Evaluating Environmental and Trophic Drivers of Gulf of America King Mackerel Using a Spatially Explicit Ecosystem Model

Matthew S. Woodstock & Skyler R. Sagarese

SEDAR99-WP-05

26 March 2026

Please cite this document as:

Woosstock, Matthew S. and Skyler R. Sagarese. 2026. Evaluating Environmental and Trophic Drivers of Gulf of America King Mackerel Using a Spatially Explicit Ecosystem Model. SEDAR99-WP-05. SEDAR, North Charleston, SC. 20 pp.

SEDAR 99-WP-05: Evaluating Environmental and Trophic Drivers of Gulf of America King Mackerel Using a Spatially Explicit Ecosystem Model

Matthew S. Woodstock[1,2,*], Skyler R. Sagarese[3]

[1]Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami, Miami, USA
[2]NOAA Southeast Fisheries Science Center, Miami, FL, USA
[3]NOAA Southeast Fisheries Science Center, Beaufort, NC, USA

Abstract

The Gulf of America King Mackerel (*Scomberomorus cavalla*) fishery has experienced severe declines in recent landings that may be driven by factors typically not included in traditional stock assessment frameworks. We developed a spatially explicit Model of Intermediate Complexity for Ecosystems (MICE) within the Ecospace framework to test alternative hypotheses for this decline, including environmental shifts (interannual temperature changes; harmful algal blooms (red tides)), trophic dynamics (prey reduction), anthropogenic drivers (reduced fishing effort), and juvenile bycatch mortality (shrimp trawl effort). By comparing simulated early (1980-1984) and late (2019-2023) periods, we demonstrated that localized environmental mortality and extreme variations in juvenile bycatch were insufficient to drive the observed Gulf-wide decline in landings. Instead, the MICE framework isolated two mechanisms capable of reproducing the empirical landings deficit: a bottom-up trophic collapse (prey reduction) and a socioeconomic reduction of fleet participation (reduced fishing effort). Critically, while these two drivers yield nearly identical catch trajectories, they represent fundamentally opposing biological states, a depleted population versus an underexploited stock. Our findings indicate that recent declines in King Mackerel landings are decoupled from shrimp fleet bycatch and red tide anomalies, presenting a binary challenge for management. We recommend that future assessments prioritize fishery-independent indices of abundance of both King Mackerel and their prey to attribute the source of the catch decline and avoid misguided management interventions.

1. Introduction

King Mackerel (*Scomberomorus cavalla*) supports one of the most economically significant migratory fisheries in the Gulf of America (formerly Gulf of Mexico; Gulf, hereafter), yet recent declines in landings and perceived changes in stock productivity have raised critical questions regarding the adequacy of traditional single-species assessment frameworks for this species. The fishery has a complex multi-sectoral structure, with management split between commercial and recreational fishery interests. The commercial sector primarily utilizes run-around gillnets and hook-and-line gear, with specific regional quotas assigned to the western, northern, and southern zones. Conversely, there is only one recreational management sector that spans the entire U.S.

Gulf that often accounts for the majority of the total annual catch. This sector includes private anglers, anglers fishing from shore, and a for-hire charter fleet, primarily employing trolling techniques. Management of both sectors is governed by the Gulf Council (formerly the Gulf of Mexico Fishery Management Council), which utilizes a jurisdictional boundary at the Miami-Dade/Monroe county line to separate the Gulf and Atlantic migratory groups.

Significant concerns were raised by the Gulf Council in 2024 over the Gulf King Mackerel stock, which led to a formal data request for the SEFSC to review available information, work which was ultimately presented at the January 2025 Gulf Council meeting (Hendon et al. 2025). Preliminary results were presented for Gulf King Mackerel including fishery-independent indices, landings trends, number of areas fished by commercial gears from logbook data, and mean length-at-age. While potential hypotheses were presented related to baitfish abundance and sea surface temperature trends, no formal ecosystem analyses were conducted. As mandated by the Southeast Data, Assessment, and Review (SEDAR 99) Terms of Reference, there is an urgent need to explore alternative hypotheses for recent declines in these fisheries, including environmental shifts and anthropogenic drivers (SEDAR, 2024).

Traditional stock synthesis models can struggle to differentiate between true biomass depletion and shifts in spatial availability or catchability (q) driven by changing oceanographic conditions. Furthermore, the Gulf is a highly dynamic ecosystem where King Mackerel interact with fluctuating forage bases and are potentially subject to significant juvenile mortality from the shrimp trawl fishery (SEDAR, 2020). To address these complexities, this study utilizes a spatially explicit Model of Intermediate Complexity for Ecosystems (MICE) developed within the Ecospace framework (Steenbeek et al. 2013; Plagányi et al., 2014) that focuses on King Mackerel, its fisheries, its key predators and prey, and competitors. MICE frameworks are specifically designed to bridge the gap between single-species models and complex ecosystem-based simulations by focusing on a subset of key species and their primary abiotic drivers. This project explored potential hypotheses that could result in the observed declines in King Mackerel landings from 2016-2023, and the co-occurring biomass trends. These hypotheses included bycatch from changing shrimp fishing effort, influence of harmful algal blooms on the West Florida Shelf, interannual changes in oceanographic conditions, reduced prey abundance, and reduced fishing effort. We also discuss the drivers behind King Mackerel population changes to identify the mechanisms that may affect the population in the future.

2. Methods

2.1 MICE Model Development

The ecosystem framework utilized in this study was derived from the comprehensive Gulf-wide Ecospace model described in Harris et al. (2026). The Ecospace model has undergone a large amount of development effort, including a robust diet analysis and explorations into the drivers behind several economically important species (Sagarese et al. 2016; Sagarese et al. 2017;

Berenshtein et al. 2021). While the parent model encompasses the full breadth of the U.S. Gulf continental shelf food web, we distilled the system into a model of intermediate complexity (MICE) to focus specifically on King Mackerel and its primary ecological dependencies. The model domain consists of a high-resolution (~14km^2) Ecospace grid covering the U.S. Gulf Exclusive Economic Zone (EEZ) continental shelf from the U.S.-Mexico border to the Florida Keys, bisected into eastern and western regions at the Mississippi River. Importantly, this regional delineation is for analysis purposes only, and does not influence model processes (e.g., animal movement), allowing the potential of mixing. Although King Mackerel are also found in Gulf Mexican waters (Fable et al. 1987; Arreguín-Sánchez et al. 1995), this region was excluded from the analysis. The model includes physical bottom habitats (e.g., mud, sand, hardbottom) from the dbSeabed database (see Harris et al. 2026 for additional details). The MICE retains King Mackerel across two life stages (age 0-1 and 1+) alongside critical forage groups (e.g., Gulf Menhaden [*Brevoortia patronus*; 25% of adult diet] and small pelagic forage fishes [22% of adult diet]; Sagarese et al. 2016) and primary competitors (e.g., Spanish Mackerel [*Scomberomorus maculatus*]). This reduction in complexity from the parent model allows for more rigorous statistical fitting and scenario testing while maintaining the spatial-environmental drivers (i.e. temperature and salinity) that govern migratory behavior.

Table 1. *The functional groups and basic input parameters in the Ecospace model. Parameters were derived from Harris et al. (2026). Aggregate groups were parameterized using the biomass-weighted average value from relevant species (e.g., species that consumed King Mackerel) in the parent model. Values represent the conditions at the beginning of the model run (1980)*

Group name	**Biomass (B; lbs km^{-2})**	**Total Mortality (Z; year^{-1})**	**Consumption to Biomass Ratio (QB; year^{-1})**	**Ecotrophic Efficiency (EE)**
King Mackerel (0 yr)	1.46E+00	1.46	14.06	0.42
King Mackerel (1+)	3.09E+02	0.22	3.50	0.32
Spanish Mackerel (0 yr)	2.62E+00	2.00	19.55	0.82
Spanish Mackerel (1+)	1.39E+02	0.52	5.17	0.38
Large Sharks	3.77E+02	0.31	3.05	0.39
Small Coastal Sharks	7.72E+01	0.57	5.73	0.89
Marine Mammals	1.37E+02	0.16	15.00	0.63
Pelagic Pursuers	4.12E+02	1.25	10.24	0.14
Large Reef Piscivores	6.04E+02	0.51	4.71	0.39
Small Demersal Piscivores	1.25E+03	0.61	5.76	0.34
Menhaden	1.97E+04	1.59	24.23	0.22
Small Pelagic Forage	6.62E+03	1.23	12.02	0.83
Shrimp	1.41E+03	3.56	19.20	0.36
Cephalopods	3.31E+03	3.20	13.70	0.44
Benthic Invertebrates	1.09E+05	3.29	16.37	0.41
Zooplankton	5.51E+04	10.00	74.00	0.95
Primary Producers	4.52E+05	41.84		0.13
Detritus	2.21E+05			0.06

Fishing Fleets

The parent Ecospace model included a commercial and recreational fishing fleet that targeted King Mackerel, but did not distinguish between different management regions or sampling gears. The MICE had five King Mackerel fishing fleets: north handline (HL), south handline, west handline, south gillnet, and a Gulf-wide recreational fleet. Fishing effort was spatially constrained through a gravity model, assuming all fleets access water from each coastline grid cell (within 14 km). Fishing fleets were only allowed to fish within their respective management zones and initial commercial fleet-specific landings values were calculated from the parent model landings weighted by the current quota allocation percentage (i.e., greater current quota resulted in a greater percentage of the initial landings value from the parent model). The MICE also included a shrimp trawl fleet that represented brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), and pink shrimp (*Farfantepenaeus duorarum*), a menhaden reduction fleet, and an aggregate multi-species fleet that harvested other functional groups. Initial discard values were gathered from the parent model and weighted appropriately for the MICE. Ecospace has fishing effort multiplier parameters that regulate the rate and magnitude of the fleet's response to changes in effort. All fishing effort multipliers were kept at the default value of 1, except for the shrimp fleet, which was given a multiplier of 3 during initial model fitting, making the shrimp trawl landings and bycatch more responsive to changes in effort.

Oceanographic Conditions

The Ecospace spatiotemporal framework is designed to integrate space and time varying oceanographic conditions, such as seasonal and interannual water temperature and salinity. The environmental conditions are combined with functional group-specific environmental preference and tolerance functions to regulate species distributions and reduced foraging success in suboptimal habitats. The environmental conditions in this model were surface temperature, surface salinity, and water column integrated net primary productivity (NPP) monthly hindcast products (1993-2023) from the MOM6-COBALT downscaled ocean model (MOM6, hereafter; Ross et al. 2023). Monthly climatologies (monthly averages for each grid cell) were calculated for each environmental factor and applied for 1980-1992 model years to bridge the start date of the parent model (1980) to the earliest date of the MOM6 hindcast (1993). The NPP oceanographic product was applied to Ecospace as a multiplier of primary production, where a high NPP value increased production in a specific location at a specific time, and low NPP value decreased production. Early integrations of the NPP product led to unstable model results that omitted primary production everywhere except for the Mississippi River delta, an anticipated result because of the high nutrient load of the Mississippi River. To reduce the influence of the Mississippi River, the NPP values were first log transformed, downweighting extreme values, and then scaled for the median to be a primary production multiplier of 1. Other scaled, log-transformed NPP values were calculated as the quotient of the log-transformed value in a particular grid cell and the median log-transformed value. A bilinear interpolation was utilized to fill missing values near the coastline, which were omitted when converting the MOM6 output to the appropriate spatial scale of the MICE.

2.2 Calibration and Data Fitting

A necessary component of the MICE was to capture the north-south seasonal migratory dynamics of King and Spanish Mackerel, as well as menhaden, particularly on the West Florida Shelf. Early investigations using Ecospace's default monthly environmental envelope modeling produced lagged animal movements that unintentionally penalized foraging success. Three adjustments were made as a remedy for this situation: 1) the model was converted to a weekly timestep, rather than the monthly default; 2) the dispersal rate parameters for all migratory species were enhanced to 10,000km yr^{-1} to allow for appropriate movement speeds and the penalty for an animal being in a bad habitat was removed to assume that a highly mobile animal will depart unfavorable conditions, and, 3) since the environmental drivers were still a monthly timestep, weekly habitat capacity drivers were developed to promote latitudinal shifts in species distributions that smoothed the environmental transition. The weekly habitat capacity drivers did not entirely omit any region of the Gulf but rather changed the most preferred location during a particular model week. This shift allowed the environmental drivers to restrict particular locations, while aiding the seasonal migration. The resulting model effectively produced seasonal migrations within the U.S. EEZ without artificially penalizing the migratory species (Figure 1).

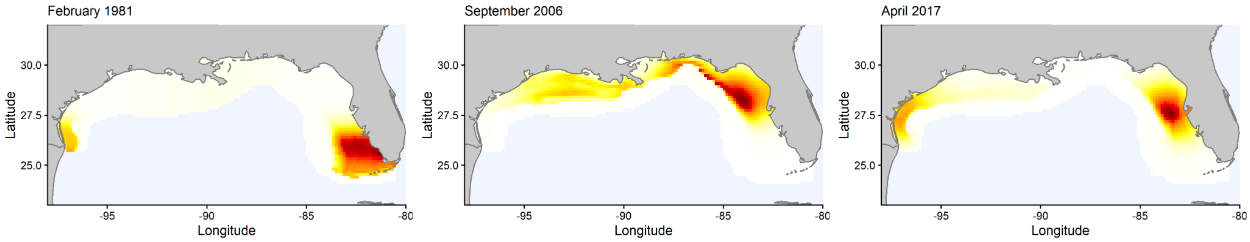

Figure 1. *Examples of King Mackerel (1+) spatial distributions from three timesteps in the base model run. Warm colors (red) represent a high biomass, while light colors (white) represent little to no biomass.*

The MICE was calibrated using a multi-stage fitting procedure to ensure consistency with historical observations from 1980 through 2016. Data were sourced from biomass and catch time series from relevant SEDAR assessments, including SEDAR 38 for Gulf King Mackerel and SEDAR 28 for Gulf Spanish Mackerel. An automated calibration procedure was utilized to adjust default trophic parameters (i.e., vulnerabilities) and fit the model outputs to reference time series. The automated calibration procedure uses a novel genetic algorithm to search the available vulnerability parameter space and converge upon an optimal solution. This specific calibration ran 124 iterations per generation (i.e., the number of total trophic interactions in the MICE), and retained the top 10 runs from each generation (closest fits to observed data) to account for the possibility of non-monotonic relationships in the parameter space. Similar automated methods have been developed for Ecosim models (Bentley et al. 2024), but this is the first application of an automated Ecospace model.

Table 2. *Recent Gulf King Mackerel landings (1000 lbs) by fishing sector. Com = Commercial, HL = hook and line, NA = Data not available, * = Preliminary data*

Calendar Year	**Recreational**[1]	**Com. Northern**[2]	**Com. Western**[2]	**Com. Southern HL**[2]	**Com. Southern Gillnet**[2]
2011	2806	NA	NA	NA	NA
2012	4103	320	1114	796	510
2013	2807	260	1037	613	615
2014	4615	229	1364	696	544
2015	2354	182	1223	659	530
2016	2779	472	1159	732	538
2017	2345	539	1068	873	553
2018	2279	393	1093	688	631
2019	1622	325	1188	628	517
2020	1730	545	863	506	587
2021	1023	299	466	425	594
2022	1368	228	310	34	616
2023	1688	201	396	41	481
2024	1482*	298	292	406	673

2.3. Scenarios and Analysis

Several scenarios were conducted from the calibrated model to explore the hypothetical mechanisms behind the observed decline in King Mackerel landings (Table 2). These scenarios included adjustments to shrimp effort, reduced prey fields, the inclusion of negative harmful algal bloom effects (i.e., King Mackerel mortality; redistribution of fishing effort), and reduced Gulf-wide fishing effort (Table 3). The full (base) model included MOM6-COBALT oceanographic conditions and King Mackerel fishing effort corresponding to SEDAR 38 trends, shrimp fishing effort that resulted in catch/biomass trends from the 2018 shrimp stock synthesis

---

[1] Reported recreational fishing data were sourced from: https://www.fisheries.noaa.gov/southeast/recreational-fishing-data/gulf-mexico-historical-recreational-landings-and-annual-catch on 3/18/2026. Data were reported here based on the start of the year of the fishing season.

[2] Reported commercial fishing data were sourced from: https://www.fisheries.noaa.gov/southeast/commercial-fishing/gulf-america-historical-commercial-landings-and-annual-catch-limit#king-mackerel-southern-subzone-gillnet-as-reported on 3/18/2026. Data were reported here based on the start of the year of the fishing season.

update (Hart 2018a; Hart 2018b; Hart 2018c), and menhaden fishery effort trends that produced catch/biomass trends from the SEDAR 63 assessment (SEDAR 2018). The harmful algal bloom scenario leveraged data from the Florida Wildlife Commission historical harmful algal bloom database (2015-2023; FWC FWRI 2026) to create weekly HAB raster layers from grid cells that had occurrences of greater than 100,000 cells L^{-1}. In the model, the presence of a HAB in a grid cell resulted in King Mackerel mortality and avoidance by fisheries, simulating an extreme immediate, localized response. This model did not incorporate sub-lethal effects of HABs (as in Vilas et al. 2023) because the physiological impacts of HABs to King Mackerel, a highly mobile, pelagic species, were enigmatic. With the exception of the reduced fishing effort scenario, fishing effort remained at 2016 levels throughout the rest of the simulation. Biomass, landings, and bycatch trends, as well as the spatial distribution of fishing effort were analyzed from each scenario and compared to the full model. Comparisons were made using five-year averages of the initial years of the model (1980-1984) and the last five years of the model (2019-2023).

Table 3. *The scenarios conducted from the MICE model to explore several hypothetical mechanisms that may explain a recent decline in King Mackerel landings.*

Scenario	Description
S1. Full Model	Status quo conditions
S2. High Shrimp Effort	+50% Shrimping effort to demonstrate the effect of an expanded shrimp fishery
S3. Low Shrimp Effort	-50% Shrimping effort to account for recent reductions in effort (Dettloff 2024)
S4. Prey Reduction	Severe reduction in Menhaden and small pelagic fishes at 2015 to capture reductions in baitfish noted by fishermen (GMFMC 2019)
S5. Florida Harmful algal blooms (HABs)	Addition of FWC HAB data which has been suggested to negatively impact King Mackerel catches (Wall et al. 2009)
S6. Reduced Fishing Effort	Gradual reduction in King Mackerel fleet effort beginning 2016

3. Results

3.1 Catch Trends

Analysis of the integrated Gulf-wide catch metrics between the early (1980 to 1984) and late (2019 to 2023) simulation periods reveals that only two scenarios successfully reproduce the observed decline in targeted King Mackerel landings. The full model baseline, along with the Florida HABs and both shrimp effort scenarios, produced virtually identical trajectories that failed to generate a systemic drop in removals, instead resulting in Gulf-wide catch increases ranging from 26-30% (Table 4). Conversely, a decline in targeted landings was only achieved under the prey reduction and reduced fishing effort scenarios, which yielded Gulf-wide catch declines of 65% and 26%, respectively (Figure 2; Table 4). By isolating these Gulf-wide trends, the model demonstrates that King Mackerel landings deficits are likely driven by broader trophic collapses or socioeconomic fleet dynamics rather than isolated environmental or bycatch mortality events.

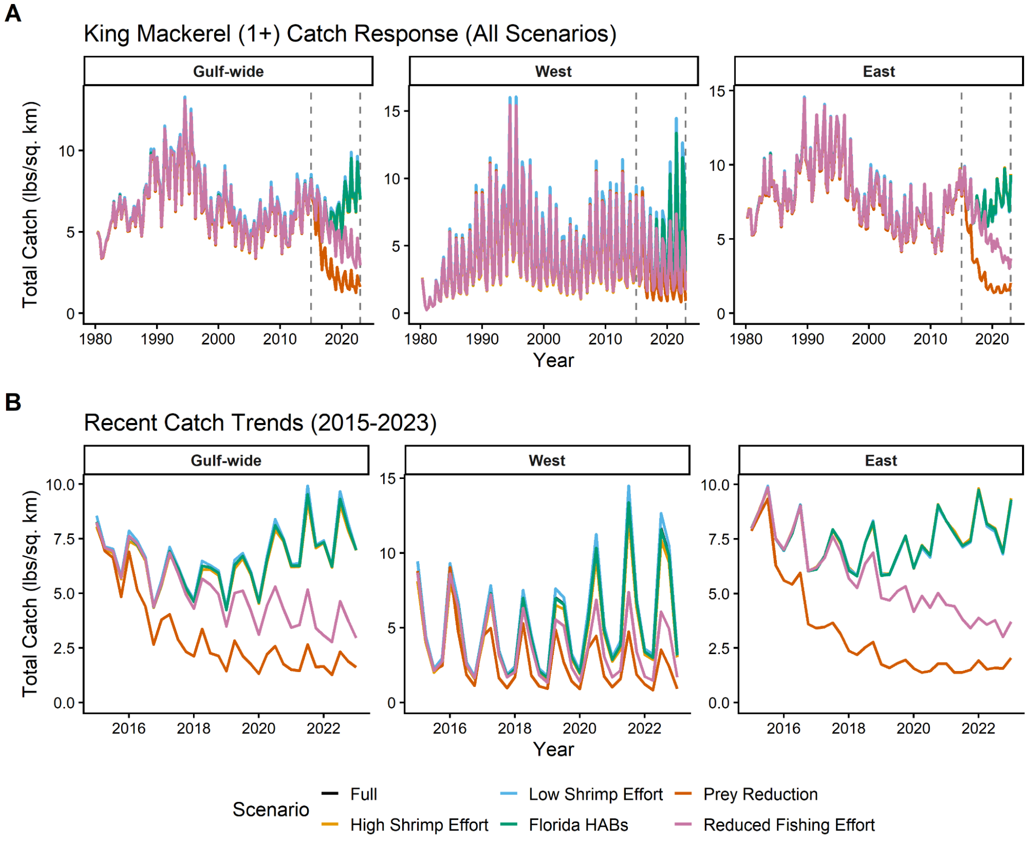

Figure 2. *King Mackerel (1+) catch trends from the six scenarios (colors) conducted from the MICE. A) The full trajectory of targeted King Mackerel (1+) trend among each scenario. B) The recent catch trends, showing differences among scenarios in recent years.*

Deconstructing these catch trends across the eastern and western Gulf management zones results in spatial disparities that are often masked by aggregated Gulf-wide data. In the group of scenarios that failed to produce Gulf-wide catch declines (full, Florida HABs, shrimp effort), the western Gulf experienced massive increases in targeted removals ranging from 218-245% compared to the 1980-1984 time period, which artificially offset simultaneous eastern Gulf catch declines of 1% (Table 4). Even in the reduced fishing effort and prey reduction scenarios, which lowered total Gulf-wide catch, removals in the west still increased by 100% and 30%, respectively. Conversely, King Mackerel catches in the eastern region decreased by 44% and 78% in the reduced fishing effort and prey reduction scenarios. These regional divergences highlight the necessity of spatially explicit assessment frameworks, as assuming uniform catchability across the Gulf fails to capture the localized mechanisms driving the recent failures of the eastern fishery.

Table 4. *King Mackerel (1+) biomass and targeted catch results from each scenario and each region. Biomass and catch results are represented as the % change between the early (1980-1984) and late (2019-2023) time periods.*

Scenario	**Region**	**Biomass (% change)**	**Catch (% change)**
Full	Gulf-wide	69.1	28.0
	West	209.1	230.7
	East	39.5	-0.7
High Shrimp Effort	Gulf-wide	66.7	25.9
	West	202.2	218.3
	East	38.6	-0.6
Low Shrimp Effort	Gulf-wide	71.9	30.0
	West	217.7	245.4
	East	40.5	-1.4
Florida HABs	Gulf-wide	69.0	27.7
	West	208.1	229.4
	East	39.6	-0.9
Prey Reduction	Gulf-wide	-53.1	-64.6
	West	-0.3	29.8
	East	-64.4	-78.1
Reduced Fishing Effort	Gulf-wide	90.5	-26.0
	West	251.3	100.4
	East	56.5	-43.9

The annualized catch trends by fleet reveal that the recreational sector, responsible for the majority of total removals, mirrors the aggregated Gulf-wide patterns. Commercial fleets harvest lower catch magnitudes and display distinct regional nuances (Figure 3). Notably, the hook-and-line fleets exhibit a divergence from the recreational sector under the reduced fishing effort scenario, where the catch density increases as the fleet capitalizes on the compensatory biomass expansion. However, under the prey reduction scenario, catch densities decline across every gear type. While fishing effort reductions can produce fleet-specific outcomes, a reduction in prey reduces landings for all participants regardless of gear or operational domain.

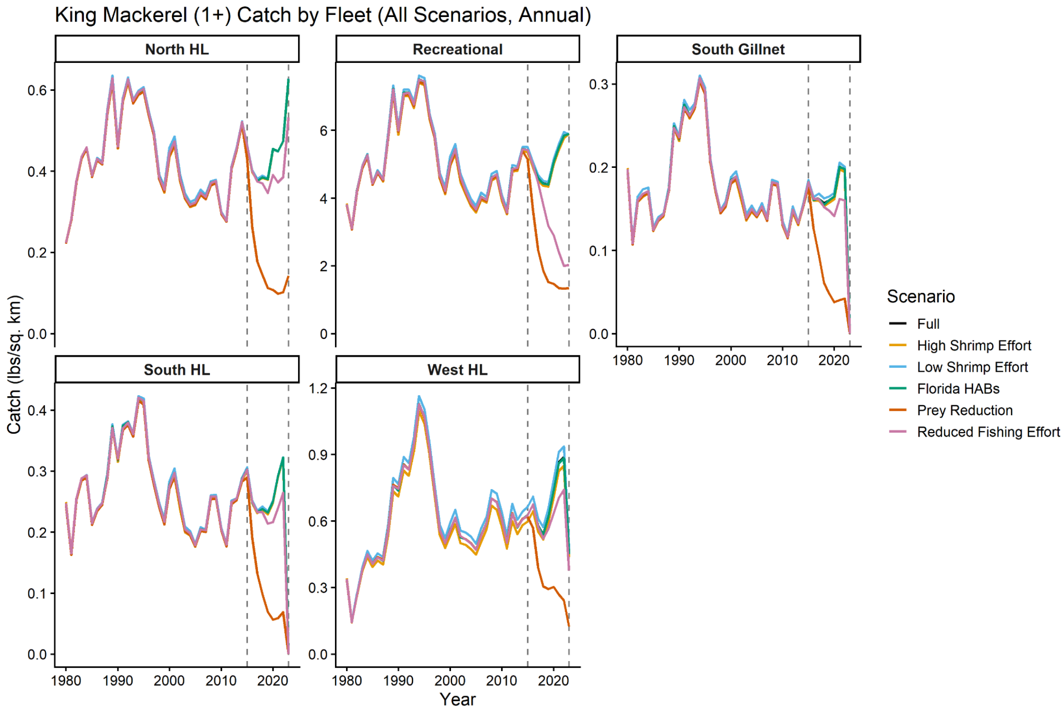

Figure 3. *Fleet-specific King Mackerel (1+) catch trends for each scenario (colors). Vertical lines indicate the time period of observed catch declines (2016-2023). Values are annualized to remove seasonal signature present in other figures, as the seasonal migration eliminates catches once King Mackerel are no longer in the domain. HL = hook and line*

3.3 Biomass Outcomes

Gulf-wide adult King Mackerel biomass trajectories varied significantly depending on the simulated driver, distinguishing between scenarios that produced similar catch declines. The full model, Florida HABs, and shrimp effort scenarios produced virtually identical population expansions, with Gulf-wide adult biomass increasing by 67-72% from the early to late period. The reduced fishing effort scenario generated the most substantial Gulf-wide biomass growth at 91%, confirming a strong compensatory population rebound when anthropogenic removals are restricted. Conversely, the prey reduction scenario was the only hypothesis to trigger a systemic collapse, plummeting Gulf-wide adult biomass by 53%, relative to the baseline (Figure 4). Delineating these disparate biomass outcomes is critical for evaluating stock status, as it shows a steep decline in landings can signify either an underexploited population or a trophic-driven biomass crash.

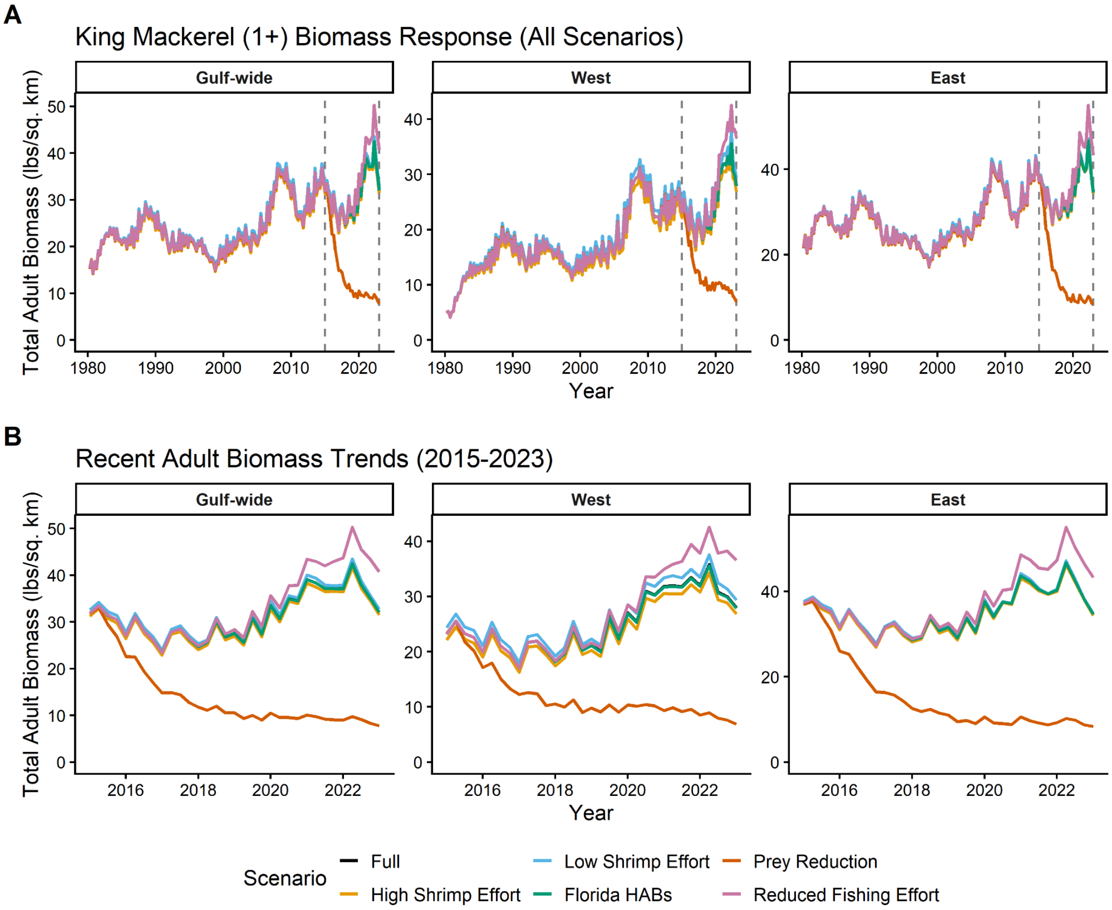

Figure 4. *King Mackerel (1+) biomass trends from the six scenarios (colors) conducted from the MICE. A) The full trajectory of targeted King Mackerel (1+) trend among each scenario. B) The recent biomass trends, showing differences among scenarios in recent years.*

Regional evaluations of adult biomass reveal that the population is resilient in both regions among all scenarios, except for the prey reduction scenario. Across the identical increased biomass scenarios (full, Florida HABs, shrimp effort), the western Gulf exhibited large biomass increases ranging 202-218% percent increase, whereas the eastern Gulf showed more constrained biomass increases (39-40%; Table 4). Furthermore, while the reduced fishing effort scenario allowed both regions to increase biomass (west up 251%, east up 57% percent), the prey reduction scenario demonstrated that King Mackerel (1+) biomass may decline when there is a reduction in key forage fish prey, and this decline is particularly prominent in the eastern region (64% decline). The predicted western region biomass decline from the prey reduction scenario is drastically different from all other scenarios, but only returns the King Mackerel adult biomass close to the 1980 biomass level (Figure 4). These distinct regional outcomes underscore that Gulf-wide biomass stability is localized within the broader Gulf domain, requiring management strategies that should address the regional differences among trends and their drivers.

Analysis of the fishery phase trajectories from 1980 to 2023, which map Gulf-wide King Mackerel (1+) biomass against total landings, reveals that the simulated scenarios diverge into three distinct terminal states (Figure 5). The full model baseline, Florida HABs, high shrimp effort, and low shrimp effort scenarios are characterized by a long-term increase of both biomass and catch. In contrast, the prey reduction scenario exhibits an inflection point in recent years, driving a simultaneous reduction of both biomass and landings. Conversely, the reduced fishing effort scenario diverges during the same timeframe; as catch drops abruptly, the stock shifts toward a compensatory biomass expansion. These temporal shifts illustrate the current management challenge, where a reduction in catch can either signal a depleted stock, or a robust, underexploited population.

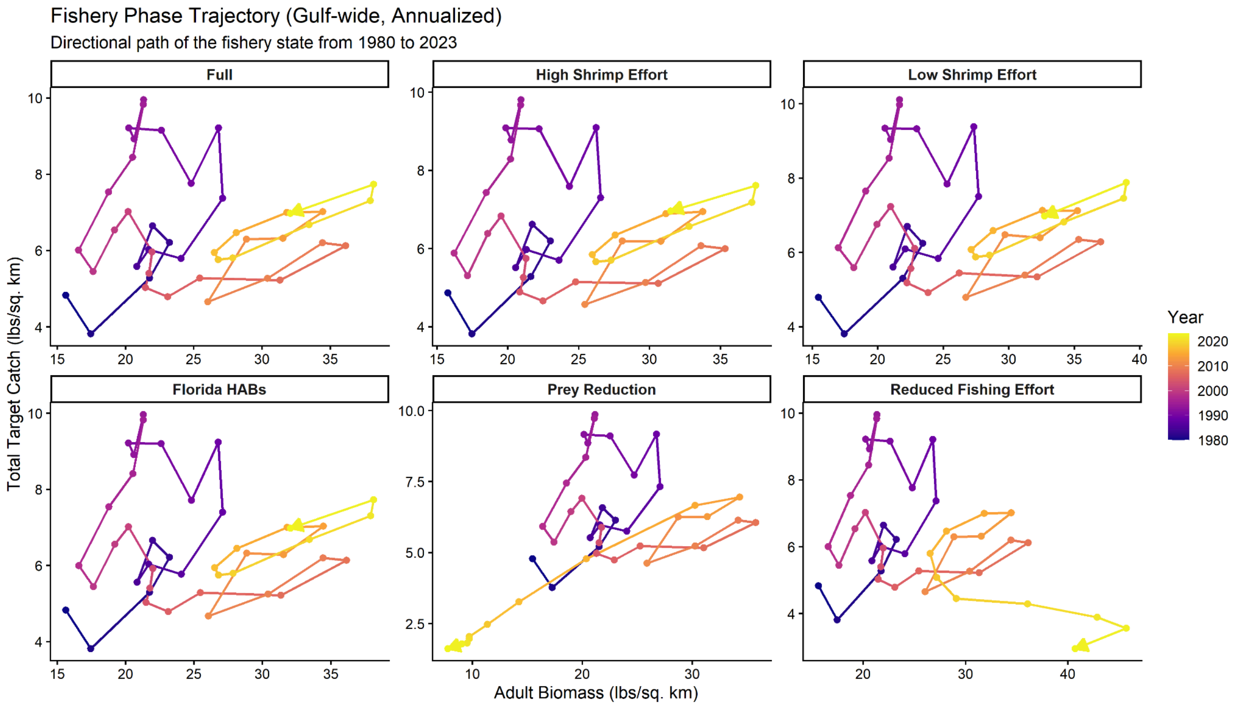

***Figure 5.** Fishery phase trajectory (1980–2023) mapping Gulf-wide adult King Mackerel (1+) biomass against total target catch across all scenarios. Years are indicated by the color gradient and directional arrows.*

4.3 Change in Fishing Effort

Spatially explicit changes in fishing effort were evaluated between the early (1980 to 1984) and late (2019 to 2023) simulation periods to determine if the fleets were actively relocating in response to ecosystem changes. Across all hypotheses, the geographic footprint of the commercial and recreational fleets remained highly consistent. While the absolute magnitude of effort scaled up or down according to the specific scenario, the spatial allocation of that effort did not significantly shift into new domains with the exception of a seaward shift for fleets operating on the West Florida shelf in all scenarios. This consistent seaward shift may be indicative of a seaward movement of the King Mackerel stock in the Gulf eastern region, driven by long-term environmental changes. That shift in fishing effort distribution is likely a much more complex socioeconomic issue that is considered in this MICE, but if these predictions are realized, they could further limit the economic viability of King Mackerel fishing trips. Notably, the Florida HABs did not have long-term impacts on the distribution of King Mackerel fleets, suggesting that redistributions of fishing effort must be driven by long-term impacts. The observed declines in empirical landings observed from the prey reduction and reduced fishing effort scenarios cannot be attributed to a geographic mismatch between the stock and the fishery, reinforcing that the catch reductions are driven by overall biomass or effort reductions rather than localized spatial redistributions.

4.4 Juvenile Bycatch in the Shrimp Fishery

Juvenile removals scaled directly with the prescribed changes in shrimp fishing effort; the high shrimp effort scenario generated the highest bycatch, while the low shrimp effort scenario produced the lowest (Figure 6). Spatially, this bycatch remained heavily concentrated in the western Gulf, aligning with the primary footprint of the penaeid shrimp fleet. The prey reduction scenario also resulted in a steep decline in juvenile bycatch, reflecting the broader reduction of the King Mackerel biomass prior to their recruitment into the fishery. Despite these extreme simulated variations in juvenile mortality, the respective adult biomass trajectories remained largely uncoupled from shrimp fleet dynamics. This demonstrates that under current ecosystem conditions, fluctuations in shrimp trawl bycatch do not act as the primary biological bottleneck driving the depletion of the adult stock.

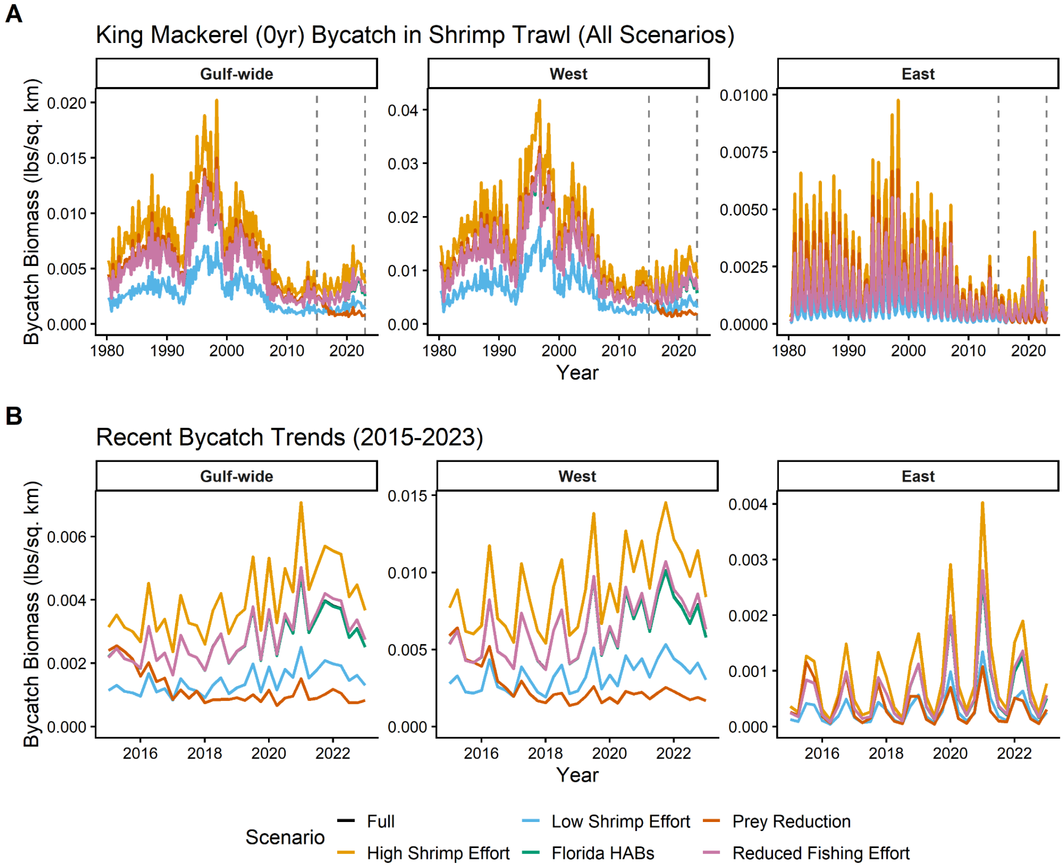

Figure 6. *King Mackerel (age-0) bycatch trends from the shrimp fleet in the six scenarios (colors). A) The full trajectory of targeted King Mackerel (age-0) bycatch trend among each scenario. B) The bycatch trends from 2016-2023, showing differences among scenarios in recent years. Note, the full scenario is covered by the Florida HABs scenario because of their similarity at the scale of the plotting.*

4. Discussion

A primary objective of this MICE analysis was to test prevalent hypotheses regarding the recent declines in Gulf King Mackerel landings. Among stakeholders, episodic environmental events, most notably the severe and prolonged *Karenia brevis* (red tide) blooms modeled on the West Florida Shelf in 2018, have been cited as a potential cause for less fish (SEDAR, 2024). Integrating these episodic mortality events into quantitative models is recognized as a critical priority for vulnerable species in the Gulf to adequately capture population dynamics (Sagarese et al., 2021). While the integration of red tide mortality into spatial models has been shown to drastically alter highly localized food web structures for demersal species (Vilas et al. 2023), our results demonstrate that these events were insufficient to drive the sustained collapse in King Mackerel landings. The MICE showed that red tide may cause nearshore mortality, which may cause food web-related impacts for other species, but this mortality is neither persistent nor wide-reaching enough to reduce King Mackerel landings by over the observed 70 percent. Furthermore, because the geographic footprint of fishing effort and spatial anomalies remained stable across scenarios, the model suggests range shifts caused by red tides did not push the stock outside the operational capacity of the fleets. There are a few biological and socioeconomic factors being assumed in this determination, such as: sub-lethal effects do not translate to drastic population impacts beyond the immediately affected area, and the operational capacity of King Mackerel fleets can avoid red tide areas. Commercial gillnetters from the Florida Keys have reported that poor nearshore water quality (including HABs) can result in a seaward shift of the King Mackerel population, which if persistent, could place greater economic burden on the fishing industry (Brendan Turley, University of Miami, pers. comm.). However, given the pelagic nature of King Mackerel and their movement distances, this MICE suggests that red tide effects have not been the sole determining factor in the observed landings declines. This result is also corroborated by a lack of documentation regarding king mackerel within red tide fish kills on the West Florida Shelf (Blake et al. 2022).

Critically, the MICE framework isolated only two scenarios capable of reproducing the recent observed landings decline: a reduction in the forage base (prey reduction) and a reduction in fleet participation (reduced fishing effort). These two hypothetical scenarios produce similar catch outcomes, but opposing biomass trajectories. Utilizing ecosystem models to distinguish between such contradictory biological states is an advantage of the MICE approach (Plaganyi et al., 2014). The prey reduction scenario indicates the King Mackerel population is heavily influenced by bottom-up trophic forcing and reliant on forage fishes (e.g., Menhaden, small pelagics). Forage fish populations may be negatively affected by drought and nutrient conditions, as well as targeted fisheries (Berenshtein et al. 2026), and a hypothetical collapse in prey availability is anticipated to lead to starvation and a biomass crash, subsequently reducing King Mackerel landings. If this scenario reflects reality, the stock may currently be heavily depleted with little opportunity to recover unless there is a rebound of prey. Contrary to this scenario, however, the most recent Gulf Menhaden stock assessment (SEDAR 63; terminal year = 2017) estimated gradually increasing trends in recruitment, fecundity, and age-1+ biomass since the early 1990s for Gulf Menhaden; the adult index for that assessment (Louisiana gill net data) illustrated a similar gradually increasing trend over the same period, with the recruitment index (Louisiana, Mississippi and Alabama seine data) increasing but at a less pronounced rate. Conversely, the reduced fishing effort scenario suggests that the stock is not depleted. In this model, the reduction in landings was forced as a hypothetical scenario, where effort steadily declined from 2016 through 2023 in all fleets and regions of the Gulf. In reality, fishing effort changes are more nuanced. For example, there may be local differences in fishing effort changes based on regional economic pressures, water access points, or changing angler behavior. Under this scenario, treating the drop in landings as an index of abundance would lead to catchability bias, where CPUE and catch incorrectly signal a population crash that does not exist (Hilborn and Walters, 1992; Wilberg et al., 2009; Grüss et al., 2023). Neither of the scenarios produced the drastic decline in commercial hook-and-line harvest in the western region, which suggests that the drivers on that fishery are either more severe than were modeled here, or combined drivers (e.g., prey reduction and reduced fishing effort) may have compounding effects on the fishery.

Historically, the bycatch of age-0 King Mackerel within the Gulf penaeid shrimp fishery has been viewed as a potential bottleneck for stock recovery (SEDAR, 2020). Annual estimates of shrimp bycatch (1972-2017) in the SEDAR 38 Update Gulf King Mackerel stock assessment had a median value of 1.998 million fish, ranging from about 230,000 to over 12.4 million fish. Evaluating the relative impact of early life-history mortality is necessary, as excessive juvenile removals can undermine actions to improve the capacity of an adult stock (Pikitch et al., 2004; Grüss et al., 2017). However, this MICE refutes the hypothesis that fluctuations in shrimp effort are responsible for the observed landings deficit. By demonstrating that large variations in shrimp trawl intensity produced no deviation in adult King Mackerel biomass trajectories, the model indicates juvenile discard mortality and adult productivity are decoupled. This disconnect aligns with broader theories suggesting that for highly fecund species, anthropogenic bycatch impacts are overwhelmed by larval and early juvenile mortality rates (Walters et al., 1997; SEDAR, 2020). Consequently, while monitoring shrimp fleet effort remains important, this MICE suggests that trophic failure or changing socioeconomic catchability are more immediate threats to the King Mackerel fisheries productivity.

This MICE presents a challenge for the SEDAR 99 assessment and the Gulf Council. The model indicates that the observed decline in landings is likely not the result of a spatial shift or a transient red tide anomaly. There are two potentially viable hypotheses that may be occurring: a trophic-driven biomass collapse or a socioeconomic reduction of fishing effort. It is imperative to identify the mechanism behind catch declines to avoid misguided management interventions (Punt et al., 2016). If fishery-independent surveys show a concurrent decline in the biomass of King Mackerel or its prey (e.g., clupeids, anchovies), it provides evidence for the prey reduction hypothesis. If, however, fishery-independent indices show stable or increasing King Mackerel or prey abundance, it refutes the prey reduction hypothesis, which may also support the effort reduction hypothesis. The challenge is that most fishery-independent surveys in the Gulf do not employ gear which effectively samples pelagic predator or prey species outside of shallow estuaries. Not only does this inhibit the development of a fishery-independent index for managed species such as King Mackerel, it also limits the application of most surveys in accurately assessing trends in the pelagic prey base. For Gulf Menhaden, the only adult index used in its most recent assessment (SEDAR 63) was specific to Louisiana (gillnet data) and showed an overall gradual increase in abundance since the early 1990s. The recruitment index used in that assessment was also regionally limited (Louisiana, Mississippi and Alabama seine data) and did not indicate a declining abundance trend. While limited in scope, those data would not support the prey reduction hypothesis, giving further credence to the effort reduction hypothesis. Validation of these model results will likely require improvements to fisheries-independent surveys for pelagic species in the Gulf, including the application of advanced technologies (e.g., eDNA). Ultimately, this MICE analysis demonstrates not only the utility of ecosystem modeling for exploring environmental parameters and ecosystem-based information in a population dynamics framework, but for eliminating potential hypotheses and narrowing the focus of tactical stock assessments (Plaganyi et al., 2014).

References

Arreguín-Sánchez, F., Cabrera, M. A., & Aguilar, F. A. (1995). Population dynamics of the King Mackerel (*Scomberomorus cavalla*) of the Campeche Bank, Mexico. Scientia Marina, 59: 637–645.

Bentley, J.W., Chagaris, D., Coll, M., Heymans, J.J., Serpetti, N., Walters, C.J. & Christensen, V., (2024). Calibrating ecosystem models to support ecosystem-based management of marine systems. ICES Journal of Marine Science, 81: 260-275. https://doi.org/10.1093/icesjms/fsad213

Berenshtein, I., Kirtman, B., de Mutsert, K., & Chagaris, D.D. (2026). Historical depletion and future drought-driven risks to Gulf of Mexico fisheries production. Nature Communications. 17: 2409. https://doi.org/10.1038/s41467-026-69116-6

Berenshtein, I., Sagarese, S.R., Lauretta, M.V., Nuttall, M.A. & Chagaris, D.D. (2021). Technical documentation of a U.S. Gulf of Mexico-wide Ecosystem model. NOAA Technical Memorandum. NMFS-SEFSC-751, 229 p. https://doi.org/10.25923/zj8t-e656.

Blake, S.D., McPherson, M., Karnauskas, M., Sagarese, S.R., Rios, A., Stoltz, A.D., Mastitski, A. & Jepson, M. (2022). Use of fishermen's local ecological knowledge to understand historic red tide severity patterns. Marine Policy, 145: 105253. https://doi.org/10.1016/j.marpol.2022.105253

Dettloff, K. 2024. Estimation of Commercial Shrimp Effort in the Gulf of Mexico. SEDAR87-DW-01. SEDAR, North Charleston, SC. 31 pp. Available at: https://sedarweb.org/documents/sedar-87-dw-01-estimation-of-commercial-shrimp-effort-in-the-gulf-of-mexico/

Fable, W. A., Jr., Trent, L., Bane, G. W., & Ellsworth, S. W. (1987). Movements of King Mackerel, *Scomberomotus cavalla*, tagged in southeast Louisiana, 1983–85. Marine Fisheries Review, 49, 98–101.

Florida Fish and Wildlife Conservation Commission- Fish and Wildlife Research Institute (FWC-FWRI). 2026. Historic Harmful Algal Bloom Events 2015-2023. http://myfwc.com/research/redtide/monitoring/. Accessed 3/3/2026.

GMFMC (Gulf of Mexico Fishery Management Council). (2019). Something's Fishy with King Mackerel Response Summary. Available at: https://gulfcouncil.org/fishery-management/fisheries-science/fisherman-feedback/

Grüss, A., Rose, K. A., Simons, J., Ainsworth, C. H., Babcock, E. A., Chagaris, D. D., de Mutsert, K., Froeschke, J., Himchak, P., Kaplan, I.C., O'Farrell, H., & Zetina Rejon, M. J. (2017). Recommendations on the use of ecosystem modeling for informing ecosystem-based fisheries management and restoration outcomes in the Gulf of Mexico. Marine and Coastal Fisheries, 9: 281-295. https://doi.org/10.1080/19425120.2017.1330786

Grüss, A., Thorson, J.T., Anderson, O.F., O'Driscoll, R.L., Heller-Shipley, M. and Goodman, S., 2023. Spatially varying catchability for integrating research survey data with other data sources: case studies involving observer samples, industry-cooperative surveys, and predators as samplers. Canadian Journal of Fisheries and Aquatic Sciences, 80: 1595-1615. https://doi.org/10.1139/cjfas-2023-0051

Harris, H.E., Sagarese S.R., Woodstock M.S., and D.D. Chagaris. 2026. A U.S. Gulf-wide Ecopath with Ecosim and Ecospace model for the continental shelf incorporating spatial-temporal environmental drivers. NOAA Technical Memorandum NMFS-SEFSC-797. https://doi.org/10.25923/zagd-vq81

Hart, R.A. 2018a. Stock Assessment Update for Brown Shrimp (*Farfantepenaeus aztecus*) in the U.S. Gulf of Mexico for the 2017 Fishing Year. Southeast Fisheries Science Center. Galveston, TX. 19 pp.

Hart, R.A. 2018b. Stock Assessment Update for Pink Shrimp (*Farfantepenaeus duorarum*) in the U.S. Gulf of Mexico for the 2017 Fishing Year. Southeast Fisheries Science Center. Galveston, TX. 17 pp.

Hart, R.A. 2018c. Stock Assessment Update for White Shrimp (*Litopenaeus setiferus*) in the U.S. Gulf of Mexico for the 2017 Fishing Year. Southeast Fisheries Science Center. Galveston, TX. 20 pp.

Hendon, R., Ingram W., Karnauskas, M., and Turley, B. (2025). Gulf of Mexico King Mackerel: A preliminary assessment and response to GMFMC data request. Gulf of Mexico Fishery Management Council Meeting. Available at: https://gulfcouncil.org/meetings/january-2025-council-meeting/

Hilborn, R., and Walters, C. J. (1992). Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Springer. 570 pp.

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Koukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAllister, M.K., Pope, J., & Sainsbury, K.J. (2004). Ecosystem based fishery management. Science, 305: 346-347. https://doi.org/10.1126/science.1098222

Plagányi, É. E., Punt, A. E., Hillary, R., Morello, E. B., Thébaud, O., Hutton, T., Pillans, R.D., Thorson, J.T., Fulton, E.A., Smith, A.D.M., Smith, F., Bayliss, P., Haywood, M., Lyne, V., & Rothlisberg, P. C. (2014). Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish and Fisheries, 15: 1-22. https://doi.org/10.1111/j.1467-2979.2012.00488.x

Punt, A. E., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A., & Haddon, M. (2016). Management strategy evaluation: best practices. Fish and Fisheries, 17: 303-334. https://doi.org/10.1111/faf.12104

Ross, A.C., Stock, C.A., Adcroft, A., Curchitser, E., Hallberg, R., Harrison, M.J., Hedstrom, K., Zadeh, N., Alexander, M., Chen, W., Drenkard, E.J., du Pontavice, H., Dussin, R., Gomez, F., John, J.G., Kang, D., Lavoie, D., Resplandy, L., Roobaerrt, A., Saba, V., Shin, S-I., Siedlecki, S., & Simkins, J. (2023). A high-resolution physical-biogeochemical model for marine resource applications in the northwest Atlantic (MOM6-COBALT-NWA12 v1. 0). Geoscientific Model Development Discussions, 16: 6943-6985.

Sagarese, S.R., Nuttall, M.A., Geers, T.M., Lauretta, M.V., Walter III, J.F. & Serafy, J.E. (2016). Quantifying the trophic importance of Gulf menhaden within the northern Gulf of Mexico ecosystem. Marine and Coastal Fisheries, 8: 23-45. https://doi.org/10.1080/19425120.2015.1091412

Sagarese, S.R., Lauretta, M. V, & Walter III, J.F. 2017. Progress towards a next generation fisheries ecosystem model for the northern Gulf of Mexico. Ecological Modeling. 345:75–98. https://doi.org/10.1016/j.ecolmodel.2016.11.001

Sagarese, S.R., Vaughan, N.R., Walter III, J.F. & Karnauskas, M. (2021). Enhancing single-species stock assessments with diverse ecosystem perspectives: a case study for Gulf of Mexico red grouper (Epinephelus morio) and red tides. Canadian Journal of Fisheries and Aquatic Sciences, 78: 1168-1180. https://doi.org/10.1139/cjfas-2020-0257

SEDAR 2018. SEDAR 63 Gulf Menhaden Stock Assessment Report. SEDAR, North Charleston, SC. 352 pp.

SEDAR. (2020). SEDAR 38 Update: Gulf of Mexico King Mackerel Stock Assessment Report. SEDAR, North Charleston SC.

SEDAR. (2024). SEDAR 99 Gulf of Mexico Migratory Group King Mackerel Assessment Terms of Reference. SEDAR, North Charleston SC.

Steenbeek, J., Coll, M., Gurney, L., Mélin, F., Hoepffner, N., Buszowski, J., & Christensen, V. (2013). Bridging the gap between ecosystem modeling tools and geographic information systems: Driving a food web model with external spatial–temporal data. Ecological Modelling, 263: 139-151. https://doi.org/10.1016/j.ecolmodel.2013.04.027

Vilas, D., Buszowski, J., Sagarese, S., Steenbeek, J., Siders, Z. & Chagaris, D. (2023). Evaluating red tide effects on the West Florida Shelf using a spatiotemporal ecosystem modeling framework. Scientific Reports, 13: 2541. https://doi.org/10.1038/s41598-023-29327-z

Wall, C. C., Muller-Karger, F. E., & Roffer, M. A. (2009). Linkages between environmental conditions and recreational king mackerel (*Scomberomorus cavalla*) catch off west‐central Florida. Fisheries Oceanography, 18: 185-199. https://doi.org/10.1111/j.1365-2419.2009.00507.x

Walters, C. J., Christensen, V., & Pauly, D. (1997). Structuring dynamic models of exploited ecosystems from trophic mass balance assessments. Reviews in Fish Biology and Fisheries, 7: 139-172. https://doi.org/10.1023/A:1018479526149

Wilberg, N. J., Thorson, J. T., Linton, B. C., & Berkson, J. (2009). Incorporating time varying catchability into population dynamic models. Reviews in Fisheries Science, 18: 7-24. https://doi.org/10.1080/10641260903294647