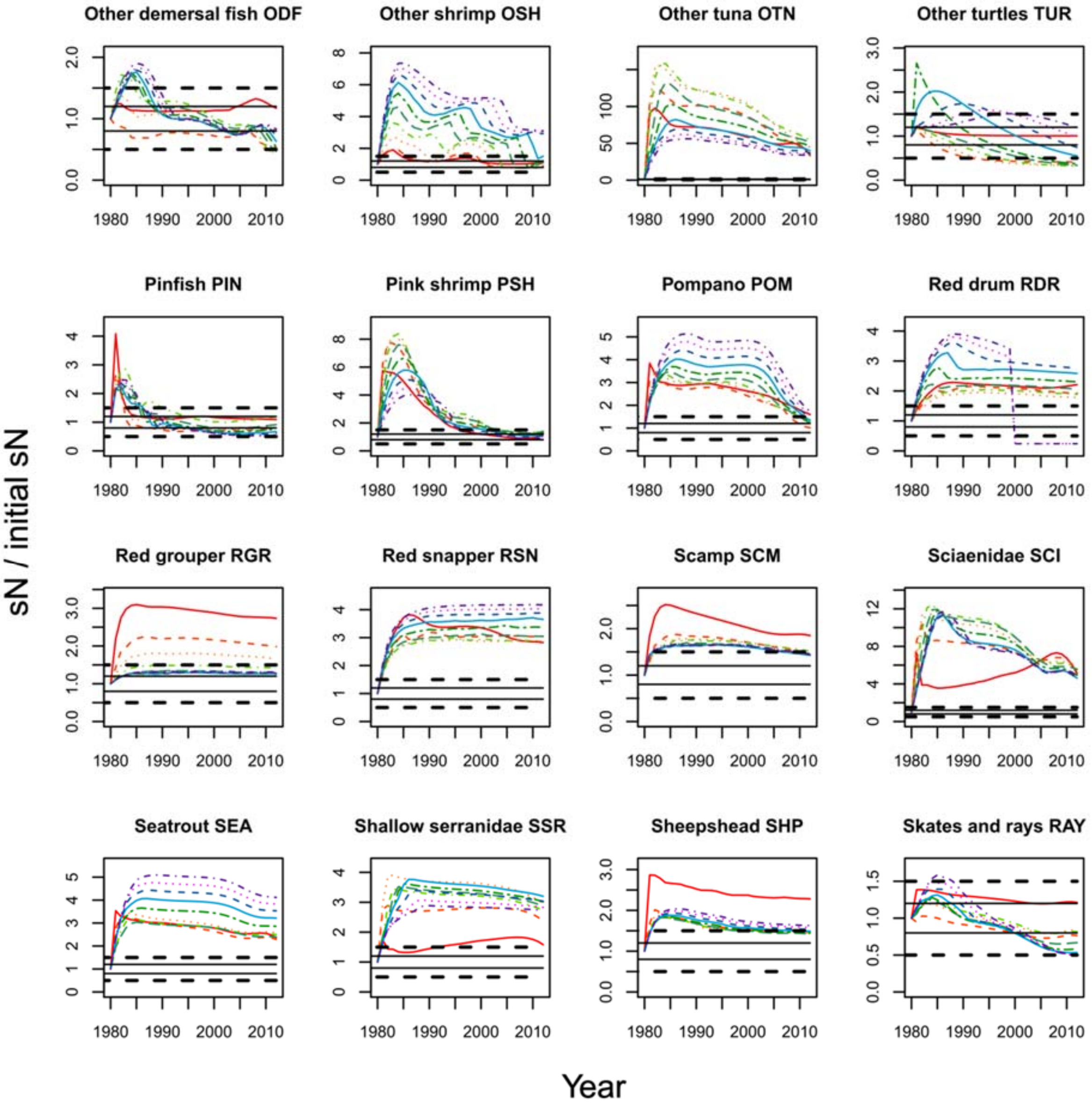


Figure B.6. (cont.)

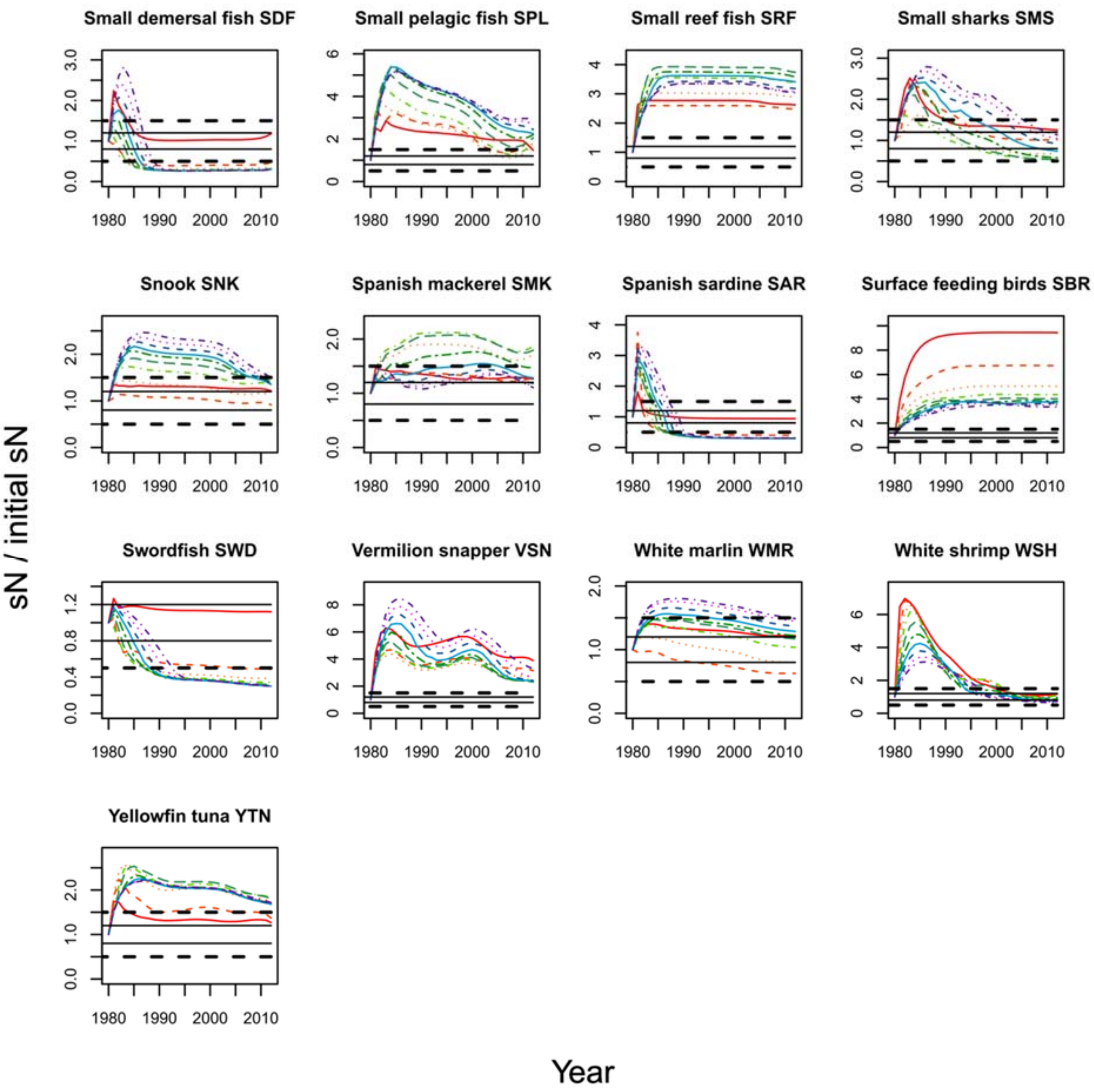


Figure B.7. Equilibrium catch and biomass curves for selected reef associated and demersal species.

Biomass is indicated by a solid line; catch is indicated by a dotted line. Labels show functional group short code.

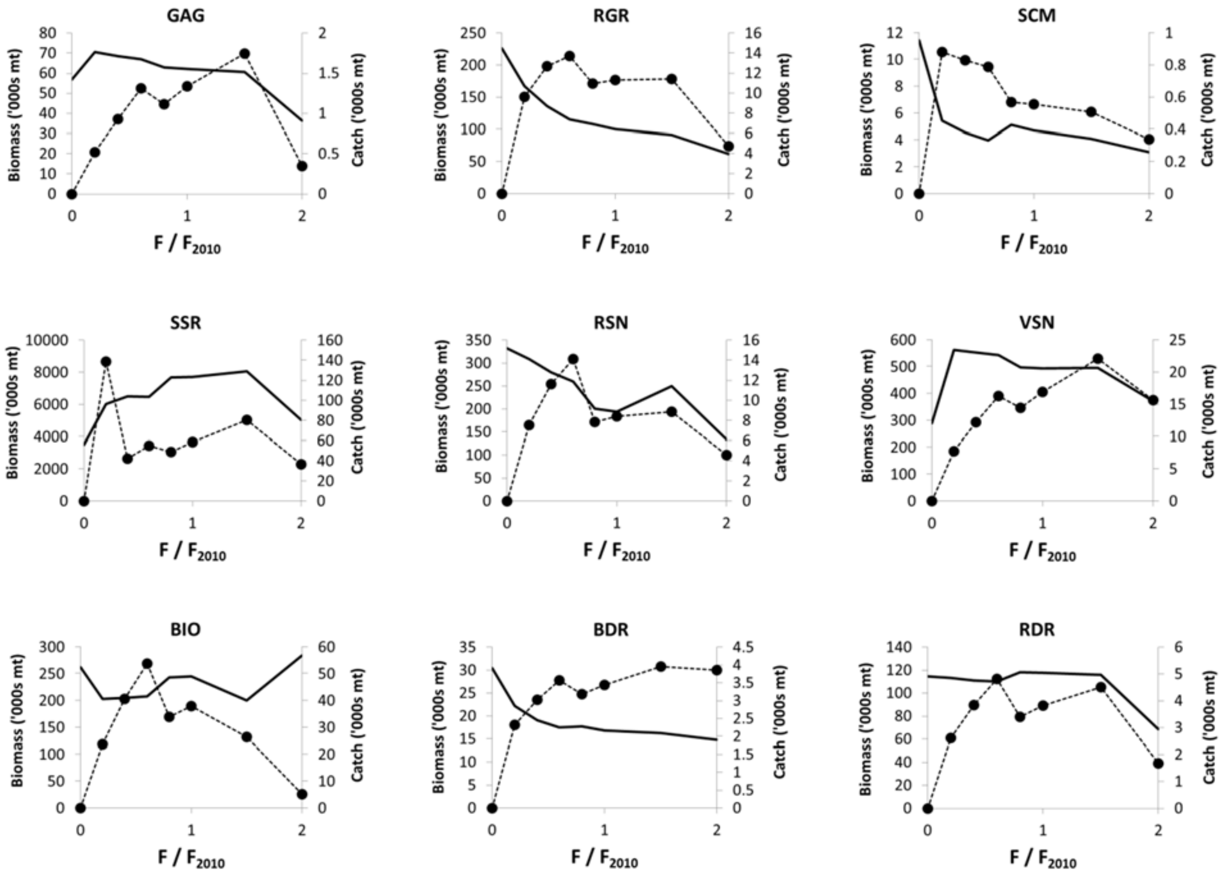


Figure B.8. Equilibrium catch and biomass curves for selected pelagic species

Biomass is indicated by a solid line; catch is indicated by a dotted line.