SEDAR

Southeast Data, Assessment, and Review

SEDAR 87
Stock Assessment Report

Gulf of America White Shrimp

August 2025

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

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Note: Each report section is numbered independently.

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SECTION I: Introduction

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Overview

SEDAR 87 addressed the stock assessment for Gulf white, pink, and brown shrimp. The process consisted of an in-person Data Workshop, with several webinars before and after the workshop, series of assessment webinars, and an in-person Review Workshop. The assessment was conducted by the SEFSC.

The Stock Assessment Report is organized into 6 sections. Section I – Introduction contains a brief description of the SEDAR Process, Assessment and Management Histories for the species of interest, and the management specifications requested by the Cooperator. The Data Workshop Report can be found in Section II. It documents the discussions and data recommendations from the Data Workshop Panel. Section III is the Assessment Process report. This section details the assessment model, as well as documents any changes to the data recommendations that may have occurred after the data workshop. Consolidated Research Recommendations from all stages of the process can be found in Section IV for easy reference. Section V documents the discussions and findings of the Review Workshop (RW). Finally, Section VI – Addenda and Post-Review Workshop Documentation consists of any analyses conducted during or after the RW to address reviewer concerns or requests. It may also contain documentation of the final RW-recommended base model, should it differ from the model put forward in the Assessment Report for review.

The final Stock Assessment Report (SAR) for Gulf white shrimp was disseminated to the public in August 2025. The Council's Scientific and Statistical Committee (SSC) will review the SAR. The SSCs are tasked with recommending whether the assessments represent Best Available Science, whether the results presented in the SARs are useful for providing management advice and developing fishing level recommendations for the Council. An SSC may request additional analyses be conducted or may use the information provided in the SAR as the basis for their Fishing Level Recommendations (e.g., Overfishing Limit and Acceptable Biological Catch). The Gulf Council's SSC will review the assessment at its October 2025 meeting, followed by the Council receiving that information at its November 2025 meeting. Documentation on SSC recommendations is not part of the SEDAR process and is handled through each Council.

1 SEDAR PROCESS DESCRIPTION

SouthEast Data, Assessment, and Review (**SEDAR**) is a cooperative Fishery Management Council process initiated in 2002 to improve the quality and reliability of fishery stock assessments in the South Atlantic, Gulf of Mexico, and US Caribbean. SEDAR seeks improvements in the scientific quality of stock assessments and the relevance of information available to address fishery management issues. SEDAR emphasizes constituent and stakeholder participation in assessment development, transparency in the assessment process, and a rigorous and independent scientific review of completed stock assessments.

SEDAR is managed by the Caribbean, Gulf, and South Atlantic Regional Fishery Management Councils in coordination with NOAA Fisheries and the Atlantic and Gulf States Marine Fisheries Commissions. Oversight is provided by a Steering Committee composed of NOAA Fisheries representatives: Southeast Fisheries Science Center Director and the Southeast Regional Administrator; Regional Council representatives: Executive Directors and Chairs of the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils; a representative from the Highly Migratory Species Division of NOAA Fisheries, and Interstate Commission representatives: Executive Directors of the Atlantic States and Gulf States Marine Fisheries Commissions.

SEDAR is normally organized around two workshops and a series of webinars. First is the Data Workshop, during which fisheries, monitoring, and life history data are reviewed and compiled. The second stage is the Assessment Process, which is conducted via a workshop and/or a series of webinars, during which assessment models are developed and population parameters are estimated using the information provided from the Data Workshop. The final step is the Review Workshop, during which independent experts review the input data, assessment methods, and assessment products. The completed assessment, including the reports of all 3 stages and all supporting documentation, is then forwarded to the Council SSC for certification as 'appropriate for management' and development of specific management recommendations.

SEDAR workshops are public meetings organized by SEDAR staff and the lead Cooperator. Workshop participants are drawn from state and federal agencies, non-government organizations, Council members, Council advisors, and the fishing industry with a goal of including a broad range of disciplines and perspectives. All participants are expected to contribute to the process by preparing working papers, contributing, providing assessment analyses, and completing the workshop report.

2 MANAGEMENT OVERVIEW

2.1 Fishery Management Plans and Amendments

***Original FMP*:**

The Shrimp Fishery Management Plan (FMP) was implemented as federal regulation May 20, 1981. The principal thrust of the plan was to enhance yield in volume and value by deferring harvest of small shrimp to provide for growth. Principle actions included:

1. Establishing a cooperative Tortugas Shrimp Sanctuary with the state of Florida to close a shrimp trawling area where small pink shrimp comprise the majority of the population most of the time.
2. A cooperative 45-day seasonal closure with the state of Texas to protect small brown shrimp emigrating from bay nursery areas; and
3. Seasonal zoning of an area of Florida Bay for either shrimp or stone crab fishing to avoid gear conflict.

The FMP also established reporting systems for vessels, dealers, and processors. This final rule is effective May 15, 1981.

***FMP Amendments affecting Penaeid Shrimp*:** *(in chronological order)*

Amendment 1, approved in 1981, provided the Regional Administrator (RA) of the National Marine Fisheries Service (NMFS) with the authority to adjust by regulatory amendment the size of the Tortugas Sanctuary or the extent of the Texas closure, or to eliminate either closure for one year. It updated and revised the text of the fishery management plan (FMP). This final rule is effective April 15, 1983.

Amendment 2 updated catch and economic data in the fishery management plan (FMP). This final rule is effective May 31, 1981.

Amendment 3 resolved another shrimp-stone crab gear conflict on the west central Florida coast. This final rule is effective August 31, 1984.

Amendment 4, partially approved in 1988 and finalized in 1989, identified problems that developed in the fishery and revised the objectives of the FMP accordingly. The annual review process for the Tortugas Sanctuary was simplified, and the Gulf Council's and RA review for the Texas closure was extended to February 1st. Disapproved was a provision that white shrimp taken in the exclusive economic zone (EEZ) be landed in accordance with a state's size/possession regulations to provide consistency and facilitate enforcement with the state of Louisiana. This latter action was to have been implemented at such time when Louisiana provided for an incidental catch of undersized white shrimp in the fishery for seabobs.

In July 1989, NMFS published revised guidelines for FMPs that interpretatively addressed the Magnuson Act National Standards. These guidelines require each FMP to include a scientifically measurable definition of overfishing and an action plan to arrest overfishing should it occur. In 1990, Texas revised the period of its seasonal closure in Gulf waters from June 1 to July 15, to May 15 to July 15. The FMP did not have enough flexibility to adjust the cooperative closure of federal waters to accommodate this change, thus an amendment was required.

Amendment 5 also defined overfishing for Gulf brown, pink, and royal red shrimp and provided for measures to restore overfished stocks if overfishing should occur. Action on the definition of overfishing for white shrimp was deferred, and seabobs and rock shrimp were deleted from the management unit. This duration of the seasonal closure to shrimping off Texas was adjusted to conform with the changes in state regulations.

Amendment 6 (1993) eliminated the annual reports and reviews of the Tortugas Shrimp Sanctuary in favor of monitoring and an annual stock assessment. Three seasonally opened areas within the sanctuary continued to open seasonally, without need for annual action. A proposed definition of overfishing of white shrimp was rejected by NMFS as not being based on the best available data.

Amendment 7, finalized in 1994, defined overfishing for white shrimp and provided for future updating of overfishing indices for brown, white, and pink shrimp as new data become available. A total allowable level of foreign fishing (TALFF) for royal red shrimp was eliminated; however, a redefinition of overfishing for this species was disapproved.

Amendment 9 addresses the issue of reducing the bycatch of juvenile red snapper in the shrimp trawl fishery. This final rule is effective May 14, 1998.

Amendment 12 established two marine reserves in the EEZ in the vicinity of the Dry Tortugas, Florida known as Tortugas North and Tortugas south, in which fishing for coastal migratory pelagic species is prohibited. This action complements previous actions taken under the National Marine Sanctuaries Act. This final rule is effective August 19, 2002.

Amendment 11 requires all vessels harvesting shrimp from the EEZ to obtain a commercial shrimp vessel permit from NMFS; prohibits the use of traps to harvest of royal red shrimp from the EEZ; and prohibits the transfer or royal red shrimp at sea. Permits required 12/5/02. This final rule is effective December 5, 2002.

Amendment 10 requires the installation of NMFS-certified bycatch reduction devices (BRD) that reduce the bycatch of finfish by at least 30% by weight in each net used aboard vessels trawling for shrimp in the Gulf EEZ east of Cape San Blas, Florida (85° 30″ W. Longitude). Excepted are vessels trawling for groundfish or butterfish. A single try net with a headrope length of 16 feet or less per vessel and no more than two rigid-frame roller trawls limited to 16 feet or less, such as those used in the Big Bend area of Florida are also exempted. This final rule is effective February 9, 2004.

Amendment 13 establishes an endorsement to the existing federal shrimp vessel permit for vessels harvesting royal red shrimp; (2) Defines maximum sustainable yield (MSY), optimum yield (OY), the overfishing threshold, and the overfished condition for royal red and penaeid shrimp stocks in the Gulf for stocks that currently lack such definitions; (3) Establishes bycatch reporting methodologies and improve collection of shrimping effort data in the exclusive economic zone; (4) Requires completion of a Gulf Shrimp Vessel and Gear Characterization Form; (5) Establishes a moratorium on the issuance of commercial shrimp vessel permits; and (6) Requires reporting and certification of landings during a moratorium. Action 10 would establish a moratorium on the issuance of new commercial shrimp vessel permits, which would be a form of limited access. This final rule is effective October 26, 2006.

Amendment 14, part of Joint Reef Fish Amendment 27/Shrimp Amendment 14 was submitted to NMFS in June 2007, and establishes a target reduction goal for juvenile red snapper mortality of 74% less than the benchmark years of 2001-2003, reducing that target goal to 67% beginning in 2011, eventually reducing the target to 60% by 2032. If necessary, a seasonal closure in the shrimp fishery will occur in conjunction with the annual Texas closure. The need for a closure will be determined by an annual evaluation by the NMFS RA. The joint amendment also addresses overfishing and bycatch issues in both the red snapper directed fishery and the shrimp fishery. The amendment sets total allowable catch (TAC) at 5.0 mp between 2008 and 2010. The commercial sector will receive a quota of 2.55 mp, with the remaining quota of 2.45 mp going to the recreational sector. The amendment also reduces the commercial size limit to 13”, reduces the recreational bag limit to two fish, eliminates a bag limit for captain and crew aboard a for-hire vessel, and sets the recreational fishing season from June 1 – September 30 (which may be extended by approximately 30 days if the Council’s presumed assumption of a 10% post-hurricane reduction in recreational fishing effort is realized). In addition, all commercial and recreational reef fish fisheries will be required to use non-stainless steel circle hooks when using natural baits, as well as venting tools and dehooking devices. This final rule is effective February 28, 2008, except for § 622.41(m) which is effective June 1, 2008.

Amendment 15 adjusts stock status determination criteria to be consistent with the new population metrics for penaeid shrimp. It also modifies the framework procedure for the Shrimp FMP to include changes to accountability measures (AM) for the royal red shrimp fishery through the standard documentation process for open framework actions, and make editorial changes to the framework procedure to reflect changes to the Council advisory committees and panels. AMs that could be implemented or changed would include:

- In-season AMs
    - Closure and closure procedures
    - Trip limit implementation or change
    - Implementation of gear restrictions
- Post-season AMs
    - Adjustment of season length
    - Implementation of closed seasons/time periods
    - Adjustment or implementation of trip or possession limits
    - Reduction of the annual catch limit (ACL)/annual catch target (ACT) to account for the previous year overage
    - Revoking a scheduled increase in the ACL/ACT if the ACL was exceeded in the previous year
    - Implementation of gear restrictions
    - Reporting and monitoring requirements

This final rule is effective December 30, 2015.

Amendment 17A extends the current Gulf commercial shrimp permit moratorium for 10 more years. The intent of this final rule and Amendment 17A is to protect federally managed Gulf shrimp stocks while promoting catch efficiency, economic efficiency, and stability in the fishery. This final rule is effective August 22, 2016.

Amendment 17B defines and aggregate MSY of 112,531,374 pounds of tails and an aggregate optimum yield of 85,761,596 pounds of tails. This amendment allows for the creation of a Federal Gulf shrimp reserve pool permit when certain conditions are met. It also sets minimum threshold number of active shrimp permits at 1072 and mandates that the Council convene a review panel to review the details of a permit pool if the number of permits reaches 1,175. This amendment also allows vessels possessing shrimp to transit through federal waters without a federal permit if their trawl doors and nets are out of the water the bag straps are removed. This final rule is effective January 22, 2018.

Amendment 18 increases the allowable amount of shrimp trawl fishing effort in the area of federal waters monitored for juvenile red snapper bycatch. This area in shrimp statistical zones 10-21 is found in federal waters 10-30 fathoms deep roughly off the coasts of Mississippi, Louisiana, and Texas. The effort reduction threshold is set to 60% below the effort in baseline years 2001-2003. The amendment also reviews the shrimp FMP framework procedure to allow changes to allowable fishing effort through an expedited process. This final rule is effective March 9, 2020.

2.2 Regulatory Amendments

August 2006: The purpose of this regulatory amendment is to change the bycatch reduction certification criterion for red snapper from penaeid shrimp trawling in the EEZ. Revising the BRD certification criterion to address shrimp trawl bycatch more comprehensively and realistically is expected to increase flexibility, promote innovation, and allow for the certification of a wider variety of BRDs. Having a wider variety of BRDs available to the fishery would allow fishermen to choose the most effective BRD for the specific local fishing conditions and enhance overall finfish reduction. This final rule is effective March 14, 2008.

July 2013: The purpose of this action is to maintain NMFS' ability to monitor and document offshore effort for the Gulf shrimp fleet through an electronic logbook (ELB) program. The need is to base conservation and management measures on the best scientific information available and to minimize bycatch to the extent practicable, as required by the Magnuson-Stevens

2.3 Management Program Specifications

Table 2.3.1. General Management Information

Species	Brown, White, and Pink Shrimp
Management Unit	Gulf of America
Management Unit Definition	Gulf of America
Management Entity	Gulf Council
Management Contacts SERO / Council	Matt Freeman (Gulf Council) Frank Helies (SERO)

Table 2.3.2. Specific Management Criteria

Criteria	Current- Amendment 17B (2018)		Proposed	
	Definition	Value	Definition	Value
Overfished	MSST = SSB_{MSY}	See SSB_{MSY}	MSST = SSB_{MSY}	SEDAR 87
Overfishing	MFMT	See MFMT value	MFMT	SEDAR 87
MSY	Aggregate, lb of tails	112,531,374	Aggregate, lb of tails	SEDAR 87
MFMT	F_{MSY}	Brown: 9.12 White: 3.48 Pink: 1.35	F_{MSY}	SEDAR 87
SSB_{MSY}	Lb of tails	Brown: 6,098,824 White: 365,715,146 Pink: 23,686,906	Lb of tails	SEDAR 87
OY	Aggregate, lb of tails	85,761,596	Aggregate, lb of tails	SEDAR 87

Terminal F	Exploitation	*unknown*	Exploitation (2024)	SEDAR 87
Terminal Biomass[1]	Biomass	*unknown*	Biomass (2024)	SEDAR 87
Exploitation Status	F/MFMT	*unknown*	F/MFMT (2024)	SEDAR 87

Table 2.3.3. General projection information.
(This provides the basic information necessary to bridge the gap between the terminal year of the assessment and the year in which any changes may take place or specific alternative exploitation rates should be evaluated, and guidance for the information managers required from the projection analyses.)

Requested Information	**Value**
First Year of Management	2027 Calendar Year
Landings	pounds of tails
Exploitation	F & Probability F>MFMT
Biomass (total or SSB, as appropriate)	SSB & Probability SSB>MSST (and Prob. SSB>B_{MSY} if under rebuilding plan)

Table 2.3.4. Quota Calculation Details

Note: mp = million pounds; gw = gutted weight.

Current quota values (2023)	**Pounds of tails**
• Brown Shrimp	See aggregate MSY and OY definitions in Table 2.6.2
• White Shrimp	
• Pink Shrimp	
Next Scheduled Quota Change	None
Annual or averaged quota?	Annual
Does the quota include bycatch/discard?	No

2.4 Federal Management and Regulatory Timelines for Penaeid Shrimp

Harvest Restrictions (Trip Limits*)
*Trip limits do not apply during closures (if season is closed, then trip limit is 0)

First Yr In Effect	Fishery	Harvest limitation	Region Affected	Amendment Number or Rule Type
2020	White, Pink, Brown	**Action 1:** Modify the target reduction goal for juvenile red snapper of shrimp trawl bycatch mortality from 67% less than the benchmark years of 2001-2003 to 60%.	Gulf Council EEZ	Amendment 18; https://gulfcouncil.org/wp-content/uploads/Final-Shrimp-Amendment-18.pdf
2015	White, Pink, Brown	**Action 1.1:** Modify the Maximum Sustainable Yield (MSY) for Penaeid Shrimp. [Set MSY values in lbs of tails each for brown, white, and pink shrimp.] **Action 1.2:** Modify the Overfishing Threshold for Penaeid Shrimp. [Set the overfishing threshold as the maximum fishing mortality threshold, with values each for brown, white, and pink shrimp.] **Action 1.3:** Modify the Overfished Threshold for Penaeid Shrimp. [Set the overfishing threshold as the minimum stock size threshold, with values in lbs of tails each for brown, white, and pink shrimp.]	Gulf Council EEZ	Amendment 15; https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-15-FINAL_508Compliant.pdf
2008	White, Pink, Brown	**Action 6:** Establish a target reduction of red snapper shrimp trawl bycatch mortality on red snapper 74 percent less than the benchmark years of 2001-2003 for the years 2008 through 2010. Reduce the target goal to 67 percent beginning in 2011, and thereafter reduce the target goal, as necessary, to acheive a target reduction goal of 60 percent by 2032.	Gulf Council EEZ	Amendment 14; https://gulfcouncil.org/wp-content/uploads/FISHERY%20MANAGEMENT/SHRIMP/amendments/Final%20RF%20Amend%2027-%20Shrimp%20Amend%2014.pdf

2006	White, Pink, Brown	**Action 6:** MSY for the penaeid shrimp stocks falls within the range of values defined by the lowest and highest landings taken annually from 1990-2000 that does not result in recruitment overfishing as defined herein: MSY for the brown shrimp stock is between 67 and 104 MP of tails, MSY for the white shrimp stock is between 35 and 71 MP of tails, MSY for the pink shrimp stock is between 6 and 19 MP of tails. **Action 7:** OY for the penaeid shrimp stocks equals MSY.	Gulf Council EEZ	Amendment 13; https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-13_508Compliant.pdf
1994	White, Pink, Brown	**Action 1:** White shrimp recruitment overfishing is indicated when parent stock level is reduced below 330 million shrimp (Figure 3). Parent stock for white shrimp is defined as the number of age 7+ (months) shrimp during the period May through August. **Action 3:** Section 6.2.1.1.4 [from Shrimp Amendment 5] is revised as follows to include white shrimp and to provide for adjusting index levels as new data become available. [Full text is on page 12/36 of the amendment PDF.]	Gulf Council EEZ	Amendment 7; https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-7.pdf
1989	White, Pink, Brown	**Action 3:** [Determined OY, overfishing, recruitment overfishing, and actions to be taken if recruitment overfishing occurs for brown, white, and pink shrimp; pages -27 of the amendment PDF.]	Gulf Council EEZ	Amendment 5; https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-5.pdf

Harvest Restrictions (Fishery Closures*)
*Area specific regulations are documented under spatial restrictions

First Yr In Effect	Fishery	Closure Type	Region Affected	Amendment Number or Rule Type
2008	White, Pink, Brown	**Action 7:** Establish if necessary a seasonal closure beginning on the same start date as the closure of the EEZ off Texas in the 10 to 30-fathom zone of selected areas within statistical zones 10-21 in the Gulf of Mexico. The need for the closure and its extent and duration will be determined based on the annual evaluation of the level of shrimp effort and associated red snapper mortality, taking into consideration mortality reductions associated with improved BRDs and other gear improvements. Any closure would be implemented in accordance with the framework outlined in Action 8.	Gulf Council EEZ	Amendment 14; https://gulfcouncil.org/wp-content/uploads/FISHERY%20MANAGEMENT/SHRIMP/amendments/Final%20RF%20Amend%2027-%20Shrimp%20Amend%2014.pdf
1989	White, Pink, Brown	**Action 1:** Measure 2 of the FMP as amended is revised as follows: Establish with the state of Texas a cooperative closure of the Gulf waters under Texas jurisdiction and the adjacent U.S. EEZ when a sustain portion of the brown shrimp in these waters weighs less than a count of 65 tails to the pound (39 heads-on shrimp to the pound). The U.S. Department of Commerce will close the EEZ, and the time of closing shall correspond to the closure by Texas of its Gulf waters. Closure normally occurs 30 minutes after sunset on May 15 to 30 minutes after sunset on July 15; however, the effects of climatic variation on shrimp growth may necessitate flexibility in the closing and opening dates to provide for an earlier, later, longer, or shorter closure of no more than 90 days nor less than 45 days. Provision is to be made to allow taking of royal red shrimp beyond the 100 fathom contour (where brown shrimp do not occur).	Gulf Council EEZ	Amendment 5; https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-5.pdf
1989	White, Pink, Brown	**Action 4:** [Revised the date by which the NMFS assessment of the fishery is due from December 1st to December 15th. The date by which the Regional Director must publish intent to revise or not to revise is moved from January 15th to February 1st.]	Gulf Council EEZ	Amendment 4; https://gulfcouncil.org/wp-content/uploads/FISHERY%20MANAGEMENT/SHRIMP/SHRIMP%20Amend-04%20Final%201988-08.pdf
1981	White, Pink, Brown	**Measure 2:** Establish a cooperative closure of the territorial sea of Texas and the adjacent U.S. FCZ with the State of Texas and the U.S. Department of Commerce during the time when a substantial portion of the brown shrimp in these waters weigh less than a count of 65 tails to the pound (39 heads-on shrimp to the pound). [Full text is on page 203/246 of the Original Shrimp FMP PDF.]	Gulf Council EEZ	Original Shrimp Fishery Management Plan; https://gulfcouncil.org/wp-content/uploads/Original-Shrimp-Fishery-Management-Plan.pdf

Harvest Restrictions (Spatial Restrictions - General)

Area	First Yr In Effect	Effective Date	End Date	First Day Closed	Last Day Closed	Restriction in Area	FR Reference	Amendment Number or Rule Type	FR Section	Amendment Number or Rule Type
Madison-Swanson	2000	6/19/00	6/2/04	Year round		Fishing prohibited except HMS[1]	65 FR 31827	Reef Fish Regulatory Amendment	622.34	Reef Fish Regulatory Amendment
	2004	6/3/04	8/19/21	1-May	31-Oct	Fishing prohibited except surface trolling	70 FR 24532 74 FR 17603	Reef Fish Amendment 21 Reef Fish Amendment 30B	622.34 NA	Reef Fish Amendment 21 Reef Fish Amendment 30B
	2004	6/3/04	8/19/21	1-Nov	30-Apr	Fishing prohibited	70 FR 24532 74 FR 17603	Reef Fish Amendment 21 Reef Fish Amendment 30B	622.34 NA	Reef Fish Amendment 21 Reef Fish Amendment 30B
	2021	8/20/21	Ongoing	Year round		Fishing prohibited	86 FR 38416	RF Framework Action	622.34	Reef Fish Regulatory Amendment
Steamboat Lumps	2000	6/19/00	6/2/04	Year round		Fishing prohibited except HMS[1]	65 FR 31827	Reef Fish Regulatory Amendment	622.34 NA	Reef Fish Amendment 21 Reef Fish Amendment 30B
	2004	6/3/04	Ongoing	1-May	31-Oct	Fishing prohibited except surface trolling	70 FR 24532 74 FR 17603	Reef Fish Amendment 21 Reef Fish Amendment 30B	622.34 NA	Reef Fish Amendment 21 Reef Fish Amendment 30B
	2004	6/3/04	Ongoing	1-Nov	30-Apr	Fishing prohibited	70 FR 24532 74 FR 17603	Reef Fish Amendment 21 Reef Fish Amendment 30B	622.34	Reef Fish Amendment 30B Supplement
	2021	8/20/21	Ongoing	Year round		Fishing prohibited	86 FR 38416	RF Framework Action	622.34	Reef Fish Framework Action
The Edges	2010	7/24/09	Ongoing	1-Jan	30-Apr	Fishing prohibited	74 FR 30001	Reef Fish Amendment 30B Supplement	934 622.34	Sanctuary Designation Essential Fish Habitat Amendment 3
Flower Garden	1992	1/17/92	Ongoing	Year round		Fishing with bottom gears prohibited[3]	56 FR 63634	Sanctuary Designation	635.71 622.34	Tortugas Amendment Essential Fish Habitat Amendment 3
Riley's Hump	1994	2/7/94	8/18/02	1-May	30-Jun	Fishing prohibited	59 FR 966	Reef Fish Amendment 5	622.34	Essential Fish Habitat Amendment 3
Tortugas Reserves	2002	8/19/02	Ongoing	Year round		Fishing prohibited	67 FR 47467	Tortugas Amendment	622.34	Essential Fish Habitat Amendment 3
Pulley Ridge	2006	1/23/06	Ongoing	Year round		Fishing with bottom gears prohibited[3]	70 FR 76216	Essential Fish Habitat (EFH) Amendment 3	622.34	Essential Fish Habitat Amendment 3
McGrail Bank	2006	1/23/06	Ongoing	Year round		Fishing with bottom gears prohibited[3]	70 FR 76216	Essential Fish Habitat (EFH) Amendment 3	622.34	Essential Fish Habitat Amendment 3
Stetson Bank	2006	1/23/06	Ongoing	Year round		Fishing with bottom gears prohibited[3]	70 FR 76216	Essential Fish Habitat (EFH) Amendment 3	622.34	Essential Fish Habitat Amendment 3

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[1] HMS: highly migratory species (tuna species, marlin, oceanic sharks, sailfishes, and swordfish)

[2] SWG: shallow-water grouper (black, gag, red, red hind, rock hind, scamp, yellowfin, and yellowmouth)

[3] Bottom gears: Bottom longline, bottom trawl, buoy gear, pot, or trap

[3] Bottom gears: Bottom longline, bottom trawl, buoy gear, pot, or trap

Harvest Restrictions (Spatial Restrictions – Shrimp Specific)

First Yr In Effect	Fishery	Closure Type	Region Affected	Amendment Number or Rule Type
2008	White, Pink, Brown	**Action 7:** Establish if necessary, a seasonal closure beginning on the same start date as the closure of the EEZ off Texas in the 10 to 30-fathom zone of selected areas within statistical zones 10-21 in the Gulf of Mexico. The need for the closure and its extent and duration will be determined based on the annual evaluation of the level of shrimp effort and associated red snapper mortality, taking into consideration mortality reductions associated with improved BRDs and other gear improvements. Any closure would be implemented in accordance with the framework outlined in Action 8.	Gulf Council EEZ	Amendment 14; https://gulfcouncil.org/wp-content/uploads/FISHERY%20MANAGEMENT/SHRIMP/amendments/Final%20RF%20Amend%2027-%20Shrimp%20Amend%2014.pdf
1989	White, Pink, Brown	**Action 4:** [Revised the date by which the NMFS assessment of the fishery is due from December 1st to December 15th. The date by which the Regional Director must publish intent to revise or not to revise is moved from January 15th to February 1st.]	Gulf Council EEZ	Amendment 4; https://gulfcouncil.org/wp-content/uploads/FISHERY%20MANAGEMENT/SHRIMP/SHRIMP%20Amend-04%20Final%201988-08.pdf
1981	White, Pink, Brown	**Measure 2:** Establish a cooperative closure of the territorial sea of Texas and the adjacent U.S. FCZ with the State of Texas and the U.S. Department of Commerce during the time when a substantial portion of the brown shrimp in these waters weigh less than a count of 65 tails to the pound (39 heads-on shrimp to the pound). [Full text is on page 203/246 of the Original Shrimp FMP PDF.]	Gulf Council EEZ	Original Shrimp Fishery Management Plan; https://gulfcouncil.org/wp-content/uploads/Original-Shrimp-Fishery-Management-Plan.pdf

Harvest Restrictions (Gear Restrictions*)

*Area specific gear regulations are documented under spatial restrictions

Gear Type	First Yr In Effect	Gear/Harvesting Restrictions	Region Affected	FR Reference	Amendment Number or Rule Type
Turtle excluder device	2000	Any shrimp trawler that is in the Atlantic Area or Gulf Area must have an approved TED installed in each net that is rigged for fishing. A net is rigged for fishing if it is in the water, or if it is shackled, tied, or otherwise connected to any trawl door or board, or to any tow rope, cable, pole or extension, either on board or attached in any manner to the shrimp trawler. Exceptions to the TED requirement for shrimp trawlers are provided in paragraph (d)(2)(ii) of this section.	Gulf Council EEZ	CFR § 223.206; https://www.ecfr.gov/current/title-50/chapter-II/subchapter-C/part-223/subpart-B	
Turtle excluder device	~1987	*[See PDF pages 351-364 for TED Regulation History at https://media.fisheries.noaa.gov/dam-migration/99187727.pdf]*	Gulf Council EEZ		
Bycatch reductive device	1998	**Alternative A:** Require the installation of NMFS-certified BRDs that meet or exceed the bycatch reduction criteria established by the Council in each net used aboard vessels trawling for shrimp in specified areas of the Gulf of Mexico EEZ. Exempted are vessels trawling for royal red shrimp beyond the 100-fathom countour and vessels trawling for groundfish or butterfish. A single try net with a headrope length of 16 feet or less per vessel and no more than two rigid-frame roller trawls limited to 16 feet or less, such as those used in the Big Bend area of Florida are also exempted. **Alternative B:** Require the use of the NMFS-certified BRDs in shrimp trawls in the EEZ of the Gulf of Mexico within the 100-fathom contour west of Cape San Blas, Florida.	Gulf Council EEZ		Shrimp Amendment 9; https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-9.pdf
Bycatch reduction device	2004	**Option A** (added to the language in Shrimp Amendment 9): BRDs must reduce the bycatch of finfish by at least 30% by weight.	Gulf Council EEZ		Shrimp Amendment 10; https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-10_508Compliant.pdf
Bycatch reduction device	2008	**Action 1:** Change the bycatch reduction criteria to a reduction in the bycatch of total finfish by 30% by weight.	Gulf Council EEZ		August 2006 Regulatory Amendment; https://gulfcouncil.org/wp-content/uploads/August-2006-Regulatory-Amendment_508Compliant.pdf

2.5 State Management and Regulatory Timelines for Penaeid Shrimp

Please see the following working papers for individual state regulations:

SEDAR87-RW-01	State Management History - Texas
SEDAR87-RW-02	State Management History - LA
SEDAR87-RW-03	State Management History - MS
SEDAR87-RW-04	State Management History - AL
SEDAR87-RW-05	State Management History - FL

3 ASSESSMENT HISTORY AND REVIEW

Pre-SEDAR assessments of Gulf Council penaeid shrimp stocks were historically based on Virtual Population Analysis (VPA) models originally developed by Nichols (1984). These VPA models were updated in 1986 (Nichols 1986), 1988 (Nance and Nichols 1988) and 1989 (Nance 1989).

In 2008, results from the pink shrimp VPA model indicated that the stock was undergoing overfishing (NMFS 2009). However, because other fishery indicators, e.g., catch per unit effort (CPUE), did not corroborate this finding, SEFSC staff recommended that the VPA model be thoroughly reviewed.

In June, 2009 an internal NMFS review panel was convened and tasked with critically reviewing the VPA. The panel noted that the calibration of the VPA model had not been updated since its inception in the early 1980s and concluded that the pink shrimp VPA assessment was not suitable for making a status determination. They recommended that new fisheries models should be investigated for future assessments for all three stocks.

In 2010, a preliminary model was developed in Stock Synthesis (Hart and Nance 2010, Hart 2012a) for Pink shrimp and then adapted to Brown (Hart 2012b) and White (Hart 2012c) shrimp. All three models concluded that the stocks were not overfished or undergoing overfishing. The Stock Synthesis models were updated in 2016 (Hart 2016a,b,c) and 2018 (Hart 2018a,b,c) with similar conclusions. However, in June 2019 SEFSC staff convened an internal model review workshop and found several concerning issues with the Stock Synthesis assessment models and recommended that alternative approaches be explored.

This is the first SEDAR assessment for Gulf Council shrimp.

References:

Hart, R. A. 2018a. Stock assessment for pink shrimp (Farfantepenaeus duorarum) in the U.S. Gulf of Mexico for the 2017 fishing year. NOAA Fisheries, Southeast Fisheries Science Center. Gavelston, Texas.

Hart, R. A. 2018b. Stock assessment update for white shrimp (Litopenaeus setiferus) in the U.S. Gulf of Mexico for the 2017 fishing year. NOAA Fisheries, Southeast Fisheries Science Center. Gavelson, Texas.

Hart R. A. 2018c. Stock assessment update for brown shrimp (Farfantepenaeus aztecus) in the U.S. Gulf of Mexico for the 2017 fishing year. NOAA Fisheries, Southeast Fisheries Science Center. Gavelson, Texas.

Hart, R. A. 2016a. Stock Assessment Update for Brown Shrimp (Farfantepenaeus aztecus) in the U.S. Gulf of Mexico for 2015.NOAA Fisheries Southeast Fisheries Science Center.

Hart, R. A. 2016b. Stock Assessment Update for White Shrimp (Litopenaeus setiferus) in the U.S. Gulf of Mexico for 2015. NOAA Fisheries Southeast Fisheries Science Center.

Hart, R. A. 2016c. Stock Assessment Update for Pink Shrimp (Farfantepenaeus duorarum) in the U.S. Gulf of Mexico for 2015 NOAA Fisheries Southeast Fisheries Science Center.

Hart, R. A. 2012a. Stock Assessment of Pink Shrimp (Farfantepenaeus duorarum) in the U.S. Gulf of Mexico for 2011. NOAA Technical Memorandum NMFS-SEFSC-639, 12 p.

Hart, R. A. 2012b. Stock Assessment of Brown Shrimp (Farfantepenaeus aztecus) in the U.S. Gulf of Mexico for 2011. NOAA Technical Memorandum NMFS-SEFSC-638, 37 p.

Hart, R. A. 2012c. Stock Assessment of White Shrimp (Litopenaeus setiferus) in the U.S. Gulf of Mexico for 2011. NOAA Technical Memorandum NMFS-SEFSC-637, 36 p.

Hart, R. A., and J. M. Nance. 2010. Gulf of Mexico Pink Shrimp Assessment Modeling Update: From a Static VPA to an Integrated Assessment Model, Stock Synthesis. NOAA Technical Memorandum NMFS-SEFSC-604, 32p.

Nance, J. M. 1989. Stock assessment for brown, white, and pink shrimp in the U.S. Gulf of Mexico, 1960-1987. NOAA Technical Memorandum, NMFS-SEFC-221.

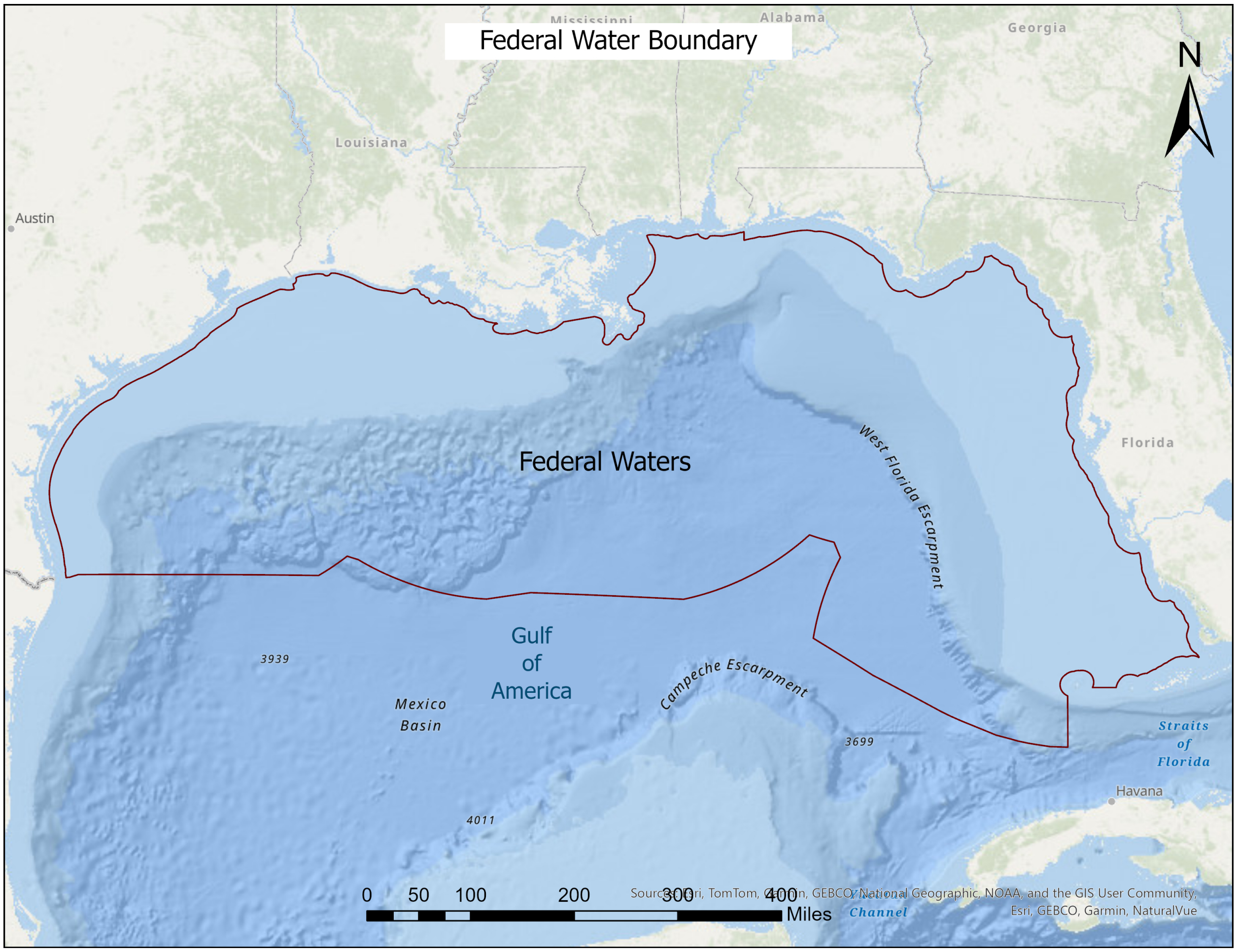
Nance, J. M. and Nichols, S. 1988. Stock assessments for brown, white, and pink shrimp in the U.S. Gulf of Mexico, 1960-1986. NOAA Technical Memorandum, NMFS-SEFC-203.

Nichols, S. 1986. Stock assessment of brown, white and pink shrimp in the U.S. Gulf of Mexico, 1960-1985. NOAA Tech. Memo. NMFS-SEFC-179.

Nichols, S. 1984. Updated assessments of brown, white and pink shrimp in the U.S. Gulf of Mexico. Paper presented at the Workshop on Stock Assessment. Miami, Florida, May 1984.

NMFS. 2009. Annual Report to Congress on the Status of U.S. Fisheries-2008. U.S. Department of Commerce, NOAA, Natl., Mar. Fish. Serv., Silver Spring, MD, 23 pp.

4 REGIONAL MAPS



Sources: Esri, TomTom, Garmin, GEBCO, National Geographic, NOAA, and the GIS User Community, Esri, GEBCO, Garmin, NaturalVue

Figure 4.1 Gulf Council Management Region.

5 SEDAR ABBREVIATIONS

ABC	Acceptable Biological Catch
ACCSP	Atlantic Coastal Cooperative Statistics Program
ADMB	AD Model Builder (software program)
ALS	Accumulated Landings System: SEFSC fisheries data collection program
AMRD	Alabama Marine Resources Division
APAIS	Access Point Angler Intercept Survey
ASMFC	Atlantic States Marine Fisheries Commission
B	Biomass (stock) level
BAM	Beaufort Assessment Model
B_{msy}	B capable of producing MSY on a continuing basis
BSIA	Best Scientific Information Available

CHTS	Coastal Household Telephone Survey
CFMC	Caribbean Fishery Management Council
CIE	Center for Independent Experts
CPUE	Catch Per Unit Effort
EEZ	Exclusive Economic Zone
F	Fishing mortality (instantaneous)
FES	Fishing Effort Survey
FIN	Fisheries Information Network
F_{MSY}	F to produce MSY under equilibrium conditions
F_{OY}	F rate to produce OY under equilibrium
$F_{XX\%\ SPR}$	F rate resulting in retaining XX% of the maximum spawning production under equilibrium conditions
F_{max}	F maximizing the average weight yield per fish recruited to the fishery
F_o	F close to, but slightly less than, Fmax
FL FWCC	Florida Fish and Wildlife Conservation Commission
FWRI	Florida Fish and Wildlife Research Institute
GA DNR	Georgia Department of Natural Resources
GLM	General Linear Model
GMFMC	Gulf of Mexico Fishery Management Council
GSMFC	Gulf States Marine Fisheries Commission
GULF FIN	GSMFC Fisheries Information Network
HMS	Highly Migratory Species
LDWF	Louisiana Department of Wildlife and Fisheries
M	natural mortality (instantaneous)
MARFIN	Marine Fisheries Initiative
MARMAP	Marine Resources Monitoring, Assessment, and Prediction
MDMR	Mississippi Department of Marine Resources
MFMT	Maximum Fishing Mortality Threshold: value of F above which overfishing is deemed to be occurring
MRFSS	Marine Recreational Fisheries Statistics Survey: combines a telephone survey of households to estimate number of trips with creel surveys to estimate catch and effort per trip
MRIP	Marine Recreational Information Program
MSA	Magnuson Stevens Act
MSST	Minimum Stock Size Threshold: value of B below which the stock is deemed to be overfished
MSY	Maximum Sustainable Yield
NC DMF	North Carolina Division of Marine Fisheries
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration

OST	Office of Science and Technology, NOAA
OY	Optimum Yield
SAFMC	South Atlantic Fishery Management Council
SC DNR	South Carolina Department of Natural Resources
SEAMAP	Southeast Area Monitoring and Assessment Program
SEDAR	Southeast Data, Assessment and Review
SEFIS	Southeast Fishery-Independent Survey
SEFSC	Southeast Fisheries Science Center, NMFS
SERFS	Southeast Reef Fish Survey
SERO	Southeast Regional Office, NMFS
SRFS	State Reef Fish Survey (Florida)
SRHS	Southeast Region Headboat Survey
SPR	Spawning Potential Ratio: B relative to an unfished state of the stock
SSB	Spawning Stock Biomass
SS	Stock Synthesis
SSC	Scientific and Statistical Committee
TIP	Trip Interview Program: biological data collection program of the SEFSC and Southeast States
TPWD	Texas Parks and Wildlife Department
Z	total mortality (M+F)

SEDAR

Southeast Data, Assessment, and Review

SEDAR 87

Gulf of Mexico White, Pink, and Brown Shrimp

SECTION II: Data Workshop Report

August 2024

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

This information is distributed solely for the purpose of peer review. It does not represent and should not be construed to represent any agency determination or policy.

1 INTRODUCTION

1.1 WORKSHOP TIME AND PLACE

The SEDAR 87 Data Workshop was held September 18-22, 2023, in Tampa, FL. In addition to the in-person workshop, a series for webinars were held before (August 2023) and after (November 2023 – May 2024) the meeting.

1.2 TERMS OF REFERNCE

1. Gather data through 2022 (where possible) for Gulf of Mexico White, Pink, and Brown shrimp.

2. Review, discuss, and tabulate available life history information for each stock being assessed.
   - Evaluate growth data where available. Determine the adequacy of available life history information for different types of assessment or population model
   - Evaluate and discuss the sources of uncertainty and error, and data limitations (such as temporal and spatial coverage) for each data source.

3. Create a conceptual model based on feedback from a variety of industry representatives in the Data Workshop to capture their institutional knowledge.

4. Provide measures of population abundance that are appropriate for stock assessment.
   - Consider all available and relevant fishery-dependent and -independent data sources
   - Document all programs evaluated; address program objectives, methods, coverage, sampling intensity, and other relevant characteristics.
   - Provide maps of fishery and independent survey coverage, where possible.
   - Develop fishery and survey CPUE indices by appropriate strata (e.g., area) and include measures of precision and accuracy.
   - Provide appropriate measures of uncertainty for the abundance indices to be used in stock assessment models.
   - Document pros and cons of available indices regarding their ability to represent abundance.
   - For recommended indices, document any known or suspected temporal patterns in catchability not accounted for by standardization.
   - Provide appropriate measures of uncertainty for the abundance indices.

5. Provide commercial catch statistics for each stock where possible. Document species-specific issues.
   - Provide maps io fishery effort and harvest by sector and/or gear by species, where possible.
   - Provide estimates of uncertainty around each set of landings and effort estimates.

6. Describe any known evidence regarding ecosystem, climate, species interactions, habitat considerations, species range modifications and/or episodic events that would reasonably be expected to affect shrimp population dynamics, and the effectiveness of reference points.

   - Provide species envelopes, i.e. minimum and maximum values of environmental boundaries (e.g. depth, temperature, substrate, relief) based on observations of occurrence.

   a. Develop hypotheses to link the ecosystem and climatic events identified in addressing this TOR to population and fishery parameters that can be evaluated and modeled.

7. Integrate economists into the stock assessment model development process in order to explore models that can address questions such as benefits of seasonal/spatial closures, impacts of fuel prices on total effort, and ex-vessel prices of different market categories, if possible.
    a. Detail the early 2000 industry consolidation and impacts of ex-vessel price on effort

8. Provide recommendations for future research in areas such as sampling, fishery monitoring, and stock assessment.

9. Prepare a Data Workshop report providing complete documentation of workshop actions and decisions in accordance with project schedule deadlines.

1.3 LIST OF PARTICIPANTS

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Data Process Webinar Observers

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1.4 LIST OF DATA WORKSHOP WORKING PAPERS & REFERNCE DOCUMENTS

Document #	Title	Authors	Date Submitted
Documents Prepared for the Data Workshop			
SEDAR87-DW-01	Estimation of Commercial Shrimp Effort in the Gulf of Mexico	Kyle Dettloff	30 August 2023 Updated: 27 Sept 2023

			Updated: 7 Nov 2023 Updated: 14 December 2023 Updated: 2 April 2024 Updated: 17 May 2024 Updated: 20 August 2024
SEDAR87-DW-02	Social Dimensions of the Gulf of Mexico Shrimp Fishery: Overview	David Griffith	31 August 2023
SEDAR87-DW-03	Commercial Landings of Gulf of Mexico Shrimp Self-Reported Survey 2005-2020	Rebecca Smith, Alan Lowther, J. Williams	5 September 2023
SEDAR87-DW-04	Vessel and Gear Characterizations of Gulf of Mexico Shrimp Self-Reported Survey 2005-2020	Rebecca Smith, Alan Lowther, J. Williams	5 September 2023
SEDAR87-DW-05	Gulf of Mexico Brown, Pink, and White Shrimp Weight-Length Regression using SEAMAP Data	Molly H. Stevens	1 September 2023
SEDAR87-DW-06	Commercial Shrimp Landings of Gulf of Mexico Final Title: Gulf of Mexico Commercial Brown, Pink and White Shrimp Landings	Jade Chau, Alan Lowther, and Kimberley Johnson Final Document Authors: Sarina Atkinson, Alan Lowther, Kyle Dettloff, and Steven Smith	1 September 2023 Updated: 6 Nov 2023 Updated: 5 February 2024 Updated: 13 June 2024
SEDAR87-DW-07	*Economics of the Federal Gulf of Mexico Shrimp Fishery*	Christopher Liese	1 September 2023
SEDAR87-DW-08	General Economic Measures for Fuel Price Trend, Inflation Adjustment, and Discounting	Christopher Liese	1 September 2023

SEDAR87-DW-09	Gulf of Mexico Spatial-Temporal Environmental Data	Holden Harris	14 September 2023
SEDAR87-DW-10	Shrimp Import Data	Alan Lowther	18 September 2023
SEDAR87-DW-11	Indices of relative abundance for Pink Shrimp, and summary of data availability for Pink, Brown, and White Shrimp, from inshore surveys of Florida's Gulf coast estuaries	Dwayne D. Edwards, Derek M. Tremain, Meagan N. Schrandt, and Theodore S. Switzer	21 September 2023 Updated: 30 November 2023
SEDAR87-DW-12	Inshore brown and white shrimp relative abundance in Louisiana	Office of Fisheries, Louisiana Department of Wildlife and Fisheries	1 November 2023 Updated: 4 January 2024
SEDAR87-DW-13	Brown, White and Pink Shrimp Abundance Indices from SEAMAP Groundfish Surveys in the Northern Gulf of Mexico	Adam G. Pollack and David S. Hanisko	18 Oct 2023
SEDAR87-DW-14	Summary of the Gulf of Mexico Shrimp Effort Data Collection	Alan Lowther	6 Nov 2023 Updated 5 January 2024
SEDAR87-DW-15	Social Dimensions of Gulf of Mexico Shrimping	David Griffith, Christopher Liese, Mike Travis, Matt Freeman, David Records	29 November 2023
SEDAR87-DW-16	SEDAR 87 Commercial Fishery Landings and Effort Figures for White, Pink, and Brown Shrimp in the US Gulf of Mexico, 1960–2021	Jo A. Williams, Kimberley Johnson, and Alan Lowther	12 February 2024
Reference Documents			
SEDAR87-RD01	SEAMAP Trawl Shrimp Data and Index Estimation Work Group Report		

SEDAR87-RD02	The Annual Economic Survey of Federal Gulf Shrimp Permit Holders: Implementation and Descriptive Results for 2008	Christopher Liese and Michael D. Travis
SEDAR87-RD03	Mississippi Department of Marine Resources and University of Southern Mississippi Gulf Coast Research Laboratory Inshore Trawl Monitoring Programs: Sampling and Lab Protocols	
SEDAR87-RD04	Marine Fisheries Crustacean Section - Independent Sampling Activities: Field Manual	Louisiana Wildlife and Fisheries
SEDAR87-RD05	Fisheries Assessment and Monitoring Program (FAMP)	Alabama Marine Resources Division
SEDAR87-RD06	AL FAMP Assessment Sampling - Standard Operating Procedures	Alabama Marine Resources Division
SEDAR87-RD07	TPWD's Gulf Trawl Sample Design	Texas Parks and Wildlife Division
SEDAR87-RD08	Commercial brown, white, and pink shrimp tail size: total size conversions	Susan L. Brunenmeister
SEDAR87-RD09	Final Report: U.S. Gulf of Mexico Commercial Shrimp Conversion Factors Validation 2020	GSMFC
SEDAR87-RD10	Conversion of "whole" and "headless" weights in commercial Gulf of Mexico shrimps	Joseph H. Kutkuhn (1962)

2 COMMERCIAL FISHERY STATISTICS

2.1 OVERVIEW

The Commercial Landings and Effort Workgroup met in Tampa on September 18–22, 2023 to examine and discuss available data sources for SEDAR 87 Gulf of Mexico White, Pink, and Brown Shrimp. Subsequent post-workshop webinars were held in November 2023, January 2024, and May 2024 to resolve remaining issues identified in the Data Workshop.

For the Data Workshop, shrimp effort estimates were available from 1960-2022. A new method for estimating shrimp effort developed by Dettloff (2023) was presented. This method uses cellular electronic logbook (cELB) vessel location data, allowing the new method to be used for years 2015–2022[1]. Commercial landings for Gulf shrimp were compiled from 1960 to 2022 using data from the Gulf Shrimp System (GSS) and State Trip Ticket (STT) data. Data providers recommended the first year in which to use STT data for each Gulf state. After the initial in-

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person Workshop, these decisions were reexamined in detail and some of these initial start dates were modified, as described later in this report.

Information regarding vessel and gear characteristics, as well as estimated landings, for the federal Gulf shrimp fleet were compiled annually using the Gulf Shrimp Landings Report and the Gulf Shrimp Vessel and Gear Characterization Form. The survey data is self-reported and has a one-year recall period. Gear aspects such as number of nets were added to the survey in 2011.

Shrimp import data were also reported for non-processed products (i.e. excluding frozen dinners containing shrimp, canned shrimp, and shrimp chips) for better comparison with domestic landings data.

[1] *2015 is the first full year in which cELB data were collected. 2022 is the most recent year in which cELB data is available for analyses.*

2.2 COMMERCIAL EFFORT AND LANDINGS WORKGROUP PARTICIPANTS

Alan Lowther	Workgroup Leader	SEFSC Miami
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Jade Chau	Data Provider	SEFSC Miami
Rebecca Smith*	Data Provider	SEFSC Galveston
Jo Williams*	Data Provider	SEFSC Galveston
Sarina Atkinson#	Data Provider/Analyst	SEFSC Miami
Steven Smith#	Data Provider/Analyst	SEFSC Miami
Roy Crabtree	Assessment Development Team	GMFMC SSC
Jim Nance	Assessment Development Team	GMFMC SSC Chair
Corky Perret	Panelist	GMFMC Shrimp AP member
Gary Graham	Panelist	GMFMC Shrimp AP member
Cheston Peterson	Rapporteur/Panelist	SEFSC/CIMAS Panama City
Laura Picariello	Panelist	GMFMC Shrimp AP member
Dominique Lazarre	Rapporteur/Panelist	SERO
Kimberley Johnson	Panelist	SEFSC Galveston

* Attended workshop via phone

\# Added after initial in-person workshop

2.3 COMMERCIAL LANDINGS TERMS OF REFERENCE (ToRs)

The Commercial Workgroup reviewed the terms of reference for SEDAR 87 and highlighted the following ones as the most relevant for the group to address:

DW ToR #1*: Gather data through 2022 (where possible) for Gulf of Mexico White, Pink, and Brown shrimp.*

Effort and landings data were provided and discussed extensively by the Workgroup.

DW ToR #2: *Review, discuss, and tabulate available life history information for each stock being assessed.*

Regarding life history aspects, the Workgroup investigated the impact of updated conversion factors (heads-on to heads-off weight) on landings data estimates. A brief summary of these discussions is presented in this report and an extensive discussion appears in the Commercial Landings working paper (WP6).

DW ToR #5*: Provide commercial catch statistics for each stock where possible. Document species-specific issues. Provide maps of fishery effort and harvest by sector and/or gear by species, where possible. Provide estimates of uncertainty around each set of landings and effort estimates.*

This was a primary focus of the Workgroup and is discussed in detail in subsequent sections.

DW ToR #8: *Provide recommendations for future research in areas such as sampling, fishery monitoring, and stock assessment.*

Research recommendations were discussed and are summarized in Section 3.9 below.

DW ToR #9*: Prepare a Data Workshop report providing complete documentation of workshop actions and decisions in accordance with project schedule deadlines.*

Drafting of the Data Workshop report presented here began at the in-person Data Workshop and has continued to this point. A draft report was sent to the assessment panel in January 2024, at which point extensive comments were made and corrections were requested. We are optimistic that these Workshop participant concerns have been addressed and that this report now represents a much-improved summary of the available commercial data products and recommendations for their use.

2.4 REVIEW OF WORKING PAPERS

SEDAR 87-DW01: Estimation of Commercial Shrimp Effort in the Gulf of Mexico

This Working Paper discusses the new effort estimation algorithm (Dettloff method) implemented for the period 2015-2022.

This method uses 10-minute interval ping cELB data to estimate the spatial and temporal distribution of shrimp effort and trip ticket reported landings to scale this estimated effort to the total fleet. In 2014, 500 Gulf of Mexico Shrimp Permit (SPGM) permit holders were selected to carry cELB units, supplemented by 100 additional vessels in 2018. Estimates with the new method are produced beginning in 2015 as this is the first year in which trip ticket data are reasonably complete Gulf-wide alongside continuously available cELB data. In general, total effort estimates under the new approach show a very close correspondence with previous LGL estimates for the years where available data allowed for a direct comparison (See Figure 12 in Dettloff 2023).

As opposed to the trip matching approach employed previously by LGL to calculate catch per unit effort (CPUE), the new approach does not depend on direct matching of effort with landings at the trip level, but instead uses landings for cELB equipped vessels at aggregate levels of quadrimester and area to scale effort. Within each time/area strata, landings from the total fleet are divided by landings from vessels with cELB devices to calculate scalars. This allows the complete distribution of cELB effort to be used in the final calculation, rather than only effort from trips that are able to be matched to landings (historically ~50% of effort). This new method also no longer relies on partial interview data or reported depths associated with landings, which are no longer available. The new scaled effort estimates can, however, be divided into custom finer-scale cells, including by depth, based on the observed cELB effort distribution. A detailed description of additional modifications is available in Dettloff (2023), as is the simplified R code upon request.

SEDAR 87 DW-03: Commercial Landings of Gulf of Mexico Shrimp from Gulf Shrimp Landings Reports 2005-2020

This Working Paper discusses the annual self-reported landings survey that is collected yearly by the Southeast Fisheries Science Center on the Annual Gulf Shrimp Landings Report. Completion of this survey is mandatory for all SPGM permit holders. It has been conducted from 2005 to present. To date, landings data are available through 2020 from this survey.

The survey data are self-reported and have a one-year recall period (i.e. shrimp landings by species for the entire previous year are requested). This annual survey collects the entire previous year's aggregated heads-off pounds and ex-vessel dollar value for each commercial shrimp species landed in the Gulf of Mexico (includes bays, bayous, State inshore and offshore waters, or U.S. Federal waters exclusive economic zone (EEZ)). This data collection will require an update to the back-end conversions of the revised Gulf States Marine Fisheries Commission (GSMFC) conversion factors for heads-on to head-off (tails) weight to ensure that the proper size category is associated with the shrimp weight. Comparison of GSS/STT landings to these annual self-reported total landings did show a similar trend over time, with a trend towards convergence in later years. However, total landings obtained by summing the self-reported landings were generally 5-20% lower than corresponding trip ticket landings. Possible reasons for these differences were discussed at the Workshop, the most likely being that only federally permitted vessels are required to submit Annual Gulf Shrimp Landings Reports. In addition, there may be issues with misidentified shrimp species by the dealers due to regional common names and differences in market values, and differences in how the species were binned (i.e. dealers may record a mixed catch as all belonging to one species if the market price is the same). Previous vessel-by-vessel comparisons indicated that the self-reported landings from the Gulf Shrimp Landings reports were higher than those from trip tickets (Mike Travis, personal communication). However, this issue was not extensively discussed at the Workshop as there was no realistic expectation that the landings from the Gulf Shrimp Landings reports would be used as a primary landings source for SEDAR 87.

SEDAR 87 DW-04: Vessel and Gear Characterization of Gulf of Mexico Shrimp Self-Reported Survey 2005-2020

This Working Paper discusses the description and quantities of gear used to catch the commercial landings that are sold to wholesalers and dealers as reported in the Vessel and Gear Characterization of Gulf of Mexico annual survey. This survey is mailed to all SPGM permit holders annually, and completion of the survey is mandatory for permit renewal. It has been conducted from 2005 to present. To date, data are available through 2020 from this survey.

The survey data are self-reported and have a one-year recall period. Data include confirmation that shrimping occurred in the Gulf of Mexico, the specific gear characteristics and types used to catch shrimp, the total days at sea and total number of trips from previous year's landings. The Vessel and Gear Characterization survey does not collect specifics to vessel size nor horsepower because that information is collected via permits. However, the number of nets used was included after 2011 as an important indicator of fishing effort. Data are only collected once each year, and represent the gear characteristics for the most frequently used gear type as only the "primary" gear is requested. In years before 2010, fishers were asked how many of their days at sea were not for fishing, as days at sea do not always mean a day of fishing (e.g., travel days). For 2010 and 2011, questions about days helping with the BP oil spill were added.

SEDAR 87 DW-06: Gulf of Mexico Commercial Brown, Pink and White Shrimp Landings

This Working Paper discusses the comprehensive landings data for all Penaeid shrimp species caught and landed in the Gulf of Mexico. It discusses the Gulf Shrimp System (GSS) and the various Gulf state trip ticket (STT) reporting systems (implemented by states in different years).

After the initial Data Workshop, this working paper was extensively edited to make corrections, clarifications, and modify recommendations on when to make the switch from GSS to STT data based on a state-by-state analysis. These modifications were discussed and reviewed at the three post-workshop webinars held between November 2023 and May 2024. This revised Working Paper serves as the primary source for the landings data recommended for use in this SEDAR and is discussed more extensively later in this document.

SEDAR 87 DW-10: Shrimp Imports Data

This Working Paper discusses the volume of shrimp products imported into the United States. Much concern and discussion has been raised regarding the amount of shrimp imported into the United States and the effect this has on the domestic shrimping industry in the Gulf of Mexico.

The paper summarized the imports on an annual basis taking data from the NOAA Fisheries Office of Science and Technology's Fisheries One-Stop Shop reporting tool (https://www.fisheries.noaa.gov/foss). All shrimp products were selected and then those most heavily processed products were removed (e.g. frozen shrimp pasta dinners). The Workgroup recognized the increasing amount of shrimp imports over the period from 1972-2022 (the years available in the FOSS database), as shown in Figure 1, and the potential consequences and effects on the Gulf shrimp fishery. A more extensive discussion of trends in shrimp imports can be found in Fissel et al. (2023).

The Commercial Landings and Effort Workgroup discussed concerns from industry that these large increases in imports are causing substantial competition with locally sourced shrimp catch. Industry members discussed an improvement in the quality of imported shrimp that are less expensive to source (e.g. wild red shrimp imported from Argentina and farmed whiteleg shrimp from Ecuador). Fishermen highlighted a decrease in ex-vessel price, in part due to a surplus of shrimp imported during the height of the pandemic. This has led to a reduction in shrimping effort because vessels are sometimes unable to sell catch to processors and dealers with limited freezer capacity. Many groups (fishing, county, and state groups) have written to Congress about the issue of foreign shrimp imports creating competition that is making domestic shrimping less viable. These concerns about imports were also a source of much discussion in a concurrent session with industry stakeholders. However, the Workgroup agreed that extensive discussions of shrimp “anti-dumping” duties and overseas environmental standards were political issues beyond the scope of the group’s scientific mission.

SEDAR 87 DW-14: Summary of the Gulf of Mexico Shrimp Effort Data Collection
This Working Paper discusses the methodologies used to estimate effort in the Gulf shrimp fishery prior to 2015.

Beginning in 1960, there have been several changes in effort data collection methodologies employed in the Gulf Shrimp fishery, and the paper outlines the various procedures and methods employed. From 1960 to the early 1990’s, effort data were collected by state and federal port agents stationed at major ports around the Gulf of Mexico. In the late 1990’s, the National Marine Fisheries Service (NMFS) in partnership with a private company, LGL Ecological Research Associates, began working on an automated system to collect vessel position data from vessels for the purpose of estimating effort. This location data could then be used to calculate vessel speed between 10-minute recordings and assess when and where shrimping activity was occurring (i.e. calculate effort). Devices were installed on vessels and the data were collected from the vessels by LGL on Secure Digital (SD) cards. In 2012, NMFS began developing a 3G cellular system that would allow vessels to automatically transmit their data to the NMFS network once the vessel was in cellular range, and, thus, the manual retrieval of SD cards would no longer be required. In 2014 a new sample of vessels was selected to use these 3G devices. This method worked well for several years, but, in December 2020, the 3G cellular network ceased to operate. Consequently, NMFS, with the assistance of the GSMFC, has asked vessel operators to periodically remove the SD cards, return them to NMFS, and install a new SD card that has been provided. Currently, NMFS and the Gulf of Mexico Fishery Management Council are seeking a new, modern approach for this data collection.

2.5 ISSUES DISCUSSED AT DATA WORKSHOP

The list below represents a summary of the ancillary conversations between Workgroup members (fishing industry, data providers, and subject experts) describing the changing state within the shrimp fishery over time.

- *Impact of Freezer Vessels on Fishing Effort*–Industry members discussed the introduction of freezer vessels to the fleet and the resulting impact on fishing effort. Freezer vessels have the ability to stay offshore for upwards of 40 days, allowing them to cover larger distances. There were concerns that recall of fishing areas associated with catch and trip information used for effort estimation might be more difficult for industry members.

- *Effort Changes Due to Natural Environmental Impacts*–Industry members highlighted a loss of shrimping effort, specifically white shrimp vessels, in the 1950s as a result of a three to four year drought in the northern Gulf of Mexico.
- *Increase in Inshore Fishing Effort*–In more recent years, some felt that there has been an increase of inshore landings and effort. There is concern that this possible increase may be impacting offshore fishing effort and catch.
- *Shrimp Peddling*–Industry members discussed concerns about "peddling" (direct to consumer sales or trading of shrimp) occurring in the sector. The fishermen believe the "peddling" has always occurred, so landings should be considered a lower bound of what is caught due to some underreporting from the sector. Some thought that peddling increased as prices offered by traditional dealers decreased and, in particular, was more common with larger size shrimp as these exhibited a greater difference in price between what dealers would pay and what could be obtained selling direct to consumers.
- *Species Misidentification*–The Commercial Landings and Effort Workgroup discussed issues with species confusion and potential misidentification that exist throughout the region. The term "hopper browns" is colloquially used to describe pink shrimp in some parts of the Gulf of Mexico (primarily, South Texas). The difference in terminology has led to a mismatch between dealer categorization of some shrimp species and the accepted scientific classification for those shrimp species. One of the problems that makes identification so difficult at the unloading facilities is that some of the hoppers have the distinctive pink spot and others do not. When freshly caught, body color is discernable from other species but becomes less distinctive with time.

2.6 COMMERCIAL EFFORT

2.6.1 Overview

An overview of a new method to calculate effort by species for brown, pink, and white shrimp detailed in Dettloff (2023) was presented. The method pairs Southeast Area Monitoring and Assessment Program (SEAMAP) Trawl Surveys data with the distribution of cELB classified fishing effort to obtain a relative allocation of effort between the three Penaeid species (brown, pink, white) and royal reds. Hence, effort estimates between species are additive to the total estimated effort. This method diverges from the historical approach for calculating effort by species (estimates available from 2012-2019) in that the previous method was based on CPUE of trips that could be potentially targeting multiple species. Thus, estimates for individual species effort could sum to values well in excess of the total effort. For this reason, estimates resulting from the two methods are not directly comparable.

Estimates by species are available from 2015-2022 under the new method (Figure 13, Dettloff 2023). Given that this method depends on the fine spatial scale of raw cELB pings, the methodology cannot be directly extended to pre-cELB historical effort estimates. As it was determined the assessment group likely will not require estimates to be divided by species for their modeling exercises, it was decided that work attempting to estimate species-specific effort back in time was not a priority, though alternative methods to produce such estimates are currently being explored.

A few suggestions/limitations were brought forward regarding the new effort allocation method. First, the suggestion was made to explore using reported trip ticket landings rather than SEAMAP data to allocate effort across species. The reasoning being that there may be differences in catch composition between a standardized, fishery independent sampling program, like SEAMAP, and commercial fleets given known differences in gear (including turtle-excluder devices and bycatch reduction devices) and targeting practices. This data source, however, comes with many limitations of its own, including potential species misidentification, multi-species trips reported as a single species, lack of depth information, lack of information relating to time of day, and limited spatial resolution (i.e., landings from trips that occur over multiple statistical areas are only associated with a single stat zone on the trip ticket). Thus, given that SEAMAP data contain these important variables known to be strongly associated with relative species abundances at a finer spatial resolution (i.e., 30-minute tows within a single stat zone), SEAMAP data are thought to be a more robust source of informing effort allocation across species. There are some limitations present in using SEAMAP data as well, in that: 1) the sampling frame does not contain data collected shallower than 5 fathoms in depth, so it is thought that white shrimp may be relatively underrepresented in the Northern Gulf's 0-10 fathom zone, and 2) we are relying on the assumption that relative species distributions are constant over time within strata (season, stat zone, depth zone, time of day). There is some preliminary visual evidence that this assumption is met, and relative distributions over time are certainly less variable than those across strata in any given year. However, this will not be formally explored any further until species specific estimates are deemed necessary for assessment models.

2.6.2 Recommendations

Development of a new effort estimation method began in late-2021, after the original code was unable to be executed in a timely manner to generate 2020 estimates (Dettloff 2024). Given the close correspondence with historical LGL estimates as shown in Dettloff (2024), the Workgroup recommends using the Dettloff method for total effort estimates (brown, pink, and white combined) from 2015-present, while continuing to use LGL estimates prior to 2015 as best available scientific information If species-specific estimates are required, estimations from the new method should be utilized as they are now additive to the total effort, and are able to be divided into custom spatial aggregations as needed.

2.7 COMMERCIAL CATCH/LANDINGS

2.7.1 Gulf Shrimp System (GSS)

Commercial shrimp landings data have been provided from 1960 to 2022. For this assessment the Workgroup is considering GSS data beginning in 1960, which is consistent with that used in previous Gulf shrimp stock assessments (Nichols, 1984 and Nance et al. 1989). Note that throughout this document and the Working Papers, the term “landings” refers to shrimp caught in the Gulf of Mexico as reported by the area of catch in GSS or the STT.

The data collection procedures have changed over the years. From 1960 to 1983, the federal port agents interviewed seafood dealers and recorded the landings data on paper forms. These were sent for processing to the Bureau of Commercial Fisheries (1960-1971) in Washington, DC and then, after its founding in 1971, to National Marine Fisheries Service (NMFS) Headquarters in Silver Spring, MD. Some changes were made during the mid-1970’s, including the addition of a vessel identification number (i.e. The Coast Guard documentation number for Coast Guard documented vessels) in later records.

Beginning in 1984, responsibility for processing the collected data was assumed by the SEFSC. Port Agents began collecting and recording landings data in size ranges from the seafood dealers after the trips were unloaded. Ex-vessel prices were recorded by size for both heads-on and heads-off (also referred to as “tails”). The overarching objective of the GSS was to provide ex-vessel landings, ex-vessel value, and area caught for individual commercial fishing trips. This information was entered into a desktop program using the GSS coding standard.

2.7.2 Trip Ticket Programs

Concurrent with the GSS data collection, STT reporting systems were implemented by each Gulf state in different years. Generally, the commercial seafood dealers were responsible for completing the tickets within 72 hours of taking possession of seafood purchased directly from commercial fishermen. Completed tickets were submitted to the respective state office by the 10th of the month for the preceding month. Trip tickets can be submitted as often as dealers like, as long as all of the trip tickets generated during a month are sent by the 10th of the following month. This information is sent to the Gulf States Marine Fisheries Council (GSMFC) by the Gulf states in the Fisheries Information Network (FIN) coding standard. In the case of the West Coast of Florida, the data are sent to the Atlantic Coast Cooperative Statistics Program (ACCSP). Both GSS and STT programs were primarily designed to collect information on food shrimp, so shrimp caught for bait were either not included in the first place, or, if they were included, they were excluded from the SEDAR dataset for consistency.

2.7.3 Summary of Issues

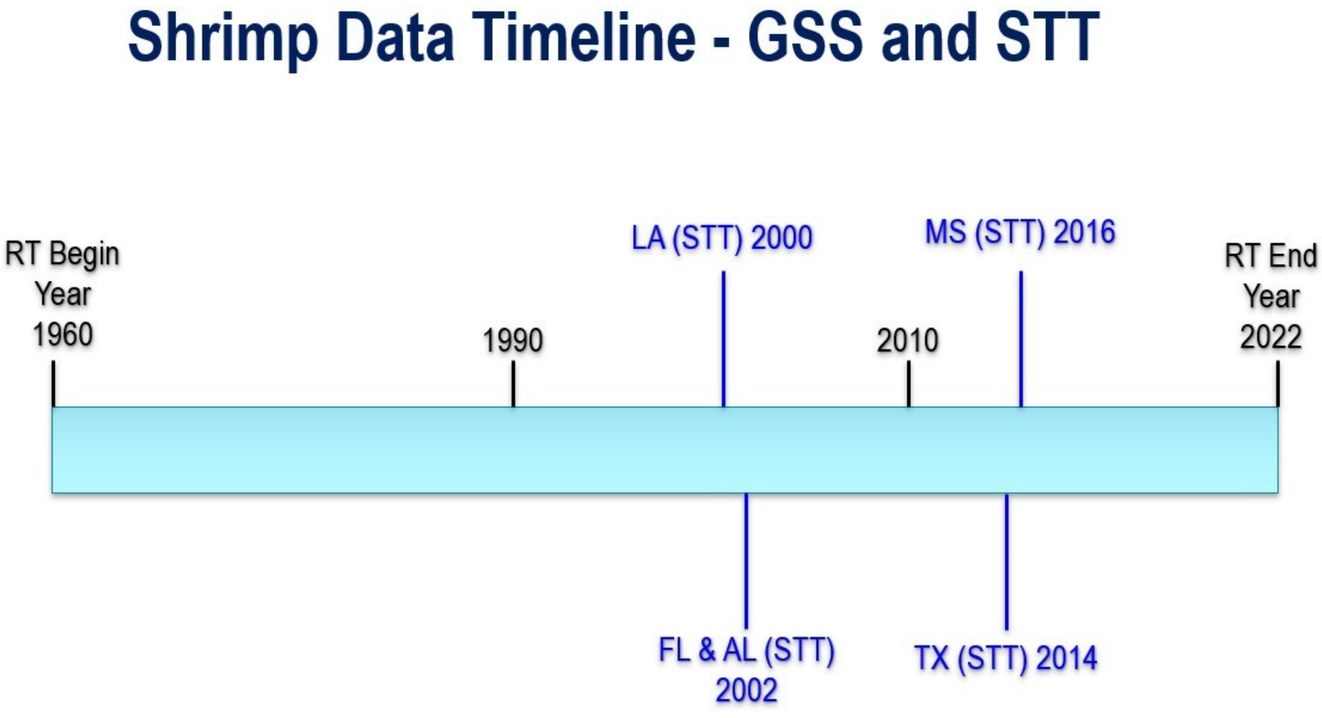
The landings for this research track did not include unreported/recreational landings. Based on the inconsistency in state data collection and reporting programs regarding the inclusion of bait shrimp, and to be consistent with previous assessments, the decision of the Commercial Workgroup was to only consider “table” or “food shrimp” and to exclude bait shrimp from the landings data. Peddling (or direct sales to the consumer without submission of a dealer report/trip ticket) and recreational landings have not been estimated.

Issue:

Transition from GSS to State Trip Tickets. Landings data are available in both the GSS and STT databases, with some or complete overlap between the data for some states and some years. For each state, the Workgroup needed to identify the best year to transition from GSS to STT reporting. The main consideration was when the individual state reported that their STT system was mature and reliable to be the primary source for shrimp landings. However, other considerations were made for completeness of the trip ticket data (e.g., not all dealers reporting to the STT program, key variables with a high percentage of missing values, etc.) and reliability of the processing procedure of GSS. Each state system became reliable at different points between 2001 and 2016. The Workgroup needed to identify the most appropriate start date for use of state trip ticket data by state.

The September 2023 data workshop identified transition dates for each state, but subsequent forensic comparisons between GSS and STT data called some of these initial conclusions into question. A detailed examination of the rationale for the transition year for each state is presented in SEDAR 87 Working Paper 6 and was presented at the May 2024 webinar. That analysis is not repeated here except for the conclusion.

Recommendation:
The start dates for each state trip ticket system were assessed by data providers and data analysts to determine the first full year when consistent data were provided by all dealers within a state. The Workgroup recommends using data from the GSS database up until the point where each state's STT data are deemed reliable, and then using data from the STT programs beginning in the specific years listed below for each Gulf state.



(where RT refers to a "research track" stock assessment)

Texas
- GSS from 1960-2013

- STT from 2014-2022

Louisiana
- GSS from 1960-1999
- STT ticket from 2000-2022

Mississippi
- GSS from 1960-2015
- STT from 2016-2022

Alabama
- GS from 1960-2001
- STT from 2002-2022

Florida West Coast
- GSS from 1960-2001
- STT from 2002-2022

Issue:
Conversion factors: The GSMFC completed a study in 2020 to update the conversion factors used to transform weights for head-on versus headless shrimp landings for brown, white, and pink shrimp landed in the Gulf of Mexico (GSMFC 2023). The Commercial Landings and Effort Workgroup discussed the suitability of using the new conversion factors for all non-whole shrimp landings and to determine the time periods when these conversions should be applied (percent changes between conversion factors for each species are presented in Table 1). The discussion centered on the question of whether there was an actual biological change over time in the whole weight to heads off ratio for the three Penaeid species, or whether these were simply better measurements of the "true" conversion factors. The former would favor an approach where the conversion factors are "phased in" over the time period, whereas the latter would support adopting the newer time conversion factors for the entire time series. The Workgroup originally recommended adopting the new conversion factors for the entire landings time series, 1960-2022.

However, in subsequent discussions it was realized that when applying the new conversion factors, the entire "heads-off" dataset, regardless of original condition type, was converted to "heads-on" and back to "heads-off", unnecessarily introducing error to the data originally landed "heads-off". Therefore, SEFSC needed to determine which of the shrimp landings had actually been converted and which were originally reported as "heads-off". Upon a close examination of the data, identifying the original condition type of the landings became problematic for the early portion of the time series (1960-1983), where some mixed condition type landings had been converted and stored as a single value, not allowing these data to be converted back to their original units. Beginning in 1984, SEFSC were able to reliably determine the original condition of landing from the GSS and STT data. Therefore, the original recommendation was modified to begin the use of the new GSMFC conversion factors beginning in 1984. Only landings originally reported in heads-on weight needed to be revised. Those already reported in heads-off weight were not adjusted.

Revised Recommendation (May 2024 webinar):

The Workgroup recommends providing final landings data that utilizes the revised GSMFC conversion factors for shrimp landings reported in "heads-on" weight for the portion of the time series (1984-2022) where it could be reliably determined if the landing amount had been converted from heads-on to heads-off.

Issue:

Stock boundary: Historically, area reporting under the GSS did not exactly conform to the boundary between the Gulf of Mexico Fishery Management Council and the South Atlantic Fishery Management Council (SAFMC). Refer to Working Paper 6 (Atkinson et al 2024) for a detailed examination of this issue. The GSS included all shrimp caught in Areas 1-21, which includes small areas under SAFMC jurisdiction. For consistency with GSS and previous assessments and amendments, and due to inconsistency in area reporting under Florida trip tickets in the Florida Keys, the recommendation was to include all shrimp caught in Areas 1-21 and the Panel concurred with this recommendation at the May 2024 webinar.

Recommendation (May 2024 webinar):

The Workgroup recommends including all shrimp caught in Areas 1-21.

Data processing steps discussed at the Post-Data Workshop Webinars:

SEDAR 87 Working Paper 6 (Atkinson et al. 2024) provides additional details regarding data processing steps that were undertaken between the Data Workshop and the post-Data Workshop webinars.

Data aggregation: The details of the data aggregation procedures outlined during the Data Scoping call are described below.

- Fishing areas 1-21 were aggregated into three areas where areas 1-10, 11-17, and 18-21 were combined.
- Landings were categorized by inshore and offshore using definitions used in the Dettloff (2023) effort algorithm.
- Shrimp market sizes were grouped into three "market size bins" of small (more than 67 shrimp tails per pound), medium (between 31 and 67 shrimp tails per pound), and large (fewer than 31 shrimp tails per pound). Eight industry standard size bins (Table 2) were aggregated into these three bins.
- Landings were aggregated into three seasons, January to April (JFMA), May to August (MJJA), and September to December (SOND).

Imputation of missing data: Missing values for value, area, and market size bins were imputed using procedures outlined in the SEDAR 87 Working Paper 6 (Atkinson et al. 2024).

Recommendation (May 2024 webinar):

The Workgroup recommends using the landings dataset that includes all modifications discussed above. Landings by year for 1960-2022 are summarized in Table 3.

Characterization of uncertainty: SEDAR 87 Working Paper 6 (Atkinson et al. 2024) presents uncertainty estimates by state and time period, where data compiled by NMFS Headquarters (pre-1984) is assigned a 20 percent uncertainty estimate, post-1984 GSS data is assigned a 10 percent uncertainty, and STT data is assigned 5 percent uncertainty. This is meant to reflect the maturity of the STT programs.

2.8 MAPS

Figures 2 and 3 below are examples of maps generated for the effort and landings. For a complete set of these figures for 1960-2022, please refer to SEDAR 87 Working Paper 16 (Williams 2024).

2.9 COMMENTS ON ADEQUACY OF DATA FOR ANALYSIS

The effort estimates described here are only as good as the data they depend on. Figure 4 below demonstrates the time series of species-specific effort estimates grouped by historical area. Even with the advantage of fine-scale cELB pings, incomplete data (e.g., boxes not functioning or not turned on for complete trips) or missing/inaccurate landings reports have the potential to create bias in estimates. Because data collection from 2021 to present has been dependent on the receipt of physical memory chips twice annually, this creates additional potential for incomplete vessel position data to be received, thereby potentially biasing effort estimates downward. Figure 5 illustrates a decline in the proportion of overall landings covered by vessels with cELB units in recent years.

Completely missing chips are not necessarily a problem in terms of bias, because if there are no landings associated with them, it is assumed they did not fish, and if there are landings associated with them those landings will contribute to the scaling of the total effort estimate as if they were a vessel that did not have a chip. The twice per year retrieval becomes a problem only if partial-year data is received, since the corresponding vessel would be considered an "ELB" vessel in terms of the landings' scalar, but potentially only half of their actual effort is being scaled. This problem is mitigated in the latest version of the effort estimation program by accounting for vessels that report landings for the entire year but only effort for one half of the year and adjusting the scalars accordingly. An updated version of the working paper which details this change (Dettloff 2024) will be submitted.

Additionally, the new effort estimation method is strongly dependent on the other assumptions outlined in the working paper, including representativeness of vessels with cELB units both in terms of spatial fishing behavior and CPUE. It is uncertain whether these assumptions are satisfied through time given the static selection of vessels that were required to use a cELB (selection completed in 2014 and not subsequently updated). Limitations with estimating inshore effort were discussed. But since we do not have an inshore survey, we are limited to assuming there is no difference between inshore and offshore CPUE, and applying the offshore CPUEs to inshore landings to estimate inshore effort.

Landings estimates recommended here are based on the best information available, and the assumptions and decisions outlined in this document are more fully elaborated in SEDAR 87 Working Paper 6. The SEFSC plans to continue its investigation of the historical data collection, compilation, and analysis processes in hopes of resolving remaining differences between the different data streams, including unresolved differences in pink shrimp landings between the SEDAR 87 dataset and previously published estimates, as detailed in Working Paper 6. This historical data reconciliation process has been hindered by the lack of sufficient documentation and staff turnover, but we plan to continue these efforts. It should be noted that perfect correspondence should not be expected, and thus we have carefully laid out the rationale for the decisions made. Going forward we expect to use the standard methodology outlined here.

2.10 RESEARCH RECOMMENDATIONS

- Continue investigations into the methodology of the GSS to better understand differences between GSS and STT programs where they overlap.
- Improve effort data collection for inshore shrimping trips.
- Develop a method to quantify under-reporting of landings in the shrimp fishery, perhaps through the use of separate socio-economic surveys.
- Quantify the prevalence of misidentification of “hopper” brown shrimp within each Gulf state.
- Continue investigations into estimation of species-specific effort.

2.11 LITERATURE CITED

Atkinson, S., Lowther, A., Dettloff, K., Smith, S. 2024. Gulf of Mexico Commercial Brown, Pink and White Shrimp Landings. SEDAR87-DW-06. SEDAR, North Charleston, SC. 38 pp.

Dettloff, K. 2023. Estimation of Commercial Shrimp Effort in the Gulf of Mexico. SEDAR87-DW-01. SEDAR, North Charleston, SC. 23 pp.

Fissel, B, Kitts, A., Dalton, M., Kosaka, R., Krigbaum, M., Marvasti, A., Squires, D., Thunberg, E., Travis, M., and Walden, J. 2023. Characteristics of the U.S. Seafood Trade Deficit. Marine Fisheries Review, 84(1-2), p. 1-60.

GSMFC. 2023. Final Report: U.S. Gulf of Mexico Commercial Shrimp Conversion Factors Validation 2020. SEDAR87-RD-09. SEDAR, North Charleston, SC. 11 pp.

Lowther, A. 2023. Shrimp Import Data. SEDAR87-DW-10. SEDAR, North Charleston, SC. 2 pp.

Lowther, A. 2023. Summary of the Gulf of Mexico Shrimp Effort Data Collection. SEDAR87-DW-14. SEDAR, North Charleston, SC. 5 pp.

Nance, J.M., E.F. Klima, and T.E. Czapla 1989. Gulf of Mexico Shrimp Stock Assessment Workshop. NOAA Technical Memorandum, NMFS-SEFC-239.

Nichols, S. 1984. Updated Assessments of Brown, White, and Pink Shrimp in the U.S. Gulf of Mexico. NMFS-SEFSC SAW/84/SHR/2. 28 pp.

Smith, R., Lowther, A., Williams, J. 2023. Commercial Landings of Gulf of Mexico Shrimp from Self-Reported Landings Survey 2005-2020. SEDAR87-DW-03. SEDAR, Miami, FL. 11 pp.

Smith, R., Lowther, A., Williams, J. 2023. Vessel and Gear Characterization of Gulf of Mexico Shrimp Self-Reported Survey 2005-2020. SEDAR87-DW-04. SEDAR, Miami, FL. 26 pp.

2.12 TABLES

Table 1. The previously used conversion factor compared to the 2020 conversion factor recommended by the Gulf States Marine Fisheries Commission (GSMFC). These conversion factors convert heads-off weight to heads-on weight for brown, pink, and white shrimp.

Species	Old Factor	New GSMFC Factor	Percent Change
Brown shrimp	1.61	1.548	-3.9%
White shrimp	1.54	1.568	1.8%
Pink shrimp	1.60	1.565	-2.2%

Table 2. Size code categories used by the Industry from 1963-1983.

SIZE CODE	SIZE 1/SIZE2
1	01/14
2	15/20
3	21/25
4	26/30
5	31/40
6	41/50
7	51/66
8	>67

Table 3. Gulf of Mexico annual landings (1960-2022) of brown, pink, and white shrimp (heads-off pounds).

Year	Brown Shrimp	Pink Shrimp	White Shrimp
1960	61,787,343	20,658,592	28,128,567
1961	29,337,308	9,457,389	13,286,812
1962	26,620,055	15,329,969	18,376,826
1963	44,595,570	17,998,991	37,911,412
1964	33,170,644	20,986,099	35,949,464
1965	49,586,453	14,106,139	26,353,833
1966	50,881,790	12,986,068	23,698,216
1967	83,993,526	8,972,168	19,877,150
1968	63,881,322	10,168,061	26,363,949
1969	56,516,843	9,891,776	39,441,753
1970	68,679,925	11,929,699	40,579,303
1971	75,525,205	10,124,270	38,176,369
1972	75,945,771	10,811,607	32,809,222
1973	47,873,467	13,992,645	30,722,335
1974	50,759,468	14,374,393	26,874,478
1975	48,279,340	13,747,431	25,742,846
1976	77,863,267	13,021,513	36,518,116
1977	96,919,453	16,204,603	46,209,815
1978	87,508,037	16,011,393	48,036,180
1979	71,403,312	13,846,691	34,856,133
1980	68,269,927	12,877,492	42,705,545
1981	99,508,484	18,773,126	46,108,156
1982	74,804,488	11,644,028	39,219,608
1983	61,352,577	12,628,671	42,189,194
1984	82,204,088	14,698,527	55,958,235
1985	87,155,338	15,930,980	58,854,018
1986	100,564,407	11,723,343	70,052,138
1987	94,070,956	10,486,082	52,833,598
1988	82,840,325	9,135,939	44,638,937
1989	96,348,265	8,622,144	36,117,305
1990	105,912,096	7,454,083	43,701,940
1991	89,467,559	6,790,159	45,244,280
1992	70,831,209	6,341,170	47,342,282
1993	69,832,922	9,488,603	38,577,835
1994	68,881,037	10,088,773	45,334,632
1995	78,839,517	14,058,321	48,662,618
1996	76,339,327	19,341,126	35,430,587
1997	68,274,442	12,688,112	38,566,210
1998	81,615,721	17,164,094	54,187,635
1999	83,684,364	8,029,582	54,098,203
2000	98,932,949	7,447,382	70,635,889
2001	91,692,069	9,697,033	53,882,461
2002	77,478,385	8,055,429	52,647,979

2003	87,295,206	8,072,700	60,080,446
2004	76,981,943	8,613,703	66,674,049
2005	60,218,104	7,270,807	63,825,452

Table 3. Continued

Year	Brown Shrimp	Pink Shrimp	White Shrimp
2006	90,114,767	6,474,199	85,117,985
2007	73,833,069	3,461,935	65,033,011
2008	52,776,230	4,874,778	64,908,634
2009	77,549,679	4,028,248	73,683,853
2010	45,815,047	5,434,330	57,987,614
2011	74,496,273	4,551,515	56,981,681
2012	66,147,560	3,829,903	66,355,424
2013	67,611,609	4,029,532	55,550,691
2014	68,075,256	6,404,250	60,054,484
2015	64,960,821	5,536,597	53,687,668
2016	49,575,404	5,243,166	69,073,085
2017	57,019,097	11,394,487	68,765,459
2018	71,207,036	12,989,394	51,608,632
2019	41,008,599	7,755,248	65,769,998
2020	41,602,300	7,729,692	58,843,276
2021	43,048,733	7,930,843	62,806,461
2022	32,461,721	9,975,079	68,189,356

2.13 FIGURES

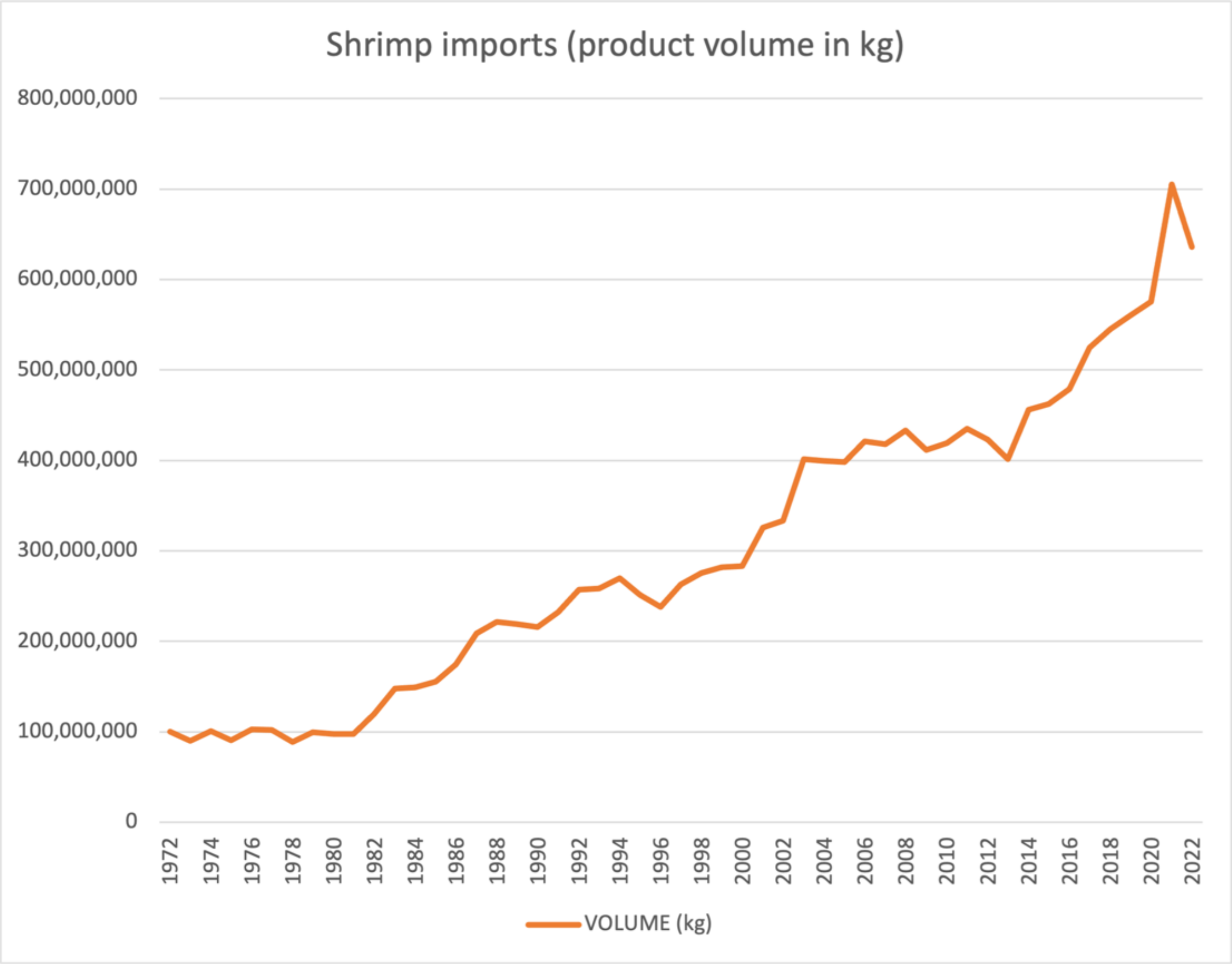


Figure 1. Total kg of shrimp imports, 1972-2022.

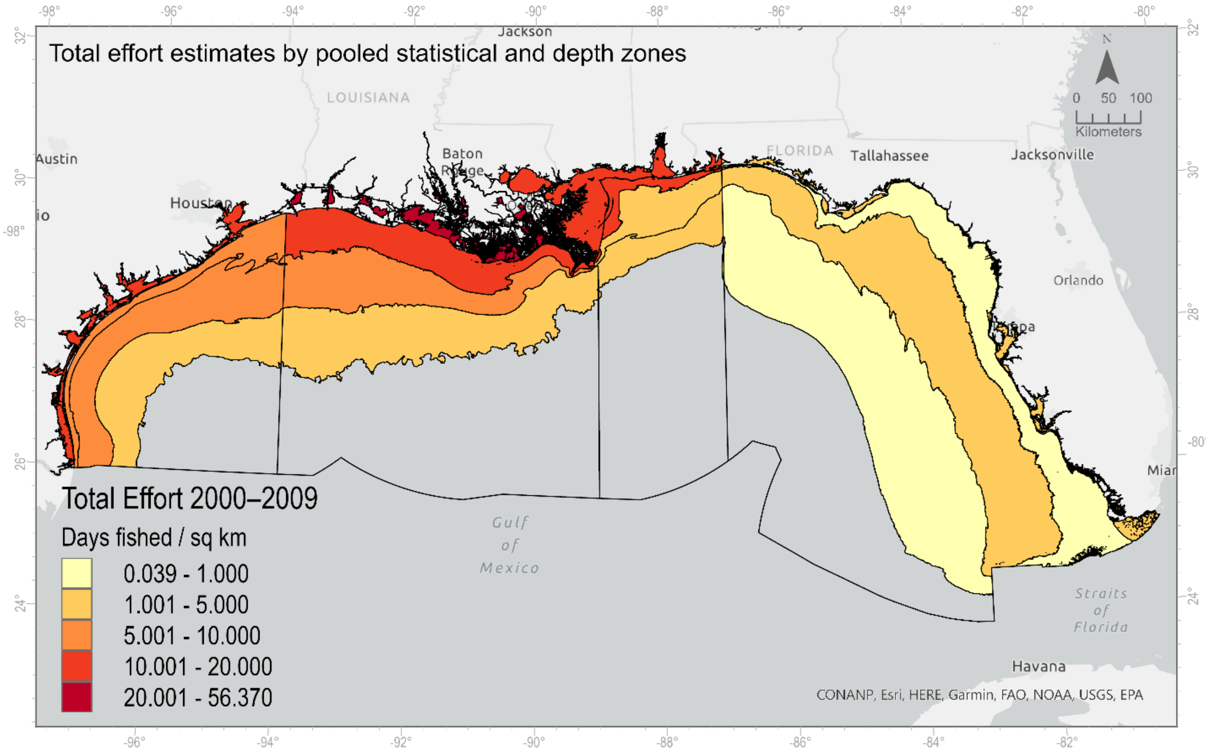


Figure 2. Total effort estimates for aggregated statistical and depth zones, 2000-2009 (Figure 31 in WP-16).

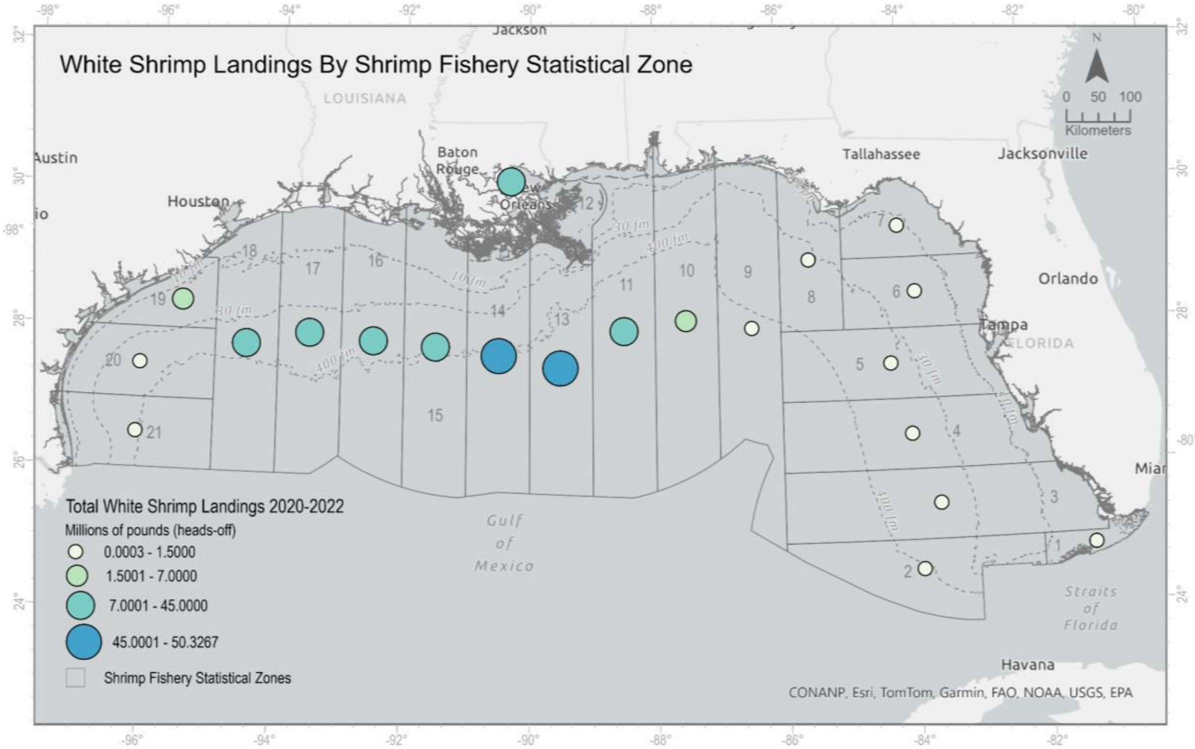


Figure 3. Total heads-off pounds landed of white shrimp in the U.S. Gulf of Mexico from 2020-2022, by statistical zone (Figure 52 in WP-16).

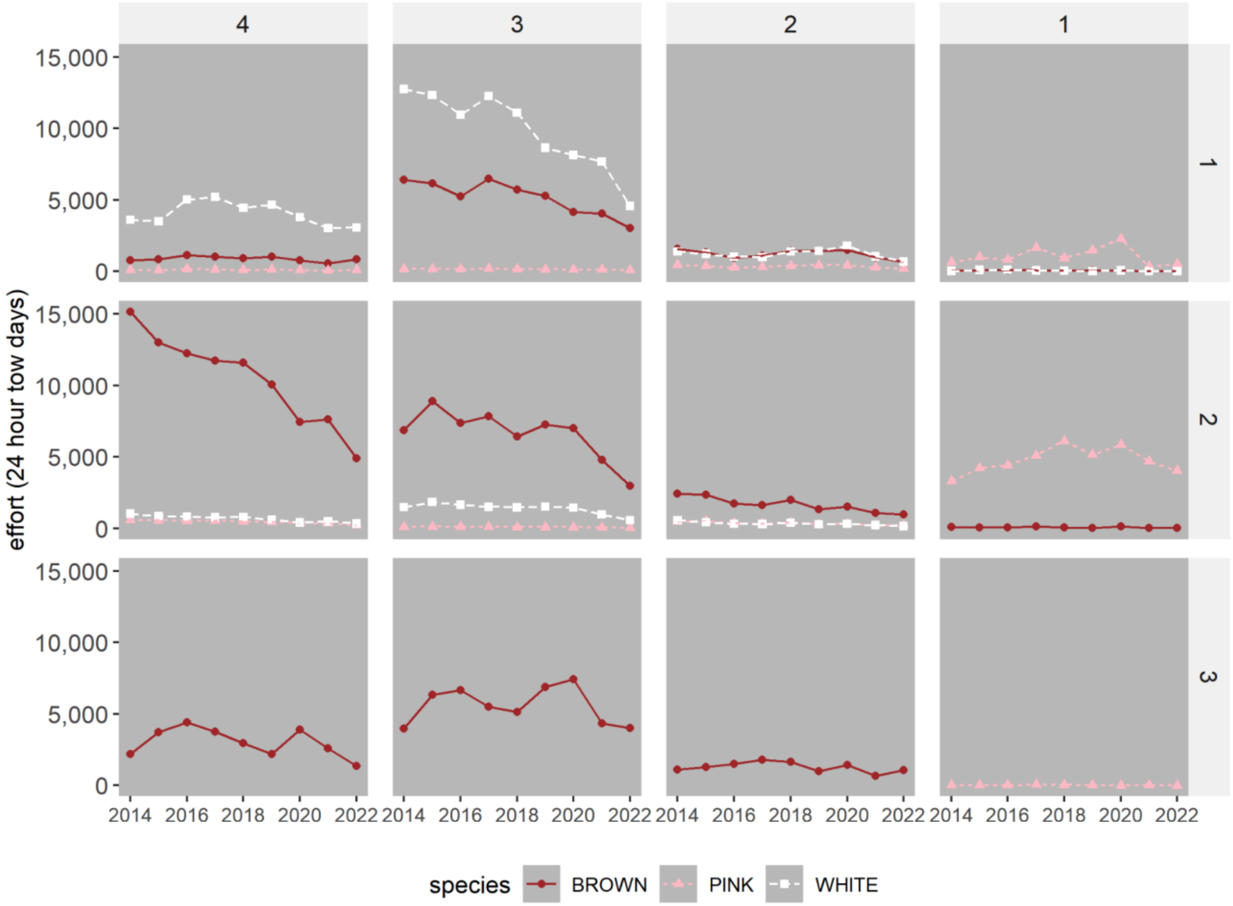


Figure 4. Time series of species-specific effort estimates grouped by historical area (horizontal axis, 1 = stat zones 1-9, 2 = 10-12, 3 = 13-17, 4 = 18-21) and depth zone (vertical axis; 1 = 0-10 fm, 2 = 10-30 fm, 3 = 30+ fm).

Figure 5. cELB coverage of offshore Penaeid landings by stratum over time as of November 2023. Panels represent areas and lines represent quadrimesters.

3 ENVIRONMENTAL DRIVERS/INDUSTRY REPORT

3.1 OVERVIEW

3.1.1 Group Membership

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3.2 TERM OF REEFERENCE 3

Create a conceptual model based on feedback from a variety of industry representatives in the Data Workshop to capture their institutional knowledge.

We held a listening session for industry and state representatives on Wednesday, September 20, 2023. The goal of the listening session was: “to generate local ecological knowledge on the Gulf of Mexico shrimp fishery.” The meeting objectives were as follows:

Listening Session Objectives:

- Obtain an oral history of the Gulf of Mexico shrimp fishery to inform the ongoing SEDAR87 Research Track Assessment (see also https://voices.nmfs.noaa.gov/search?search_api_fulltext=shrimp)
- Identify stakeholder-defined conceptual management objectives
- Identify uncertainties that might impact our ability to understand the fishery or stock
- Obtain stakeholder feedback on management approaches that would be successful for this fishery
- Collect local ecological knowledge for shrimp and associated fishery
- Identify drivers that impact the stock and fishery
- Inform a conceptual map/model that describes the stock and fishery

This is the first in a series of planned listening sessions to occur in 2024. The primary drivers impacting the shrimp fishery identified at the session were:

1. Increased importing. The large amount of farmed shrimp imports is driving down the cost of locally caught wild shrimp, and this substantially decreases the profitability of fishing.
2. Increased operating costs. The primary driver identified was the increased cost of diesel fuel. Increased labor costs were also discussed.
3. Habitat availability and environmental quality. Shrimp are impacted by freshwater input, which is changing along the coast as estuaries are replumbed and other water management protocols change.

Following the remaining listening sessions, a conceptual map will be generated to summarize the factors that impact shrimp in the Gulf of Mexico.

3.3 TERM OF REFERENCE 6

Describe any known evidence regarding ecosystem, climate, species interactions, habitat considerations, species range modifications and/or episodic events that would reasonably be expected to affect shrimp population dynamics, and the effectiveness of reference points.

- Provide species envelopes, i.e. minimum and maximum values of environmental boundaries (e.g. depth, temperature, substrate, relief) based on observations of occurrence.
- Develop hypotheses to link the ecosystem and climatic events identified in addressing this TOR to population and fishery parameters that can be evaluated and modeled.

3.3.1 Life history and seasonality

Penaeid shrimp in the Gulf of Mexico are a short-lived species whose productivity is largely environmentally driven. Brown, white, and pink shrimp follow a similar ontogeny wherein adults spawn offshore, and their planktonic larvae disperse into nearshore estuarine habitat. This nearshore marsh habitat serves as a nursery area for several months until the subadults migrate offshore (**Fig. 1**). Because of this life history, there is a particularly weak relationship between the number of adult spawners and the number of postlarvae that enter the estuary. It is consequently proposed that the juvenile and subadult life stages, wherein shrimp reside within nearshore estuarine habitats, are the stages in which density dependence occurs. Notably, these are also the areas in which environmental drivers of shrimp have been primarily studied; much less is known about how environmental drivers impact shrimp in federal waters. *Therefore, we propose that the environmental drivers that will have the greatest impact on brown, white, and pink shrimp productivity will be from the nearshore environmental conditions that impact the juvenile and subadult life stages.*

Species-specific environmental preferences shape habitat utilization in the Gulf of Mexico (**Fig. 2**, **Fig. 3**, Table 1; e.g., Turner and Brody 1983, see discussion throughout). Pink shrimp, for example, are relatively more tropical and generally inhabit saline waters with sandy bottoms; their distribution is largely concentrated in coastal Florida and southern Texas in waters from 0 to approximately 70 m (Renfro and Brusher 1982; pers. comm. J. Nance, NOAA Fisheries, james.m.nance@noaa.gov). Adult pink shrimp bury in bottom substrate during the day in salty offshore waters, and smaller pink shrimp that overwinter within estuaries bury themselves in colder temperatures for protection. Adult white shrimp prefer fresher waters and inhabit coastal waters. White shrimp are in the same region as brown shrimp, but are in relatively fresher (less saline) and shallower waters of 0 to about 35 m; (Renfro and Brusher 1982; pers. comm. J. Nance). Adult brown shrimp appear to have broader environmental tolerances and inhabit intermediate salinity and relatively deeper depths (27 - 73 m, up to 183 m; J. Nance). Like white shrimp, adult brown shrimp inhabit muddy bottoms, primarily residing along the northwest edge of the Gulf of Mexico (**Fig. 2**). Adult brown shrimp were found to be more abundant at shallower depths (14-27 m) in the summer and early fall, and deeper (≥ 46 m) in the fall and winter (Renfro and Brusher 1982). Adult brown shrimp bury during the day and swim into the water column at night, while adult white shrimp are present in the water column during the day; this leads to differential fishery targeting practices by species, despite the spatial overlap in habitat.

For the juveniles and subadults, seasonal estuary residence times differ by species (**Table 2**). Brown shrimp are harvested all year and reportedly spawn year-round with peaks in the winter (December - January, J. Nance; late winter along the northwest coast of Florida, Christmas and Eztold 1977), fall (October-December, Cook and Lindner, 1970; September-November in the northwest Gulf of Mexico; Temple and Fischer 1968), and/or in the spring and summer (May and September, Renfro and Brusher 1982; March - May, Cook and Lindner 1970; fisheries.noaa.gov/species/brown-shrimp). Brown shrimp spawning activity appears to be depth-dependent (Cook and Lindner 1970). Renfro and Brusher (1982) reported that spawning occurs year-round at deeper depths (64-110 m) and peaks during late spring and in the fall at shallower depths (27-46 m). Brown shrimp enter estuaries in the spring (February - March, J. Nance, fisheries.noaa.gov/species/brown-shrimp) peaking in March - May in Galveston Bay, Baxter 1966; Baxter and Renfro 1967) or late winter-to-spring (Christmas and Eztold 1977; January-June with peaks from February-April in Louisiana; George 1962; Gaidry and White 1973; White and Boudreaux 1977). Juveniles utilize tidal wetlands as nurseries from March - November for approximately two months (Zimmerman and Nance 2000). Brown shrimp reportedly emigrate from inshore nursery areas in late spring (e.g., May, Renfro and Brusher 1982; J. Nance). As such, *spring environmental drivers have historically shown to have the greatest impact on brown shrimp abundance and productivity*. Li and Clarke (2005) found that brown shrimp abundance was positively correlated with April - May sea surface temperature averaged across the continental shelf.

White shrimp spawn in the spring spanning through the fall (March - April, J. Nance; March - September; fisheries.noaa.gov/species/white-shrimp; April - October with a peak in May - June, Renfro and Brusher 1982; March - November with a peak in June - July, Lindner and Anderson 1965; April - August, Temple and Fischer 1968; as early as February to as late as October, Bryan and Cody 1975), with a peak in June - July corresponding to warm water temperatures (Bryan and Cody 1975; Lindner and Anderson 1956). They enter estuaries in the summer (July - August, J. Nance; April - early May, fisheries.noaa.gov/species/white-shrimp) before emigrating back offshore in the fall as water temperature declines (September - November, J. Nance; September-December, Lindner and Cook 1970; Renfro and Brusher 1982). Juveniles inhabit nursery areas from May - November (Zimmerman and Nance 2000) and are most abundant in nurseries in Louisiana from June - September (Gaidry and White 1973). *Estuarine conditions in late summer and early fall are thus most likely to impact white shrimp abundance and productivity.*

Pink shrimp are located in more tropical conditions and spawn throughout the year, with spawning peaking in spring or summer in the warmest months (April - July; Christmas and Eztold 1977, fisheries.noaa.gov/species/pink-shrimp). Juvenile and subadult pink shrimp then primarily inhabit estuarine nursery areas from summer (June - October; Costello et al. 1986) through the winter and emigrate offshore in the spring (Christmas and Eztold 1977; fisheries.noaa.gov/species/pink-shrimp). Early recruits emigrate in the fall and later recruits overwinter in estuaries and migrate offshore in the spring (Copy of Brown, white, pink life history.pptx). Criales et al. (2015) found through oceanographic transport modeling that larvae released during the summer months near Marquesas had the highest larval settlement rates, while winter settlement rates were five times lower. Thus, *estuarine conditions in summer through fall or winter will most likely impact pink shrimp abundance and productivity*.

3.3.2 Environmental drivers

We discussed potential environmental drivers that could impact penaeid shrimp within the context of several modeling frameworks:

- Vector Autoregressive Spatio-Temporal (VAST) modeling is a statistical framework used for analyzing spatio-temporal data, and will be used to estimate abundance, density, and distribution of species over space and time. VAST is particularly useful for fisheries and environmental science, since it can account for both observation and process error.
- Empirical Dynamic Modeling (EDM) includes a suite of non-parametric modeling methods for analyzing time series data based on state-space reconstruction for modeling complex, nonlinear dynamic systems in ecology.
- Bayesian frameworks, including JABBA (Just Another Bayesian Biomass Assessment), may be used to assess the biomass of population stocks over time in situations where traditional, data-intensive stock assessment methods are not feasible due to the scarcity of data.

The mechanisms driving the relationships between environmental conditions and larval/postlarval/juvenile shrimp population dynamics are poorly understood, and even less so for adult shrimp. Environmental drivers have been suggested to influence migratory and nursery emigration patterns, growth, spawning behavior, catchability, and we discuss these mechanistic hypotheses throughout. Consequently, we prioritize and identify relatively easily measurable variables that may correlate with shrimp productivity. While the relative importance of each environmental driver may vary by species, we highlight that the temporal period over which the environmental variable is summarized or collected may have a greater impact on the strength of the resulting relationship. *Further analyses, like general additive modeling, are likely required to identify which environmental drivers most influence each shrimp species.* We reference Turner and Brody (1983) for habitat suitability indices for postlarval and juvenile life stages of white and brown shrimp in estuarine nurseries. We note that environmental relationships are often correlated with space and thus environmental covariates may explain little additional variability in the data when added to spatial variables within a model (e.g., VAST).

There is a distinction between environmental drivers affecting species distribution and catchability and those impacting stock abundance and productivity. The VAST modeling framework can distinguish between covariates influencing catchability versus those that impact habitat. For EDM and JABBA models, it is likely more meaningful to identify drivers that will impact stock productivity and abundance. For surplus production models (e.g., JABBA), the likely mechanism for incorporating environmental drivers would be through a time-varying population growth rate and/or time-varying carrying capacity (Thiaw et al 2009). While meaningful correlations between environmental drivers and stock productivity can be observed at a point in time, it is important to consider that the environment is nonstationary and that these relationships may change over time.

When discussing available data, we considered the spatiotemporal scale of available data and whether the data could be hindcasted and forecasted. We prepared two tables to summarize available data from myriad sources. **Table 3** identifies online data portals with relevant environmental data, and **Table 4** details fisheries independent monitoring programs from federal and Gulf states natural resource agencies.

3.3.3 Salinity

Each shrimp species has a slightly different salinity preference, and accordingly, changes in salinity will have species-specific effects (**Figure 3**). Juvenile brown shrimp were found to be most abundant in estuaries where salinity ranged from 10-20 ppt, and accordingly, Gunter et al. (1964) hypothesized that salinity would be a key environmental driver for brown shrimp. White shrimp have been shown to inhabit a wide range of salinities ranging from <1 ppt to >40 ppt (https://www.fao.org/3/ac765t/AC765T13.htm), and Gunter et al. (1964) reported that white shrimp prefer salinities less than 10 ppt. Gunter and Edwards (https://www.fao.org/3/ac741t/AC741T20.htm) reported a significant positive correlation between 2-year lagged annual rainfall and white shrimp catch in Texas, suggesting that rainfall could be a key driver of shrimp abundance.

For brown shrimp, which prefer higher salinity, extreme rain events that result in low-salinity estuary conditions will likely negatively affect their populations. These rain events may cause cohorts of sub-adult shrimp to “flush out” of estuaries early and result in higher natural mortality rates, both from lower salinity tolerance and increased predation offshore. These early emigrations following large freshwater inflows have been observed in North Carolina (Hunt et al. 1980; Jones and Sholar 1981, Laney and Copeland 1981). Freshwater diversions may also affect the ability of juvenile brown shrimp to feed and thus growth rates and survival (Rozas and Minello 2011). It is notable that salinity in some areas (as well as other environmental conditions) can be dramatically altered due to large-scale environmental engineering projects—in particular, the recent and planned diversions of the Mississippi River (https://www.wired.com/story/the-controversial-plan-to-unleash-the-mississippi-river/). It's also hypothesized that the recent large-scale environmental engineering changes in the Everglades and Florida Bay have resulted in higher salinity and driven increased catch rates of pink shrimp (Browder and Robblee 2009). Salinity has been proposed to be an important driver of recruitment in pink shrimp (Criales et al. 2015).

Salinity is a relatively easily measurable variable and correlates with many other environmental conditions, including precipitation, river discharge, and variations in mixed layer depth. Data sources for monitoring salinity include measures for precipitation, river discharge, inshore sampling, and ocean modeling products. Precipitation records are available from NOAA National Marine Weather Service climate data products (e.g., for coastal Texas, weather.gov/wrh/climate?wfo=hgx). The RC4USCoast data set provides monthly time series as well as long-term averaged monthly climatological patterns for twenty-one variables, including alkalinity and dissolved inorganic carbon concentration. Surface, bottom, and averaged daily spatial-temporal salinity data is available from HYCOM (SEDAR87-DW-09). The HYCOM (Hybrid Coordinate Ocean Model; hycom.org) is a numerical ocean model that integrates satellite observations, in situ measurements, and oceanographic data to simulate and forecast ocean currents, temperature, salinity, and other oceanographic variables with high spatial and temporal resolution. Although HYCOM boasts high spatial and temporal resolutions, the model might not capture high resolution freshwater inputs, such as from the Mississippi River, to accurately represent freshwater plumes. State sampling programs typically collect data on salinity (**Table 4**), or states may collect salinity through local environmental monitoring programs.

3.3.4 Temperature

Extreme temperatures in estuary conditions can impact behavior and mortality rates of shrimp. For inshore post-larval shrimps, temperatures approximately 15°C mark their lower tolerance limit. Prolonged exposure to low temperatures reduces feeding and growth rates, which can potentially cause mortality in severe events (J. Nance). A lower bound on temperature preference for brown and white shrimp of approximately 15°C/59°F was observed in estuaries and the lab (Venkataramaiah 1971). Temperatures below 4.4°C and above 32.2°C can cause mass mortality and/or physiological stress (Gunter and Hildebrand 1951 and Kutkuhn 1966, respectively). Temperature has also been shown or hypothesized to influence individual growth rate (Christmas and Eztold 1977 and references therein), spawning activity (Linder and Anderson 1956; Perez-Farfante 1969), recruitment (Baxter and Renfro 1967). Conversely, elevated temperatures can result in reduced oxygen levels, cause direct temperature stress, increase consumption rates, and facilitate proliferation of certain pathogens and diseases. Temperature (**Figure 3**) may thus be correlated with other meaningful variables (e.g., disease) that are challenging to monitor. Li and

Clarke (2005) found links between annual sea surface temperature during April and May and brown shrimp abundance in Alabama, Mississippi, Louisiana, and Texas.

Data sources for temperature include water quality measurements from all of the Gulf states' inshore sampling programs (**Table 4**) and ocean modeling products. HYCOM derived bottom seawater temperature is available and viewable at the following repository links: high-resolution and processed low-resolution (SEDAR87-DW-09).

3.3.5 Dissolved oxygen

White and brown shrimp both inhabit areas affected by the Gulf of Mexico hypoxic zone. Changes in dissolved oxygen (DO) may affect the distribution, migration, and catchability of early life stages (megalopae and juveniles) within estuarine and nearshore habitats, as well as offshore adult populations, likely due to avoidance behavior (Zimmerman and Nance 2001). Reduced DO may further result in mechanistic impacts, including through increased mortality or reductions in growth and reproduction through impacts on shrimp metabolism and bioenergetics (Zimmerman and Nance 2001). Zimmerman and Nance (2001) reported a negative correlation between hypoxia and catch of brown shrimp, though this relationship was not significant for white shrimp, likely due to their lesser reliance on offshore habitat. Changes in DO are driven by changes in water temperature and biological metabolism throughout the water column (Kemp and Boynton 1980). The biological responses from DO reductions might not be instantaneous; rather, cumulative exposure can result in a lagged decrease in fishery landings (Huang et al. 2010). Considering the interaction between temperature, DO, and shrimp bioenergetics, it is important to carefully consider the relationship between environmental and shrimp monitoring data from FIM efforts in each of the GOM states.

Dissolved oxygen data can be obtained from nearshore state FIM sampling or other state coastal monitoring programs (**Table 4**). While this information is collected from the SEAMAP survey, these observations are made 1-2 m above the sea floor and may not be indicative of oxygen available for shrimp on the benthos. Overall, we consider that DO is relatively challenging to measure and cannot be spatially extrapolated with confidence.

3.3.6 Larval and postlarval transport

Shrimp eggs and larvae are dependent on atmospheric and oceanographic dynamics to ensure transport into the nursery estuaries (Criales et al. 2015; FAO Fish Synop). Inshore transport is driven by larval and postlarval behavior (e.g., diel vertical migration), flood tide transport, wind-forcing, storms, and marine inundations. Consequently, wind, current, and physical oceanographic processes may impact shrimp abundance and productivity.

Data sources to inform environmental indices for larval and postlarval transport include a hurricane index that calculates accumulated cyclone energy, tidal and wind records, and NOAA buoy data (**Table 3**).

3.3.7 Nutrients and primary production

Nutrient delivery into the estuary and near-shore marine environment drives the ecosystem's primary production. The three shrimp species represent relatively low-trophic groups in the marine food web, and may thus be controlled by bottom-up environmental and biological processes. Nutrient delivery is largely driven by river discharge into the Gulf of Mexico and interacts with other environmental variables such as dissolved oxygen, salinity, and temperature. The Mississippi River Basin contributes approximately 70-80% of the total nitrogen load and about 90% of the total phosphorus load to the Gulf of Mexico (Dunn 1996). High nutrient inputs are largely responsible for the seasonal hypoxia from nutrient-fueled algal blooms that, upon decomposition, consume available oxygen (Rabalais et al. 2022).

Sources for these data include river discharge from the RC4USCoast river chemistry dataset. Spatial-temporal maps for nutrients and primary production are readily available for this assessment from the MODIS satellite-based sensor that provides high-resolution oceanographic imaging available from 2003-2022 (SEDAR87-DW-09). Specifically, MODIS data is available for chlorophyll-a, normalized carbon fluorescence, and particulate organic carbon. GOM state monitoring programs also collect nearshore water quality data separately from their FIM survey programs that includes measures such as chlorophyll-a, turbidity, and light attenuation (**Table 4**).

3.3.8 Habitat quality and availability

Shrimp rely on marshes, mangroves, and seagrass beds as a nursery areas, which have been proposed as the environmental bottlenecks to shrimp productivity. These nursery habitats serve as sources of food and refuge from predators. Vegetation structure (spartina or mangrove) habitat increases post-larval settlement and production (Turner and Brody 1983 and references therein); some species may preferentially benefit from mangrove habitat due to the added complexity. Seagrass is particularly important for pink shrimp. Shrimp particularly benefit from marsh edge habitat (Minello et al. 1994), which increases and then decreases as marsh deteriorates or is physically broken through anthropogenic impacts. Further, substrate type may influence the distribution of shrimp, since substrate preferences vary by species (Turner and Brody 1983 and references therein).

Data to inform this driver includes the NOAA NERRs marsh elevation data (**Table 3**). Some states also collect this information (**Table 4**).

3.4 Episodic events

Episodic events may have meaningful impacts on the productivity of shrimp. For example, given the importance of physical oceanographic processes for larval transport and survival, it has been anecdotally reported that “the next year after hurricanes are the best catches,” suggesting that hurricanes may “stir up” or “flesh out” any nutrients or other physical water properties that impact shrimp. Hurricane activity may serve as a proxy for changes to winds, salinity, temperature, or other related environmental drivers that may impact larval transport (e.g., Criales et al. 2010). Other potentially influential events include red tide, oil spills, changes in state water management (e.g., Mississippi River diversions), disease outbreaks, and decadal climatic indices, such as the El Nino Southern Oscillation (ENSO).

Importantly, the timing of these events will strongly influence the magnitude of the impact felt on each species. For example, a strong rain event in April or May in Louisiana would significantly impact brown shrimp when juveniles and subadults inhabit estuaries. In contrast, an event of similar magnitude in June or July would have a significantly reduced impact on brown shrimp.

It may also be worth considering that any of the above-listed environmental drivers may not influence the distribution or productivity of shrimp until the driver hits a threshold level. For example, temperature may not impact shrimp below a maximum temperature, but if waters exceed a threshold temperature, the stock would be adversely impacted (e.g., see FAO Fish Synopses for brown, white, and pink shrimp). Preliminary exploratory analyses (e.g., GAMs) may be able to address the observation of environmental thresholds.

Information on these processes may come from the hurricane intensity index, Florida HAB monitoring index, state records on water management, or a climatic index (e.g., ENSO) (**Table 3**).

3.5 Inshore Environmental Data from Fisheries and State Water Quality Monitoring Programs

We inventoried environmental data collected by Gulf states and federal fisheries independent monitoring programs in **Table 4**. These sampling programs generally measure temperature and salinity (via conductivity). Most also measure turbidity and DO, and some measure pH. Habitat data is collected by the Florida and Texas monitoring programs. Acquiring the data generally requires directly contacting the resource management agent, and we detail information for the point of contact for each data set.

Sampling designs include random and fixed schemes. Stratified random sampling designs (Florida and Texas) are consistent with the assumptions of most statistical methodologies by allowing all sampling units a non-zero probability of being selected (Gruss et al. 2018). Fixed-station sampling methods (Alabama and Mississippi) visit the same locations repeatedly to track changes over time. Five Gulf-wide programs are conducted under SEAMAP and SEFSC, including summer/fall trawls, spring/summer/fall and annual longline surveys, and fall/spring plankton sampling.

It has been recommended that state fisheries independent monitoring surveys could be analyzed to identify the timing that small shrimp appear in coastal and estuarine waters. These areas and time periods should be prioritized for extracting meaningful environmental data that may impact the productivity of shrimp.

3.6 Environmental Drivers Conclusions

We highlight salinity or some metric of freshwater input as the primary or most influential environmental driver of overall productivity for all three shrimp species; secondarily, we propose exploring the impacts of temperature on shrimp dynamics. Both salinity and temperature were selected because of their link to habitat preferences and distribution, as well as their correlation with other potentially important processes (e.g., freshwater input) and the existence and ease of data accessibility, use, and manipulation to fit a variety of modeling structures.

We hypothesize that these drivers will have the greatest impact on shrimp while they inhabit their nearshore, estuarine nursery habitat, as this is where density dependence is expected to occur. We recommend that these drivers match shrimp usage temporally; in particular, brown, white, and pink shrimp environmental drivers should be measured from the spring, late summer and early fall, and summer through fall, respectively.

3.7 DATA GAPS AND ADDITIONAL RESEARCH RECOMMENDATIONS

We highlight data gaps and research recommendations that will improve understanding of environmental impacts on shrimp.

Updated life history information – Much of the life history obtained for shrimp was conducted in the 1960-1970s. Given the short generation time of shrimp, high environmental influence on productivity, and nonstationary environmental dynamics, life history dynamics have likely changed, and these parameters should be updated (e.g., SEDAR87-DW-05).

Density dependence - The suggestion to prioritize environmental impacts on the estuarine stages of shrimp relies on the assumption that this is the region in which density dependence occurs. Expert guidance has suggested that there is no relationship between post larvae entering the estuary and the number of spawning adults in the population (J Nance). While previous efforts suggest that density dependence occurs during estuary residence (e.g., Galveston Bay sub-adult survey to predict brown fishery dynamics for the upcoming year), further research to support this assumption would further validate the assumptions made herein.

Population connectivity models for brown and white shrimp – Research linking spawning adults to their nursery estuary may provide guidance on which estuarine habitats are most productive. Priority could then be given to these most influential nursery habitats for research and conservation.

Mechanistic environmental relationships – Hypothesized environmental drivers presented in this report are correlative only and do not attempt to identify the mechanistic relationship underlying these correlations. Further research identifying the exact driver and the organismal and stock-wide response to these drivers would improve this effort. Updated environmental relationships should be generated or explored.

State FIM data standardization - Additional research should be conducted to standardize and calibrate state-by-state surveys.

Role of shrimp as key forage species - As forage species, shrimp play a key role in the ecosystem. Additional research may clarify linkages between shrimp and predator species and better clarify the extent of predator-induced mortality (e.g., Fujiwara et al. 2016). These linkages may inform how these interrelated species should be managed from an ecosystem-based perspective.

3.8 LITERATURE CITED

Baxter, K. N. and W. C. Renfro, Seasonal occurrence and size distribution of postlarval brown and white shrimp near Galveston, Texas with notes on species identification, U.S. Fish Wildl. Serv., Fish. Bull., 66, 149-158, 1967.

Browder, J.A. and Robblee, M.B., 2009. Pink shrimp as an indicator for restoration of everglades ecosystems. Ecological Indicators, 9(6), pp.S17-S28.

Bryan, C. E. and T. J. Cody, A study of commercial shrimp, rock shrimp and potentially commercial finfish 1973-1975, in Part I. White Shrimp, *Penaeus setiferus* (Linn.), Spawning in the Gulf of Mexico off Texas Coast, Fish. Branch, Texas Parks and Wildl. Dept., P.L. 88- 309 Proj. 2-202-R:1-29, 1975.

Christmas, J. Y. and D. J. Etzold, The shrimp fishery of the Gulf of Mexico United States: a regional management plan. Tech. Rep. No. 2, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, 1977.

Cook, H. L. and M. J. Lindner, Synopsis of biological data on the brown shrimp *Penaeus aztecus* Ives, 1891, FAO Fish. Rep. (57) 4, 1471-1497, 1970.

Costello, T. J., D. M. Allen, AND J. H. Hudson. 1986. Distribution, seasonal abundance, and ecology of juvenile northern pink shrimp, *Penaeus duorarum*, in the Florida Bay area. National Oceanic and Atmospheric Administration Technical Memorandum NMFS-SEFC-161. June 1986. United States Department of Commerce, Miami, Florida.

Criales, M.M., Cherubin, L.M. and Browder, J.A., 2015. Modeling larval transport and settlement of pink shrimp in South Florida: dynamics of behavior and tides. *Marine and Coastal Fisheries*, *7*(1), pp.148-176.

Criales, M.M., Robblee, M. B., Browder, J. A., Cardenas, H., and T. Jackson. 2010. Nearshore concentration of pink shrimp *Farfantepenaeus duorarum* postlarvae in northern Florida Bay in relation to the nocturnal flood tide. Bulletin of Marine Science 86: 51–72.

Dunn, D.D., 1996. Trends in nutrient inflows to the Gulf of Mexico from streams draining the conterminous United States, 1972-93 (Vol. 96, No. 4113). US Department of the Interior, US Geological Survey.

FAO Species Synopsis for Brown shrimp: https://www.fao.org/3/ac765t/AC765T14.htm

FAO Species Synopsis for Pink shrimp: https://www.fao.org/3/ac765t/AC765T15.htm

FAO Species Synopsis for White shrimp: https://www.fao.org/3/ac765t/AC765T13.htm

Fujiwara, M., Zhou, C., Acres, C., Martinez-Andrade, F. 2016. Interaction between Penaeid shrimp and fish populations in the Gulf of Mexico: importance of shrimp as forage species. PLoS ONE: 11(11): e0166479.

Gaidry, W.J., III, White C.J. 1973. Investigations of commercially important penaeid shrimp in Louisiana estuaries. La. Wildl. Fish. Comm. Tech. Bull. 8. 154 pp.

George, M.J. 1962. Preliminary observations of the recruitment of postlarvae and growth of juveniles of the brown shrimp, *Penaeus aztecus* Ives, in Barataria Bay. La. Wild. Fish. Comm. 9the Biennial Rep., 1960-1961: 160-163.

Grüss, A., Perryman, H.A., Babcock, E.A., Sagarese, S.R., Thorson, J.T., Ainsworth, C.H., Anderson, E.J., Brennan, K., Campbell, M.D., Christman, M.C. and Cross, S., 2018. Monitoring programs of the US Gulf of Mexico: inventory, development and use of a large monitoring database to map fish and invertebrate spatial distributions. *Reviews in Fish Biology and Fisheries*, 28, pp.667-691.

Gunter, G., J.Y. Christmas and R.K. Killebrew, 1964 Some relations of salinity to population distributions of motile estuarine organisms, with special reference to penaeid shrimp. Ecology, 45(1):181–5

Gunter, G. and H.H. Hildebrand, 1954 The relation of total rainfall of the State and catch on the marine shrimp (*Penaeus setiferus*) in Texas waters. Bull.mar.Sci. Gulf Caribb., 4(2):95–103

Gunter, G., Edwards, J.C. 1969. The relation of rainfall and fresh water drainage to the production of penaeid shrimp (*Penaeus flubiatilis* Say and *Penaeus aztecus* Ives) in Texas and Louisiana waters. FAO Fish. Rep. 57: 875-892.

Harris, H. 2023. Gulf of Mexico Spatial-Temporal Environmental Data. SEDAR87-DW-09. SEDAR, North Charleston, SC. 8 pp.

Hunt, J.H., Carroll, R.J., Chinchilli, V., Frankenburg, D. 1980. Relationship between environmental factors and brown shrimp production in Pamlico Sound, North Carolina. N.C. Dep. Nat. Resour. Comm. Devel., Div. Mar. Fish., Spec. Sci. Rep. 33: 1-29.

Huang, L., Smith, M.D. and Craig, J.K., 2010. Quantifying the economic effects of hypoxia on a fishery for brown shrimp *Farfantepenaeus aztecus*. Marine and Coastal Fisheries, 2(1), pp.232-248.

Kemp, W.M. and Boynton, W.R., 1980. Influence of biological and physical processes on dissolved oxygen dynamics in an estuarine system: Implications for measurement of community metabolism. Estuarine and Coastal Marine Science, 11(4), pp.407-431.

Jones, R.A., Sholar, T.M. 1981. The effects of freshwater discharge on estuarine nursery areas of Pamlico Sound, North Carolina. N.C. Dep. Nat. Resour. Comm. Devel., Div. Mar. Fish., Completion Rep., Proj. CEIP 79-11. 60 pp.

Kesner-Reyes, K., Segschneider, J., Garilao, C., Schneider, B., Rius-Barile, J., Kaschner, K., & Froese, R. (2019, October). AquaMaps Environmental Dataset: Half-Degree Cells Authority File (HCAF ver.7, 10/2019). Retrieved from https://www.aquamaps.org/main/envt_data.php.

Kutkuhn, J.H. 1966. The role of estuaries in the development and perpetuation of commercial shrimp resources. Pp 16-36 in R.F. Smith, A.H. Swartz, and W. H. Massmann, eds. A symposium on estuarine fisheries. Am. Fish. Soc. Spec. Publ. 3.

Laney, R.W., Copeland, B.J. 1981. Population dynamics of penaeid shrimp in two North Carolina tidal creeks. Rep. 81-1 to Carolina Power and Light Company, Raleigh, N.C. 161 pp.

Li, J., Clarke, A.J. 2005. Sea surface temperature and the brown shrimp (*Farfantepenaeus aztecus*) population on the Alabama, Mississippi, Louisiana and Texas continental shelves. Estuar. Coast. Shelf Sci., 64: 261-266, 10.1016/j.ecss.2005.02.019

Lindner, M. J. and W.W. Anderson, Growth, migrations, spawning and size distribution of shrimp, *Penaeus setiferus*, U.S. Fish Wildl. Serv., Fish Bull., 106, 554-645, 1956.

Lindner, M. J. and H. L. Cook, Synopsis of biological data on the white shrimp *Penaeus setiferus* (Linn.), 1767, FAO Fish. Rep., 57, 1439-1469, 1970.

Minello, T.J., Zimmerman, R.J., Medina, R., 1994. The importance of edge for natant macrofauna in a created salt marsh. *Wetlands*, 14, pp. 184-198.

Ogburn, M.B., Criales, M.M., Thompson, R.T. and Browder, J.A., 2013. Endogenous swimming activity rhythms of postlarvae and juveniles of the penaeid shrimp *Farfantepenaeus aztecus, Farfantepenaeus duorarum*, and *Litopenaeus setiferus*. *Journal of Experimental Marine Biology and Ecology*, *440*, pp.149-155.

Palomares, M.L.D. and D. Pauly. Editors. 2023. SeaLifeBase. World Wide Web electronic publication. https://www.sealifebase.ca (11/2023).

Perez-Farfante, I. 1969. Western Atlantic shrimp of the genus *Penaeus*. U.S. Fish Wildl. Serv. Fish. Bull. 67: 461-591.

Rabalais, N.N., Turner, R.E. and Scavia, D., 2002. Beyond Science into Policy: Gulf of Mexico Hypoxia and the Mississippi River: Nutrient policy development for the Mississippi River watershed reflects the accumulated scientific evidence that the increase in nitrogen loading is the primary factor in the worsening of hypoxia in the northern Gulf of Mexico. BioScience, 52(2), pp.129-142.

Renfro, W.C., Brusher H.A. 1982. Seasonal Abundance, Size Distribution, and Spawning of Three Shrimps (*Penaeus aztecus, P. setiferus,* and *P. duorarum*) in the Northwestern Gulf ofMexico, 1961-1962. NOAA Technical Memorandum NMFS-SEFC-94. 47 pp.

Rozas, L.P., Minello, T.J. 2011. Variation in penaeid shrimp growth rates along an estuarine salinity gradient: implications for managing river diversions. J. Exp. Mar. Biol. Ecol., 397(2): 196-207.

Temple, R.F. and C.C. Fischer, 1968 Seasonal distribution and relative abundance of planktonic-stage shrimp (*Penaeus spp.*) in the northwestern Gulf of Mexico, 1961. Fishery Bull.U.S. Fish Wildl. Serv., 66(2):323–34

Thiaw, M., Gascuel, D., Jouffre, D., Thiaw, O.T., 2009. A surplus production model including environmental effects: Application to the Senegalese white shrimp stocks. *Progress in Oceanography*, 83, pp. 351-360.

Turner, R.E., Brody, M.S. 1983. Habitat suitability index models: northern Gulf of Mexico brown shrimp and white shrimp. U.S. Dept. of Int. Fish Wildl. Serv. FWS/0BS-82/10.54. 24pp.

Venkataramaiah, A. 1971. Study of the salinity relationship of the commercial shrimp (Family Penaeidae) in estuarine waters. Contract No. DACW39-71-C-008. (Prog. Rep. June 1971-August 1971). U.S. Army.

White, C.J., Boudreaux, C. J. 1977. Development of an areal management concept for gulf penaeid shrimp. La. Wildl. Fish. Comm. Tech. Bull. 22. 77 pp.

Zimmerman, R.J. and Nance, J.M. (2001). Effects of Hypoxia on the Shrimp Fishery of Louisiana and Texas. In Coastal Hypoxia: Consequences for Living Resources and Ecosystems (eds N.N. Rabalais and R.E. Turner). https://doi.org/10.1029/CE058p0293

3.9 TABLES

Table 1

Environmental preference data for brown, white, and pink shrimp. Preference parameters for depth, temperature, salinity, primary production, oxygen concentration, distance from land, and area bounding box are provided by AquaMaps (Kesner-Reyes et al. 2019) and SeaLifeBase (Palomares et al. 2023). Data were queried for the environmental envelope preferences, representing the absolute and preferred ranges. The absolute minima (first column) represents the minimum in extracted data or 25th percentile - 1.5 × interquartile (whichever is lesser). The preferred minima (second column) represents the 10th percentile of the observed variation in the environmental predictor, and the preferred maxima (third column) represents the 90th percentile. The absolute maxima (last column) represents the maximum in extracted data or 75th percentile + 1.5 × interquartile (whichever is greater).

Brown shrimp			
DepthMin (m)	DepthPrefMin (m)	DepthPrefMax (m)	DepthMax (m)
0	27	54	160
TempMin (°C)	TempPrefMin (°C)	TempPrefMax (°C)	TempMax (°C)
12.2	17.6	28.1	32.3
SalinityMin (ppt)	SalinityPrefMin (ppt)	SalinityPrefMax (ppt)	SalinityMax (ppt)
19	28.5	36.1	36.6
PrimProdMin (mgC·m^{-3}·day^{-1})	PrimProdPrefMin (mgC·m^{-3}·day^{-1})	PrimProdPrefMax (mgC·m^{-3}·day^{-1})	
0	0.5	18.8	
OxyMin (mmol·m^{-3})	OxyPrefMin (mmol·m^{-3})	OxyPrefMax (mmol·m^{-3})	OxyMax (mmol·m^{-3})
145.5	177.2	227.4	268.9
LandDistMin (km)	LandDistPrefMin (km)	LandDistPrefMax (km)	LandDistMax (km)
0	8	153	385
NMostLat (°)	SMostLat (°)	WMostLong (°)	EMostLong (°)
39	8	-98	-60

Notes: found throughout the Gulf of Mexico, but they're abundant from AL->Mexico (north-western Gulf of Mexico), at depths of 4–160 m, with highest densities at 27–54 m. From sealifebase: Penaeus aztecus - Benthic; depth range 0 - 200 m (Ref. 356), usually 27 - 54 m. https://www.sealifebase.ca/summary/Penaeus-subtilis.html			
White shrimp			
DepthMin (m)	DepthPrefMin (m)	DepthPrefMax (m)	DepthMax (m)
0	8	36	55
TempMin (°C)	TempPrefMin (°C)	TempPrefMax (°C)	TempMax (°C)
14.6	16.4	27	31.2
SalinityMin (ppt)	SalinityPrefMin (ppt)	SalinityPrefMax (ppt)	SalinityMax (ppt)
19	26.5	36.2	36.7
PrimProdMin (mgC$\cdot$m$^{-3}\cdot$day^{-1})	PrimProdPrefMin (mgC$\cdot$m$^{-3}\cdot$day^{-1})	PrimProdPrefMax (mgC$\cdot$m$^{-3}\cdot$day^{-1})	
-0.2	0.8	33.3	
OxyMin (mmol$\cdot$m^{-3})	OxyPrefMin (mmol$\cdot$m^{-3})	OxyPrefMax (mmol$\cdot$m^{-3})	OxyMax (mmol$\cdot$m^{-3})
126.6	178.6	243.4	277
LandDistMin (km)	LandDistPrefMin (km)	LandDistPrefMax (km)	LandDistMax (km)
0	8	149	385
NMostLat (°)	SMostLat (°)	WMostLong (°)	EMostLong (°)
42	-36	-98	-34
Notes: Found throughout the Gulf of Mexico, but they're most abundance from AL->Mexico (north-western Gulf of Mexico), at depths of 8 – 55 m, with highest densities at 11 – 36 m (shallower depths than brown shrimp). Live in mud, silt, and sandy bottoms.			
Pink shrimp			
DepthMin (m)	DepthPrefMin (m)	DepthPrefMax (m)	DepthMax (m)
0	4	48	137
TempMin (°C)	TempPrefMin (°C)	TempPrefMax (°C)	TempMax (°C)

16	22.4	28	32.2
SalinityMin (ppt)	SalinityPrefMin (ppt)	SalinityPrefMax (ppt)	SalinityMax (ppt)
22.1	32.6	36.2	38.1
PrimProdMin (mgC·m^{-3}·day^{-1})	PrimProdPrefMin (mgC·m^{-3}·day^{-1})	PrimProdPrefMax (mgC·m^{-3}·day^{-1})	
0.2	1.4	31.6	
OxyMin (mmol·m^{-3})	OxyPrefMin (mmol·m^{-3})	OxyPrefMax (mmol·m^{-3})	OxyMax (mmol·m^{-3})
145.7	200.5	248.7	269.7
LandDistMin (km)	LandDistPrefMin (km)	LandDistPrefMax (km)	LandDistMax (km)
1	4	118	478
NMostLat (°)	SMostLat (°)	WMostLong (°)	EMostLong (°)
40	18	-97	-74
Notes: Occur offshore Costello et al 1986; at depths of 4 – 48 m, but adults are found as deep as 137 m			

Table 2

Overview of life-history timing for Gulf of Mexico shrimp species. Activities are occurring in all colored months, while darker colors represent timing of peak estuarine usage or spawning. Timing was compiled from expert experience (J. Nance), SEFSC shrimp outreach presentation materials (Copy of Brown, white, pink life history (1).pptx), and publicly available species report pages from NOAA Fisheries (https://www.fisheries.noaa.gov/species/brown-shrimp, https://www.fisheries.noaa.gov/species/white-shrimp, https://www.fisheries.noaa.gov/species/pink-shrimp). Additional refinement of this table may be warranted.

Estuarine Usage timing												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Brown		🟫	🟫	🟫	🟫							
White					░	░	░	▓	▓	▓	░	
Pink*	░	░	░			░	░	░	▓	▓	░	░
Spawning timing												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Brown	🟫											🟫
White			░	░	░	▓	▓	░	░	░		
Pink*	░	░	░	▓	▓	▓	▓	▓	▓	▓	░	░

Table 3

Online environmental data resources. (Google sheet.)

process	**data source**	**link**	**spatial resolution**	**temporal resolution**	**caveats**
Riverine inputs	RC4USCoast: A river chemistry dataset	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0260455			
Hurricane index	accumulated cyclone energy calculation	https://github.com/SEFSC/IEA-GWEM-DataSynth/tree/main/Ecospace-environmental-drivers	6-hourly storm tracks, can be subset at any spatial or temporal scale	can create index at monthly, yearly, or other scale	
Salinity (surface, bottom, averaged)	HYCOM ocean model	https://github.com/SEFSC/IEA-GWEM-DataSynth/tree/main/Ecospace-environmental-drivers	Gulf of Mexico	1993-2022	Consideration needed for high-resolution insure use
Temperature (surface, bottom, averaged)	HYCOM ocean model	https://github.com/SEFSC/IEA-GWEM-DataSynth/tree/main/Ecospace-environmental-drivers	Gulf of Mexico	1993-2022	Consideration needed for high-resolution insure use
Chlorophyll-A	MODIS satellite imagery	https://github.com/SEFSC/IEA-GWEM-DataSynth/tree/main/Ecospace-environmental-drivers	Gulf of Mexico	2003-present	
Normalized carbon fluorescence	MODIS satellite imagery	https://github.com/SEFSC/IEA-GWEM-DataSynth/tree/main/Ecospace-environmental-drivers	Gulf of Mexico	2003-present	
Particulate organic carbon	MODIS satellite imagery	https://github.com/SEFSC/IEA-GWEM-DataSynth/tree/main/Ecospace-environmental-drivers	Gulf of Mexico	2003-present	

Marsh elevation	NOAA NERRS system	https://www.fisheries.noaa.gov/inport/item/47712	Apalachicola Bay and Mission Aransas NERRs	Ap. Bay 2014-2022; Mission Aransas 20111 only	
Florida HAB monitoring	FWC	https://myfwc.com/research/redtide/monitoring/database/	SW Florida	1953-present	To request data, email: HABdata@MyFWC.com.
Water height	NOAA tides & currents	https://tidesandcurrents.noaa.gov/products.html			
Rainfall	NOAA NWS	https://www.weather.gov/wrh/climate?wfo=hgx			
Remote sensing	USF virtual buoys	https://optics.marine.usf.edu/projects/vbs.html	Central west Florida and West Florida Shelf	2014-present	
USGS National Water Information System	Water quality sondes	https://waterdata.usgs.gov/monitoring-location/301429089145600/#parameterCode=00065&period=P7D&showMedian=true	National monitoring	Varies by station	

Table 4

Inventory of inshore environmental data from Gulf state fisheries independent monitoring programs conducted in Texas, Louisiana, Texas, Mississippi, Alabama, and Florida.

State	**Organization and sampling program(s)**	**Design**	**Biological sampling (overview)**	**Habitat data collected**	**Water quality data collected**	**Spatial coverage**	**#**	**Format**	**POC**	**Caveats and notes**
Florida	Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute (FWRI) Fisheries independent monitoring (FIM)	Monthly stratified random sampling	Two seine types and trawls	Substrate types (i.e., habitat type, e.g., mud, sand, oyster); SAV: visual estimation of percent cover and percent composition by species; Shoreline type (collected by matrix, e.g., black / red / white mangrove) but is generally collapsed for analyses, e.g., "mangrove / terrestrial structure" for a site with multiple mangrove species and rip-rap.	Temperature, DO (mg/L), conductivity / salinity (ppt), pH. Measurements collected at surface and every meter and at bottom. Can get surface, averaged, or bottom.	Data goes back 1998 on monthly for four estuaries: Charlotte Harbor, Tampa Bay, Cedar Key, and Apalachicola Bay. Also have spotty, “one-off” sampled areas.	Monthly; 1998-present for the four LTM estuaries.	CSV files	meagan.schrandt@myfwc.com	There's. data sheet of reference codes (e.g., ‘M’ for mud). Sampling records bycatch, including drift algae, which may be consequential for juvenile shrimp.
Alabama	Alabama Department of Conservation Natural Resources (DCNR) Marine Resources Division (MRD)	Monthly fixed stations	Trawls, seines, "hydros" reef sites, gill nets	Depth for trawls.	Temperature, DO, and salinity. Measurements taken at bottom for trawls, midwater for seines, bottom for hydros.	24 trawl sites, 10 seines, and 9 hydros in coastal Miss. waters. Seines and hydros are inshore. Trawl sites are inshore or close to shore if in the Gulf	Sampling began in 1981 but not all stations are continuous. Continuous trawl monitoring started in 1992.	All data on a single, huge, exclamation-point delimited text file. >1M rows and 12	General: jessica.marchant@dcnr.alabama.gov | Gillnet data: chase.katechis@dcnr.alabama.gov | Hydro stations data: jason.hermann@dcnr.alabama.gov. Office phone: 251-861-2882	DISL will have buoys and monitoring programs. Continuous monitoring water quality multiparameter sondes and long-term weather data.

								columns.		
Mississippi	Mississippi Department of Marine Resources Fisheries Independent Monitoring (MDMR)	Monthly fixed stations	16 foot trawls	Depth. Most of the bottom would be mud. A few would be sand.	Temperature, DO, salinity, turbidity (always with secchi, now also with FMU), recently pH Surface and bottom measurements.	Mississippi sound, Biloxi Bay, St. Louis Bay	4 sites from 1974, hiatus 1980-1983, returns in 1984. 1996 expanded to 6 sites. 2009 increased to 12 sites. 2019 increased to 20.	CSV and Excel	Jason Saucier, jason.saucier@dmr.ms.gov	
Mississippi	Mississippi Department of Marine Resources Fisheries Independent Monitoring (MDMR)	Fixed WQ sondes	Sondes	None	Temperature and salinity, some with DO	11 sites. Mississippi sound and in estuaries	2008 to present	CSV download	Darrell Lambeth, Supervisory Hydrologist, dlambeth@usgs.gov | https://dmr.ms.gov/hydrological-monitoring/	Some data can be taken of the site for QA/QC
Louisiana	Louisiana Department of Wildlife and Fisheries (LDWF)	Six foot trawls stratified (Mar-Jul). Finfish fixed and stratified. Trawl sites are fixed.	Bio sampling: Offshore trawls, inshore trawls (6' and 16'), trammel nets, gill nets, oyster dredges. Constant recorder devices in the water. POC Nicole Smith nsmith@wlf.la.gov	Depth, bottom type, proximity to marsh	Temperature, DO, conductivity, salinity, turbidity. Top and bottom.	Spread over coastal LA.	Monthly or bi-monthly. Data back to 1965. Standardized in 1978. Environmental data more limited in early sampling.	Can be exported as CSV or Excel. Large files.	Michael Harden, mharden@wlf.la.gov. 225-765-2371 ext 1747.	Rainfall data can be pulled from LSU climatology. Mississippi flow has been shown to correlate with Brown shrimp success. Other LA state agencies: CPRA, DNR,

										and DEQ.
Texas	Texas Parks and Wildlife Department	Monthly stratified random sampling	Bag seins, bay trawls, gill nets, oyster dredges, and Gulf trawls	Qualitative. Bottom type. Habitat information mainly associated with bag seins. Recent effort to supplement habitat information.	Temperature, salinity, DO, turbidity. Bag sein and gill net will be surface collection. Trawl will be bottom collection.	9 major bays.	Monthly. Data starts in most bays in 1982. All of the Bays by 1986. 20 sampling sites for each bay per month.	Can be provided in CSV or Excel.	Mark Fisher, Science Director, Mark.Fisher@tpwd.state.tx.us. Habitat information from Emma Clarkson; Emma.Clarkson@tpwd.texas.gov 361-694-0226.	Comprehensive sampling. All gears have year-around coverage, except gill nets are conducted spring and fall. Only data gap is April-May 2020.
Gulf-wide	NOAA Southeast Area Monitoring and Assessment Program (SEAMAP) groundfish survey	Seasonal (summer / fall) stratified random	Trawls	Recently started doing camera drops on some surveys	Temperature, DO, salinity, turbidity, fluorescence. From CTD. Have altimeter (or an altitude meter) to assess how far off the bottom	Brownsville, TX to Florida Keys. 9-110 m depth.	Summer and fall cruises. Measurements for full time series (1987). Reliably from 2001. Sampling 911 CTD.	Access or CSV through data portal	Adam Pollack and Jeff Rester. Data portal: https://seamap.gsmfc.org/	Temperature and salinity is reliable back to the start of the timeseries. DO is less reliable until the early-2000s, then becomes reliable.
Gulf-wide	SEAMAP longline survey	Seasonal (spring/summer/fall) stratified random	Longline	None	Likely temperature, salinity, DO. Unsure of others.	Texas to Alabama. Out to 10 m.	Seasonal sampling. Started around 2007.	Access or CSV through data portal	Jeff Rester, Gulf States Marine Fisheries Commission. Data portal: https://seamap.gsmfc.org/	Inshore state sampling.
Gulf-wide	NMFS SEFSC longline	Annual (summer) stratified	Longline	Recently started doing camera drops on some surveys	Temperature, DO, salinity, turbidity, fluorescence. From	Gulf-wide. 9-366 m depth	Started 1995 to present.	Data dump. Access	Adam Pollack. adam.pollack@noaa.gov	DO more reliable after early-2000s

	survey	random			CTD.			or CSV.		
Gulf-wide	NMFS SEFSC Fall Plankton Survey	Annual fixed stations	Plankton tows	None	Temperature, DO, salinity, turbidity, fluorescence. From CTD.	Gulf-wide. 9 to several hundred meters	1982 to present	Data dump. Access or CSV.	David Hanisko. david.s.hanisko@noaa.gov	DO more reliable after early-2000s
Gulf-wide	NMFS SEFSC Spring Plankton Survey	Annual fixed stations	Plankton tows	None	Temperature, DO, salinity, turbidity, fluorescence. From CTD.	Gulf-wide. Off-shelf. Deep.	1982 to present	Data dump. Access or CSV.	David Hanisko. david.s.hanisko@noaa.gov	DO more reliable after early-2000s

3.11 FIGURES

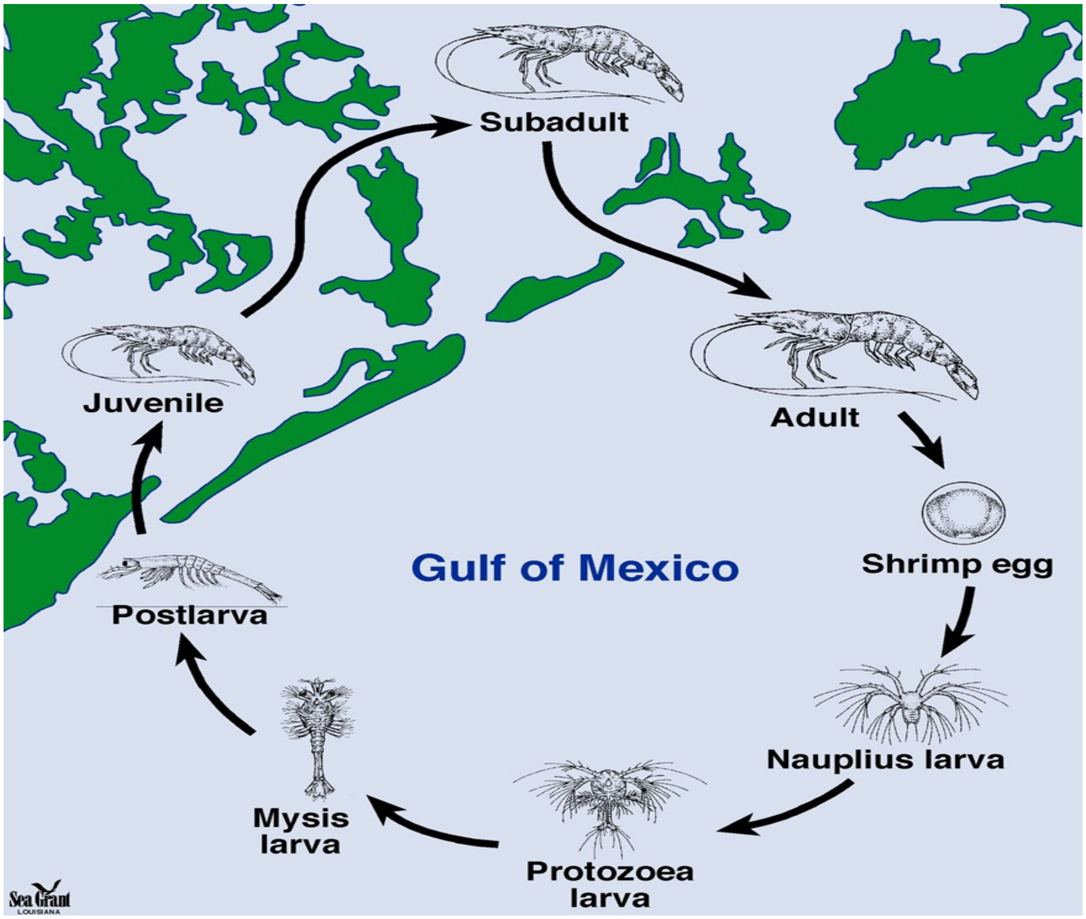


Figure 1

Representative life cycle for brown, white, and pink shrimp. Schematic from Florida Sea Grant.

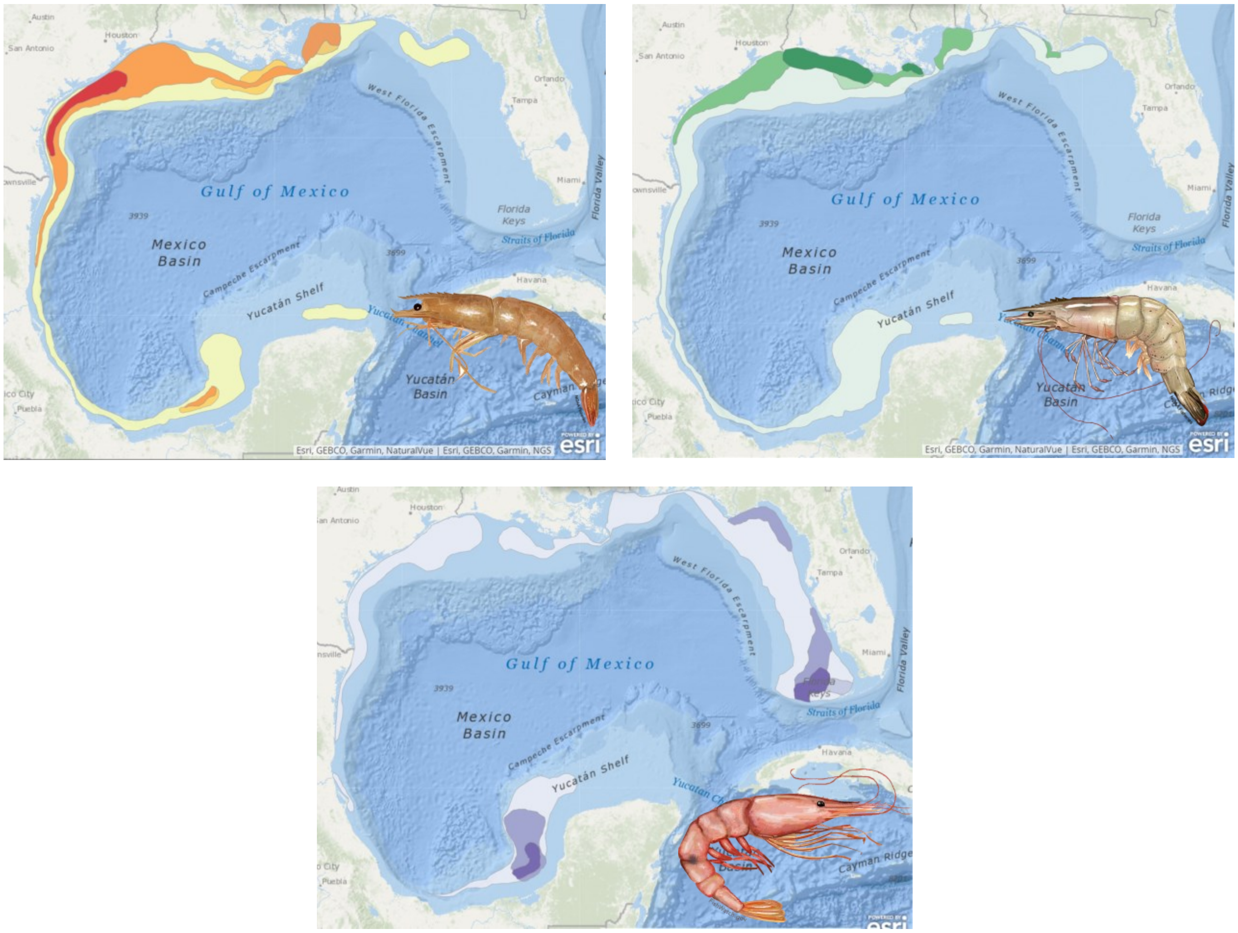


Figure 2

Distribution of shrimp catch by species. Maps were adapted from the Gulf of Mexico shrimp fishery story map. Species shown clockwise beginning in the top left are brown, white, and pink shrimp.

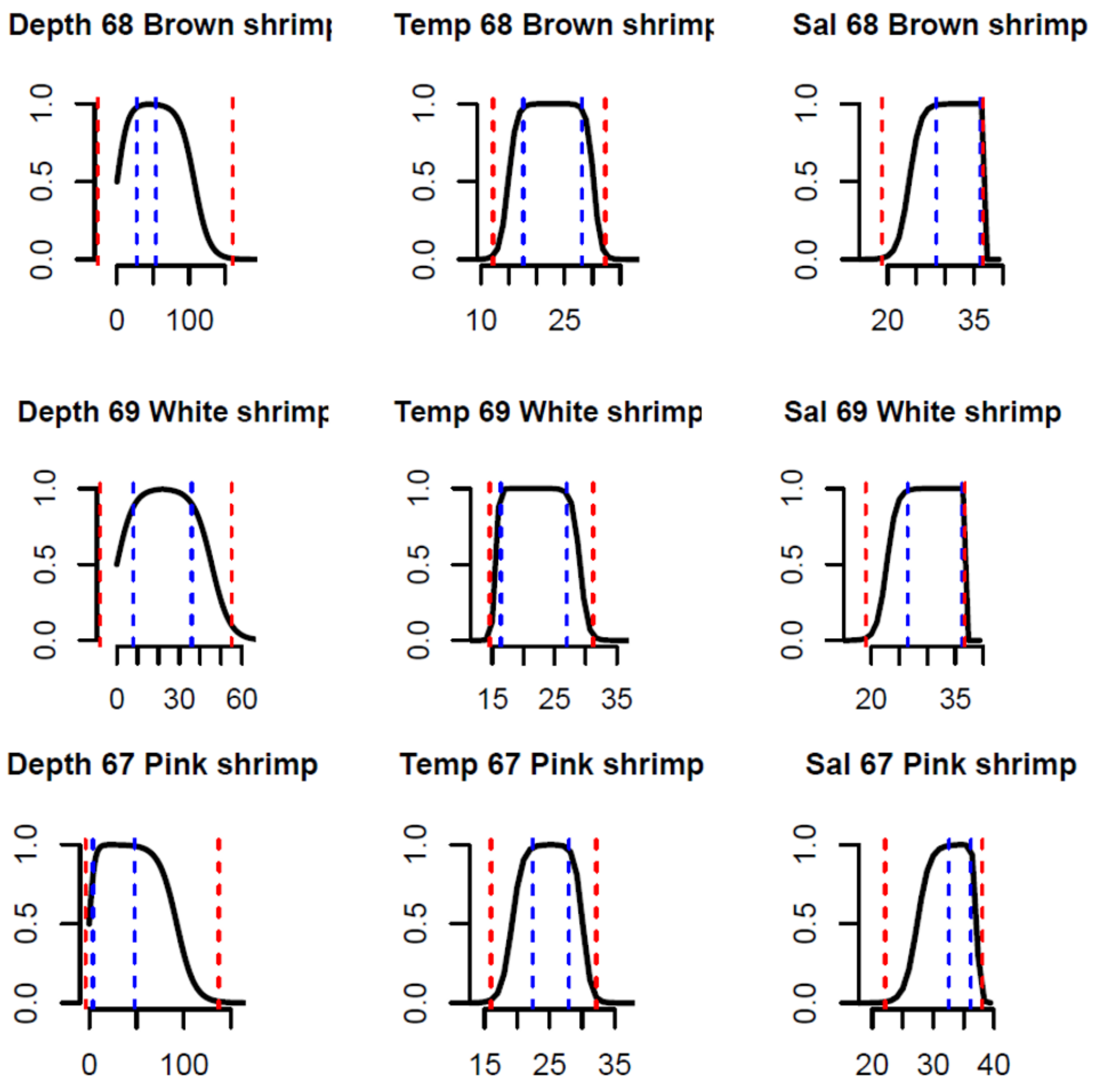


Figure 3

Depth (left), temperature (middle), and salinity (right) environmental preference envelopes for brown (top), white (middle), and pink (bottom) shrimp from an Ecopath with Ecosim and Ecospace model for the Gulf of Mexico, courtesy of Holden Harris. The units for depth are m, temperature is degrees C, and salinity is in ppt. Environmental preference functions were calculated with a double-logistic equation with four preference parameters: absolute minima and maxima (inner dashed blue lines) and preferred minima (outer dashed red lines)

4 INDICES OF POPULATION ABUNDANCE

4.1 OVERVIEW

The Index Working Group (IWG) was tasked with reviewing raw data and indices of abundance from surveys associated with sampling programs from the five Gulf States (Texas, Louisiana, Mississippi, Alabama, and Florida) and the Southeast Area Monitoring and Assessment Program (SEAMAP). Data for brown shrimp, white shrimp and pink shrimp were reviewed independently for small, medium, and large size categories (Table 1) across three discrete spatial areas in the northern Gulf of Mexico (Figure 1). Section 2 lists the contributed working papers containing the full descriptions of the sampling programs, individual surveys, datasets, analytical methods, and model diagnostics, reviewed by the IWG. All sampling programs, surveys, and associated data (nominal time series, abundance indices, etc.) were evaluated following the criteria listed in Section 3. Rationalizations for the recommendation or exclusion of a survey and/or data are given in the 'Comments on Adequacy for Assessment' in their respective sections.

4.1.1 Terms of Reference

The IWG was tasked with the following Terms of Reference

- Provide measures of population abundance that are appropriate for stock assessment.
    - Consider all available and relevant fishery-dependent and -independent data sources
    - Document all programs evaluated; address program objectives, methods, coverage, sampling intensity, and other relevant characteristics.
    - Provide maps of fishery and independent survey coverage, where possible.
    - Develop fishery and survey CPUE indices by appropriate strata (e.g., area) and include measures of precision and accuracy.
    - Provide appropriate measures of uncertainty for the abundance indices to be used in stock assessment models.
    - Document pros and cons of available indices regarding their ability to represent abundance.
    - For recommended indices, document any known or suspected temporal patterns in catchability not accounted for by standardization.
    - Provide appropriate measures of uncertainty for the abundance indices.

4.1.2 Group membership

Members of the IWG included: Adam Pollack (co-workgroup lead), David Hanisko (co-workgroup lead), Peyton Cagle, Dwayne Edwards, Jessica Marchant, Fernando Martinez-Andrade, Michelle Masi, Jason Saucier, Meagan Schrandt, Katie Siegfried, Ted Switzer, and James Tolan.

There were also several members of the Assessment Development Team and Workshop Panel that sat in on several workgroup sessions.

4.2 REVIEW OF WORKING PAPERS

The IWG reviewed the following working papers:

SEDAR87-DW-05 - Gulf of Mexico Brown, Pink, and White Shrimp Weight-Length Regression using SEAMAP Data

SEDAR87-DW-11 - Indices of relative abundance for Pink, Brown, and White Shrimp from surveys conducted in several Florida Gulf coast estuaries

SEDAR87-DW-12 - Inshore brown and white shrimp relative abundance in Louisiana

SEDAR87-DW-13 - Brown, White and Pink Shrimp Abundance Indices from SEAMAP Groundfish Surveys in the Northern Gulf of Mexico

SEDAR87-RD01 - SEAMAP Trawl Shrimp Data and Index Estimation Work Group Report

SEDAR87-RD03 - Mississippi Department of Marine Resources and University of Southern Mississippi Gulf Coast Research Laboratory Inshore Trawl Monitoring Programs: Sampling and Lab Protocols

SEDAR87-RD04 - Marine Fisheries Crustacean Section - Independent Sampling Activities: Field Manual

SEDAR87-RD05 - AL MRD Fisheries Assessment and Monitoring Program (FAMP)

SEDAR87-RD06 - AL MRD FAMP Assessment Sampling - Standard Operating Procedures

SEDAR87-RD07 - TPWD’s Gulf Trawl Sample Design

4.3 SURVEY EVALUATIONS

All surveys and associated data presented to the IWG were evaluated based on the following criteria:

- Temporal range
- Spatial range
- Consistent survey design (e.g. fixed sampling sites, stratified random etc.)
- Standardized sampling methodology (e.g. gear, vessels, effort, etc.)
- Ages and/or sizes represented
- Appropriate analytical methods

Surveys within each sampling program were independently evaluated based on the criteria listed above and deemed to be either Suitable or Not Suitable. The surveys then entered the second stage of review to determine whether or not their data would be recommended for use in the assessment. Based on the two determinations, surveys were assigned one of the following categories by the IWG:

- Suitable and Recommended: Based on the criteria listed above, the survey met the minimum requirements for being considered for use in the assessment and was deemed to be a representative example of the population trends for a given area.
- Suitable and Not Recommended: Based on the criteria listed above, the survey met the minimum requirements for being considered for use in the assessment and was deemed not to be a representative example of the population trends for a given area.
- Not Suitable (Not Recommended): Based on the criteria listed above, the survey did not meet the minimum requirements for being considered for use in the assessment

Evaluation of abundance indices used the same criteria listed above for the surveys and were deemed to be either Representative or Not Representative.

4.4 FISHERY-INDEPENDENT INDICES

4.4.1 SEAMAP

The Southeast Area Monitoring and Assessment Program (SEAMAP) is a collaborative effort between federal, state and university programs, designed to collect, manage and distribute fishery independent data throughout the region. The Summer and Fall Groundfish surveys initially covered an area between Brownville, TX and Mobile Bay, AL. It should be noted that shrimp statistical zone (SSZ) 10 was dropped from the survey universe in 1989 because of the increased number of hangs in the area as Alabama expanded their artificial reef permit area.

Beginning in 1987, the SEAMAP summer and fall groundfish surveys adopted a unified sample design. Strata were still defined by area and depth zone, but with an additional stratum based on time of day (day and night) incorporated into the design. Towing time was variable during the survey, ranging from 10 (min) to 55 (max) minutes, and was dependent on the time required to completely tow through a depth zone. If the depth zone could not be covered in 55 minutes, multiple tows were made at the station. The survey gear consists of a 12.8 m (42 ft) semi-balloon shrimp trawl with a 12.8 m headrope and does not contain a turtle excluder device (TED) or any bycatch reduction devices (BRD).

Major changes in the SEAMAP sample design occurred between the 2008 summer and fall surveys. Stratification by time of day was dropped, tow time was standardized to 30 minutes, and sampling effort allocated proportionally by the spatial area represented by each shrimp statistical zone and depth zone combination. Minor changes to depth zones were made during subsequent years with the current design utilizing two depth zones, which have been consistent since 2013. While the change in sample design occurred in 2008, it is important to note that the state partners did not adopt the new sample design until 2010.

In 2008, SEAMAP received supplemental funding that provided the opportunity to conduct experimental bottom trawl surveys on the West Florida Shelf. Based on the success of the experimental trawl surveys by the state of Florida, the surveys were fully expanded in 2010 to include the area from Mobile Bay, AL to Key West, FL using identical gear as the historical SEAMAP survey.

Methods of Estimation:

Working Paper Number: SEDAR87-DW-13

Data Type: Fishery Independent

Time Series: 1987-2022

Standardization: Delta-lognormal (Lo et al. 1992)

Submodel Variables: Year, time of day, statistical zone, depth

Abundance Indices: Tables 7 to 32 in working paper

Comments on Adequacy for Assessment:

Sampling Program:

SEAMAP, consisting of the Summer and Fall Groundfish Surveys, was deemed an appropriate sampling program for brown shrimp, white shrimp, and pink shrimp. This program represents a long-term fishery independent survey that successfully captures the target shrimp species across the northern Gulf of Mexico. Representation of the three size classes was species dependent, however the underrepresented size category data could be combined with the other size categories if needed.

Index of Abundance:

Brown shrimp:

The IWG reviewed and evaluated 30 brown shrimp abundance indices and/or data series with the final decision for inclusion shown in Table 3. In general, all size classes across statistical zones 18-21 and 11-17 and both survey designs (1987-2008 and 2009-2022) were deemed ‘Representative’. For statistical zones 8-10, no indices were able to be constructed for the Summer Groundfish Survey due to the low catch rates for all size categories. For the Fall Groundfish Survey, abundance indices were calculated for only the large and medium size classes, but deemed to be ‘Not Representative’, mainly due to the low catch rates.

White shrimp:

The IWG reviewed and evaluated 30 white shrimp abundance indices and/or data series with the final decision for inclusion shown in Table 4. For the Summer Groundfish Survey, only the abundance indices for the large size category were deemed to be ‘Representative’ for statistical zones 18-21 and 17-11. The abundance index for the medium size category was deemed ‘Not Representative’, and an abundance index was not able to be produced for the small size category due to low catches. In addition, no abundance indices were able to be produced for statistical zones 8-10.

Pink shrimp:

The IWG reviewed and evaluated 6 pink shrimp abundance indices and/or data series with the final decision for inclusion shown in Table 5. For the Summer Groundfish Survey, the abundance indices for the large and medium size classes were deemed 'Representative', while the index for the small size category was deemed 'Not Representative'. For the Fall Groundfish Survey, all the abundance indices were deemed 'Not Representative' due to issues with spatial coverage during the early part of the time series and that it is potentially indexing the same portion of the population as the Summer Groundfish Survey.

4.4.2 TEXAS

Gulf Trawl:

The Texas Parks and Wildlife – Coastal Fisheries Division samples five Gulf areas within the Texas Territorial Sea (shoreline to nine nautical miles offshore), where 16 samples are collected every month in each area (80 samples per month in total).

Data are collected as a stratified cluster sampling design; each Gulf area serves as non-overlapping strata with a fixed number of samples per month. A cluster sample is defined as a type of probability sample where each sample unit is a collection, or cluster, of elements. Specifically, locations are sampled and include every organism encountered at that location as part of the sample.

Gulf trawl sample locations are randomly selected from grids (1-minute latitude by 1-minute longitude) within the Texas Territorial Sea that contain water >1.8 m deep in at least ⅓ of the grid and are known to be free of obstructions. One half of the samples in each area are collected during each half (days 1-15 and 16-31) of the month to ensure good temporal distribution of samples.

Trawls are 6.1 m (20 ft) wide otter trawls with 38 mm (1.5 in) stretched nylon multifilament mesh throughout. Trawl doors are 1.2 m (48 in) long and 0.5 m (20 in) wide; and constructed of 13 mm (0.5 in) plywood with angle iron framework and iron runners. Trawls are towed linearly, parallel to the fathom curve; direction of tow (north or south) is randomly chosen for the initial tow and alternated on subsequent tows. All tow times are 10 minutes in duration. No grid is sampled more than once per month. Sampling takes place during daytime, from 1/2 hour before sunrise to 1/2 hour after sunset.

Organisms greater than 5 mm total length, captured in the trawl or stranded on the boat deck, are identified to the lowest possible phylogenetic unit (genus and species preferred). Up to 50 randomly selected shrimp of each commercial species (brown, white and pink) are measured. Sex and female maturity stage are determined for up to 50 white shrimp.

Water quality parameters of bottom salinity (ppt), water temperature (°C), dissolved oxygen (ppm) and turbidity [Nephelometric Units (NTU)] are measured prior to each Gulf trawl sample.

<u>Methods of Estimation:</u>

Working Paper Number:

Data Type: Fishery Independent

Time Series: 1987-2022

Standardization: Nominal Index combined for all areas sampled across all years.

Submodel Variables: N/A

Abundance Indices: N/A

Comments on Adequacy for Assessment:

Sampling Program:

The IWG recommends using the 20-foot Gulf trawl survey data for shrimp abundance index development beginning in 1987. This survey captures a wide range of size classes and is conducted throughout the year with samples collected monthly at randomly chosen stations. Despite representing a smaller spatial extent than the SEAMAP survey and limited spatial overlap, these data represent a larger temporal series for shrimp abundance

Index of Abundance:

The IWG reviewed nominal CPUE time series for small, medium and large size categories of brown shrimp and white shrimp. The time series for the small size category of brown shrimp and white shrimp were deemed 'Representative', while the medium and large size category were deemed 'Not Representative' due to the low catch rates in those size categories.

Bay Trawl:

The Texas Parks and Wildlife – Coastal Fisheries Division samples nine major bay systems along the Texas coast, where 20 bay trawl samples are collected every month in larger bays (Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay) and 10 bay trawl samples are collected every month in smaller bays (Sabine Lake, East Matagorda Bay, upper Laguna Madre, lower Laguna Madre). A total of 140 bay trawl samples are collected every month.

Data are collected as a stratified cluster sampling design; each bay serves as non-overlapping strata with a fixed number of samples per month. A cluster sample is defined as a type of probability sample where each sample unit is a collection, or cluster, of elements. Specifically, locations are sampled and include every organism encountered at that location as part of the sample.

Bay trawl sample locations are randomly selected from grids (1-minute latitude by 1-minute longitude) within each bay system that contain water >1 m deep at mean low tide in at least ⅓ of the grid and are known to be free of obstructions. One half of the samples in each bay are collected during each half (days 1-15 and 16-31) of the month to ensure good temporal distribution of samples.

Trawls are 6.1 m (20 ft) wide otter trawls with 38 mm (1.5 in) stretched nylon multifilament mesh throughout. Trawl doors are 1.2 m (48 in) long and 0.5 m (20 in) wide; and constructed of 13 mm (0.5 in) plywood with angle iron framework and iron runners.

Trawls are towed at 3 mph in a circular manner, tow times are 10 minutes in duration. No grid is sampled more than once per month. Sampling takes place during daytime, from 1/2 hour before sunrise to 1/2 hour after sunset.

Organisms greater than 5 mm total length, captured in the trawl or stranded on the boat deck, are identified to the lowest possible phylogenetic unit (genus and species preferred). Up to 50 randomly selected shrimp of each commercial species (brown, white and pink) are measured.

Water quality parameters of bottom salinity (ppt), water temperature (°C), dissolved oxygen (ppm) and turbidity [Nephelometric Units (NTU)] are measured prior to each Gulf trawl sample.

Methods of Estimation:

Working Paper Number:

Data Type: Fishery Independent

Time Series: 1987-2022

Standardization: Nominal Index combined for all areas sampled across all years.

Submodel Variables: N/A

Abundance Indices: N/A

Comments on Adequacy for Assessment:

Sampling Program:

TPWD recommends using the 20-foot bay trawl survey data for shrimp abundance index development beginning in 1987. This survey captures a wide range of size classes and is conducted throughout the year with samples collected monthly at randomly chosen stations

Index of Abundance:

The IWG reviewed nominal CPUE time series for small, medium and large size categories of brown shrimp and white shrimp. The time series for the small size category of brown shrimp and white shrimp were deemed ‘Representative’, while the medium and large size category were deemed ‘Not Representative’ due to the low catch rates in those size categories.

4.4.3 LOUISIANA

The Marine Fisheries Division develops management recommendations for Louisiana’s shrimp resources through an ongoing systematic sampling and monitoring program which utilizes a variety of gear types designed to provide technical data on shrimp population dynamics and associated hydrological and environmental conditions and has resulted in the most extensive and continuous coast wide data set among the Gulf states which dates to the early 1960's.

This fisheries-independent (FI) monitoring program is largely based upon methodology developed during the Cooperative Gulf of Mexico Estuarine Inventory and Study (GMEI; Perret et al. 1971). That project was conducted in cooperation with the Gulf States Marine Fisheries Commission (GSMFC), the states of Alabama and Mississippi, and the National Marine Fisheries Service (NMFS) laboratories at Galveston, Texas and St. Petersburg, Florida.

Standardized sampling methods and procedures used in the GMEI were developed by the Technical Coordinating Committee of the GSMFC.

The FI 4.9 m (16 ft) trawl survey database dates back to 1965 for some areas in Louisiana. The program utilizes a 4.9 m (16 ft) otter trawl in state inshore waters to sample and monitor the abundance, size, and distribution of penaeid shrimp, blue crab, and groundfish in the larger inshore bays, waterways, and passes. Sampling and station selection for the 4.9 m (16 ft) trawl survey were standardized by the late 1970's, which is why an index time series beginning in 1980 is recommended. Enhanced monitoring was initiated in late 2010 by adding stations to increase the spatial coverage of the survey within each Coastal Study Area. For each 4.9 m (16 ft) trawl sample, the net is towed for ten minutes (timed when the trawl first begins to move forward to when it stops forward movement) at a constant speed and in a sinusoidal pattern to avoid prop wash in shallow waters. This survey also provides data for indices of abundance for use in stock assessment for blue crab and some finfish species.

For additional details of the 16-foot inshore otter trawl, see SEDAR 87 RD04: Marine Fisheries Crustacean Section – Independent Sampling Activities: Field Manual.

In addition to the 4.9 m (16 ft) trawl gear, the FI monitoring program also utilizes a 1.8 m (6 ft) trawl in state inshore nurseries and a 6.1 m (20 ft) trawl in state outside waters. The 1.8m (6 ft) trawl survey dates back to the late 1960s and is designed to monitor shrimp recruitment. This trawl survey changes over time from established standardized sample locations to stratified random in 2013. The 6.1 m (20 ft) trawl survey began with standardized sample locations in 2013.

Methods of Estimation:

Working Paper Number: SEDAR 87 DW-12: Inshore brown and white shrimp relative abundance in Louisiana

Data Type: Fishery Independent

Time Series: 1980-2022

Standardization: Delta-lognormal (Lo et al 1992 sans bias correction)

Submodel Variables: N/A

Abundance Indices: N/A

Comments on Adequacy for Assessment

Sampling Program:

LDWF recommends using the FI 16-foot trawl survey data for shrimp abundance index development beginning in 1980. This survey captures a wide range of size classes and is conducted throughout the year with samples collected monthly at each station.

For brown shrimp, LDWF recommends developing an index of abundance from 1980-2022 for the months of March-June only. These months cover the primary period that brown shrimp recruit into estuarine waters and when developing sub-adults leave.

For white shrimp, LDWF recommends developing an index of abundance from 1980-2022 for all months of the year. White shrimp are present in inshore waters throughout the year as overwintering adults in spring months and as new recruits in summer months, giving the best option for an abundance index that includes all size classes.

LDWF does not recommend using the 6-foot trawl data because this data does not give good representation of all class sizes; this gear is primarily sampled in interior marshes looking for recruitment abundance and average size. The 20-foot offshore trawl data was expanded in 2010 using the 16-foot trawl, but later transitioned into a larger 20-foot balloon trawl in 2013. Because of this short time series, the 20-foot offshore data is not recommended.

Index of Abundance:

Brown shrimp:

The IWG reviewed annual abundance indices for brown shrimp developed for three size categories using samples from the months of March – June only. The three size categories for the brown shrimp indices are small (TL <115.6mm), medium (TL ≥115.6 - ≤151.8mm), and large (TL ≥151.8mm). The small and medium size categories of brown shrimp were deemed ‘Representative’, while the large size category was deemed ‘Not Representative’ due to the low catch rates.

White shrimp:

The IWG reviewed annual abundance indices for white shrimp developed for three size categories using samples from all months of the year. The three size categories for the white shrimp indices are small (TL <108.1mm), medium (TL ≥108.1 - ≤144.3mm), and large (TL >144.3mm). All size categories of white shrimp were deemed ‘Representative’.

See SEDAR 87 DW-12: Inshore brown and white shrimp relative abundance in Louisiana for details on indices.

4.4.4 MISSISSIPPI

MS Long-term Monitoring Program:

Long-term trawl monitoring for shrimp and other species began in Mississippi in 1973. The program provides ongoing monitoring and assessment of commercially and recreationally important fish and shellfish species in Mississippi territorial waters to provide fisheries managers with current biological data required for management decisions. The trawl monitoring program also provides a long-term database to profile inshore species abundance through time to detect long-term changes in abundance.

Sampling is conducted using a 19 mm (.75 in) bar mesh 4.9 m (16 ft) (headrope measurement) otter trawl and with a 6 mm (.25 in) liner in the cod end. All trawls are towed at a constant speed for 10 minutes. The standard (rostrum to telson) length (mm), and individual weight (g) of up to 20 individuals are recorded and the total weight (g) is recorded for all penaeid shrimp species by station.

Mississippi’s long-term trawl monitoring program originally included four fixed stations located along a transect in the Mississippi Sound, Back Bay of Biloxi and Bernard Bayou (Biloxi Transect). The Biloxi Transect was expanded in 2009 to include two additional stations in the

Mississippi Sound located inside Horn Island and at Dog Keys Pass. Six trawl sites were also added in 2009 along a transect in the western Mississippi Sound, St. Louis Bay and the Jourdan River (Western Sound). In 2019 following an historic opening of the Bonnet Carré Spillway, eight trawl sites were added in the western Mississippi Sound to monitor the long-term effects of freshwater from the spillway's operation and to monitor baseline conditions.

Biloxi Transect monitoring work was completed by University of Southern Mississippi, Gulf Coast Research Laboratory (GCRL) from 1973-2017, and by Mississippi Department of Marine Resources (MDMR) from 2018-2022. Western Sound trawl monitoring was completed by MDMR from 2009-2017, and by GCRL from 2019-2022. Expanded Western Sound monitoring was completed by MDMR from 2019-2022.

MS Shrimp Monitoring Program:

The objective of Mississippi's shrimp monitoring program is to monitor size and seaward migration of shrimp within the Mississippi Sound. Historically, sampling was conducted only from April to June twice per week to collect brown shrimp lengths. Average shrimp size is determined and daily growth rates are estimated to project when shrimp could reach legal size. This monitoring program historically included nine fixed sample stations and a 10th station was added in 2016. The program was expanded to include monthly, year-round sampling in 2019 so that shrimp sizes could be monitored year-round and to ensure that existing management strategies such as seasonal area closures are still appropriate to protect subsequent shrimp crops.

The shrimp monitoring program is conducted using a 19 mm (.75 in) bar mesh 4.9 m (16 foot) (headrope measurement) otter trawl. All trawls are towed at a constant speed for 10 minutes. Penaeid shrimp and identified to species. The standard (rostrum to telson) length (mm) of up to 50 individuals are recorded and the total weight (g) and total number are recorded for all penaeid shrimp species by station.

Methods of Estimation:

Working Paper Number: SEDAR 87 RD03

Data Type: Fishery Independent

Time Series: 1984-2022

Standardization: Delta-lognormal (Lo et al 1992 sans bias correction)

Submodel Variables: N/A

Abundance Indices: N/A

Comments on Adequacy for Assessment:

Sampling Program:

MS Long-Term Monitoring Program:

- Length data of penaeid shrimp is not available for samples collected from 1973-1983 so only 1984-2022 data was recommended for consideration in establishing an index.

- Due to variability between habitat type between the long-term original four sites and the sites which were added in 2009 and 2019 only the original four sites were recommended for consideration in establishing an index.
- Peak abundance of juvenile and subadult Brown Shrimp within the survey area occurs from March to June. Due to the lack of Brown Shrimp in other months the MDMR recommended that only March to June data be considered for establishing an index.

Shrimp Monitoring Program:

Due to seasonality of data collection - samples collected April - June only from 2008-2018, the lack of individual weights, and the difference in gear from the long-term monitoring program - unlined trawl vs. liner trawl - this data is not recommended for consideration in establishing an index.

Index of Abundance:

Nominal indices based on the Mississippi trawl data were provided to the working group for White and Brown shrimp. Mississippi data was also combined with Louisiana and Alabama data and combined indices for White and Brown shrimp were presented to the group.

4.4.5 ALABAMA

The fisheries assessment and monitoring program (FAMP) is a fishery independent database that helps to determine the status of populations of marine organisms throughout Alabama coastal waters. This data is available to fisheries managers to use in the analysis of growth, seasonal and geographical distribution, changes in population structures and correlation of abundance with some abiotic factors for all Alabama marine fauna. Monthly sampling for all penaeid shrimp, *Callinectes* sp. crabs and finfish species started in October 1980. All organisms were enumerated and weighed according to SEAMAP procedures beginning in 1990. In 1998 the program shifted to an interagency program with ADEM; water quality parameters and the number of sites sampled were expanded but effort was reduced to one sampling regime per quarter. After determining that quarterly sampling did not provide enough definition to accurately observe trends, monthly sampling was resumed in October 2000. Given the revisions of the SEAMAP program and the importance for similar sample collection/processing throughout the Gulf, AMRD adjusted the FAMP program in order to produce data complementary to SEAMAP protocols beginning in May 2010. Sample sites were selected at the beginning of the program to be most representative of the marine fauna found in Alabama waters. Current sample locations and gear used at those sites in Mississippi Sound, Mobile Bay, the Perdido system, Little Lagoon and Alabama's territorial sea can be found in Section 3 and 4 of the following working paper: SEDAR87-RD-05. Three methods of sample collection are/were employed within these areas to target a wide range of fauna throughout their life history. Seine hauls and Beam Plankton nets are/were used to target juvenile life stages utilizing shoreline habitats, and otter trawls are used to target juvenile and adult stages occurring within deeper waters. Beam-Plankton sampling was discontinued after December 2018. Due to the variability in seine and BPL sampling methods and the limited capture of species of interest, only data obtained from trawl samples is recommended for use in this assessment.

For trawl sample collection procedures, see reference document SEDAR87-RD06.

For gear specifications, see reference document SEDAR87-RD06, Appendix E.

Excluded Data:

- Trawl samples collected in the Perdido System prior to 2013 were removed from the data set due to variations in gear used.
- Size class data obtained from trawl samples collected from 1985 to 2000, as shrimp were only counted and not measured during this time frame.

Methods of Estimation:

Working Paper Number:

Data Type: Fishery Independent

Time Series:

Total abundance data: February 1981- December 2021

Size class data: February 1981- May 1985, October 2000 - December 2021

Standardization: N/A (data was not standardized)

Submodel Variables: N/A

Abundance Indices: N/A

Comments on Adequacy for Assessment:

Sampling Program:

AMRD FAMP

Due to the variability in seine and BPL sampling methods and the limited capture of species of interest, only data obtained from trawl samples is recommended for use in this assessment.

Index of Abundance:

No abundance indices were reviewed by the IWG, only nominal time series.

4.4.6 FLORIDA

The Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWC-FWRI) has conducted fisheries-independent monitoring (FIM) surveys in estuaries of Florida's Gulf Coast since 1989. Initial surveys (FWC-FWRI long-term FIM) in Charlotte Harbor, Tampa Bay, Cedar Key, and Apalachicola Bay used small-mesh seines, otter trawls, and multi-panel gillnets during a limited 10-week seasonal window in the fall and spring. In 1998, these surveys were modified to a monthly stratified-random sampling design that used a 21.3 m × 1.8 m center-bag haul seine (3.2 mm nylon mesh), a 6.1 m otter trawl (38 mm stretched mesh with a 3.2 mm nylon mesh liner in the cod end), and a 183 m × 3 m center-bag haul seine (37.5 mm stretch nylon mesh). The 21.3 m seine was deployed in shallow (≤1.5 m) shoreline and nearshore habitats (approximate area sampled = 140 m^2). The 21.3 m seine was also deployed in tidally influenced river habitats in a semi-circular set from the stern of a vessel and retrieved along the shoreline (approximate area = 68 m^2). In bay habitats, trawls were towed for 10 minutes along a path approximately 0.2 nautical miles (approximate area = 1,482 m^2). Trawls deployed in river habitats were towed for 5 minutes, traveling approximately 0.1 nautical miles (approximate area = 741 m^2). The 183 m seine was deployed along shoreline habitats (≤2.5 m), forming a rectangular shape, and sampled an approximate area of 4,120 m^2. Two sampling changes are of note for developing indices of abundance from FWC-FWRI long-term FIM data. First, bay trawl sampling was originally (1998–2004) seasonal and in 2005 became monthly, resulting in a nearly three-fold increase in annual effort for all estuaries. And second, 21.3 m seine sampling was expanded in 2016 in Charlotte Harbor to include tidal tributaries and creeks, with the intent of providing more data for juvenile Snook, resulting in a nearly five-fold increase in annual effort in Charlotte Harbor.

The FWC-FWRI-FIM program also conducts a complementary survey in polyhaline (salinity >18) seagrass areas of various Gulf Coast estuaries. In 2008, the polyhaline seagrass habitat survey was initiated to complement the existing long-term FIM surveys to better describe species assemblages associated with this under-sampled habitat within the long-term FIM survey. The polyhaline seagrass survey is conducted monthly (June–November) in St. Andrew Bay, Apalachicola Bay, the Big Bend region, Tampa Bay, and Charlotte Harbor. The survey was originally a multi-gear survey, using the same 6.1 m otter trawl and 183 m hauls seine as the long-term FIM survey. Both gear types were used to sample polyhaline seagrass habitats with ≥50% submerged aquatic vegetation cover. Haul seines were set in a rectangular shape along a shallow shoal (<0.5 m water depth) and trawls were towed in 1.0 m to 7.6 m of water depth. Each trawl was towed for 5 minutes, traveling approximately 0.1 nautical miles (approximate area sampled = 741 m^2). After evaluating the ability of the polyhaline survey to yield statistically powerful data for detecting temporal trends in species' abundance, the survey was amended in 2019 to discontinue the use of haul seines and increase the sample size (number of nets deployed) of the 6.1 m otter trawl.

Methods of Estimation:

Working Paper Number: SEDAR 87 DW-11

Data Type: Fishery Independent

Time Series:

- **Pink Shrimp :**1998-2022 (FWC-FWRI long-term), 2008-2022 (FWC-FWRI polyhaline seagrass)
- **Brown Shrimp:** 2001-2022 (FWC-FWRI long-term)
- **White Shrimp:** 2001-2022 (FWC-FWRI long-term)

Standardization: Generalized Linear Model (GLIMMIX, SAS Institute 2006)

Submodel Variables:

- **Pink Shrimp** (FWC-FWRI long-term): SAV percentage, Gear, Bottom type, Month, Bay, Salinity quantile, Year, Depth quantile, Temperature quant, Shore type
- **Pink Shrimp** (FWC-FWRI polyhaline seagrass): Bay, Salinity quantile, Bottom type, Year, Shore type, Month, Temperature quantile, SAV percent
- **Brown Shrimp** (FWC-FWRI long-term): Zone, Bottom type, Salinity quantile, Month, Effort (sampled area over 100m^2), SAV presence, Year, Depth quantile

- **White Shrimp** (FWC-FWRI long-term): Salinity quantile, Gear, Bottom type, Shore type, Month, Effort (sampled area over $100m^2$), Year, Depth quantile, SAV presence

Abundance Indices: Tables 17 to 20 in working paper.

Comments on Adequacy for Assessment:

Sampling Program:

The FWC-FWRI Long-term FIM survey is conducted in Charlotte Harbor, Tampa Bay, Cedar Key, and Apalachicola Bay, using three primary gears: a 21.3 m center-bag haul seine (3.2 mm nylon mesh), a 6.1 m otter trawl (38 mm stretched mesh with a 3.2 mm nylon mesh liner in the cod end), and a 183- center-bag haul seine (37.5 mm stretch nylon mesh). The polyhaline seagrass survey is conducted monthly (June–November) in St. Andrew Bay, Apalachicola Bay, the Big Bend region, Tampa Bay, and Charlotte Harbor, using the 6.1 m otter trawl.

Gear:

The 21.3 m seine is recommended for use in the assessment. With a 3.2 mm mesh, this gear captures a wide size range of shrimp (Figures 2-5, SEDAR 87 DW-11) in multiple habitats. Frequency of occurrence within this gear was as high as 61% for Pink Shrimp, 10% for Brown Shrimp, and 10% for White Shrimp (Tables 1-12, SEDAR 87 DW-11).

The 6.1 m otter trawl is recommended for use in the assessment. With a 3.2 mm mesh liner, this gear captures a wide range of sizes (Figures 2-5, SEDAR 87 DW-11). This gear has frequencies of occurrence as high as 69% for Pink Shrimp, 42% for Brown Shrimp, and 40% for White Shrimp. In addition, the 6.1 m otter trawl samples habitat that is not accessible to the seine gear (Tables 1-12, SEDAR 87 DW-11).

The 183 m seine is not recommended for use in this assessment. With a stretch mesh of 37.5 mm, this gear is size-selective to the larger sub-adult or adult portion of the estuarine shrimp population. In addition to the narrow size selectivity, frequency of occurrence in this gear is generally very low for all three species.

Index of Abundance:

Indices of abundance for Pink Shrimp were developed using long-term FIM data and generalized linear models; however, all years prior to 1998 were excluded from analyses due to reduced temporal coverage during the year (Figure 20, SEDAR 87 DW-11). Analyses of Pink Shrimp abundances were further reduced to only include Charlotte Harbor and Tampa Bay because Pink Shrimp were captured much less frequently in Florida's northern Gulf Coast estuaries (Tables 1-3, SEDAR 87 DW-11). Samples collected using 183 m × 3 m center-bag haul seines were also excluded from the analyses because the seine's larger mesh size led to very low catches of Pink Shrimp. A total of three indices of abundance were explored and presented to the Index Working Group for Pink Shrimp from the FWC-FWRI long-term FIM program: 1) a full model, which included all data; 2) a reduced model that excluded the Charlotte Harbor tidal tributaries and creeks sampling expansion (2016–2022); and 3) a reduced model that excluded the Charlotte Harbor tidal tributaries and creeks (2016–2022) as well as the bay trawl expansion (2005–2022). All three indices of abundance had similar temporal trends and the third model had the lowest coefficients of variation. Therefore, the model recommended by the group was the reduced model that excluded the Charlotte Harbor tidal tributaries and creeks (2016–2022) as well as the bay trawl expansion (2005–2022). The recommended final subset model (1998-2022) included data from bay and river-deployed 21.3 m seines and river-deployed 6.1 m otter trawls.

An index of abundance for Pink Shrimp was also developed from the polyhaline seagrass survey, via generalized linear model (Figure 21, SEDAR 87 DW-11). As with long-term FIM analyses, polyhaline seagrass survey analyses of Pink Shrimp excluded northern estuaries because of low catches in the northern estuaries (Tables 4, SEDAR 87 DW-11). The index of abundance from the polyhaline seagrass survey included data from the 6.1 m otter trawls from 2008 through 2022 and is recommended.

An index of abundance was developed for Brown Shrimp via generalized linear models using data from long-term FIM data collected in Apalachicola Bay (Figure 22, SEDAR 87 DW-11). Data from all other estuaries were excluded because Brown Shrimp were either rarely collected or absent in all other Gulf estuaries (Tables 5-7, SEDAR 87 DW-11). In addition, all years prior to 2001 were excluded from analysis to conserve a time series with analogous gear use and spatial coverage. River deployments of the 21.3 m center bag seine were excluded because Brown Shrimp were rarely collected in these habitats (Tables 6, SEDAR 87 DW-11). As with the Pink Shrimp indices, the 183 m haul seines were excluded because of low catch rates in this larger mesh size gear. The developed brown shrimp index was determined to be suitable and recommended for use. The final recommended subset model (2001-2022) included data from bay-deployed 21.3 m seines and bay and river-deployed 6.1 m otter trawls.

An index of abundance was developed for White Shrimp via generalized linear models using data from long-term FIM data collected in Apalachicola Bay (Figure 23, SEDAR 87 DW-11). White Shrimp catch was limited to the northern Florida Gulf Coast estuaries, with 97% of the catch occurring in Apalachicola Bay (Tables 9-12, SEDAR 87 DW-11). As with the Brown Shrimp index, all years prior to 2001 were dropped from analysis. White Shrimp catch predominantly occurred within spatial zones that encompassed the lower reaches, and discharge plume, of the Apalachicola River; therefore, all other spatial zones were excluded from the analysis. Sampling stations deploying the 183 m seine were also removed from the analysis due to low catch rates of White Shrimp. The developed White Shrimp index was determined to be suitable and recommended for use. The final recommended subset model (2001-2022) included data from bay and river-deployed 21.3 m seine and 6.1 m otter trawls.

Indices of abundance of Brown and White Shrimp were not developed from FWC-FWRI polyhaline seagrass surveys because this survey represents a shorter time series as compared to the FIM long-term Survey. In addition to the shortened time series, catches of Brown and White Shrimp within this survey were low in frequency and overall catch (Tables 8,12, SEADAR 87-DW-11).

4.4.7 COMBINED ALABAMA, MISSISSIPPI, AND LOUISIANA INDICES

Similarities in methods exist between the FI monitoring programs in Alabama, Louisiana, and Mississippi. Based on these similarities, a combined index among the three states was initiated during the Data Workshop (see above for detailed information on each state's FI monitoring programs).

Alabama, Louisiana, and Mississippi recommended using the combined FI 16-foot trawl survey data from the individual state sampling programs as the foundation for combined shrimp abundance index development. These surveys capture a wide range of size classes and are conducted throughout the year with samples collected monthly at each station. For brown shrimp, the states recommended developing an index of abundance from a potential span of 1980-2022 for the months of March-June only. These months cover the primary period that brown shrimp recruit into estuarine waters and when developing sub-adults leave. Louisiana FI data will be used for years 1980-2022, Mississippi 1984-2022, and Alabama 2001-2021. These time frames are when FI data was gathered with the inclusion of individual lengths. For white shrimp, the states recommend developing an index of abundance with a potential span of 1980-2022 for all months of the year. White shrimp are present in inshore waters throughout the year as overwintering adults in spring months and as new recruits in summer months, giving the best option for an abundance index that includes all size classes. The same potential time series of observations by state sampling programs would be considered for this index. A combined white shrimp index removing all size classification was also discussed.

Several preliminary nominal delta-lognormal combined indices of abundance for white and brown shrimp were examined during the workshop as a focus for further discussions (Figures 3-4). The core of which focused on the overlap of sampling years and potential weighting of data from the individual state sampling programs. The combined sampling programs span 1980-2022. However, all three sampling programs only overlap from 2001 to 2021 and Mississippi and Louisiana only overlap from 1984 to 2022. Therefore, raising questions as to whether a longer time series from one or two areas vs shorter times series from all three programs was more advantageous. The spatial area of inference for each of the state sampling programs also varies significantly, with the state of Louisiana accounting for the vast majority of the area of interest. The group determined that spatial weighting of data from the individual sampling programs is likely warranted and needed to be further explored.

Given the need to further explore the times series of data to include and the need to pursue potential spatial weighting of data among the three programs, the IWG recommends that combined indices of abundance from Alabama, Mississippi and Louisiana be pursued as a research recommendation.

4.5 CONSENSUS RECOMMENDATIONS

The review of data associated with individual sampling programs conducted by the states of Texas, Louisiana, Mississippi, Alabama, and Florida and the National Marine Fisheries Service are summarized in Table 2. The spatial ranges of the individual sampling programs are in Figure 2. Recommendations regarding data sets to examine representative trends in abundance for brown, white and pink shrimp are summarized respectively in Tables 3, 4 and 5. The species summaries include recommendations for each size category and sampling region.

4.6 RESEARCH RECOMMENDATIONS

- Explore survey / gear calibration studies among state and federal sampling programs
- Perform post hoc analysis to potentially account for habitat classification variables and on indices of abundance
- Examination of whether due to zeros, indices based on monthly data may best be structured to focus on core recruitment months or accommodate in model

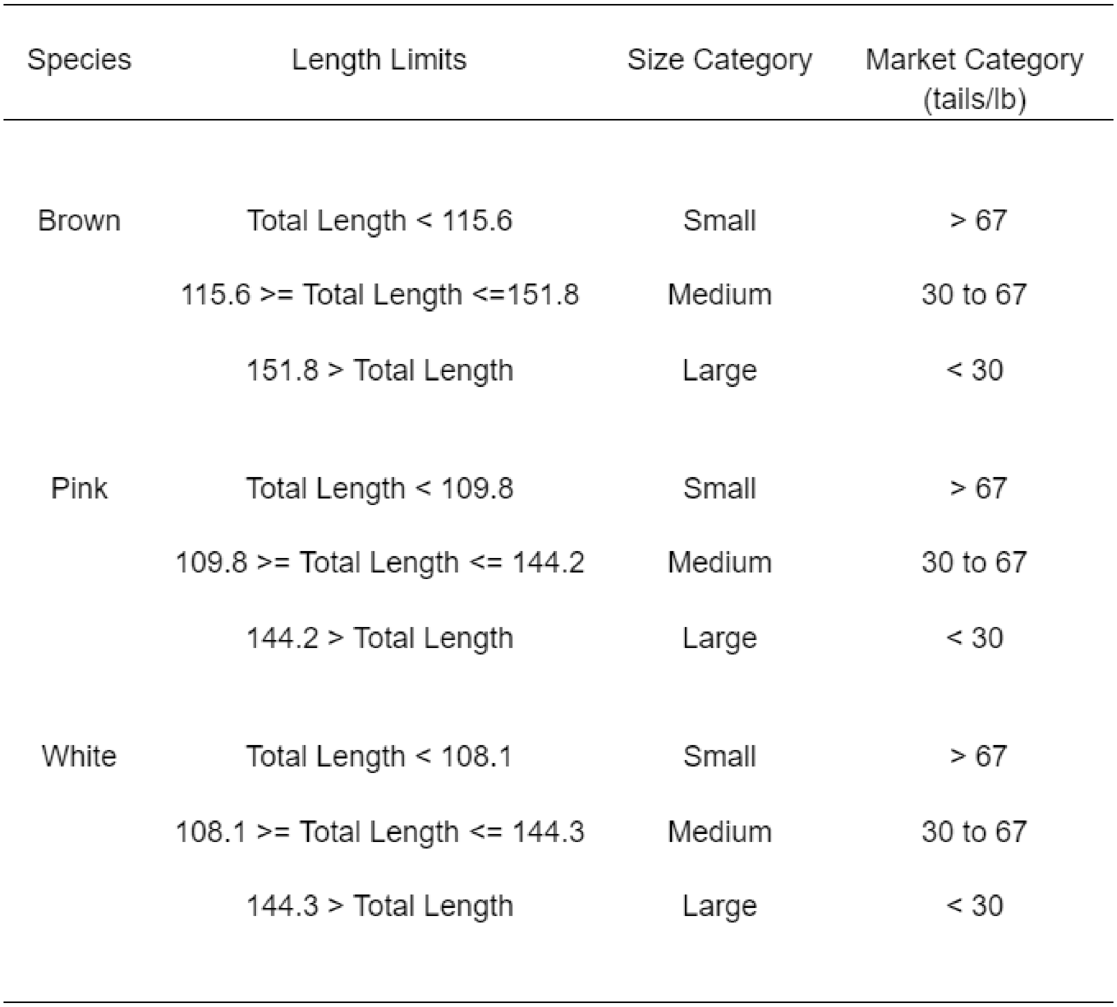
- Exploration of indices of abundance utilizing combined data from AL, MS, and LA 16 ft state sampling programs, including potentially including a weighting factor to account for differences in area sampled (surface area, habitat area, etc.)

4.7 LITERATURE CITED

Lo, N.C.H., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Science 49:2515-2526.

4.8 TABLES

Table 1. Size categories of brown shrimp, white shrimp, and pink shrimp based on total lengths and the associated market category.



Species	Length Limits	Size Category	Market Category (tails/lb)
Brown	Total Length < 115.6	Small	> 67
	115.6 >= Total Length <=151.8	Medium	30 to 67
	151.8 > Total Length	Large	< 30
Pink	Total Length < 109.8	Small	> 67
	109.8 >= Total Length <= 144.2	Medium	30 to 67
	144.2 > Total Length	Large	< 30
White	Total Length < 108.1	Small	> 67
	108.1 >= Total Length <= 144.3	Medium	30 to 67
	144.3 > Total Length	Large	< 30

Table 2. Programmatic evaluation

Agency	Survey	Evaluation
Texas	Gulf Trawl	Suitable – Recommended
Texas	Bay Trawl	Suitable – Recommended
Louisiana	6 ft trawl	Suitable – Not recommended
Louisiana	16 ft trawl	Suitable – Recommended
Louisiana	Nearshore trawl	Suitable – Not recommended
Mississippi	Long term monitoring	Suitable – Recommended
Mississippi	Shrimp monitoring	Suitable – Not recommended
Alabama	16 ft trawl	Suitable – Recommended
Alabama	Beam - Plankton	Not suitable
Alabama	Seine	Suitable – Not recommended
Florida	6.1 m trawl	Suitable – Recommended
Florida	21.3 m seine	Suitable – Recommended
Florida	183 m seine	Suitable – Not recommended
Partner (NMFS and state agencies)	SEAMAP Summer Groundfish Survey	Suitable – Recommended
Partner (NMFS and state agencies)	SEAMAP Fall Groundfish Survey	Suitable – Recommended

Table 3. Review of abundance indices for brown shrimp

Survey	Years	Statistical Zones	Size Class	Recommendation
SEAMAP Summer Groundfish Survey	1987-2008	21-18	Large	Representative
SEAMAP Summer Groundfish Survey	1987-2008	21-18	Medium	Representative
SEAMAP Summer Groundfish Survey	1987-2008	21-18	Small	Representative
SEAMAP Summer Groundfish Survey	2009-2022	21-18	Large	Representative
SEAMAP Summer Groundfish Survey	2009-2022	21-18	Medium	Representative
SEAMAP Summer Groundfish Survey	2009-2022	21-18	Small	Representative
SEAMAP Summer Groundfish Survey	1987-2008	17-11	Large	Representative
SEAMAP Summer Groundfish Survey	1987-2008	17-11	Medium	Representative
SEAMAP Summer Groundfish Survey	1987-2008	17-11	Small	Representative
SEAMAP Summer Groundfish Survey	2009-2022	17-11	Large	Representative
SEAMAP Summer Groundfish Survey	2009-2022	17-11	Medium	Representative
SEAMAP Summer Groundfish Survey	2009-2022	17-11	Small	Representative
SEAMAP Summer Groundfish Survey	2009-2022	10-02	Large	No Index

SEAMAP Summer Groundfish Survey	2009-2022	10-02	Medium	No Index
SEAMAP Summer Groundfish Survey	2009-2022	10-02	Small	No Index
SEAMAP Fall Groundfish Survey	1987-2007	21-18	Large	Representative
SEAMAP Fall Groundfish Survey	1987-2007	21-18	Medium	Representative
SEAMAP Fall Groundfish Survey	1987-2007	21-18	Small	Representative
SEAMAP Fall Groundfish Survey	2008-2022	21-18	Large	Representative
SEAMAP Fall Groundfish Survey	2008-2022	21-18	Medium	Representative
SEAMAP Fall Groundfish Survey	2008-2022	21-18	Small	Representative
SEAMAP Fall Groundfish Survey	1987-2007	17-11	Large	Representative
SEAMAP Fall Groundfish Survey	1987-2007	17-11	Medium	Representative
SEAMAP Fall Groundfish Survey	1987-2007	17-11	Small	Representative
SEAMAP Fall Groundfish Survey	2008-2022	17-11	Large	Representative
SEAMAP Fall Groundfish Survey	2008-2022	17-11	Medium	Representative
SEAMAP Fall Groundfish Survey	2008-2022	17-11	Small	Representative
SEAMAP Fall	2008-2022	10-02	Large	Not Representative

Groundfish Survey				
SEAMAP Fall Groundfish Survey	2008-2022	10-02	Medium	Not Representative
SEAMAP Fall Groundfish Survey	2008-2022	10-02	Small	No Index
Louisiana	1980-2022	Louisiana state waters	Large	Not Representative
Louisiana	1980-2022	Louisiana state waters	Medium	Representative
Louisiana	1980-2022	Louisiana state waters	Small	Representative
Texas	1985-2022	Texas Bay	Large	Not Representative
Texas	1985-2022	Texas Bay	Medium	Not Representative
Texas	1985-2022	Texas Bay	Small	Representative
Texas	1985-2022	Texas Gulf	Large	Not Representative
Texas	1985-2022	Texas Gulf	Medium	Not Representative
Texas	1985-2022	Texas Gulf	Small	Representative
Florida	2001-2022	Florida bays	Small	Representative

Table 4. Review of abundance indices for white shrimp

Survey	Years	Area	Size Class	Recommendation
SEAMAP Summer Groundfish Survey	1987-2008	21-18	Large	Representative
SEAMAP Summer Groundfish Survey	1987-2008	21-18	Medium	Representative
SEAMAP Summer Groundfish Survey	1987-2008	21-18	Small	No Index
SEAMAP Summer Groundfish Survey	2009-2022	21-18	Large	Representative
SEAMAP Summer Groundfish Survey	2009-2022	21-18	Medium	Not Representative
SEAMAP Summer Groundfish Survey	2009-2022	21-18	Small	No Index
SEAMAP Summer Groundfish Survey	1987-2008	17-11	Large	Representative
SEAMAP Summer Groundfish Survey	1987-2008	17-11	Medium	Not Representative
SEAMAP Summer Groundfish Survey	1987-2008	17-11	Small	No Index
SEAMAP Summer Groundfish Survey	2009-2022	17-11	Large	Representative
SEAMAP Summer Groundfish Survey	2009-2022	17-11	Medium	Not Representative
SEAMAP Summer Groundfish Survey	2009-2022	17-11	Small	No Index
SEAMAP Fall Groundfish Survey	1987-2007	21-18	Large	Representative
SEAMAP Fall	1987-2007	21-18	Medium	Representative

Groundfish Survey				
SEAMAP Fall Groundfish Survey	1987-2007	21-18	Small	Not Representative
SEAMAP Fall Groundfish Survey	2008-2022	21-18	Large	Representative
SEAMAP Fall Groundfish Survey	2008-2022	21-18	Medium	Not Representative
SEAMAP Fall Groundfish Survey	2008-2022	21-18	Small	Not Representative
SEAMAP Fall Groundfish Survey	1987-2007	17-11	Large	Representative
SEAMAP Fall Groundfish Survey	1987-2007	17-11	Medium	Representative
SEAMAP Fall Groundfish Survey	1987-2007	17-11	Small	Not Representative
SEAMAP Fall Groundfish Survey	2008-2022	17-11	Large	Representative
SEAMAP Fall Groundfish Survey	2008-2022	17-11	Medium	Not Representative
SEAMAP Fall Groundfish Survey	2008-2022	17-11	Small	No Index
Louisiana	1980-2022	Louisiana state waters	Large	Representative
Louisiana	1980-2022	Louisiana state waters	Medium	Representative
Louisiana	1980-2022	Louisiana state waters	Small	Representative
Texas	1985-2022	Texas Bay	Large	Not Representative

Texas	1985-2022	Texas Bay	Medium	Not Representative
Texas	1985-2022	Texas Bay	Small	Representative
Texas	1985-2022	Texas Gulf	Large	Not Representative
Texas	1985-2022	Texas Gulf	Medium	Not Representative
Texas	1985-2022	Texas Gulf	Small	Representative
Florida	2001-2022	Florida bays	Small	Representative

Table 5. Review of abundance indices for pink shrimp

Survey	Years	Area	Size Class	Recommendation
SEAMAP Summer Groundfish Survey	2010-2022	2 -10	Large	Representative
SEAMAP Summer Groundfish Survey	2010-2022	2 -10	Medium	Representative
SEAMAP Summer Groundfish Survey	2010-2022	2 -10	Small	Not Representative
SEAMAP Fall Groundfish Survey	2010-2022	2 -10	Large	Not Representative
SEAMAP Fall Groundfish Survey	2010-2022	2 -10	Medium	Not Representative
SEAMAP Fall Groundfish Survey	2010-2022	2 -10	Small	Not Representative
Florida	1998-2022	Florida bays	Small	Representative
Florida	2008-2022	Florida bays	Small	Representative

4.9 FIGURES

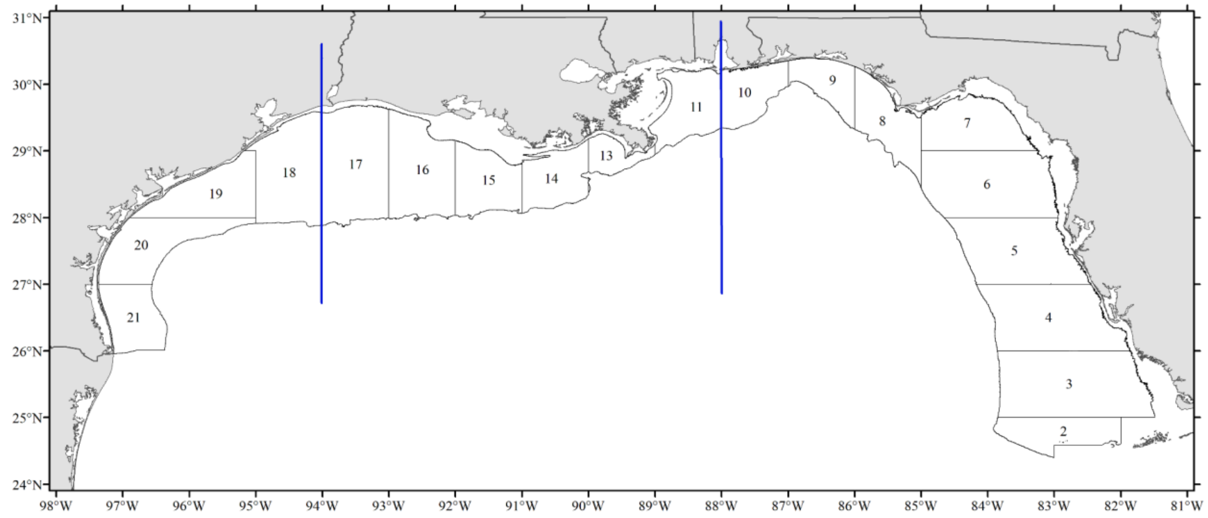


Figure 1. Gulf of Mexico statistical zones with the blue lines representing the geographical breaks used when calculating abundance indices for brown shrimp, white shrimp, and pink shrimp.

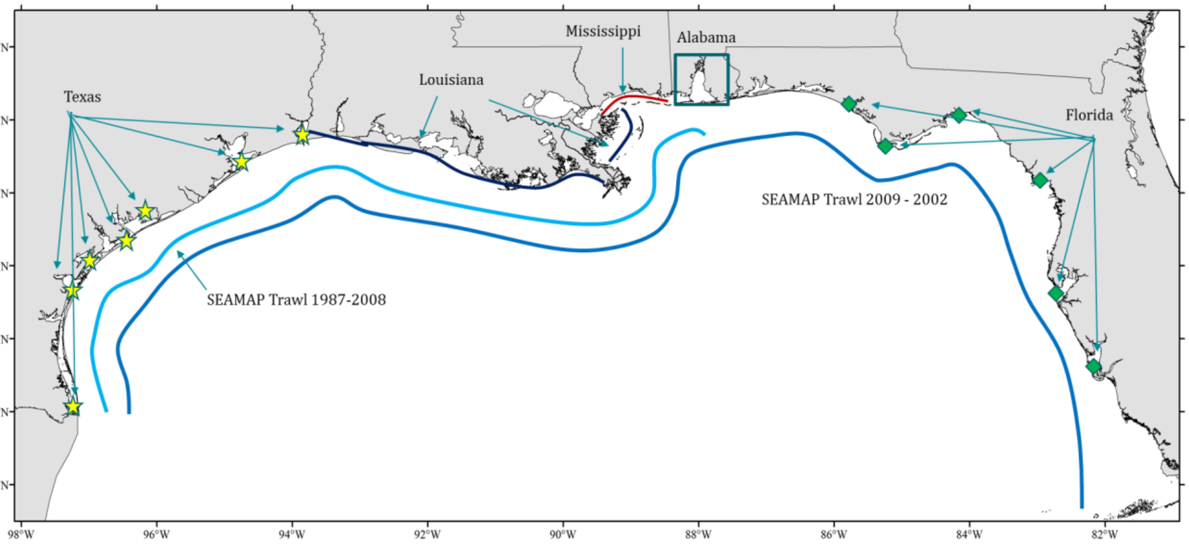
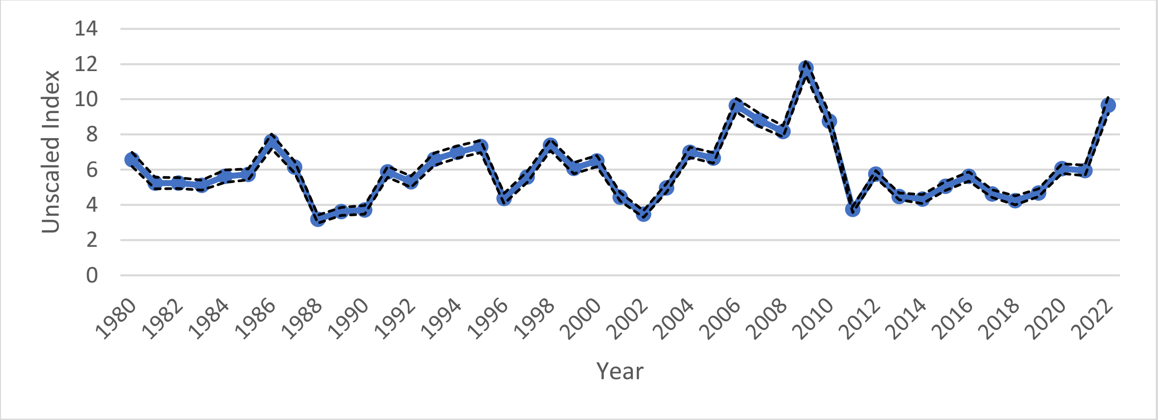
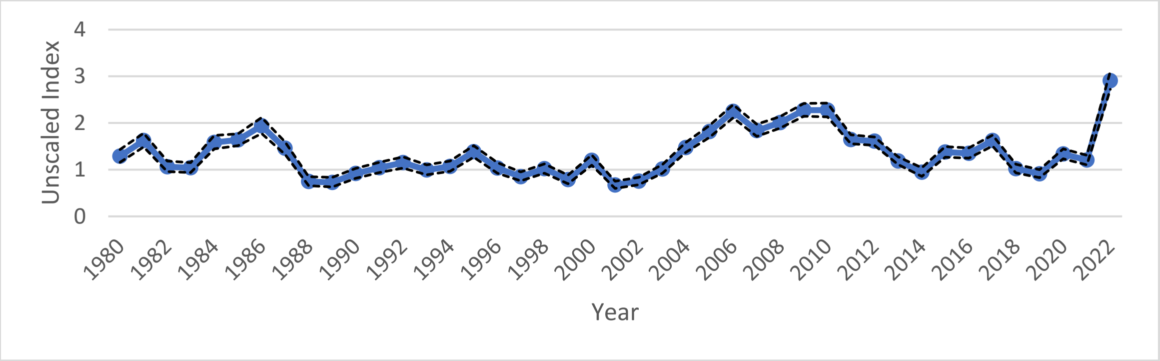


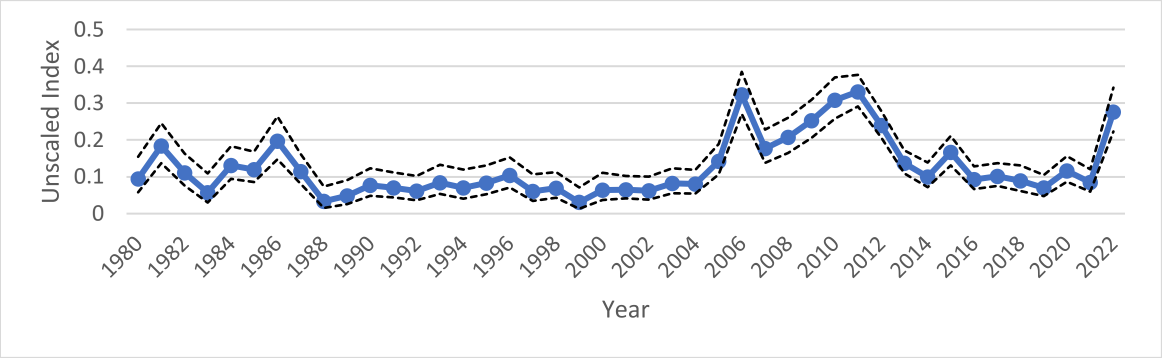
Figure 2. Generalized survey areas of federal and state sampling programs across the northern Gulf of Mexico.



a. Small

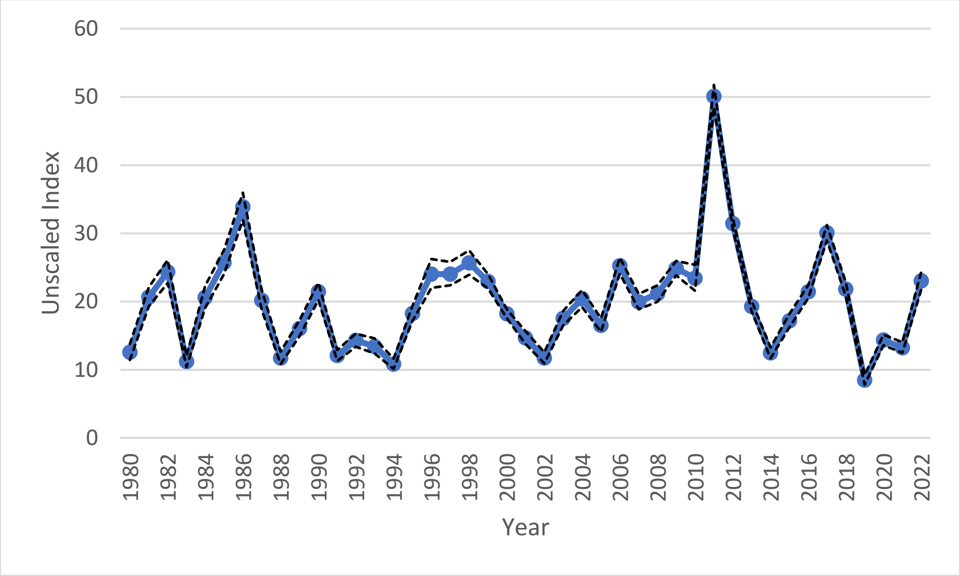


b. Medium

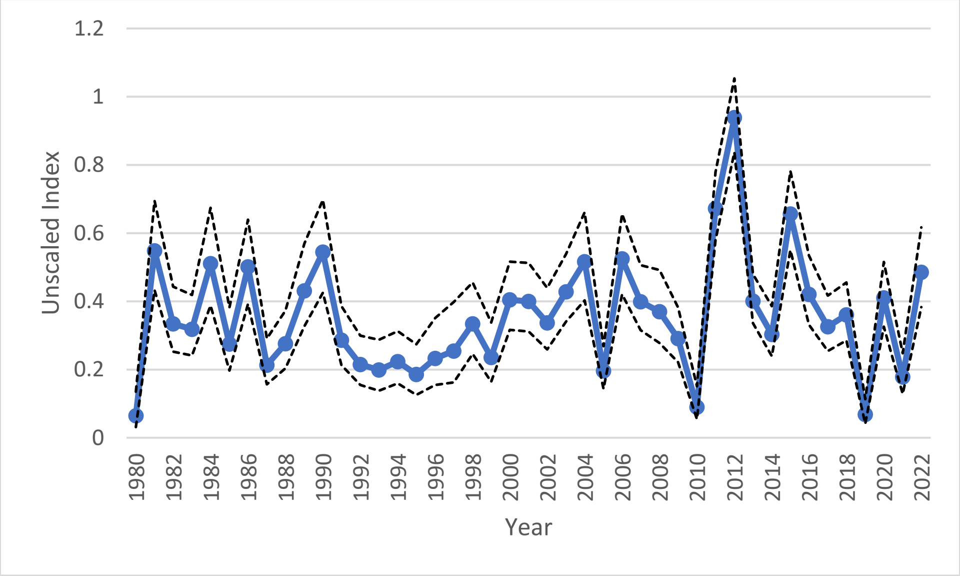


c. Large

Figure 3. Small, medium, and large white shrimp nominal indices of abundance from combined Louisiana, Mississippi, and Alabama survey data.



a. Small



b. Medium

Figure 4. Small and medium brown shrimp nominal indices of abundance from combined Louisiana, Mississippi, and Alabama survey data. There were insufficient data to generate a combined index for large brown shrimp.

5 ECONOMICS AND SOCIAL SCIENCES

5.1 OVERVIEW

Economic and social sciences were included in the Terms of Reference for the Gulf of Mexico shrimp SEDAR assessment. Incorporating social science into the stock assessment process from the start is particularly important for shrimp because they are a fluctuating annual crop where this year's harvest relates little or not to next year's recruitment or stock size. As a result, classic stock or growth overfishing are less of a concern, and other aspects of the fishery rise to prominence, including ones driven by economic or social forces, motives and behavior. Since this is the inaugural SEDAR for the Gulf of Mexico shrimp stock, it is appropriate to evaluate the full range of scientific data available. Further, this process of evaluation and documentation can inform other GOM shrimp research and management support efforts that build on or follow the stock assessment itself.

As this is the first time that data and information from economics and the social sciences are to be included in the SEDAR process, the data workshop was spent developing, in collaboration with the assessment leads, more specific and clear objectives for the workgroup to address. It was determined that a central concern of the assessment scientists is understanding---and, possibly, modeling---the economic and social drivers of the fleet's fishing effort. The science of economics helps explain the behavior of firms (in this case shrimp harvesters), with prices and markets playing a central role. As shrimp firms and production changes, the shrimpers and their communities are impacted and change as well, as the full range of social sciences document.

In the case of the GOM shrimp fishery, in broad strokes, the slow shift over 3+ decades from a scarce, high-value, wild-caught, luxury product to a high-volume, imported, farm-raised commodity led to 1) a drastic shrimp price decline; 2) a consolidation of the shrimp fleet to cut cost; 3) raised productivity (CPUE) for the remaining vessels due to less congestion on the shrimping grounds, and, finally, 4) a low-margin, "break-even" industry exposed to global shrimp and oil price fluctuations. Social consequences of these economic developments include, for example, growing reliance on (cheap) "imported" labor and reduced resilience of shrimping firms, and by extension their communities, against further shocks such as fuel price spikes, hurricane impacts, or poor shrimp recruitment years.

Available economic and social data on Gulf of Mexico shrimping vary by the time and space they cover, their correspondence across sources, and whether they are quantitative or quantifiable or primarily qualitative. Working papers provided by Liese (DW-07, DW-08) and Griffith at al. (DW-15) identify some of the factors that might be drivers of shrimping effort, including imported and GOM shrimp prices, fuel prices, and the overall economics of the harvesting industry, as well as background information on the recent history of the fishery. Qualitative social science information can assist in understanding developments in the fishery and hence validate trends, thresholds, and outliers in the quantitative fisheries data used by the assessment process.

5.1.1 Terms of Reference

The terms of reference for the SEDAR87 data workshop explicitly call for the inclusion of economics, a social science discipline:

"7. Integrate economists into the stock assessment model development process in order to explore models that can address questions such as benefits of seasonal/spatial closures, impacts of fuel prices on total effort, and ex-vessel prices of different market categories, if possible.

- Detail the early 2000 industry consolidation and impacts of ex-vessel price on effort”

5.1.2 Participants

Below are the workgroup participant of the economics and social science workgroup and their affiliations:

Matt Freeman, Economist, Gulf of Mexico Fishery Management Council, Tampa, FL

David Griffith, Professor of Anthropology, East Carolina University, Greenville, NC

Christopher Liese (group lead), Economist, NOAA SEFSC, Social Science Research Group, Miami, FL

David Records, Economist, NOAA SERO, Social Science Branch, St. Petersburg, FL

Mike Travis, Lead Economist, NOAA SERO, Social Science Branch, St. Petersburg, FL

5.1.3 Objectives

Narrow Goal:

Provide quantitative data as stock assessment inputs.

Provide qualitative information as background and explanation of developments over time in the fishery.

Broad Goal:

Integrate social scientists into the SEDAR process to learn from each other’s disciplines and identify future areas for collaboration.

Advise on the SEDAR’s input/model/output to facilitate future (economic and management) use of the assessment’s science.

5.2 REVIEW OF WORKING PAPERS AND CONSENSUS RECOMMENDATIIONS

The workgroup discussed and found consensus on recommendations for the fuel price index, inflation adjustment index, and the discount rate (on 9/19/2023) and, tentatively, on the approach/methodology for the shrimp price indices (Gulf of Mexico domestic and imports) and the qualitative write-up (9/20/23). The workgroup discussed and endorsed the economic survey data (economic performance) but no obvious use by the stock assessment could be established at this time (9/20/23). A lot of discussion focused on the recent history and developments in this fishery at the workshop, and these discussions were used to refine the early working paper on the social dimensions of the GOM fishery (SEDAR87-DW-02). The workgroup met by phone on 10/20/23 and revisited and finalized the Gulf of Mexico domestic and import shrimp price indices, as well as endorsed the final qualitative write-up (Griffith et al., DW-15).

The workgroup noted that while they could endorse the data sources/information in general, not all decisions can be made independent of the specifics of the final stock assessment models chosen and the purpose and method for including economic data. Further, the economic data will often not match the data/model resolution across many or even all of the stock assessment's dimensions. Economic data is more aggregate, often at an annual, overall fishery resolution.

5.3 QUANTITATIVE DATA

5.3.1 Fuel Price Index

There are several national and regional indices for fuel prices (gas, diesel, or crude oil; retail or wholesale; etc.). They have varying start dates, with many starting in the mid-1970s (after the world oil shocks). Because all these indices are ultimately tied to the global oil market, it is unsurprising that the price fluctuations within each are broadly the same. As a result, the specific choice of a fuel price index is not critical for SEDAR87, where the goal is to capture the underlying trends over time as opposed to absolute values. The workgroup endorsed using a regional index for retail diesel if a time series starting in 1995 is sufficient, as recommendation in the working paper (SEDAR87-DW-08). The exact choice, however, will depend on the needed time frame.

It should be noted that all provided indices are annual and have been adjusted for inflation. It is possible to provide monthly or seasonal price indices if this is deemed useful for the stock assessment purpose.

5.3.2 Inflation Adjustment

The workgroup discussed the best index to use for inflation adjusting dollar values across time. By consensus, the group agreed that the U.S. Bureau of Economic Analysis (BEA) GDP implicit price deflator should be used as proposed in the working paper. NOAA Fisheries' SERO and SEFSC analysts regularly use this index and keeping a consistent approach helps ensure science that is more comparable. Similar as for the fuel price indices, the specific choice of inflation index is probably not critical for SEDAR87 as they all broadly show the same devaluation of the U.S. dollar over time, especially at an annual level. More details are provided in the working paper (SEDAR87-DW-08).

Data file: shr_infladj_USBEA_2922_08182023.csv

5.3.3 Discount Rate

The workgroup discussed what discount rate should be used by the stock assessment, should future dollar values need to be expressed as, or compared to, today's values. The recommended discount rate for this SEDAR is 2.0%, as recommended by the Biden Administration for Federal agencies developing regulatory analysis. More details are provided in the working paper (SEDAR87-DW-08).

Data file: shr_discount_OMB_future_11052023.csv

5.3.4 Economic Survey Results including Economic Performance

The workgroup discussed the GOM shrimp economic survey data and results. The results are very interesting and support much of the narrative of this fishery. The workgroup endorsed the data as usable and scientifically sound. That said, the performance and derived economic measures are usually ***outcomes*** of the fishery rather than drivers. Hence it is not clear to the group if or how these economic metrics would be integrated into a stock assessment model. An example, though deemed not very likely by the group, could be the inclusion of a lagged fishery profit measure, i.e., assuming that last year's (average) profit influences fishing behavior the following year. Another example might be claims payments related to the DWH oil spill, though the fishery aggregate/average nature of the results obscures the huge variation within the fleet, i.e., the measure would be average payments per vessel per year, but some vessels received large payouts while many received nothing. The workgroup felt that it was premature to determine if and how these data/results might support the stock assessment and hence recommends keeping them for now. More details are provided in the working paper (SEDAR87-DW-07).

Data file: shr_econ_SSRG_0619_08182023 - formatted for printing_discussion.csv

5.3.5 Shrimp Price Indices

The workgroup was tasked with deriving a GOM shrimp price index and a shrimp import price index (or global price index) during the SEDAR87 data workshop. The price indices are entirely derivative of the dealer landings (SEDAR87-DW-06) and import data (SEDAR87-DW-10) provided and documented by the SEFSC Fisheries Statistics Division. However, the focus on price index creation was deemed within the expertise of the economics and social sciences workgroup.

The discussion focused initially on the central role of prices in our decentralized or market economy. In a decentralized economy, the fluctuation of prices serves as the critical signal that coordinates all economic activity, conceptually allocating scarce resources to their most efficient/valuable use. As such, the price of shrimp is the principal variable that drives shrimping effort, though, ultimately, it is the interplay of consumer demand for shrimp and global supply that sets the price.

While the shrimp price (in a given market) drives the fishery, two caveats were discussed. The first is the delineation of the shrimp market. Most of the shrimp consumed in the U.S. is imported, as domestic landings measure in 100+ millions of lbs while imports reflect many billions of lbs of shrimp biomass (imported in various product forms). As such shrimp imports dwarf the production in the GOM shrimp fishery. Published research (Asche et al. 2012) shows the GOM shrimp market is integrated with, and a "price taker" from, the global market. As a result, it is expected that the import shrimp price leads the GOM shrimp price, which in turn drives GOM shrimp effort. That said, segments of the GOM shrimp fishery, e.g., pink shrimp, sell to more local markets and could (also) be driven by more local price developments. A GOM shrimp price index can be derived from ex-vessel prices of GOM landings. Such an index is "closer to the fishery" and might contain the effects of more local and regional drivers, e.g., local product scarcity or glut (warehouse fire or capacity constraint).

A second caveat is that prices, resulting from the interaction of a myriad of independent supply and demand decisions, reflect or summarize ***all*** the information available to market participants. As such it is usually not possible to further identify the specific factors that drive prices, unless they are very dominant or persistent over time. Similarly, it is not possible to say, on a decadal scale, if the global shrimp price drop led to an increase in shrimp volume or vice versa, as these processes (supply, demand, and price) continuously interact (feedback), shaping the market together. In the case of shrimp, a once high-priced, scarce, luxury product generated profit, and thereby attracted interest and investment, which led to increased production, including the development of shrimp farms. As additional, lower-cost-of-production shrimp entered the global market, shrimp prices dropped, and (greatly) expanded the demand and hence the market for shrimp.

Another very important aspect of shrimp prices in particular is that the per pound price varies substantially for different shrimp size categories, i.e., larger shrimp demand a premium over smaller shrimp. The price for the largest shrimp can be many multiples of the price for the smallest. So while today, shrimp is traded as a commodity, this commodity is split into differently priced categories. It should be noted that the spread across shrimp prices has declined somewhat over the last decades as shrimp farmers can control the size of shrimp produced. In comparison, the specific species of shrimp has little to no impact on the price.

As eluded to earlier, two data sources could be used to generate shrimp price indices for SEDAR87. A GOM shrimp price index can be derived from ex-vessel prices of GOM landings reported by the dealers, and an import/global market price of shrimp index can be derived from import data ultimately collected by U.S. Customs and Border Protection (CBP). The GOM landings data provided the species information and only two shrimp product forms represent the vast majority of GOM landings, frozen heads-on shrimp (whole shrimp) and frozen heads-off shrimp ("tails"). The date of the dealer record corresponds roughly with the month the shrimp were caught, and these landings clearly correspond to the harvested biomass of the GOM shrimp fishery.

In contrast, the import data generally does not specify the shrimp species but does provide size categories for the frozen (plain) shrimp product form category (since 1990). Only in the last two years has CBP differentiated between wild-caught and farmed shrimp (since 2021). Further, the different "product forms" of imports---ranging from whole, frozen to heads-off/tails all the way to cooked, breaded, canned, etc.---obscure the weight of the actual shrimp input and hence the original biomass (from worldwide shrimp fisheries and aquaculture production). This makes measuring a standardized "volume of shrimp imports" difficult. Further, the variety of product forms also complicates the use of the import price data as the price reflects the overall value of the product, and it is impossible to determine which part of the price reflects the value added from the actual shrimp input (vs., e.g., the value added by bread crumbs and the act of breading).

That said, the amount of shrimp imported in simple, frozen forms is huge. Given these vast product flows, if the purpose of a price index is to integrate shrimp price fluctuations and trends into the stock assessment, using a subset of the import data is acceptable, e.g., volume or average price by year of frozen, heads-off shrimp. We could combine frozen heads-on and heads-off product using NMFS conversion factors, but given the lack of species information some approximation error is introduced.

The workgroup agreed that developing a price index is not trivial and depends a lot on its intended use. The workgroup agreed that more research is needed on prices and price indices on the dealer landings data, as everyone's experience dates back a decade or more, if any. The dealer data have undergone significant changes in that time, as has the fishery. On the other hand, the group agreed that a full research project would exceed the scope of this SEDAR (and take too long), and to stick to simple and proven methods. In light of that, it was decided that the index derived from the dealer data should mirror the one based on the import data. This decision also eliminates providing species-specific price indices (using the dealer data).

It was further discussed to what extent size should be incorporated into the index production. For instance, it would be possible to produce price indices for different size categories, but no use for such indices was found at the time. A straight average across all the applicable landings or imports, i.e., ignoring size categories, represents the actual prices paid and received in the specific year---and hence is an important measure---yet it suffers from distortions from shifting market shares of different shrimp sizes. Given that the focus of a price index is as a possible driver of effort, the workgroup decided that a size-adjusted price index would be most appropriate. The actual size categories are a given in the import data. A size-adjusted price index is produced by weighted-averaging across prices by size and where the weights are kept constant, similar to how the consumer price index is calculated using a fixed market basket of goods and services over time. The weights might be the series' average (over time) share of market for each size category. The group agreed on the methodology needed for generating price indices, and recommended using the average size distribution across the time series as the weights in the size-adjusted price indices.

Finally, it should be noted that all the GOM and import shrimp price data is nominal data and will need to be inflation adjusted before use in most analysis. Hence the price indices data provided to this SEDAR have been inflation adjusted using the GDP implicit price deflator. Any forward-looking analysis would not need inflation adjustment as dollar values will be hypothetical and can be based on the "current" price level. Note though, for other reasons, future dollar values will need to be discounted for most analysis.

In summary, given the previous discussion, the workgroup recommends using the size-adjusted import price index in any regression where a proxy for the primary driver of effort on the demand side is needed. The workgroup notes that if deemed useful or necessary for the stock assessment further indices can be generated from the data already submitted to this SEDAR. Such indices could differentiate by species (only for the GOM dealer data, though), by size category, e.g., large-medium-small, or by season or month. It was noted though that frozen imports have a very long shelf life and are routinely stored making assignment to a specific time period difficult.

5.4 QUALITATIVE INFORMATION

Apart from quantitative economic data provided for SEDAR 87 modeling efforts, economic and social science information can assist in understanding and validating developments, specifically trends, breaks, and outliers, in the quantitative data during the assessment process. The GOM shrimp fishery has been substantially influenced and changed by many global and local developments, including globalization/world trade and the extensive farming of shrimp, fuel price fluctuations, hurricanes, and the DWH oil spill. The workgroup discussed and documents many of these developments in the fishery and finalized a working paper (SEDAR87-DW-15), for the benefit of the assessment scientists and others not intricately familiar with the more recent history of the fishery. The working paper is primarily focused on developments since 2000, though some of the trends discussed have been in effect for longer. After many rounds of review and revision, the final version of the working paper was endorsed by all workgroup members and submitted to SEDAR87 on November 29, 2023.

This comment received from a shrimper on a 2007 economic survey creatively sums up the problems facing the Gulf of Mexico shrimp fishery since 2000 and especially during the 2006-2008 period which led to rapid industry consolidation and, possibly, again today (in 2023).

5.5 ECONOMIC DATA AND THE PROPOSED DATA STRATIFICATION

As mentioned before, the workgroup noted that while they could endorse the data sources/information in general, not all decisions can be made independent of the specifics of the final stock assessment models chosen and the purpose and method for including economic data. Further, some economic "data" is more akin to analysis, e.g., different price indices can be derived from the underlying data.

The economic data will often not match the data/model resolution across many or even all of the stock assessment's dimensions. Economic data is usually more aggregate, often at an annual, overall fishery resolution. On the proposed data stratification for SEDAR87, the workgroup generally found that, from a quantitative economic perspective, there is little difference between the three species. Prices are similar and the production methods, and hence costs, identical. While shrimp species abundance differ by region and season, most vessels harvest different species throughout the year, including by travelling and fishing throughout the entire (U.S.) GOM. Hence most economic work in this fishery aggregates all shrimp species into just 'shrimp'.

For the same reason, stratifying across area fished is not very meaningful from an economic perspective, and we only have annual economic data. Finally, while shrimp by size demand very different prices, shrimpers control over the sizes caught is limited to choosing the area fished, mostly the distance from shore. These decisions are so micro, that we do not have the economic data needed (trip-level costs) to differentiate.

The exception to the above is the time dimension. As described in the qualitative sections, the GOM shrimp fishery has undergone substantial changes over the last 30 years. Many of these changes are driven by---or captured in---the large variation of the prices for shrimp and for fuel over time, especially in year-to-year comparisons. If a further seasonal break-down of some price indices might explain more than an annual trend is an empirical question and could not be answered by the workgroup at this time.

5.6 LITERATURE CITED

Asche F., L.S. Bennear, Atle Oglend, and M.D. Smith. 2012. "US shrimp market integration." Marine Resource Economics, 27(2), 181-192

Griffith, D. 2023. Social Dimensions of the Gulf of Mexico Shrimp Fishery: Overview. SEDAR87-DW-02. SEDAR, North Charleston, SC.8 pp.

Griffith, David, Christopher Liese, Mike Travis, Matt Freeman, David Records 2023. Social Dimensions of Gulf of Mexico Shrimping. SEDAR87-DW-15. SEDAR, North Charleston, SC.12 pp.

Liese, C. 2023. Economics of the Federal Gulf of Mexico Shrimp Fishery. SEDAR87-DW-07. SEDAR, North Charleston, SC.3 pp.

Liese, C. 2023. General Economic Measures for Fuel Price Trend, Inflation Adjustment, and Discounting. SEDAR87-DW-08. SEDAR, North Charleston, SC. 6 pp

5.7 FIGURES

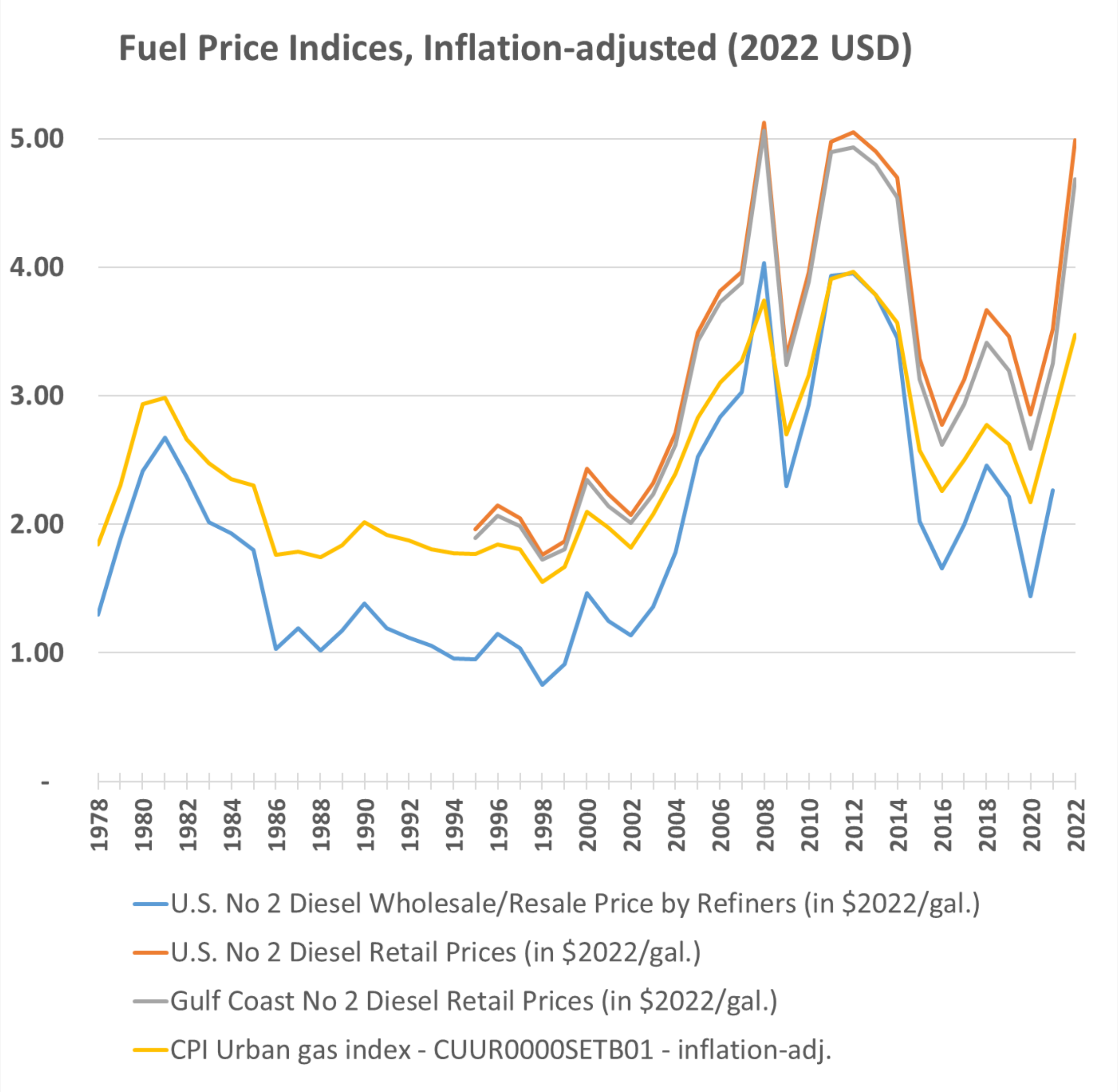


Figure 1: Data file: shr_priceIndx_SEFSC_7222_11052023.csv

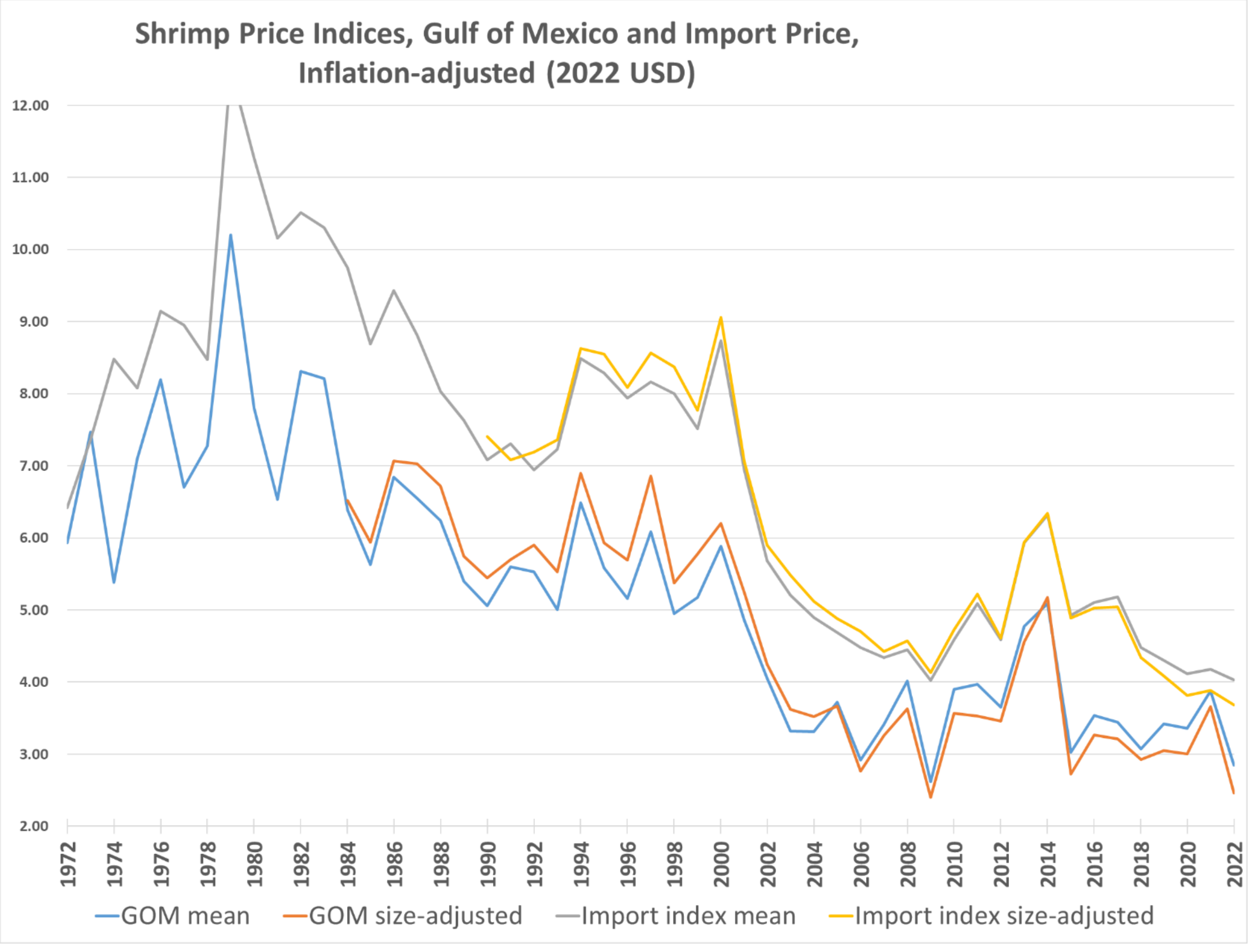


Figure 2: Data file: shr_priceIndx_SEFSC_7222_11052023.csv

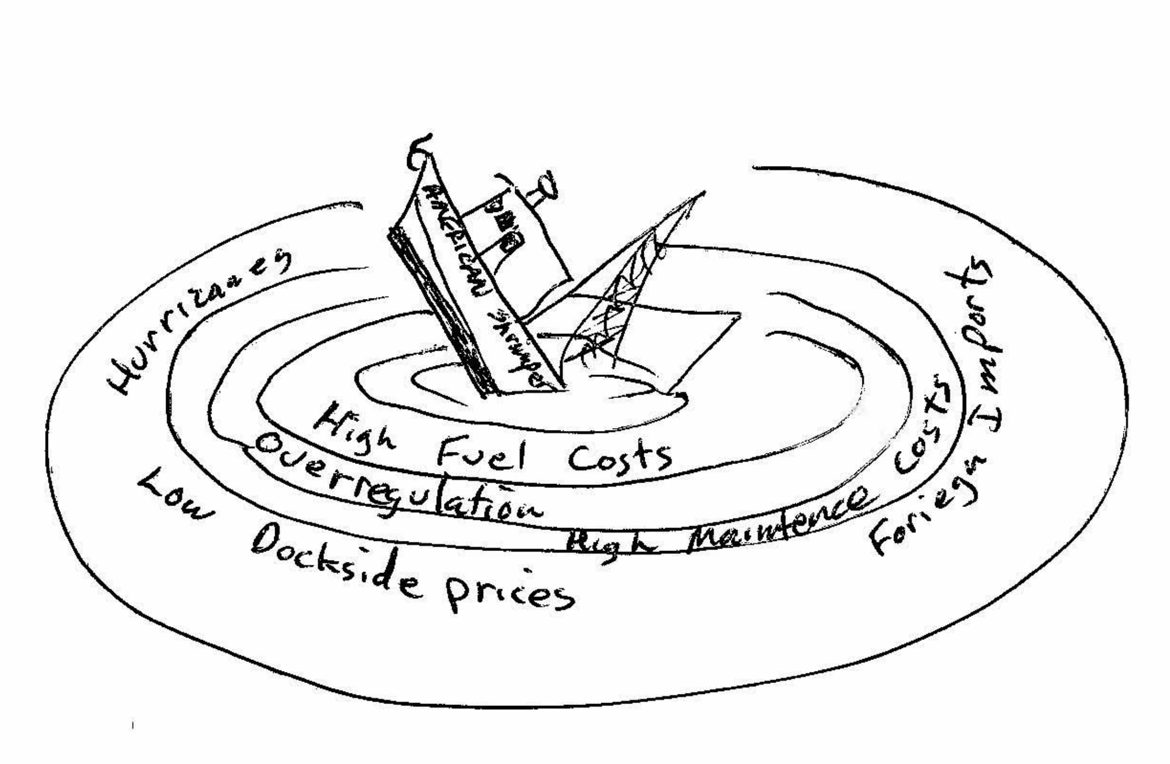


Figure 3. (source: J. D. Passwater)

SEDAR

Southeast Data, Assessment, and Review

SEDAR 87

Gulf White Shrimp

SECTION III: Assessment Process Report

Updated: 11 July 2025
Updated: 5 June 2025
Original Release: 28 May 2025

SEDAR
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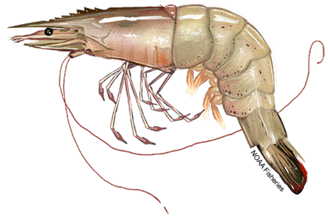
Document History

May 28, 2025 Original release

June 5, 2025 First letter of all species, regions, and size classes capitalized for consistency.

July 10, 2025 Corrected surplus production model equation in Section 3.1. Clarified EDM descriptions of escapement, catchability parameters, and transformations on y in Section 3.2.1.



SEDAR87 Gulf White Shrimp Benchmark Assessment

Gulf Branch
Sustainable Fisheries Division
NOAA Fisheries - Southeast Fisheries Science Center

July 2025

Table of contents

1. Assessment Process Proceedings

On January 20, 2025, President Trump issued Executive Order 14172 to rename the Gulf of Mexico as the Gulf of America. Any reference to Gulf of America White Shrimp in SEDAR reports and other documents refers to the same species and fishery listed in *50 CFR part 622, Subpart C* (Shrimp Fishery of the Gulf of Mexico). As of the publication of this report, all efforts were made to use "Gulf of America" per Executive Order 14172. However, previous NOAA reports (cited herein) may have referred to this water body as the "Gulf of Mexico".

1.1 Introduction

1.1.1 Workshop Time and Place

The SEDAR 87 Assessment Process (AP) for Gulf White Shrimp, *Litopenaeus setiferus*, was conducted via a series of webinars held between October 2024 and February 2025.

1.1.2 Terms of Reference

1. Review any changes in data or analyses following the Data Workshop. Summarize data as used in each assessment model. Provide justification for any deviations from Data Workshop recommendations.

2. Develop a management advice framework. Consider data availability (e.g., landings and catch-per-unit-effort [CPUE]) and management needs (e.g., harvest controls, stock status), and particular needs of the fishery and the biology of the resource.

3. Examine the impacts of social science factors on biological reference points as informed by stakeholders through industry input.

4. Recommend biological reference points for use in management.

    - Consider how reference points could be affected by management, ecosystem, climate, species interactions, habitat considerations, social or economic drivers, and/or episodic events.

5. Provide estimates of stock population parameters, including: Fishing mortality, biomass, selectivity, and/or other parameters as necessary to describe the population.

6. Characterize uncertainty in the assessment and estimated values.
    - Consider uncertainty in input data, modeling approach, and model configuration.
    - Provide appropriate measures of model performance, reliability, and 'goodness of fit'.
    - Provide measures of uncertainty for estimated parameters and derived quantities such as biological reference points and stock status if feasible.
7. Provide recommendations for future research and data collection. Emphasize items that will improve future assessment capabilities and reliability. Consider data, monitoring, and assessment needs.

8. Complete an Assessment Workshop Report in accordance with project schedule deadlines.

1.1.3 List of Participants

Assessment Process Participants

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Chris Schieble	LDWF
Rebecca Smith	NOAA
Jim Tolan	
Michael Travis	NOAA
Jo Williams	NMFS SEFSC

1.1.4 List of Assessment Process Working Papers and Reference Documents

Document #	Title	Authors	Date Submitted
Documents Prepared for the Assessment Process			
SEDAR87-AP-01	Development of estuarine environmental indices for SEDAR 87 Gulf of Mexico White, Pink, and brown shrimp stock assessment	Brendan Turley, Lisa Ailloud, and Molly Stevens	25 July 2024
SEDAR87-AP-02	Price Indices for Shrimp Imports and Gulf of Mexico Shrimp Landings by Size and Season	Christopher Liese	18 December 2024
SEDAR87-AP-03	Developing a fishery-independent index of relative abundance for Gulf of Mexico Brown Shrimp using VAST	Lisa Ailloud, Molly Stevens, Brendan Turley, Adam Pollack, and David Hanisko	31 January 2025 Updated: 11 July 2025

SEDAR87-AP-04	Developing a fishery-independent index of relative abundance for Gulf of Mexico Pink Shrimp using VAST	Lisa Ailloud, Molly Stevens, Brendan Turley, Adam Pollack, and David Hanisko	31 January 2025 Updated: 11 July 2025
SEDAR87-AP-05	Developing a fishery-independent index of relative abundance for Gulf of Mexico White Shrimp using VAST	Lisa Ailloud, Molly Stevens, Brendan Turley, Adam Pollack, and David Hanisko	31 January 2025 Updated: 11 July 2025

Reference Documents		
SEDAR87-RD12	JABBA: Just Another Bayesian Biomass Assessment	Henning Winker, Felipe Carvalho, Maia Kapur
SEDAR87-RD13	Empirical dynamic modeling for sustainable benchmarks of short-lived species	Cheng-Han Tsai, Stephan B. Munch, Michelle D. Masi, and Molly H. Stevens
SEDAR87-RD14	Recent developments in empirical dynamic modelling	Stephan B. Munch, Tanya L. Rogers, George Sugihara
SEDAR87-RD15	Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat	James T. Thorson and Lewis A. K. Barnett

2. Data Review and Update

The following list summarizes the data inputs (and units) used in the assessment modeling process along with their corresponding available temporal scale based upon recommendations from the Data Workshop process. Two assessment modeling platforms were considered: a Bayesian surplus production model, JABBA (Just Another Bayesian Biomass Assessment), and an Empirical Dynamic Modeling (EDM) platform (see *Section 3*). Data for JABBA were on an annual time scale and included commercial landings (in million pounds of tails) and an index of abundance built with LDWF survey data using Vector Auto-Regressive Spatio-Temporal (VAST) modeling (Ailloud et al. 2025). EDM explored all the datasets listed below using various levels of stratification. JABBA allowed for different start years of data inputs, while EDM was limited by the start year of the survey data. For EDM, data were stratified by fishing area [A (*Figure 1*) : 1-10, 11-17, 18-21], size [S: >67 (Small), 67-31 (Medium), <=30 (Large) tails per pound], and quadrimester of the year [Q: January-April (Winter), May-August (Summer), September-December (Fall)] where possible, and are indicated as such in the data list. Stratifications were defined based on existing definitions of the ecological distribution of shrimp and the shrimping industry.

1. Commercial landings (10 million pounds of tails): 1960-2022 [A, S, Q]
2. LDWF survey data (number of shrimp per 10min trawl): 1980-2022 [A, S, Q]
3. Ex-Vessel price indices (2022 dollars): 1960-2023 [S, Q]
4. Imports (product volume in 100 million pounds): 1972-2022 [Q]
5. Salinity (practical salinity unit): 1980-2022 [A]
6. Bottom temperature (degrees Celsius): 1980-2022 [A]

White Shrimp are distributed primarily in the western Gulf (*Figure 1* : 11-21). Possible data stratifications for White Shrimp EDM were defined as:

A) Aggregated: ANNUAL ; SIZE BINS AGG ; AREA AGG (11:21)
B) [Stratum N/A because single area]
C) Size: ANNUAL ; SIZE BINS (>67, 67-31, <=30) ; AREA AGG (11:21)
D) [Stratum N/A because single area]
E) Season: SEASONAL (SUMMER, FALL, WINTER) ; SIZE BINS AGG ; AREA AGG (11:21)
F) [Stratum N/A because single area]
G) Size_Season: SEASONAL (SUMMER, FALL, WINTER) ; SIZE BINS (>67, 67-31, <=30) ; AREA AGG (11:21)
H) [Stratum N/A because single area]

For White Shrimp, additional strata were included that aggregated the Medium and Large size classes into a Marge size class containing all shrimp greater than <=67 tails per pound.

Cml) Size: ANNUAL ; SIZE BINS (>67, <=67) ; AREA AGG (11:21)

Gml) Size_Season: SEASONAL (SUMMER, FALL, WINTER) ; SIZE BINS (>67, <=67) ; AREA AGG (11:21)

2.1 Stock Structure and Management Unit

The SEDAR 87 Gulf White Shrimp Benchmark Assessment stock boundary extends from the United States–Mexico border in the west through the northern Gulf of America waters (hereafter referred to as the Gulf) to the Dry Tortugas and Florida Keys. This includes all waters within the Gulf of Mexico Fishery Management Council (hereafter referred to as the Gulf Council) boundaries and extends to include fishing areas split by the eastern boundary off the Florida Keys (*Figure 1*: Areas 002, 001) in their entirety due to complications with reporting over time (Atkinson et al. 2024). This stock boundary distinction is most important for Pink Shrimp due to its distribution being centered in the eastern Gulf, but it was applied to all Gulf shrimp species.

2.2 Fishery-Independent Survey Data

2.2.1 Louisiana Department of Wildlife and Fisheries Survey

The Louisiana Department of Wildlife and Fisheries (LDWF) survey is a state survey run by Louisiana and is collected monthly. The Indices WG at the Data Workshop deemed these data representative for White Shrimp since 1980 for all size classes (*SEDAR87 Data Workshop Report* 2023; LDWF 2024). The monthly indices were averaged to form seasonal series of abundance for each size class (*Figure 2*), where these data were combined to form annual abundance estimates by size class (*Figure 3*). Raw annual indices for White Shrimp are shown by size class in *Table 1*. This survey operates inshore and has a much higher CPUE for Small shrimp compared to Large shrimp. A log-transformed CPUE is shown in *Figure 4* to better visualize the increase in abundance for all White Shrimp size classes in the mid-2000s.

2.2.2 Vector Autoregressive Spatio-Temporal (VAST) Index

VAST is a spatio-temporal modeling platform that can be used for standardizing indices of relative abundance. Data from one or more surveys are combined to predict population density based on both habitat covariates (that impact abundance) and spatial and spatio-temporal random effects, while controlling for catchability covariates (that impact sampling efficacy). A VAST index was developed for White Shrimp based on data from LDWF survey for input into JABBA. Details of the VAST index are documented in Ailloud et al. (2025).

2.3 Fishery-Dependent Data

2.3.1 Commercial Landings

Commercial landings of White Shrimp were constructed using data from the Gulf Shrimp System (GSS) and state trip ticket programs. Species-specific Gulf shrimp landings have been collected since the late 1950s, and their complex history within the federal and state databases, including justifications for the relative coefficients of variance (CVs) through time, is documented in great detail in Atkinson et al. (2024). Landings were converted to tail weight for input to the assessment model.

Shrimp landings (*Table 2*) have been sold and recorded in eight market categories which were aggregated into three general size classes (*Figure 5*): Large, Medium, and Small. These are shown broken out seasonally (*Figure 6*) and aggregated annually (*Figure 7*). Changing economic conditions in the mid-2000’s are described in the following section and Griffith et al. (2023) and resulted in the targeting of larger shrimp by the domestic fleet. For White Shrimp, Large landings became dominant primarily in the Summer season (*Figure 6*) while population sizes increased (*Figure 4*). White Shrimp landings peaked in 2006 with landings totaling 85.12 million pounds of tails. The seasonal distribution of White Shrimp landings through time is shown in *Figure 8*.

2.4 Economics and Social Sciences

2.4.1 Imports and Ex-vessel Price Indices

Imported shrimp have exceeded the volume of domestically caught shrimp since the 1980's (Lowther 2023; Atkinson et al. 2024). In the mid-2000s, the volume of imported shrimp increased dramatically, particularly for Large shrimp which has a higher market value, causing domestic ex-vessel prices to plummet (*Figure 9*). Time series of imports and ex-vessel prices were both considered during EDM development (Liese 2024).

2.4.2 Industry Impacts

The globalization of the shrimp market with a focus on cheap aquaculture has resulted in dire economic operating conditions for the domestic fleet (Griffith et al. 2023). Increasing fuel costs and plummeting ex-vessel prices have created a situation in which most vessels struggle to remain profitable. Further, many vessels have exited the fleet, and those that remain may oscillate between narrowing profit margins and losses (*SEDAR87 Data Workshop Report* 2023 pp. 84–94). With fewer vessels operating, the shrimping effort and associated landings have decreased overall, and the shrimp population size has increased.

Industry impacts were documented during a stakeholder listening session at the Data Workshop, with the intention of holding additional listening sessions throughout coastal Gulf shrimping communities. During this session, resource users stated that the troubles of the Shrimp Fishery cannot be improved by domestic fishery management solutions. The bulk of the problems are globally influenced, and this fishery was recommended to the National Seafood Strategy to address these problems if possible, informed by additional information gathered through the newly formed *Shrimp Futures Project*.

2.5 Environmental Indices

Annual shrimp recruitment has been tied to environmental drivers in the past (Browder et al. 2002; Zink et al. 2018; Schlenker et al. 2023). Within an assessment modeling framework, it is important to include drivers of abundance at the most meaningful spatio-temporal scale. At the SEDAR 87 Data Workshop, the Environment and Industry Working Group recommended that salinity and temperature in the nursery grounds during the months that the shrimp were in their respective nursery grounds were likely the primary environmental drivers for shrimp abundance. These two variables were hypothesized to best explain the magnitude of recruits into the population each year. The methodology used to derive White Shrimp temperature and salinity indices was outlined in Turley et al. (2023). These indices were considered in the construction of the VAST index and development of EDM.

White Shrimp is in its inshore nursery grounds August through October every year throughout its coastal range. It was hypothesized that the environment would affect the overall population abundance more directly through its impact on the young of the year in this volatile habitat. While there may be some impacts of seasonal differences in rainfall and temperature fluctuations affecting local abundance, the trends of data from both TX (north of Laguna Madre) and LA appeared to follow strikingly similar trends, indicating consistency throughout the range

(*Figure 10*). Since EDM benefits greatly from a longer time series, it was decided to include LA-only data which go back to 1980 (*Figure 11*).

2.5.1 Temperature

Temperature in the western Gulf follows trends of state temperature averages from TX (north of Laguna Madre) to LA, with LA experiencing more extreme lows in some years. The standardized temperature index represents the nursery conditions well, which was similar on average, throughout these variable estuarine habitats. The combined index was very similar to the LA only data, which were used to include data back to 1980 as opposed to 1987.

2.5.2 Salinity

While salinity in TX was much higher compared to salinity in LA, both states generally experienced co-occurring peaks and troughs, resulting in a standardized index that tracks changes in salinity well. The combined and LA-only salinity index track similar trends, but the LA-only index was included in the EDM model to obtain additional time steps.

3. Stock Assessment Model Configurations and Methods

Two modeling frameworks were evaluated for the Gulf White Shrimp SEDAR 87 Benchmark Assessment: Just Another Bayesian Biomass Assessment (JABBA) Model and Empirical Dynamic Modelling (EDM). These are described below.

3.1 Just Another Bayesian Biomass Assessment (JABBA) Model

JABBA is a Bayesian state-space surplus production model (SPM) framework that is documented in Winker et al. (2018) and is available as an R package on *GitHub*. SPMs pool the overall effects of recruitment, somatic growth, natural mortality, and associated density-dependent processes into a single production function dealing with undifferentiated biomass (Haddon 2021). The state-space formulation allows for the estimation of observation and process error, and the Bayesian formulation allows the user to define prior distributions for each parameter in the model to represent the initial beliefs about the parameter before observing any data. Primary data inputs into JABBA are indices of abundance proportional to the exploitable part of the stock biomass and a time series of fishery removals. The time series of removals can begin prior to the indices of abundance, and contrast in the data is required to appropriately map the stock dynamics.

The generalized surplus production function (Pella and Tomlinson 1969) used by JABBA is defined as

$$SPM_t = \frac{r}{m-1} B_t \left(1 - \frac{B_t}{K}^{m-1}\right)$$

where r is the intrinsic rate of population increase at time t, K is the carrying capacity, B is the stock biomass at time t, and m is the shape parameter that determines at which B/K ratio maximum surplus production is attained. The Pella-Tomlinson function above is a generalized production function with Schaefer ($m = 2$) and Fox ($m = 1$) as special cases. The Schaefer may be the most well-known, with a symmetrical production curve and Maximum Sustainable Yield (MSY) attained at half the carrying capacity, $B = K/2$.

JABBA has several features including the ability to a) fit multiple CPUE time series and associated standard errors, b) estimate or fix the process variance, c) estimate additional observation variance on individual or grouped CPUE series, and d) specify either a Fox, Schaefer or Pella-Tomlinson production function. A full JABBA model description, including formulation and state-space implementation, prior specification options, and diagnostic tools is available in Winker et al. (2018).

3.1.1 Estimated Parameters

JABBA model parameters are defined in greater detail below.

K: Carrying capacity (million lb tail weight)

m: Shape parameter of the Pella-Tomlinson that determines at which B/K ratio maximum surplus production is attained. If $m = 2$, the model reduces to the Schaefer form, with the surplus production (SP) attaining MSY at exactly $K/2$. If $0 < m < 2$, SP attains MSY at biomass levels smaller than $K/2$; the converse applies for values of m greater than 2.

ψ: Ratio of the spawning biomass in the first year to K.

q: Catchability coefficient.

r: Intrinsic rate of population increase.

σ^2: Process variance.

τ^2 : Additional observation variance for the survey index.

3.1.2 Model Configurations and Prior Assumptions

The final VAST index built on LDWF survey data presented in Ailloud et al. (2025) was used as input to JABBA alongside an annual time series of commercial catches spanning 1960-2022 (*Section 2.3.1*). The following CVs were recommended by the WG and input into JABBA to reflect uncertainty in landings based on changes in the sampling programs through time. 1960-1983: CV = 0.2, 1984-2015: CV = 0.1, 2016-2022: CV = 0.05. The time series and associated confidence intervals are shown in *Figure 12* and *13*. Model configurations and prior distributions were defined as follows:

Carrying capacity (K): uninformative prior. Lognormal distribution specified using the “range” option in JABBA with lower and upper values ranging from maximum catch to 10x maximum catch (*Figure 14*)

Production function: Pella-Tomlinson (MSY at $B_{MSY}/K = 0.4$; $CV = 0.3$) where B_{MSY} is the biomass at MSY (*Figure 15*)

Process error variance (σ^2): Default $1/\gamma(4{,}0.01)$ (*Figure 16*). This matches the level of process error where state-space SPMs are most likely to adequately perform.

Observation error variance (if estimated) (τ^2): Default $\sim 1/\gamma(0.001,0.001)$ (*Figure 17*)

r prior: informative priors were developed based on the Medium (0.2-0.8) and High (0.6-1.5) resilience categories in FishBase (Froese et al. 2019). Given that FishBase does not include any crustaceans and that shrimp are likely on the higher range of r compared to most fishes, an additional Very High (1.2-3) prior was tested (*Figure 18*)

Initial biomass depletion ratio (ψ): two alternative priors were tested to reflect Low initial depletion $lognormal(0.9{,}0.25)$ and and High initial depletion $lognormal(0.25{,}0.5)$ at the beginning of the catch time series ($\psi = B_{1960} \,/\, K$) (*Figure 19*)

A factorial design was used to test a suite of models with alternative prior assumptions about r, ψ and τ^2. The naming convention for candidate model is as follows:

SpeciesCode_ModelRun_ProductionCurve_rPrior (H:High,M:Medium,V:Very High)_PsiPrior(High:0.2,Low:0.9)_ObservationError(T=TRUE,F=False)_StartYearCatches

For example,

WSH_4_P_rM_psil0.9_sigT_60 : White Shrimp (WSH_) run number 4 (_4) using a Pella-Tomlinson surplus production curve (_P), Medium r prior (_rM), low initial depletion (_psil0.9) with additional observation error being estimated (_sigF) and a catch time series starting in 1960 (_60)

3.1.3 Model Diagnostics

Candidate models were assessed based on the following four criteria (Carvalho et al. 2021):

3.1.3.1 Model Convergence

The Geweke convergence diagnostic (CONV_gw) compares the mean of the first and last part of Markov chain to see if they are significantly different. Z scores near 0 (between -1.96 and 1.96) are considered acceptable (Geweke 1992).

Heidelberger and Welch stationarity diagnostic (CONV_hs) shows the iteration number from which the chain is considered to have converged and an associated p value, where the null hypothesis is that the sampled values come from a stationary distribution (Heidelberger and Welch 1983). ‘Failure’ of the stationarity test indicates that a longer MCMC run is needed. The Heidelberger and Welch half-width test (CONV_hw) checks whether the Markov chain sample size is adequate to estimate the mean values accurately (Heidelberger and Welch 1983).

3.1.3.2 Model Fit

Catch-per-unit-effort (CPUE) residuals runs test: CPUE indices pass the runs test (CPUE_rt_rand) if there is no evidence of a non-random residual pattern ($p > 0.05$). Any year where the residuals are larger than the threshold limit [3 standard deviations (sd) away from the mean (Anhøj and Olesen 2014)] fail the outlier test (CPUE_rt_outl).

3.1.3.3 Model Consistency

Retrospective analysis: This test checks for systematic bias in the stock status estimates. The procedure involves sequentially removing all data from the most recent period (i.e. peeling), refitting the model, and then comparing terminal year estimates of stock status [e.g. spawning stock biomass (SSB), fishing mortality (F)] to the full model. A guiding practice proposed by Hurtado-Ferro et al. (2015), suggests values of Mohn's rho (RETRO_) that fall outside a set range (-0.22 to 0.30) for shorter-lived species indicates an undesirable retrospective pattern. In addition, the direction of the retrospective bias has implications for characterizing risk associated with management advice.

Process error: The annual process error deviations should exhibit a stochastic pattern with a constant average centered around the zero (ProcB_mu) and 95% credibility intervals covering the zero value (ProcB_CI).

3.1.3.4 Prediction Skill

Hindcast cross-validation (Kell et al. 2016, 2021): this test is to check that the model has prediction skill of future states under alternative management scenarios. The procedure involves sequentially removing CPUE data from the most recent period, refitting the model with the remaining data, and then comparing known CPUE values (observations) to model estimates.

Mean Absolute Scaled Error (HX_MASE): The MASE score scales the mean absolute error of the prediction residuals to the mean absolute error of a naive in-sample prediction (i.e. equal to the last observed value). A score of 0.5 indicates that the model forecasts of CPUE values are twice as accurate as a naive in-sample prediction, indicating that the model has prediction skill. A score higher than 1 indicated that the model forecasts are no better than a random walk. If MASE < 1, the model has some level of prediction skill and passes the test.

3.1.4 Goodness of Fit

Deviance Information Criteria (DIC) was used for model selection purposes, where a lower value generally indicates a better model fit. Root-Mean-Squared-Error (RMSE) was used to quantitatively evaluate the randomness of model residuals. These criteria were used to determine the best model of those that passed the model diagnostic tests described in the previous section.

3.2 Empirical Dynamic Modelling (EDM)

Empirical Dynamic Modelling (EDM) uses lags of time series data to reconstruct the state-space of a system (Sugihara 1994; Sugihara et al. 2012; Munch et al. 2017, 2022). This form of modeling is particularly useful for short-lived species with chaotic population dynamics where drivers are often not observed directly, yet the information is embedded within the time series of abundance. Lags of abundance indices are used to reconstruct the full dynamics of the system without needing data on variables impacting abundance or specifying model form. Gaussian-Process EDM (GP-EDM) version 0.0.0.9010 on *GitHub* was used to fit the LDWF survey data aggregated at levels defined in *Section 2*. We also tested the inclusion of economic and environmental variables as covariates since they are hypothesized drivers of shrimp abundance where measurements do exist.

3.2.1 Model Configurations

3.2.1.1 Formulation with Fishery Removals

Gaussian Process regression was used to approximate the White Shrimp population delay-embedding map f

$$P\left[y_t \,\middle|\, f, (X_{t-m} - qC_{t-m}), z, V_e\right] \sim Normal(f(X_{t-m} - qC_{t-m}, z), V_e)$$

where the probability of observing abundance y at time t is dependent on the function approximation f, vector of abundance indices X with m lags ($X_{t-m} = x_{t-1}, \dots, x_{t-m}$), optional covariates z, and process variance V_e. The delay embedding map defined above was expanded to include removals (C, catch or landings) scaled by a catchability parameter q which can be fit within or among populations. Here, catchability is a scalar used to translate units of landings into survey units. The inverse of this scalar was also used to convert estimates of abundance in survey units to total biomass estimates in landings units. Covariates (z) can be included as direct drivers of abundance where measurements exist. The model is fitting to 'escapement', the composite variable $X_{t-m} - qC_{t-m}$, which is defined as the number of individuals remaining after harvesting and is assumed to be proportional to the biomass of individuals remaining after harvesting. GP-EDM with a single lag $m = 1$ can be thought of as a nonparametric production model (Thorson et al. 2014). f is dependent on the inverse length scales $\Phi = \phi_1, \dots, \phi_{i=m+z}$ and pointwise prior variance τ and follows a Gaussian Process prior with mean zero and covariance function Σ, which assumes no relationship on the shape function.

$$P\left[f \,\middle|\, \Phi, \tau\right] \sim GP(0, \Sigma)$$

The covariance function Σ is defined for abundance y

$$\Sigma(y_t, y_s) = \tau * exp\left[-\Sigma_{i=1}^{m+z} \phi_i\left((X_{it} - qC_{it}) - (X_{is} - qC_{is})\right)^2\right]$$

at times t and $s \in T$ where T is the time series length (Munch et al. 2022). The inverse length scale parameters ϕ and escapement observations $X - qC$ are provided for each $i = m + z$ where m is the lags of abundance and z is the covariates. This function is scaled by τ, and a prior is applied here that constrains the total variance of the predicted population size (y_{T+1}) to be less than twice the observed variance in $y_1, \dots, y_T$. This prior specification for process and observed variances and length scale parameters are represented by

$$P[V_e, \tau, \Phi]$$

The covariance function and inverse length scales jointly control the degree of nonlinearity of the shape function f, where $\phi = 0$ indicates a flat relationship and a large estimate for ϕ indicates a higher degree of nonlinearity. The covariance function Σ can either tighten the relationship around the observed data, favoring a smaller length scale (i.e. a larger inverse length scale parameter) or relax the relationship, facilitating a smoother function with a larger length scale (smaller ϕ). Detailed GP prior specification for EDM variance and length scale parameters can be found in Munch et al. (2017).

An optional feature of GP-EDM is to assign a linear prior on f which can aid in grounding the population to 0 as the harvest rate, U, approaches 1 (i.e. the entire population is harvested). The linear prior option assumes that the mean function for the GP is linear with respect to the first input and fits the model on the residuals of

$$y_t = \beta_0 + \beta_1[x_{t-1} - qc_{t-1}] + f(X_{t-m} - qC_{t-m}, z)$$

where $[x_{t-1} - qc_{t-1}]$ is first lag of escapement and f is the GP function approximation. If $y_t = log(x_{t+1}/x_t)$ and is backtransformed, this is equivalent to a Ricker model excluding f (Ricker 1954). In this case, we're working on deviations from growth under the assumed Ricker model. The model fits similarly to the previous configuration, but the primary difference can be observed outside of the range of observed data. This configuration helps linearly ground the fishery model abundance to zero as simulated removals approach the total population size. Without this prior, it's possible that outside of the observed range of the data, the abundance levels out to the flat prior where the population may never reach zero (and can result in extraordinarily high landings under simulated high harvest rates).

3.2.1.2 Embedding Dimension

EDM embedding dimension E is limited by the length T of the time series. An approximate maximum embedding dimension is $E \leq \sqrt{T}$. In the case of continuous seasonal data, the maximum embedding dimension is larger since the time series T is longer. Models were configured using Summer and Fall seasons as continuous time steps throughout a year and as a population-specific level within a hierarchical EDM, which will be explained in further detail below. The embedding dimension is defined as the number of population lags m (and covariates z if included) plus one, $E = m + z + 1$. For White Shrimp, the first year of the LDWF survey was 1980, resulting in 43 years of data, and a maximum embedding dimension of approximately 6 on an annual scale.

3.2.1.3 Hierarchical Model Scaling

Prior to fitting EDM models, all input data are standardized to a mean of 0 and standard deviation of 1. In the context of EDM, the term 'populations' is used to define data aggregations where information is expected to be informative. For White Shrimp, data aggregations and resulting populations that could be used to delineate levels of EDM are defined at the start of *Section 2*. For systems with multiple populations, these could be fit within a hierarchical EDM or independently.

In hierarchical models, the data must be scaled globally or locally across populations. For global scaling, the data across populations are expected to have the same mean. For White Shrimp, global scaling is likely inappropriate for most strata defined here. For example, we never expect the abundance of Large shrimp to equal the abundance of Small shrimp as would be implied by global scaling. Local scaling allows us to scale the data within the defined population time series of available data for each respective lag of population abundance or covariate. Both global and local scaling are applied within each predictor, not across all data. For example, each predictor is scaled to a mean of 0 and standard deviation of 1 for each lag and covariate. For global scaling, all data from all populations are used to scale the data; for local scaling, this is done within populations.

In independent models, definition of global or local scaling is obsolete because all data are scaled to a mean of 0 and standard deviation of 1. Independent models were tested for all data aggregations to ensure information was gained through the increased complexity and shared information from hierarchical models and with dynamic correlation.

3.2.1.4 Dynamic Correlation

Dynamic correlation ρ is defined as the degree to which the EDM population dynamics are correlated. This quantifies the similarity of population responses across predictor space and ranges from 0 to 1. Populations in hierarchical models will share the same embedding parameters and inverse length scale parameters (this includes models with $\rho = 0$, or independent dynamics). A dynamic correlation $\rho = 1$ means the dynamics of each population are identical. In other words, we assume that all delay vectors come from the same attractor. If fitting a single population or independent model, ρ reverts back to the mode of the prior, 0.5.

In hierarchical models, the dynamic correlation can be fixed or estimated. In cases where dynamic correlation is set to 0 within a hierarchical model, this will still yield different results when compared to independently fit models. This is because the hierarchical model shares information among the estimated length scale parameters ϕ for each embedding parameter.

3.2.1.5 Length Scale

Length scale parameters ϕ and the number of model inputs ($i = m + z$) define the complexity of the function represented by the GP. Each model input i incorporates an additional dimension of space, and their associated length scale parameter ϕ_i defines the wiggliness in that dimension. Low values of ϕ indicate stiff and mostly linear relationships, and large values of ϕ indicate more nonlinear relationships. A model with a single input and large ϕ_1 would have many degrees of freedom, while a model with many inputs but all ϕ_i close to 0 would have relatively few degrees of freedom (Tsai et al. 2024).

3.2.1.6 Data Transformations

Possible data transformations on the population are defined below. This transformation is applied before fitting the model and is referred to as 'ytrans' in the GP-EDM R Package.

- none: no transformation
- log: log transformation ($log(X_t)$)
- gr1: log difference transformation ($log(X_t/X_{t-1})$)
- gr2: log difference transformation on escapement ($log\left(X_t/(X_{t-1} - qC_{t-1})\right)$)

3.2.1.7 Covariates

The underlying theory of EDM is that lags of the population have information on population drivers embedded within them (Munch et al. 2020). It is possible to include some covariates directly in EDM that are believed to influence population abundance. In the case of Gulf penaeid shrimp, economic conditions have had a massive impact on the domestic fishery, which in turn directly influences the amount of shrimp left in the water. Additionally, it has been hypothesized that environmental drivers such as salinity and temperature in the shrimp nursery grounds may have a direct impact on recruitment to the population the following year (Turley et al. 2023).

While covariates have the potential to improve model fits and short-term predictive accuracy, relying on lags of the population alone for estimating the biological MSY is simpler from an operational standpoint. Including covariates in the model requires making some assumption about the future states of that covariate in projections, which cannot be done with high confidence in this context. In addition, some of the variables considered may contain some level of covariation which the model is not set up to account for in its present form.

3.2.1.8 Cross Validation

Two different cross validation approaches were explored to evaluate prediction accuracy: "leave time out" and "sequential". Prediction method "leave time out" leaves out all data points (i.e., survey data, catch, covariates) taken at the same time across all populations where population is specified within hierarchical models. The "sequential" prediction method leaves out all future time points across all populations where population is specified. In both of these methods, training data are iteratively omitted for the predictions, but the inverse length scales and variances used are those obtained using all of the training data under the originally fit model. We anticipate that "sequential" would perform worse when compared to "leave time out". Both cross validation approaches were applied to all model configurations, but ultimately the "sequential" method was preferred for model selection because our ultimate objective is to project landings and harvest rates into the future in order to accurately estimate the system's maximum sustainable yield for fishery management.

3.2.2 Goodness of Fit

Goodness of fit was measured through the estimation of R^2.

In sample fit statistics for each prediction method:

- R^2 - proportion of variance explained by model (independent or hierarchical)
- R^2_{pop} - proportion of variance explained for each population within a hierarchical model
- R^2_{scaled} - proportion of variance explained by a hierarchical model, centered and scaled by population means
- $rmse$ - root mean square error
- df - degrees of freedom, trace of the smoother matrix

Out-of-sample fit statistics for each prediction method:

- R^2_{out} - out-of-sample R^2
- R^2_{outpop} - out-of-sample R^2_{pop}
- $R^2_{outscaled}$ - out-of-sample R^2_{scaled}
- $rmse_{out}$ - out-of-sample $rmse$

These fit statistics measure the models' overall performance and ability to perform outside of the training data. Within hierarchical models, population-specific R^2_{pop} metrics measure the model's ability to track the individual populations. For example, a model may be able to track one population well, but may fit another poorly. These population-specific R^2_{pop} metrics were centered and scaled around their respective model means in the R^2_{scaled} fit statistics to more appropriately measure the overall model performance. Population-specific R^2_{pop} and R^2_{scaled} statistics were compared to R^2 statistics obtained from independent model fits of each population to ensure that the complexity of the hierarchical model was warranted (i.e. improved overall prediction skill).

3.2.3 Estimated Parameters

Parameters estimated and priors specified in GP-EDM are defined below.

- $\phi_1 : \phi_i$ - length scale parameters for $1 : i$ where i is the total m lags and z covariates ($i = m + z$); priors are set such that the expected number of local extrema for each ϕ_i is 1 (Munch et al. 2017)
- V_e - process variance
- τ - pointwise prior variance in f
- ρ - dynamic correlation between populations where values range from 0 to 1, with 0- independent no correlation and 1- identical dynamics
- q- catchability scalar that translates the units of landings into units of survey CPUE

The relative magnitude of the pointwise prior variance τ and process noise V_e gives information on how important the function is relative to the noise. Process variance is represented as a percentage of the total variance, whereas the pointwise prior variance cannot be directly translated to variance percentage because it interacts with the length scale parameters. If the model is purely deterministic, $V_e = 0$ and $\tau \approx 1$. If the model is not fitting the data well, τ is small and the process variance is close to 1.

Catchability could be estimated jointly (q=shared) or separately for each population in each model configuration. In some instances, the model obtained very good fits, but estimated catchability $q = 0$ and ignored the landings altogether. For the purposes of our work here, the link to landings is critical. To select a representative model for estimating MSY, the models were filtered to exclude any model where catchability < 0.001 (where the observed catchability in the data were typically above 0.01).

3.2.4 Estimating Maximum Sustainable Yield (MSY) with EDM

Maximum Sustainble Yield (MSY) estimates were generated following the methodology outlined in Tsai et al. (2024). Harvest rates ranging from 0:1 were projected into the future and an average of the long-term dynamics were taken for each population, then added up to obtain estimates of long-term landings. These averages were used to identify the harvest rate that maximizes landings. Models that were configured seasonally required landings and associated harvest rates to be translated to annual scales. Translating catch from a seasonal to an annual time scale was fairly simple

$$C_t = 2 * C_{t/2}$$

where t is defined as one year here, and $t/2$ represents 2 seasonal steps per year. Annual harvest rate U_t was estimated from a seasonal harvest rate $U_{t/2}$ as

$$U_t = 1 - \left(1 - U_{t/2}\right)^2$$

where the new estimated harvest rate U_t captures the portion of the population (0:1) removed via landings over the course of a year. Here, the estimated long-term biomass associated with the rate of removals does not need to be changed. The annual harvest rate U_t was further translated to an annual fishing mortality rate $F_t = -ln(1 - U_t)$. This allows for the calculation of the more familiar benchmark F_t/F_{MSY}, which is a measure of overfishing (estimated to be occurring if $F_t/F_{MSY} > 1$).

3.2.5 Model Diagnostics

Models were diagnosed and deemed reliable based on a set of criteria defined below. This methodology worked well for all Gulf shrimp species assessed within SEDAR 87. These decisions were applied to ‘no covariate’ models, since assumptions on the cyclical nature of environmental variables and the relationship between harvest rate and economic variables would be required for projections. It was determined that these assumptions should be avoided for the purposes of defining biological maxima if possible. The projection period was initially set to 50 timesteps then extended to 80 to ensure the reference points had stabilized before taking an average. The duration over which to average was determined by the length of a cycle, which was typically driven by the seasonal time steps in the model if present. The estimate of MSY is sensitive to setting an appropriate projection period that ensures the population has stabilized and an appropriate save interval that ensures only complete cycles are clipped, the latter ensures the estimate is not biased high or low (as would be observed if the time step just outside of a completed cycle is increasing or decreasing, respectively).

3.2.5.1 Model Fitting Performance

Model performance was determined by considering the suite of Goodness of Fit parameters defined above. The top 30 models from the hierarchical overall R^2_{out} and top 30 models from the $R^2_{outscaled}$ were pulled, and any overlapping models were considered. The top 5 from each of these criteria and the top 5 aggregated Gulf-wide models were considered to evaluate what was gained from added complexity.

3.2.5.2 Model Projection Performance

Projection performance was evaluated to ensure models extrapolate to MSY in a reasonable way. Model selection was already performed with this goal in mind when relying on predictmethod=sequential to obtain fit statistics. Additional diagnostics were developed to cull out unreasonable models. This included removing models that maximized catch at $U = 1$, which generally happened when models would predict that the population returns to the flat prior outside of the observed range of the data. These models were often paired with unrealistically high catch estimates due to the coupling of extreme harvest rates with populations that did not always ground to zero. It is intuitively not sustainable to remove the entire population, so these models were removed. Unrealistically high estimates of MSY were defined as greater than ten times the highest historic landings.

3.2.5.3 Model Robustness

From the remaining set of models that (1) had good fits, (2) did not solve on a bound ($U = 1$), and (3) did not estimate MSY at greater than 10x historical landings records, a retrospective pattern analysis was carried out where 1 to 5 time steps were peeled back and MSY was re-estimated. The Model Projection Performance selection criteria defined above were applied to each of these iterations. If any iteration failed, it was dropped from further consideration. This resulted in a final selection that balances model complexity and relative stability.

4. Stock Assessment Model Results

4.1 JABBA Results

4.1.1 Model Fit and Diagnostics

Diagnostic results for the top performing JABBA model runs are presented in *Figure 20*. Out of the four models retained, two showed signs of poor convergence. All models showed a persistent, increasing trend in process error deviations, with the two runs that did not allow for any additional observation error (runs 13 and 16) exhibiting strong deviations from the zero line, which indicates that changes in biomass diverge from the model expectations. Model runs were generally consistent (*Figure 21*) but none showed any prediction power (the hindcast cross validation results were poor with MASE >1) with the model systematically underestimating the index value in years 2018 and beyond (*Figure 22*).

The models were fairly insensitive to the prior assumption made about r but highly sensitive to the prior assumption made about initial depletion. Allowing additional observation error on the index did not change the point estimates considerably but did result in much higher uncertainty for all estimated parameters and derived quantities. Detailed figures showing the results of each diagnostic test are reported for run 16 (*Figure 21*, *Figure 22*, *Figure 23*).

4.1.2 Estimated Parameters and Derived Quantities

Estimated parameters for these models are provided in *Table 3* and *Figure 24*. For the models being considered here, each MSY was estimated between 70-80 million pounds of tails, a consistent estimate given the range of parameterizations (*Table 4*). There is an extremely wide range of estimates of unfished biomass shown in the surplus production models being considered (*Figure 25*), and the estimated time series of B/B_{MSY} is sensitive to the initial depletion prior (*Figure 26*). Most models dip below B/B_{MSY} periodically throughout the assessment time period until the mid-2000s (*Figure 27*), when the fishery began targeting almost exclusively Large shrimp (*Figure 7*).

Most model posteriors did not deviate significantly from the priors as there was not much contrast in the data to inform the underlying surplus production model (*Figure 28*). There was also evidence of bimodality in the posteriors for K and q, suggesting two alternative solutions and general model instability (*Figure 28*).

4.2 EDM Results

Over 5,500 model configurations were evaluated for White Shrimp to explore assumptions and ensure that results from the various iterations made sense. Up to the maximum embedding dimension was considered, with preference given to simpler models where possible. Estimated parameters, model fits, and projection capabilities are discussed below, resulting in the recommendation of a single model by the end of this section.

4.2.1 Model Configurations

Model configurations were examined to test assumptions and ensure results were as expected. The impact of using the 'sequential' method when defining the training dataset for prediction accuracy is shown in *Figure 29*, where 'leave-time-out' almost always yielded a higher out-of-sample R^2_{out} fit. In hierarchical models, large differences in population means could artificially inflate the R^2_{out} metric. Therefore, metrics were calculated to estimate goodness-of-fit that were centered and scaled around the population mean, $R^2_{scaledout}$. Hierarchical out-of-sample R^2_{out} generally yielded a higher value than the out-of-sample scaled by population-specific fits, $R^2_{scaledout}$. With these models, the goal is to fit and project each population within the model well, and $R^2_{scaledout}$ was the primary metric used to gauge model fits going forward.

Models with local scaling were considered over global scaling for all model configurations since we don't expect the populations as defined here to ever be equal (except for models with one "population" where global scaling is inherent). The distribution of out-of-sample scaled $R^2_{scaledout}$ fit statistic was shown across all model configurations (embedding dimension, population, y transformation) (*Figure 30*).

Some of the reported R^2 metrics were associated with models that ignored landings (i.e. $q \approx 0$). *Figure 31* shows the distribution of R^2 after these models were removed. From the set of models that account for landings, additional models were excluded due to the fact that they included covariates. In *Figure 32*, information can be inferred about the relative scales of population sizes and landings, where model configurations fit better to distinct catchabilities (e.g., different scales between populations and landings) compared with models that assumed shared catchabilities (e.g. similar scales between population and landings). This figure shows the model configurations that were analyzed for fit and eventual MSY estimation.

4.2.2 Model Fit and Residual Analysis

From the set of models described in the previous section, the procedures outlined in *Section 3.2.5.1* were applied, i.e. ranking the models by out-of-sample prediction accuracy for the model as a whole (R^2_{out}), scaled by population ($R^2_{outscaled}$), or both (*Section 3.2.2*). This resulted in 59 models going through MSY estimation and further model diagnostics (*Table 5*). These models had out-of-sample prediction accuracies ranging from 0.336 up to 0.87. Scaled population R^2_{scaled} metrics ranged from 0.008 up to 0.484, where a zero here would indicate that one population prediction was no better than a random forecast. These were overall very good fits to the data, and in-sample fit statistics were even greater.

4.2.3 Model Diagnostics

The subset of 59 models with the best fits was further reduced down to 5 models after testing for projection ability and model robustness as outlined in *Section 3.2.5* (*Table 6*). The remaining models were all size class models with an annual time step except for one size-aggregated annual model. All hierarchical models were locally scaled, had separately estimated catchability parameters, and had a linear prior to ground the model to zero outside the observed range of the data as harvest rates approached 1. Both of the models with no scaling on the predictor variable (y_t) were characterized by instability, with a few peels solving for MSY at $U = 1$, where estimates spiked up to well over 10x historical record landings. The 3 remaining models all had the gradient transformation on escapement for the predictor variable (y_t) and were were identically parameterized with different embedding dimensions: $E = 3,4,6$. The model with $E = 3$ (WSH_C4160), was the most unstable, with estimated MSY increasing by 300% for one of the peels and all others remaining within approximately 10% of the original estimate. This model was removed from consideration at this point. The model with $E = 6$ (WSH_C20128) estimated the current harvest rates to be approaching and occasionally exceeding MSY with a smaller estimate of standing stock biomass, conflicting with the majority of other model run outputs. This resulted in the preferred model $E = 4$ (WSH_C4182), which appeared to appropriately capture the dynamics of the system. This run estimated MSY greater than the historical landings record with a larger standing biomass, which aligns with how we understand the fishery. Top performing model parameterizations are summarized below, where WSH_C4182 was preferred due to its simpler embedding dimension and more consistent results compared to the other models.

Run	Catchability	Population	Time Step	Lags	Scaling	Transformation
C20128	Distinct	Size (S,M,L)	Annual	6	Local	gr2
C4182	Distinct	Size (S,M,L)	Annual	4	Local	gr2

Variable harvest rate projections of CPUE by size class for the recommended model are shown in *Figure 33* - *35* and associated landings are shown in *Figure 36* - *38*. These data series were used to generate average biomass and landings under all harvest rates 0:1 in *Figure 39* and *Figure 40*. The total metrics for B_{MSY} and MSY are shown in *Figure 41* and *Figure 42* where dashed lines represent the annual rate at MSY. The horizontal dotted line on the MSY figure shows the maximum landings ever caught by the fishery, 85.1 million pounds of tails in 2006, which is slightly less than the projected MSY here, 87.8 million pounds of tails.

4.2.4 Estimated Parameters and Derived Quantities

Estimated parameters from the top-performing model are shown in *Table 7*. The function-space complexity is defined jointly by the length scales, which define the degree of nonlinearity, and the covariance matrix, which can open up the ability of the model to vary within a smoother space. The estimated length scale parameters ϕ_i are all approximately equal to 1 or less and are linear and smooth for all populations in the model (*Figure 43* - *46*). The length scale parameters on lags 3 and 4, ϕ_3 and ϕ_4, are flat and effectively act as scalars to the model. The pointwise prior variance was estimated to be 0.416 and was exceeded by the function process variance of 0.821, indicating a large amount of variability unexplained by the model. The dynamic correlation of the model was 0.864, indicating a high correlation between these data, which we can observe visually most easily in *Figure 4* and *Figure 7*. These size populations had distinct catchabilities that translate fishery removals to the units of the LDWF survey (number of shrimp per 10 minute tow divided by 10 million pounds of tails): Large $q = 0.021$, Medium $q = 0.627$, and Small $q = 3.767$. These vary markedly because of the distinct relative scales between population sizes and realized landings (e.g. Large is consistently the rarest population in the survey, but is the most common size class observed in the landings in recent years).

The R^2 statistics very high for the overall metrics compared to the population-scaled metrics, indicating a poor fit for at least once of the size classes (*Table 8*). Here, the Large and Small populations performed similarly $R^2_{popout} \approx 0.20$, while Medium pulled the average down with $R^2_{popout} = 0.09$. These values contributed to the $R^2_{outscaled} = 0.174$ scaled by population means, while out-of-sample $R^2_{out} = 0.856$, indicating the latter was likely inflated by the magnitude of differences in population means. Derived population benchmarks and associated rates are shown in *Table 8* alongside model fit statistics. Annual MSY was estimated as 87.8 million pounds of tails, occurring at $F_{MSY} = 0.896$ where the population biomass at this rate is $B_{MSY} = 148.35$ million pounds of tails.

4.2.5 Fishing Mortality

Estimated fishing mortality rates through time are shown in *Table 9*. In 2022, the stock experienced 15% F_{MSY} and the stock size was ~2.5x B_{MSY}. The highest rates of fishing mortality were observed in the late 1980's prior to the economic collapse of the fleet due to aquaculture imports, but is not estimated to have ever experienced overfishing ($F/F_{MSY} < 1$).

4.2.6 Biomass and Abundance Trajectories

The White Shrimp stock was estimated to have dipped below B_{MSY} a few times throughout the time series, during high landings in both the late 1980s and the early 2000s. This could be explained by the oscillating nature of this stock, where landings in the late 1980s and early 2000s were high, particularly for Large shrimp, but the population was in a trough, resulting in $B/B_{MSY} < 1$. Given the oscillating nature of EDM, it is possible that when using averaged MSY projections, the true sustainable fishing levels in any given year could be above or below the average MSY, but it is not expected to be an issue unless the system begins chronically dipping below sustainable levels. Fits of the preferred model are shown in *Figure 47* and *Figure 48*.

5. Discussion

EDM is particularly suitable for studying populations that exhibit non-equilibrium dynamics and nonlinear state-dependent behavior (i.e. where interactions change over time and as a function of the system state). JABBA relies on very rigid SPM assumptions about stock and fishery dynamics that likely do not hold true for shrimp. EDM had better performance metrics and diagnostics than JABBA, resulting in an EDM model being recommended for providing management advice.

The JABBA models were generally poor and limited by the overarching constraints of surplus production models which aggregate dynamics, not accounting for size or spatial differences. The models were highly sensitive to the prior specification for initial depletion and showed signs of instability and little to no predictive power. This poor model performance was likely driven by the limited contrast present in the data, with landings exhibiting a one-way trip throughout the time period of the assessment and CPUE not appearing to respond to this increase in catches. In addition, it is likely that White Shrimp stock dynamics are driven more by environmental and economic factors than by the catches, which could lead the stock to appear to respond to the fishery in unexpected ways (e.g. large changes in abundance despite no changes in catch or abundance and landings increasing in unison). The Gulf White Shrimp fishery landings size compositions have changed considerably through time (*Figure 8*) due to global market conditions and increasing demand and prices yielded for Large shrimp. This likely causes a mismatch between the time series of CPUE and catches in terms of what each is indexing, further confusing the size aggregated model. Additionally, as the domestic fleet consolidated, larger and more efficient vessels remained and could be trawling in a different habitat compared to the historic distribution of the fleet. These factors are all justifications against using surplus production models that assume catch levels reflect only changes in stock abundance and that patterns of exploitation are primarily driven by shrimp availability rather than environmental or economic considerations.

EDM models showed good diagnostics and prediction accuracy. The biomass of the White Shrimp population and removals were modeled and predicted well. Size-structure was included through the use of populations within a hierarchical GP-EDM, which further improved the model fits. There was a disconnect in the relative presence of size classes between the survey (where Small was most abundant) and the fishery (where Large was the most abundant in recent years) which may have contributed to the larger process variance. Through this work, the incorporation of distinct catchabilities in the GP-EDM package was implemented, but capturing the shifting catchabilities through time (or before and after the economic transition in the mid-2000s) may improve the ability of the model to explain total variance.

One caveat of the current EDM configurations explored here is there is no feedback loop from smaller size classes to larger size classes. For example, there is no penalty on Medium and Large shrimp for removing too many Small too early under a high harvest rate. In reality, a harvest rate that maximizes Small shrimp may cause a negative feedback loop on Large shrimp that is not accounted for here. In some simulations, the peak landings for Large shrimp was at a much lower harvest rate than the Small, and when aggregating these size classes to approximate a total MSY, it is feasible that the realized Large shrimp landings would be lower due to the lack of Small shrimp growing out to Medium and Large size classes. Accounting for this negative feedback loop through mixed-age configurations is possible (Dolan et al. 2023), but it is complicated by mixing landings across calendar years to fit to population escapement, which would markedly increase management complexity, perhaps unnecessarily. The recommended EDM configuration here maximized landings of Large and Small size classes at approximately the same harvest rate with the landings for Medium maximized at a slightly higher rate, removing the immediate need to explore this caveat further.

EDM was able to capture the cyclical nature of shrimp population abundance, resulting in a more accurate population model. Lags of the population retain information on sometimes immeasurable drivers, including abundance of predators and some environmental influences. Direct inclusion of environmental and economic covariates improved model fits further, but they were not used in the final model because additional assumptions would be required on the future state of the industry and environment. Furthermore, relationships between the simulated harvest rates and these covariates would need to be addressed, and may respond in unexpected ways. Given the goal of providing a biological MSY estimate for this fishery, biological models only were used for this purpose. The models with covariates may serve other purposes and could be used to predict year-ahead abundance and landings more accurately than the model with lags alone, particularly for those tied to economic drivers.

Finally, providing management advice for this fishery using static estimates of MSY may not be appropriate due to the highly cyclical nature of this stock which is not fully captured in a long-term average. The model itself captures the dynamics, but the methods to obtain MSY through a long-run average do not. In high productivity years, the fishery may be able to harvest more than the average MSY, in low productivity years, they may push the stock into an ‘overfished’ status (see late 1980s, early 2000s). To provide management advice for a population with such large estimates of sustainable landings, the long run average should be used to ensure that the stock does not undergo overfishing. In the event of improved economic conditions where the fleet expands and under prevailing environmental conditions, this assumption could be revisited and management advice could be provided on a finer scale. Updating the model with seasonal inputs as they are available could account for the peaks and dips in productivity, allowing the fleet to take advantage of high productivity years or potentially sit out low productivity years. Because the fleet is mainly limited by the economics of the fishery, these kinds of model explorations are recommended as a future research recommendation.

6. Research Recommendations

The models provided in this report are sufficient to provide management advice for the stock. However, should future research funding become available, we have provided suggestions below.

Potential improvements to the modeling framework include accounting for removal of shrimp as it pertains to harvest rates that are optimized at varying size classes. Creating a feedback loop that appropriately represents the removal of larger shrimp that may not contribute to future generations as well as the removal of smaller shrimp that may not grow into Large shrimp should be accounted for. Sensitivities of these potential feedback loops and their impact on estimating optimal harvest rates should be investigated in both directions (i.e. Large to Small and Small to Large impacts).

Additional research into covariates may also be investigated. Direct inclusion of covariates generally resulted in improved model fits and could likely improve forecasting efficiency for trends of abundance. To forecast MSY, covariates would need to be projected into the future. For environmental covariates, the cyclical nature of these trends would need to be captured. For economic covariates, the relationship with projected harvest rates would need to be explicitly defined.

Implications of the LDWF survey capturing mostly Small shrimp in conjunction with the fishery capturing mostly Large shrimp should be investigated as it pertains to catchability estimation and resulting estimates of escapement. It is suspected that this was the primary driver for a large process variance in the model.

7. Acknowledgements

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8. References

Ailloud, L., M. Stevens, B. Turley, A. Pollack, and D. Hanisko. 2025. *Developing a fishery-independent index of relative abundance for Gulf of Mexico White Shrimp using VAST*. Page 24pp. SEDAR, SEDAR87-AP-05, North Charleston, SC.

Anhøj, J., and A. V. Olesen. 2014. *Run charts revisited: A simulation study of run chart rules for detection of non-random variation in health care processes*. PLoS One 9(11):Article e113825.

Atkinson, S., A. Lowther, K. Dettloff, and S. Smith. 2024. *Gulf of Mexico commercial brown, pink and white shrimp landings*. Page 38pp. SEDAR, SEDAR87-DW-06, North Charleston, SC.

Browder, J. A., Z. Zein-Eldin, M. M. Criales, M. B. Robblee, S. Wong, T. L. Jackson, and D. Johnson. 2002. *Dynamics of pink shrimp (Farfantepenaeus duorarum) recruitment potential in relation to salinity and temperature in Florida Bay*. Estuaries 25(6):1355–1371.

Carvalho, F., H. Winker, D. Courtney, M. Kapur, L. Kell, M. Cardinale, M. Schirripa, T. Kitakado, D. Yemane, K. R. Piner, M. N. Maunder, I. Taylor, C. R. Wetzel, K. Doering, K. F. Johnson, and R. D. Methot. 2021. *A cookbook for using model diagnostics in integrated stock assessments*. Fisheries Research 240:105959.

Dolan, T. E., E. P. Palkovacs, T. L. Rogers, and S. B. Munch. 2023. *Age structure augments the predictive power of time series for fisheries and conservation*. Canadian Journal of Fisheries and Aquatic Sciences:1–13.

Froese, R., H. Winker, G. Coro, N. Demirel, A. C. Tsikliras, D. Dimarchopoulou, G. Scarcella, M. L. D. Palomares, M. Dureuil, and D. Pauly. 2019. *Estimating stock status from relative abundance and resilience*. ICES Journal of Marine Science 77(2):527–538.

Geweke, J. 1992. Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments. Pages 169–193 *in* J. M. Bernardo, J. O. Berger, A. P. Dawid, and A. F. M. Smith, editors. Bayesian statistics. Clarendon Press, Oxford.

Griffith, D., C. Liese, M. Travis, M. Freeman, and D. Records. 2023. *Social dimensions of Gulf of Mexico shrimping*. Page 12pp. SEDAR, SEDAR87-DW-15, North Charleston, SC.

Haddon, M. 2021. Surplus production models. Pages 253–322 Using r for modelling and quantitative methods in fisheries. Chapman; Hall, London, UK.

Heidelberger, P., and P. D. Welch. 1983. Simulation run length control in the presence of an initial transient. Operations Research 31:1109–1144.

Hurtado-Ferro, F., C. S. Szuwalski, J. L. Valero, S. C. Anderson, C. J. Cunningham, K. F. Johnson, R. Licandeo, C. R. McGilliard, C. C. Monnahan, M. L. Muradian, K. Ono, K. A. Vert-Pre, A. R. Whitten, and A. E. Punt. 2015. *Looking in the rear-view mirror: Bias and retrospective patterns in integrated, age-structured stock assessment models*. ICES Journal of Marine Science 72(1):99–110.

Kell, L. T., A. Kimoto, and T. Kitakado. 2016. *Evaluation of the prediction skill of stock assessment using hindcasting*. Fisheries Research 183:119–127.

Kell, L. T., R. Sharma, T. Kitakado, H. Winker, I. Mosqueira, M. Cardinale, and D. Fu. 2021. *Validation of stock assessment methods: Is it me or my model talking?* ICES Journal of Marine Science 78(6):2244–2255.

LDWF. 2024. *Inshore brown and white shrimp relative abundance in Louisiana*. Page 11pp. SEDAR, SEDAR87-DW-12, North Charleston, SC.

Liese, C. 2024. *Price indices for shrimp imports and Gulf of Mexico shrimp landings by size and season*. Page 10pp. SEDAR, SEDAR87-AP-2, North Charleston, SC.

Lowther, A. 2023. *Shrimp import data*. Page 2pp. SEDAR, SEDAR87-DW-10, North Charleston, SC.

Munch, S. B., A. Brias, G. Sugihara, and T. L. Rogers. 2020. *Frequently asked questions about nonlinear dynamics and empirical dynamic modelling*. ICES Journal of Marine Science 77(4):1463–1479.

Munch, S. B., V. Poynor, and J. L. Arriaza. 2017. *Circumventing structural uncertainty: A Bayesian perspective on nonlinear forecasting for ecology*. Ecological Complexity 32:134–143.

Munch, S. B., T. L. Rogers, and G. Sugihara. 2022. *Recent developments in empirical dynamic modelling*. Methods in Ecology and Evolution:1–14.

Pella, J. J., and P. K. Tomlinson. 1969. *A generalized stock production model*. Inter-American Tropical Tuna Commission Bulletin 13:419–496.

Ricker, W. 1954. Stock and recruitment. J. Fish. Res. Bd. Canada 11(5):559--623.

Schlenker, L. S., C. Stewart, J. Rock, N. Heck, and J. W. Morley. 2023. *Environmental and climate variability drive population size of annual penaeid shrimp in a large lagoonal estuary*. PLOS ONE 18(5):e0285498.

SEDAR87 Data Workshop Report. 2023. Page 94pp. SEDAR, SEDAR87, North Charleston, SC.

Sugihara, G. 1994. *Nonlinear forecasting for the classification of natural time series*. Philosophical Transactions: Physical Sciences and Engineering:477–495.

Sugihara, G., R. May, H. Ye, C. Hsieh, E. Deyle, M. Fogarty, and S. Munch. 2012. *Detecting Causality in Complex Ecosystems*. Science 338(6106):496–500.

Thorson, J. T., K. Ono, and S. B. Munch. 2014. *A Bayesian approach to identifying and compensating for model misspecification in population models*. Ecology 95(2):329–341.

Tsai, C.-H., S. B. Munch, M. D. Masi, and M. H. Stevens. 2024. *Empirical dynamic modeling for sustainable benchmarks of short-lived species*. ICES Journal of Marine Science:1–12.

Turley, B., L. Ailloud, and M. Stevens. 2023. *Development of estuarine environmental indices for SEDAR 87 Gulf of Mexico White, Pink, and Brown Shrimp stock assessment*. Page 15pp. SEDAR, SEDAR87-AP-01, North Charleston, SC.

Winker, H., F. Carvalho, and M. Kapur. 2018. *JABBA: Just Another Bayesian Biomass Assessment*. Fisheries Research 204:275–288.

Zink, I. C., J. A. Browder, D. Lirman, and J. E. Serafy. 2018. *Pink shrimp Farfantepenaeus duorarum spatiotemporal abundance trends along an urban, subtropical shoreline slated for restoration*. PLOS ONE 13(11):e0198539.

9. Tables

Table 1: LDWF CPUE in number of shrimp per 10min trawl for White Shrimp by size.

Year	Large	Medium	Small
1980	0.10	2.69	22.13
1981	0.22	3.74	17.50
1982	0.13	2.33	15.86
1983	0.09	1.72	17.05
1984	0.16	3.37	18.34
1985	0.14	3.23	21.28
1986	0.28	4.78	24.28
1987	0.14	3.60	20.58
1988	0.03	1.45	10.20
1989	0.06	1.57	10.84
1990	0.08	2.15	15.80
1991	0.08	1.98	22.06
1992	0.07	2.42	19.02
1993	0.09	1.81	31.29
1994	0.12	1.69	30.86
1995	0.11	2.68	29.48
1996	0.11	2.17	17.62
1997	0.07	1.53	23.57
1998	0.08	1.72	28.48
1999	0.03	1.41	24.38
2000	0.07	2.76	28.18
2001	0.08	1.58	15.46
2002	0.07	1.54	14.59
2003	0.08	1.93	20.04
2004	0.12	2.90	32.47
2005	0.20	4.89	29.94
2006	0.66	6.36	47.48
2007	0.26	4.32	42.34
2008	0.35	5.39	34.96
2009	0.36	5.74	45.87
2010	0.53	4.93	39.20
2011	0.50	4.84	21.35
2012	0.32	3.52	31.90

Table 1 Continued: LDWF CPUE in number of shrimp per 10min trawl for White Shrimp by size.

Year	Large	Medium	Small
2013	0.22	2.65	27.33
2014	0.14	2.26	20.39
2015	0.30	3.87	26.88
2016	0.11	3.24	30.74
2017	0.13	4.61	21.86
2018	0.14	2.44	30.11
2019	0.08	1.91	23.35
2020	0.23	2.96	39.77
2021	0.11	2.80	32.67
2022	0.42	7.31	51.52

Table 2: Landings of White Shrimp in 10 million pounds of tails by size.

Year	Large	Medium	Small
1980	1.13	1.53	1.61
1981	1.68	1.60	1.33
1982	0.99	1.46	1.47
1983	1.17	1.81	1.25
1984	1.63	2.66	1.31
1985	1.56	2.68	1.64
1986	1.79	3.13	2.08
1987	1.32	2.40	1.56
1988	0.85	2.26	1.36
1989	0.85	1.40	1.36
1990	1.30	1.84	1.22
1991	1.40	1.61	1.52
1992	1.10	1.98	1.65
1993	1.03	1.58	1.25
1994	0.95	1.80	1.78
1995	1.43	2.07	1.36
1996	1.04	1.58	0.93
1997	0.93	1.58	1.34
1998	1.73	2.16	1.52
1999	1.48	1.95	1.98
2000	1.85	2.21	3.00
2001	1.66	1.50	2.23
2002	1.90	1.58	1.76
2003	1.95	1.66	2.38
2004	2.17	2.16	2.28
2005	2.34	2.11	1.89
2006	3.44	2.42	2.63
2007	2.60	1.89	2.01
2008	3.10	1.60	1.78
2009	3.11	2.15	2.10
2010	2.17	1.81	1.81
2011	3.00	1.26	1.43
2012	2.48	1.90	2.24

Table 2 Continued: Landings of White Shrimp in 10 million pounds of tails by size.

Year	Large	Medium	Small
2013	2.28	1.33	1.93
2014	1.89	1.74	2.38
2015	2.04	1.58	1.72
2016	2.55	2.02	2.31
2017	2.58	2.09	2.20
2018	1.98	1.61	1.56
2019	2.58	2.26	1.72
2020	2.41	1.88	1.58
2021	2.41	1.83	2.03
2022	3.15	2.08	1.58

Table 3: White Shrimp parameter estimates from JABBA where Runs are described using unique indentifiers (1:90), P indicates a Pella-Tomlinson surplus production curve with estimated shape parameter m, r is the relative level of the intrinsic rate of growth prior (M-Medium, H- High), psi is the initial depletion prior (0.9 low, 0.2 high), sig indicates whether additional observation error tau2 is estimated (T/F), and the last two numbers are the start year of the landings (1960). Median parameter estimates are provided with lower and upper credible intervals. K is reported in million lb tail weight.

Run	Parameter	Estimate	LCI.95	UCI.95
WSH_13_P_rH_psil0.9_sigF_60	K	394.60	286.66	1,359.02
WSH_13_P_rH_psil0.9_sigF_60	r	0.59	0.41	0.83
WSH_13_P_rH_psil0.9_sigF_60	q	0.00	0.00	0.01
WSH_13_P_rH_psil0.9_sigF_60	psi	0.86	0.54	1.30
WSH_13_P_rH_psil0.9_sigF_60	sigma2	0.04	0.04	0.05
WSH_13_P_rH_psil0.9_sigF_60	tau2	0.00	0.00	0.01
WSH_13_P_rH_psil0.9_sigF_60	m	1.40	0.82	2.43
WSH_16_P_rM_psil0.9_sigF_60	K	589.32	358.16	1,473.57
WSH_16_P_rM_psil0.9_sigF_60	r	0.34	0.19	0.54
WSH_16_P_rM_psil0.9_sigF_60	q	0.00	0.00	0.00
WSH_16_P_rM_psil0.9_sigF_60	psi	0.85	0.54	1.30
WSH_16_P_rM_psil0.9_sigF_60	sigma2	0.04	0.04	0.05
WSH_16_P_rM_psil0.9_sigF_60	tau2	0.00	0.00	0.01
WSH_16_P_rM_psil0.9_sigF_60	m	1.05	0.60	1.84
WSH_4_P_rM_psil0.9_sigT_60	K	1,064.70	521.66	2,382.11
WSH_4_P_rM_psil0.9_sigT_60	r	0.26	0.15	0.53
WSH_4_P_rM_psil0.9_sigT_60	q	0.00	0.00	0.00
WSH_4_P_rM_psil0.9_sigT_60	psi	0.85	0.51	1.27
WSH_4_P_rM_psil0.9_sigT_60	sigma2	0.01	0.00	0.04
WSH_4_P_rM_psil0.9_sigT_60	tau2	0.09	0.03	0.24
WSH_4_P_rM_psil0.9_sigT_60	m	1.33	0.72	2.39
WSH_76_P_rM_psil0.2_sigT_60	K	1,208.82	746.10	2,585.88
WSH_76_P_rM_psil0.2_sigT_60	r	0.24	0.15	0.42
WSH_76_P_rM_psil0.2_sigT_60	q	0.00	0.00	0.00
WSH_76_P_rM_psil0.2_sigT_60	psi	0.13	0.08	0.22
WSH_76_P_rM_psil0.2_sigT_60	sigma2	0.00	0.00	0.02
WSH_76_P_rM_psil0.2_sigT_60	tau2	0.09	0.05	0.17
WSH_76_P_rM_psil0.2_sigT_60	m	2.00	1.26	3.38

Table 4: White Shrimp reference points from selected JABBA models in Table 3. K, Bmsy and MSY are reported in million lb tail weight.

Run	K	Bmsy	Fmsy	MSY
WSH_13_P_rH_psil0.9_sigF_60	394.60	168.02	0.43	74.57
WSH_16_P_rM_psil0.9_sigF_60	589.32	223.56	0.33	73.49
WSH_4_P_rM_psil0.9_sigT_60	1,064.70	454.86	0.20	80.25
WSH_76_P_rM_psil0.2_sigT_60	1,208.82	604.39	0.12	72.30

Table 5: White Shrimp fit statistics for top performing models where run names are described by strata A:G, species, start year, landings units, shared catchability b (T/F), population, time step (YEAR2 is seasonal), embedding dimension E, scaling (global vs. local), y transformations (log, gr1, gr2, none), and linear prior (_ricker if used).

Run	R2_out	R2_outscale
A20052_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E6_global_ytransnone_ricker	0.370	0.370
A1828_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E5_global_ytranslog_ricker	0.366	0.366
A1696_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E5_global_ytransnone_ricker	0.364	0.364
A20056_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E6_global_ytranslog_ricker	0.360	0.360
A1916_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E3_global_ytransgr1_ricker	0.356	0.356
C3412_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E5_local_ytransnone_ricker	0.868	0.336
C20072_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E6_local_ytransnone_ricker	0.870	0.327
C3896_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E3_local_ytransgr1_ricker	0.870	0.298
C3368_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E3_local_ytransnone_ricker	0.869	0.301
C2840_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E3_local_ytransgr1_ricker	0.869	0.296
C3104_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E3_local_ytransgr2_ricker	0.868	0.278
C3126_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E4_local_ytransgr2_ricker	0.868	0.279
C2862_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E4_local_ytransgr1_ricker	0.867	0.292
C3940_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E5_local_ytransgr1_ricker	0.867	0.298
C3148_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E5_local_ytransgr2_ricker	0.865	0.278
C728_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E3_local_ytransgr1	0.865	0.216
C20120_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E6_local_ytransgr1_ricker	0.865	0.293
C750_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E4_local_ytransgr1	0.863	0.197
C20096_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E6_local_ytransgr2_ricker	0.863	0.273
C1784_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E3_local_ytransgr1	0.863	0.199
C1806_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E4_local_ytransgr1	0.863	0.202
C3676_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E5_local_ytranslog_ricker	0.861	0.221
C992_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E3_local_ytransgr2	0.861	0.057
C1014_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E4_local_ytransgr2	0.860	0.044
C1828_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E5_local_ytransgr1	0.859	0.203
C4160_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E3_local_ytransgr2_ricker	0.857	0.170
C20112_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E6_local_ytranslog_ricker	0.857	0.215
C20128_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E6_local_ytransgr2_ricker	0.857	0.211
C4182_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E4_local_ytransgr2_ricker	0.856	0.174
C20056_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E6_local_ytransgr1	0.855	0.191
C244_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E5_local_ytransnone	0.854	0.245
C772_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E5_local_ytransgr1	0.852	0.191
C1036_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E5_local_ytransgr2	0.849	0.008
C20024_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E6_local_ytransgr1	0.848	0.178
C20008_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E6_local_ytransnone	0.847	0.227

Table 5 Continued: White Shrimp fit statistics for top performing models where run names are described by strata A:G, species, start year, landings units, shared catchability b (T/F), population, time step (YEAR2 is seasonal), embedding dimension E, scaling (global vs. local), y transformations (log, gr1, gr2, none), and linear prior (_ricker if used).

Run	R2_out	R2_outscale
E20202_WSH1980_CPUEtail10mp_bshareF_GULFYEAR2_E6_global_ytransnone_ricker	0.484	0.484
E7218_WSH1980_CPUEtail10mp_bshareF_GULFYEAR2_E5_global_ytranslog_ricker	0.407	0.407
G21014_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E6_local_ytransnone	0.706	0.392
G21078_WSH1984_CPUEtail10mp_bshareF_SIZEYEAR2_E6_local_ytransnone	0.708	0.390
G16778_WSH1984_CPUEtail10mp_bshareF_SIZEYEAR2_E4_local_ytransnone_ricker	0.680	0.389
G14666_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E4_local_ytransnone_ricker	0.680	0.389
G14710_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E5_local_ytransnone_ricker	0.691	0.385
G10442_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E4_local_ytransnone	0.687	0.377
G14622_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E3_local_ytransnone_ricker	0.647	0.368
G12598_WSH1984_CPUEtail10mp_bshareF_SIZEYEAR2_E5_local_ytransnone	0.700	0.366
G10486_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E5_local_ytransnone	0.699	0.366
A1960_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E5_global_ytransgr1_ricker	0.351	0.351
G21158_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E6_local_ytranslog_ricker	0.665	0.345
C21072_WSH1980_CPUEtail10mp_bshareT_SIZEYEAR_E6_local_ytransnone_ricker	0.828	0.344
C21104_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E6_local_ytransnone_ricker	0.827	0.344
A20060_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E6_global_ytransgr1_ricker	0.343	0.343
C13412_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E5_local_ytransnone_ricker	0.826	0.341
G10398_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E3_local_ytransnone	0.637	0.341
C13940_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E5_local_ytransgr1_ricker	0.829	0.341
C21120_WSH1980_CPUEtail10mp_bshareF_SIZEYEAR_E6_local_ytransgr1_ricker	0.828	0.338
G15194_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E4_local_ytranslog_ricker	0.662	0.337
A860_WSH1980_CPUEtail10mp_bshareF_GULFYEAR_E3_global_ytransgr1	0.336	0.336
G20014_WSH1984_CPUEtail10mp_bshareT_SIZEYEAR2_E6_local_ytransnone	0.756	0.336
G2554_WSH1984_CPUEtail10mp_bshareF_SIZEYEAR2_E4_local_ytransnone	0.736	0.335

Table 6: Retrospective analysis of the White Shrimp MSY estimates for top tier performing models with increasing peels. _0 indicates the base model, and _1:5 indicates 1 through 5 time steps of data peeled back. The maximum landings throughout the history of the fishery is 85.12 million pound of tails (8.51 tail10mp), and MSY_factor is the amount of times MSY is over this value. MSY_drop indicates whether the average MSY estimate was greater than 5 or 10 times the historical high, and F_drop indicates that the model solved at harvest rate U=1 and was excluded from further consideration. MSY, and Bmsy are in millions of pounds of tails. Run details are included in the previous table.

Run	MSY	BMSY_mp	MSY_factor	MSY_drop5	MSY_drop10	F_drop
WSH_A1696_0	11.63	13.90	1.37	0	0	0
WSH_A1696_1	15.03	21.04	1.77	0	0	0
WSH_A1696_2	55,336.91	55,336.91	6,501.20	1	1	1
WSH_A1696_3	228,533.05	228,533.05	26,848.97	1	1	1
WSH_A1696_4	11,102.99	11,102.99	1,304.42	1	1	1
WSH_A1696_5	7.77	7.77	0.91	0	0	1
WSH_C4160_0	8.79	14.85	1.03	0	0	0
WSH_C4160_1	9.60	11.76	1.13	0	0	0
WSH_C4160_2	9.42	11.54	1.11	0	0	0
WSH_C4160_3	27.77	68.03	3.26	0	0	0
WSH_C4160_4	8.45	14.27	0.99	0	0	0
WSH_C4160_5	9.53	11.68	1.12	0	0	0
WSH_C20128_0	7.09	13.89	0.83	0	0	0
WSH_C20128_1	7.17	10.04	0.84	0	0	0
WSH_C20128_2	7.06	9.89	0.83	0	0	0
WSH_C20128_3	7.00	8.17	0.82	0	0	0
WSH_C20128_4	6.96	9.75	0.82	0	0	0
WSH_C20128_5	7.06	9.61	0.83	0	0	0
WSH_C4182_0	8.78	14.84	1.03	0	0	0
WSH_C4182_1	9.05	11.37	1.06	0	0	0
WSH_C4182_2	8.91	14.55	1.05	0	0	0
WSH_C4182_3	8.62	11.12	1.01	0	0	0
WSH_C4182_4	8.66	11.16	1.02	0	0	0
WSH_C4182_5	8.85	11.11	1.04	0	0	0
WSH_C21104_0	8.25	8.78	0.97	0	0	0
WSH_C21104_1	6,687,161.31	6,687,161.31	785,634.36	1	1	1
WSH_C21104_2	1,005,413.36	1,005,413.36	118,119.97	1	1	1
WSH_C21104_3	8.57	8.94	1.01	0	0	0
WSH_C21104_4	8.25	8.42	0.97	0	0	0
WSH_C21104_5	7.97	8.31	0.94	0	0	0

Table 7: White Shrimp parameter estimates for the top performing model.

Parameter	WSH_C4182
CatchabilityLarge	0.021
CatchabilityMedium	0.627
CatchabilitySmall	3.767
DynamicCorrelation	0.864
LengthScale1	1.216
LengthScale2	0.039
LengthScale3	0.000
LengthScale4	0.000
PointwisePriorVariance	0.416
ProcessVariance	0.821

Table 8: White Shrimp MSY estimates for the top performing model.

Statistic	WSH_C4182
MSY_10mptails	8.780
Fmsy	0.896
Umsy_annual	0.592
Bmsy_10mp	14.835
df	9.579
R2	0.887
R2Scaled	0.312
R2_outsample	0.856
R2Scaled_outsample	0.174

Table 9: White Shrimp status through time based on benchmarks from the recommended model. Land10mp- landings in 10 millions of pound of tails, Frate- fishing mortality rate, Best_10mp- estimate of population size in 10 millions of pound of tails, FFmsy- Frate relative to Fmsy, BBmsy- Best relative to Bmsy.

Year	land10mp	Frate	Best_10mp	FFmsy	BBmsy
1980	4.27	0.333	14.65	0.372	1.04
1981	4.61	0.332	20.95	0.370	0.90
1982	3.92	0.436	13.86	0.487	0.77
1983	4.22	0.372	11.28	0.415	0.79
1984	5.59	0.361	17.65	0.402	0.92
1985	5.88	0.386	17.24	0.431	1.03
1986	7.00	0.409	27.02	0.456	1.23
1987	5.28	0.364	17.65	0.407	1.02
1988	4.46	0.822	6.46	0.918	0.49
1989	3.61	0.661	7.96	0.738	0.52
1990	4.37	0.387	11.29	0.432	0.76
1991	4.52	0.328	12.86	0.366	1.01
1992	4.73	0.428	12.00	0.478	0.90
1993	3.86	0.189	15.33	0.211	1.39
1994	4.53	0.276	16.74	0.307	1.37
1995	4.86	0.223	17.17	0.249	1.35
1996	3.54	0.256	13.49	0.286	0.83
1997	3.85	0.275	12.07	0.307	1.06
1998	5.42	0.268	13.91	0.300	1.27
1999	5.41	0.412	10.23	0.460	1.08
2000	7.06	0.529	15.40	0.590	1.30
2001	5.39	0.791	10.20	0.883	0.72
2002	5.24	0.641	9.60	0.716	0.68
2003	5.99	0.607	12.30	0.678	0.92
2004	6.62	0.331	18.78	0.370	1.49
2005	6.34	0.278	25.36	0.310	1.47
2006	8.49	0.237	53.69	0.265	2.28
2007	6.50	0.208	30.12	0.232	1.97
2008	6.48	0.212	34.34	0.237	1.71
2009	7.35	0.197	38.42	0.220	2.18
2010	5.79	0.198	43.11	0.221	1.87
2011	5.69	0.267	36.76	0.298	1.12
2012	6.62	0.316	29.33	0.353	1.50

Table 9 Continued: White Shrimp status through time based on benchmarks from the recommended model. Land10mp- landings in 10 millions of pound of tails, Frate- fishing mortality rate, Best_10mp- estimate of population size in 10 millions of pound of tails, FFmsy- Frate relative to Fmsy, BBmsy- Best relative to Bmsy.

Year	land10mp	Frate	Best_10mp	FFmsy	BBmsy
2013	5.54	0.315	21.92	0.351	1.27
2014	6.00	0.584	15.81	0.651	0.96
2015	5.35	0.278	27.46	0.310	1.30
2016	6.89	0.348	18.59	0.389	1.43
2017	6.87	0.450	19.48	0.502	1.12
2018	5.15	0.239	18.51	0.266	1.37
2019	6.56	0.376	12.93	0.420	1.06
2020	5.88	0.183	26.32	0.205	1.80
2021	6.27	0.286	18.11	0.320	1.49
2022	6.81	0.132	44.99	0.147	2.48

10. Figures

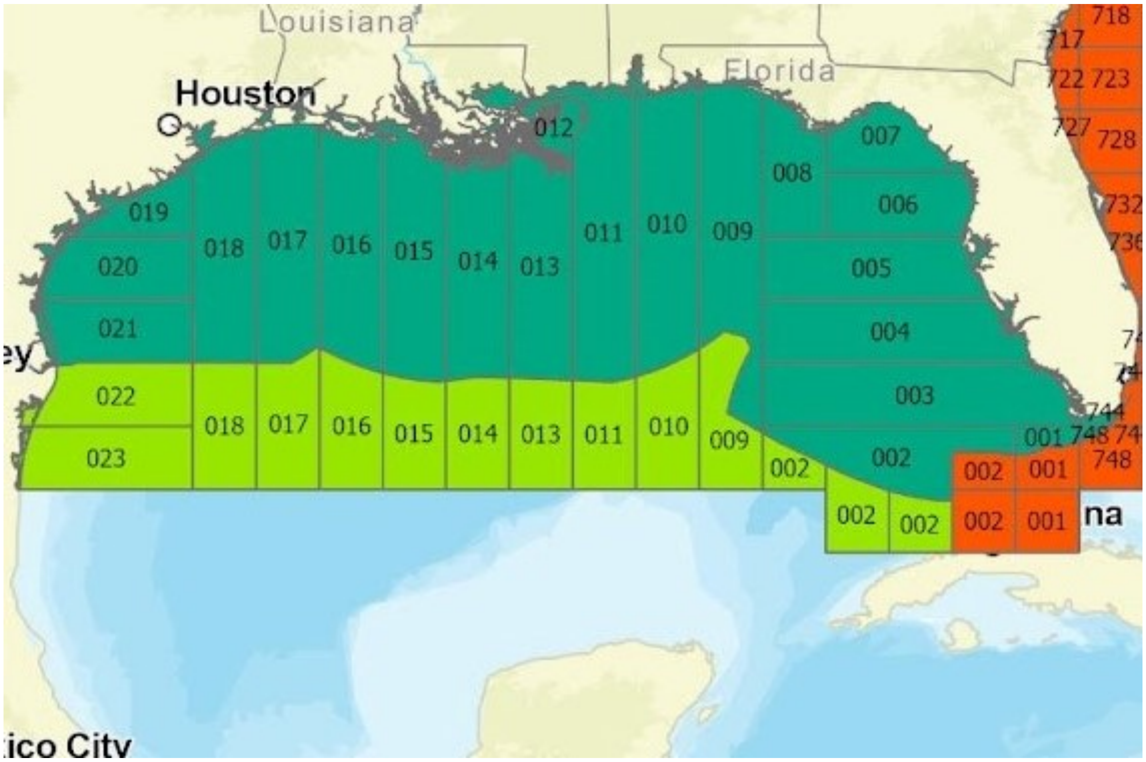


Figure 1: Map of the Gulf of America, where dark green is the Gulf defined by Gulf of Mexico Fishery Management Council boundaries, light green is Gulf international waters, and red is typically managed by the South Atlantic Fishery Management Council. Fishing areas 001 and 002 in their entirety were included in the analyses here per the recommendation of WP-06.

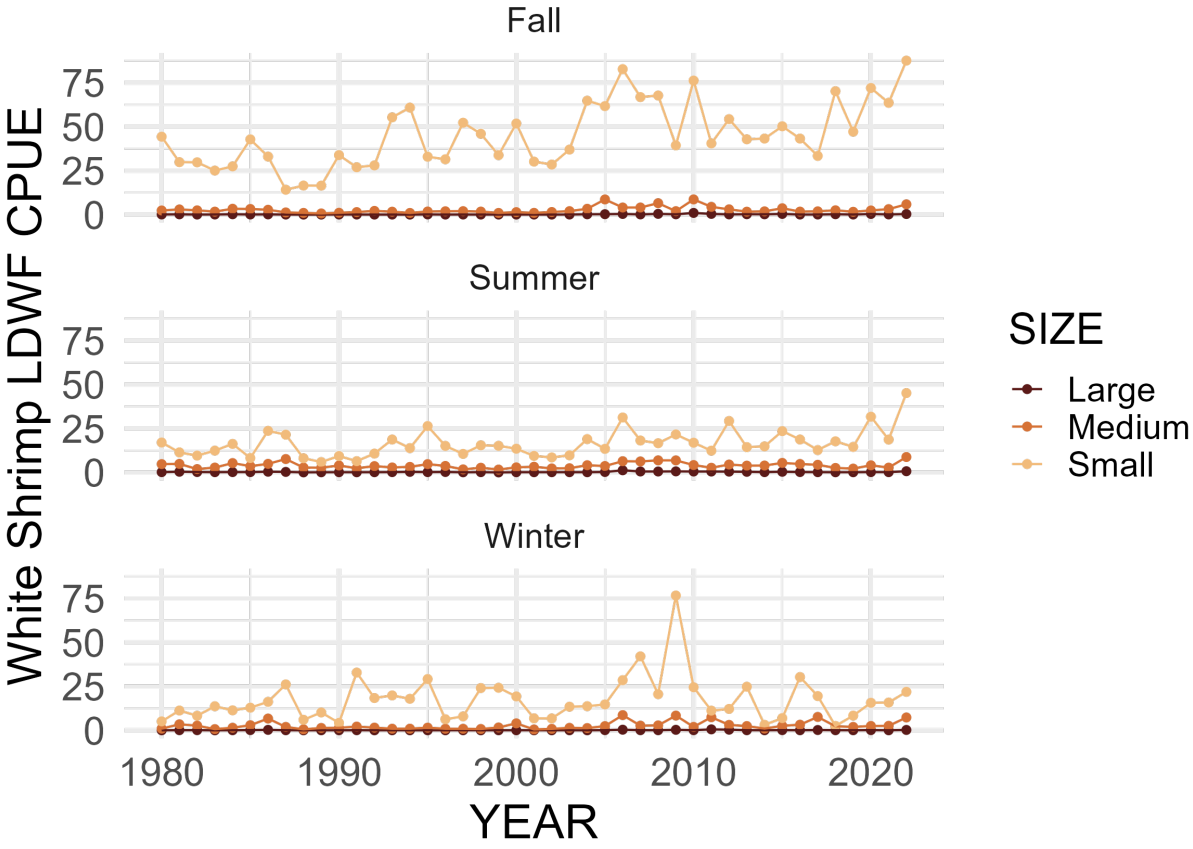


Figure 2: White Shrimp CPUE separated by size and season.

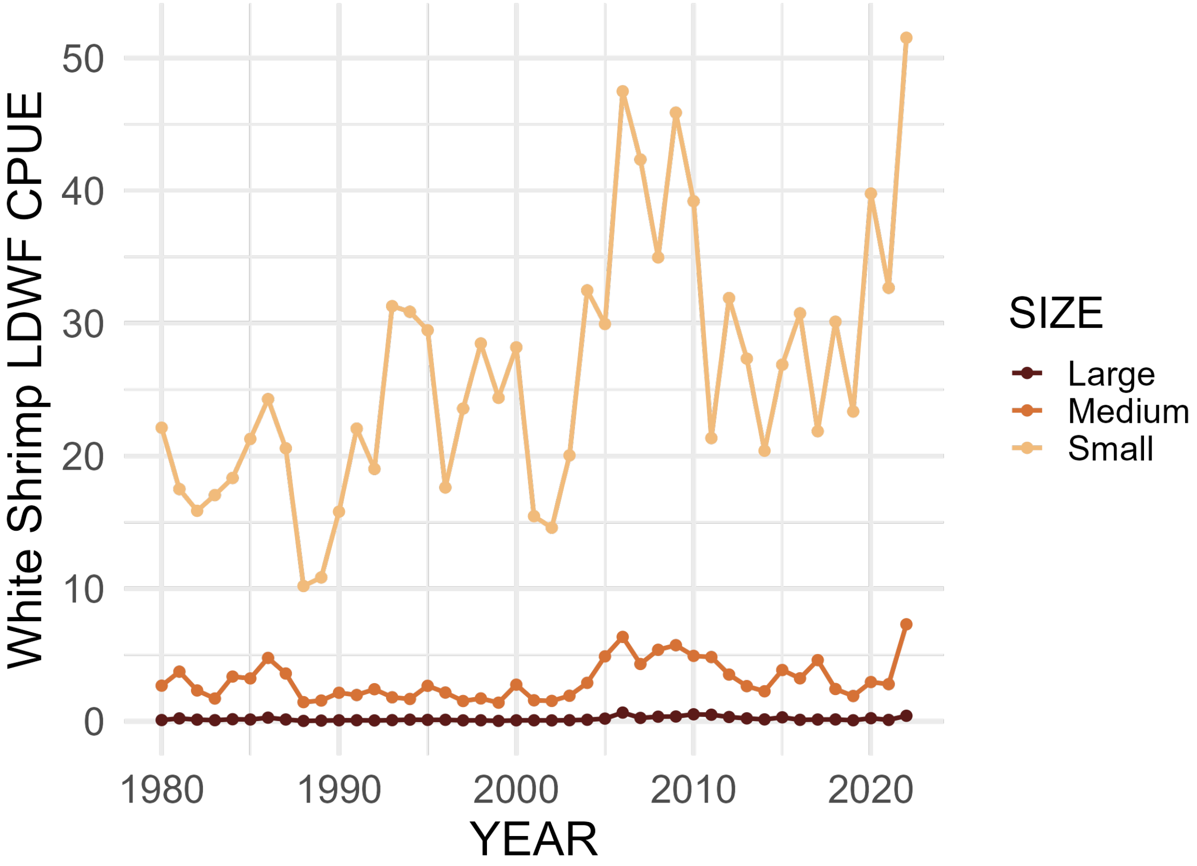


Figure 3: White Shrimp CPUE separated by size.

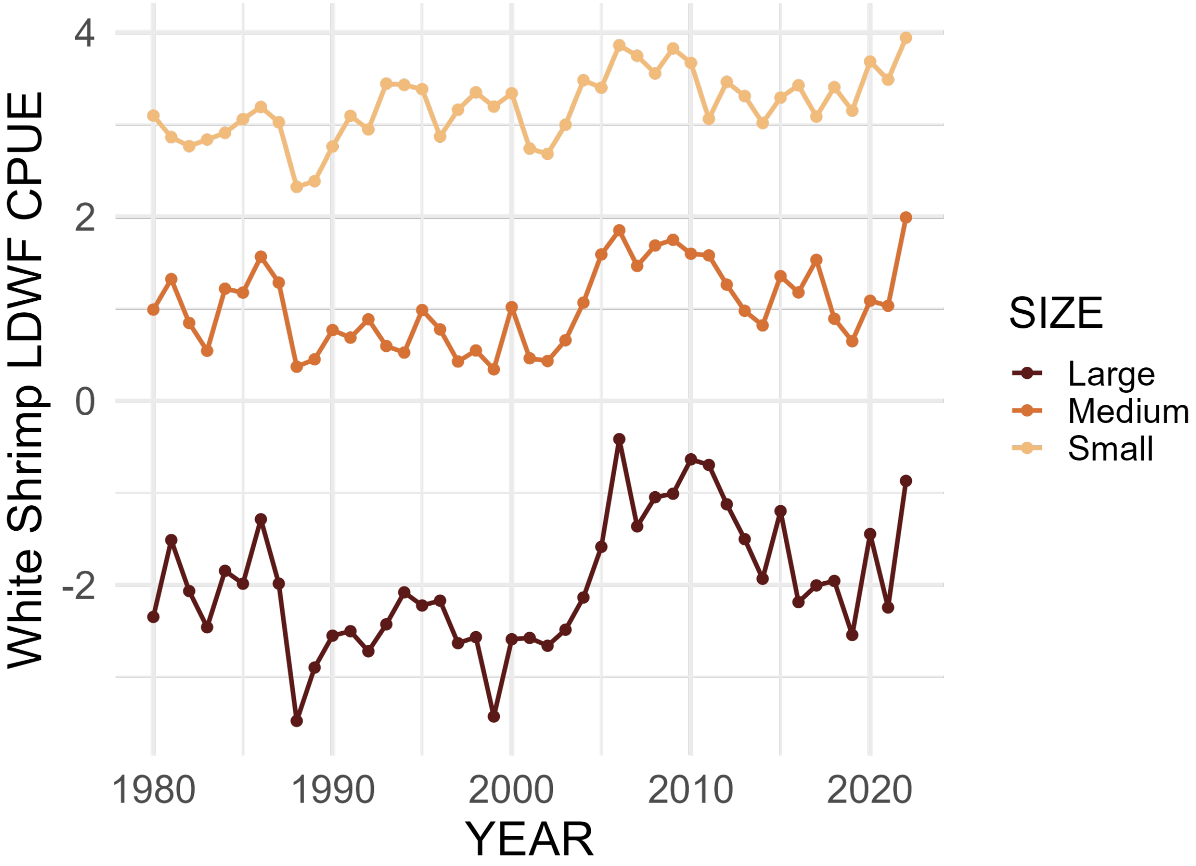


Figure 4: Log-transformed White Shrimp CPUE separated by size.

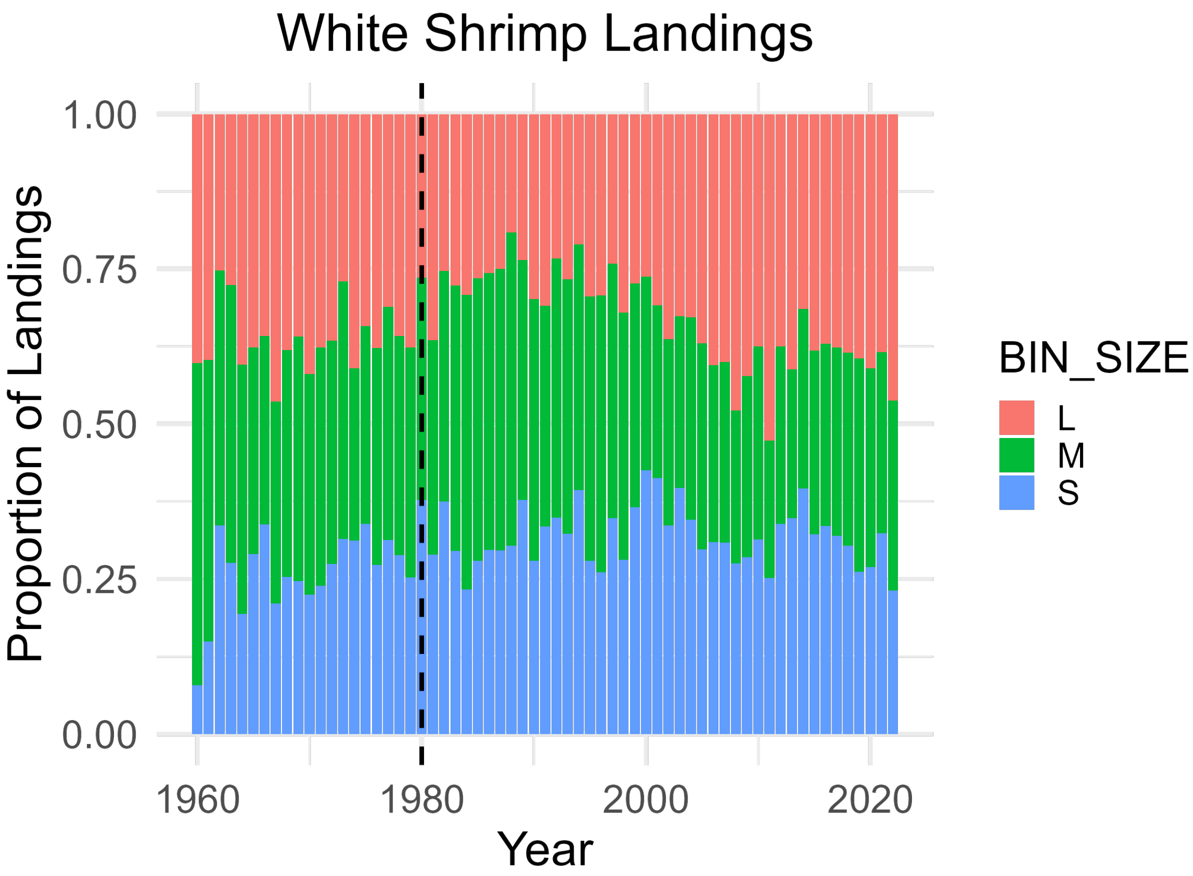


Figure 5: Proportion of landings by size class. The dashed line indicates the first year of the VAST index.

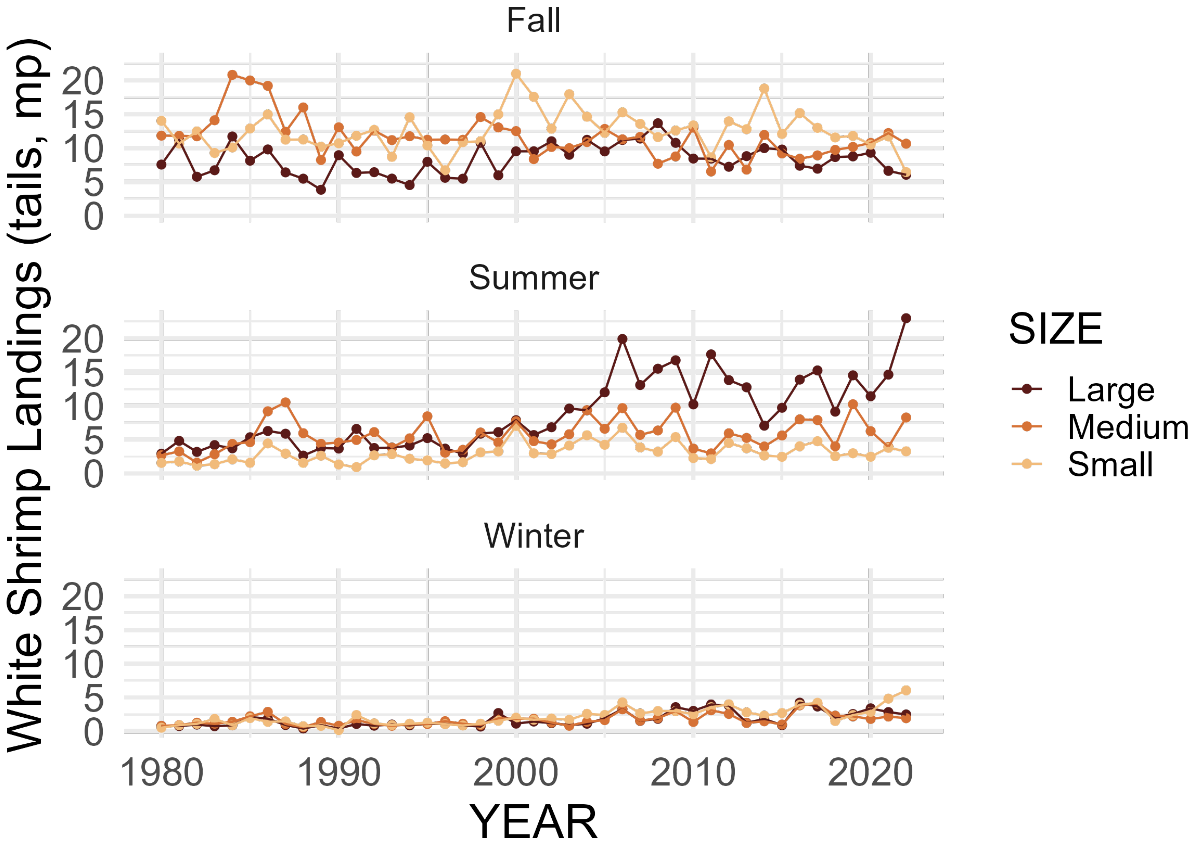


Figure 6: White Shrimp landings in millions of pounds of tails separated by size and season.

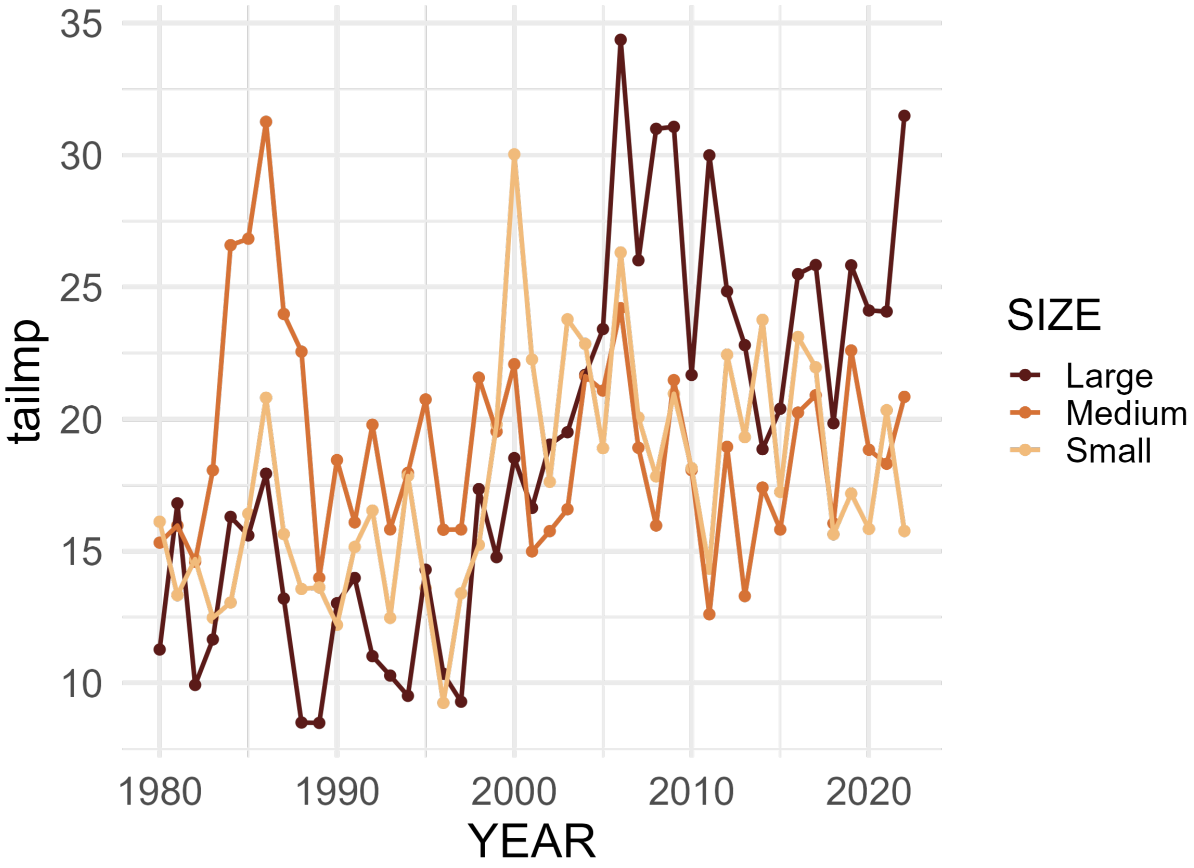


Figure 7: White Shrimp landings in millions of pounds of tails separated by size.

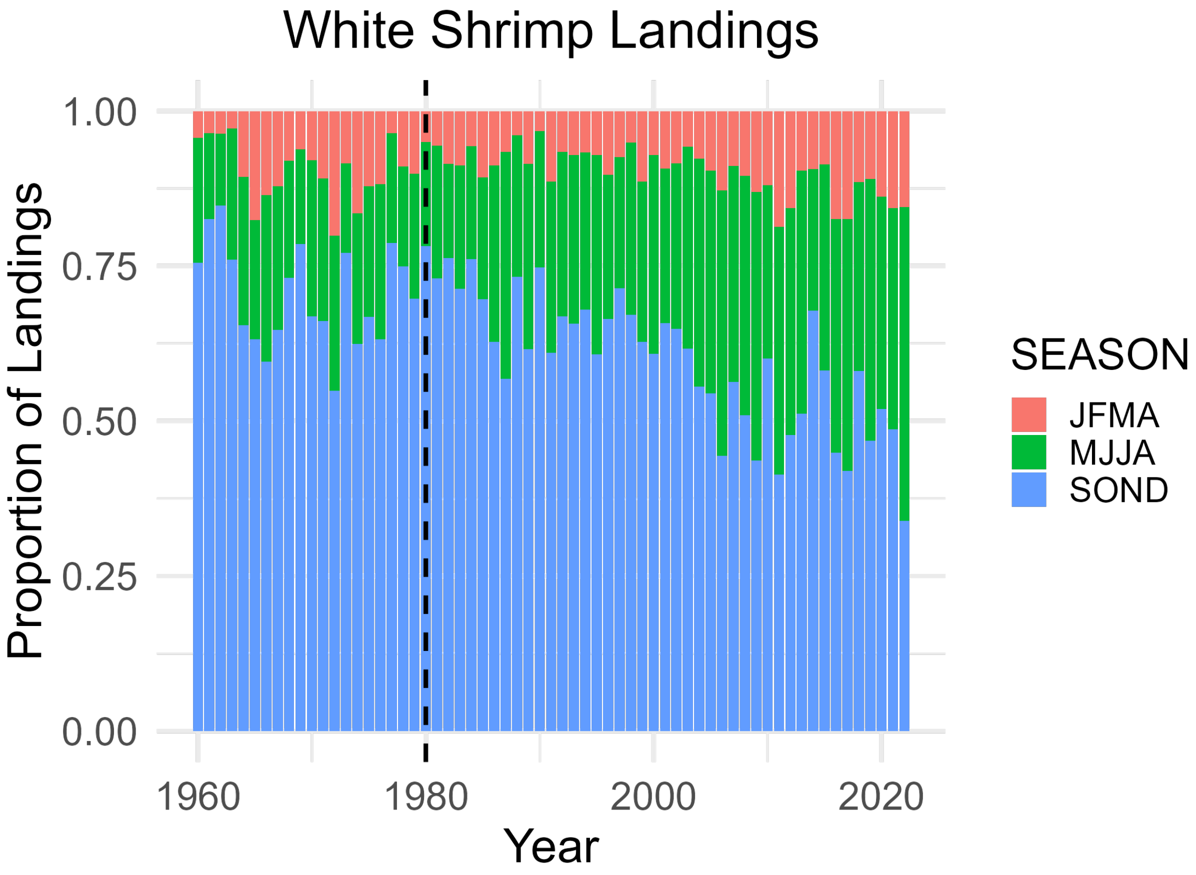


Figure 8: Seasonal distribution of White Shrimp landings.

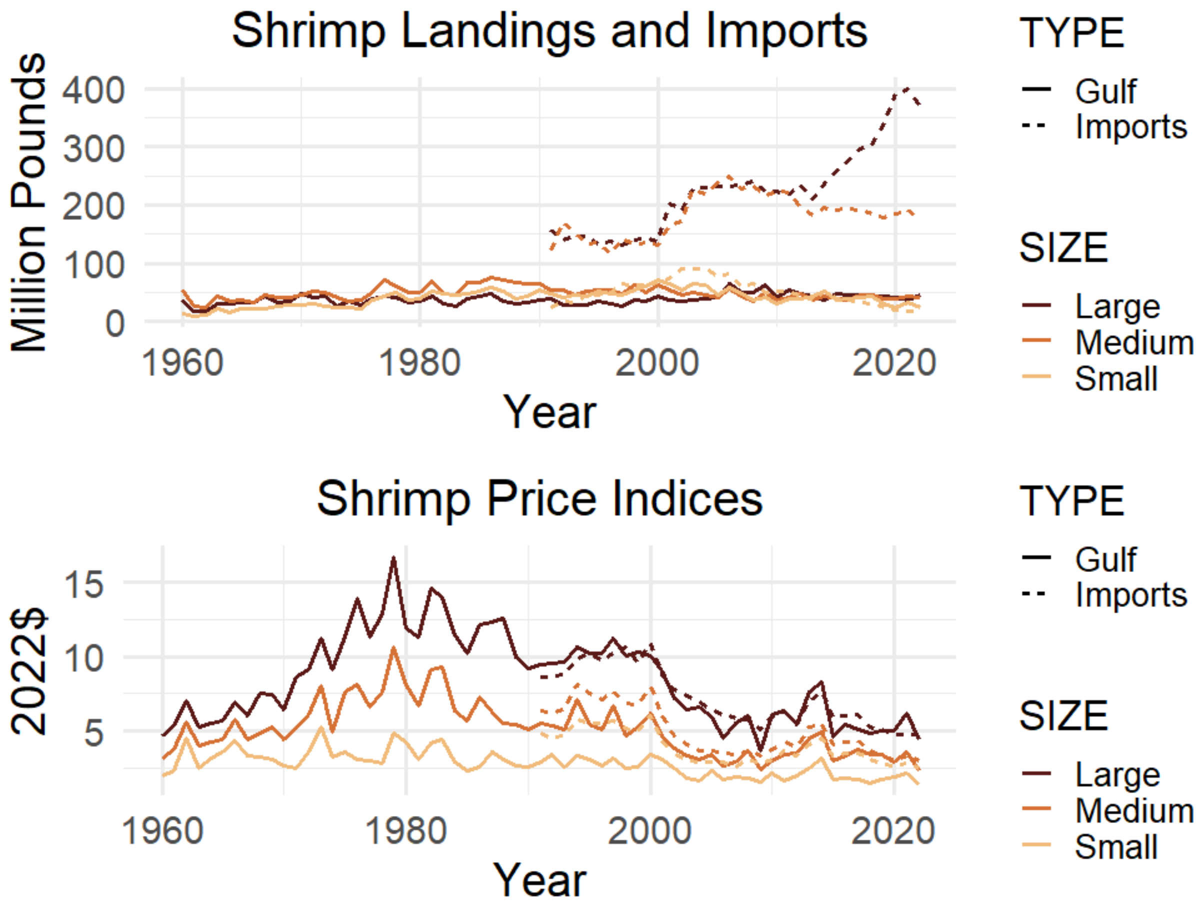


Figure 9: Domestic Gulf shrimp landings compared to global imports into the US by size category (top panel). This increase in supply has resulted in a crash of the ex-vessel price and domestic price index by size category, with all sizes decreasing, but Lsarge yielding the highest amount (bottom panel).

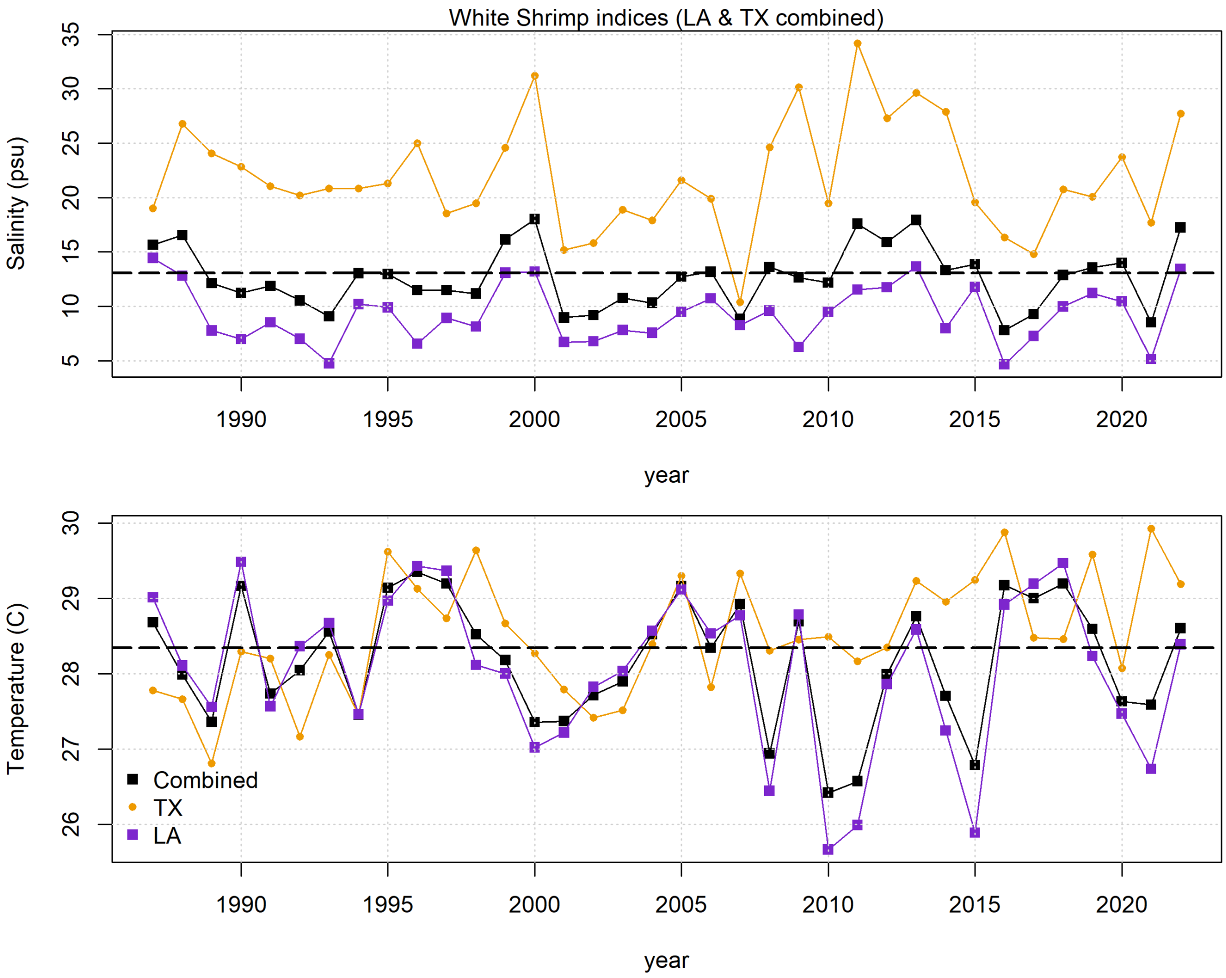


Figure 10: White Shrimp combined TX and LA environmental indices, truncated when TX data become available in 1987.

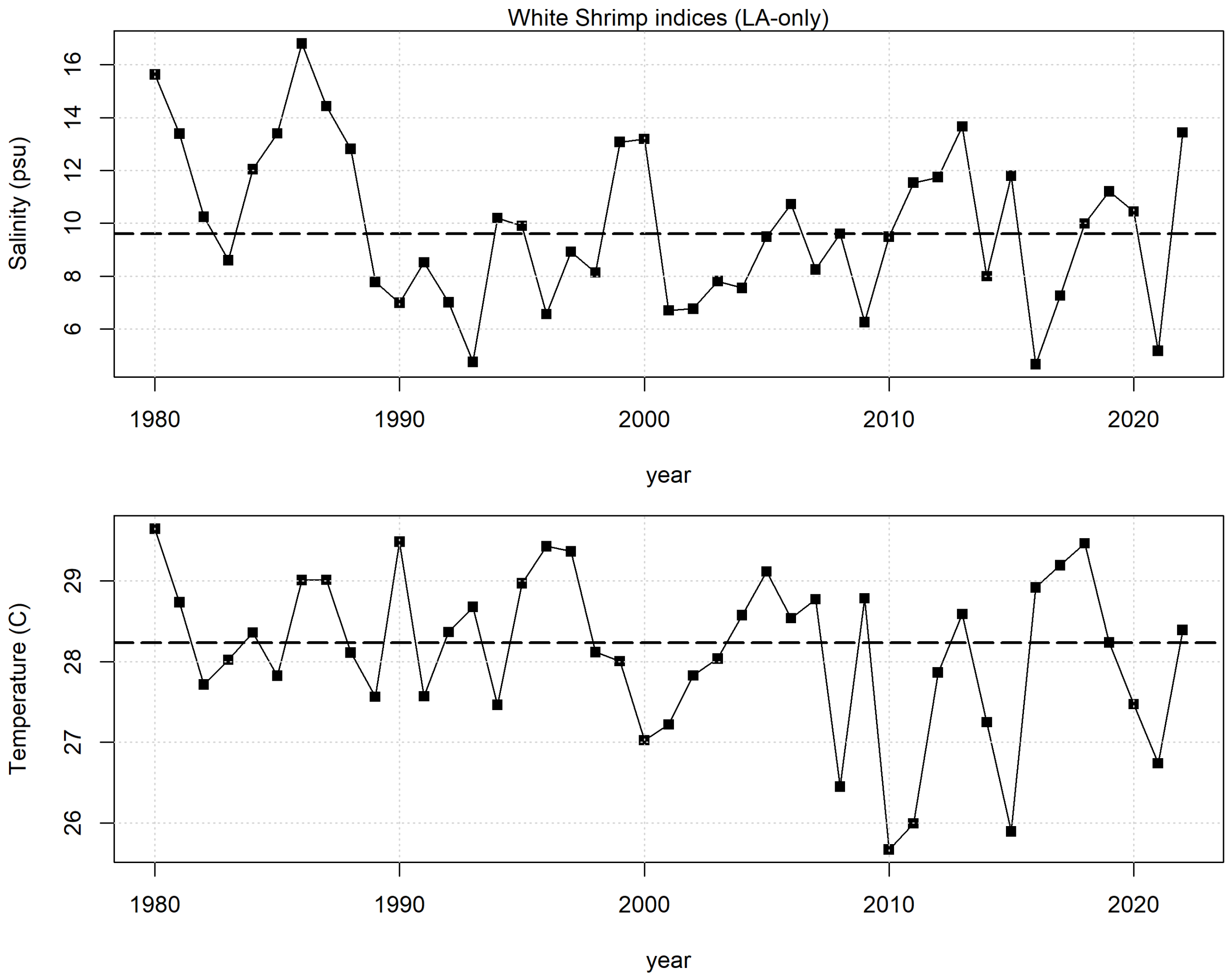


Figure 11: White Shrimp LA environmental indices to the beginning of the time series in 1980.

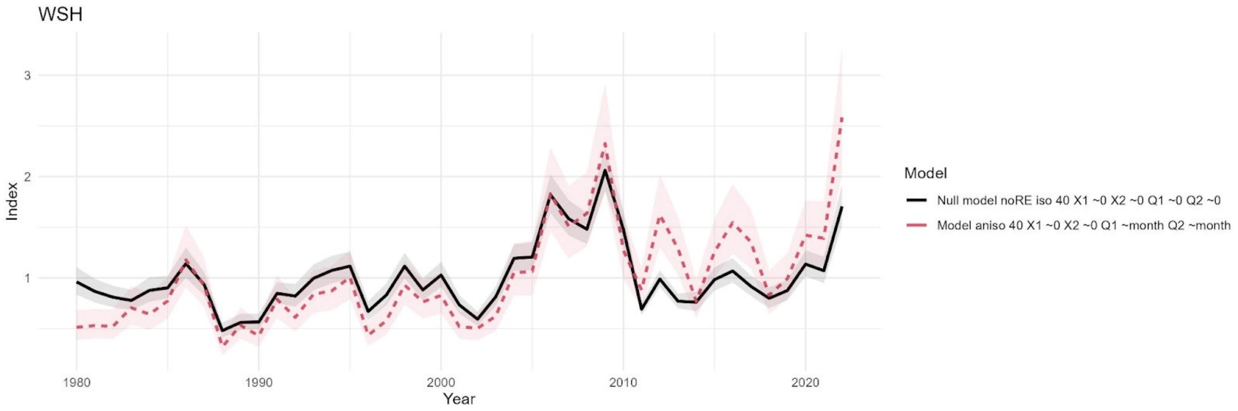


Figure 12: Final VAST index (red dashed line) and associated 95% confidence interval (red shading) incorporated into the JABBA model.

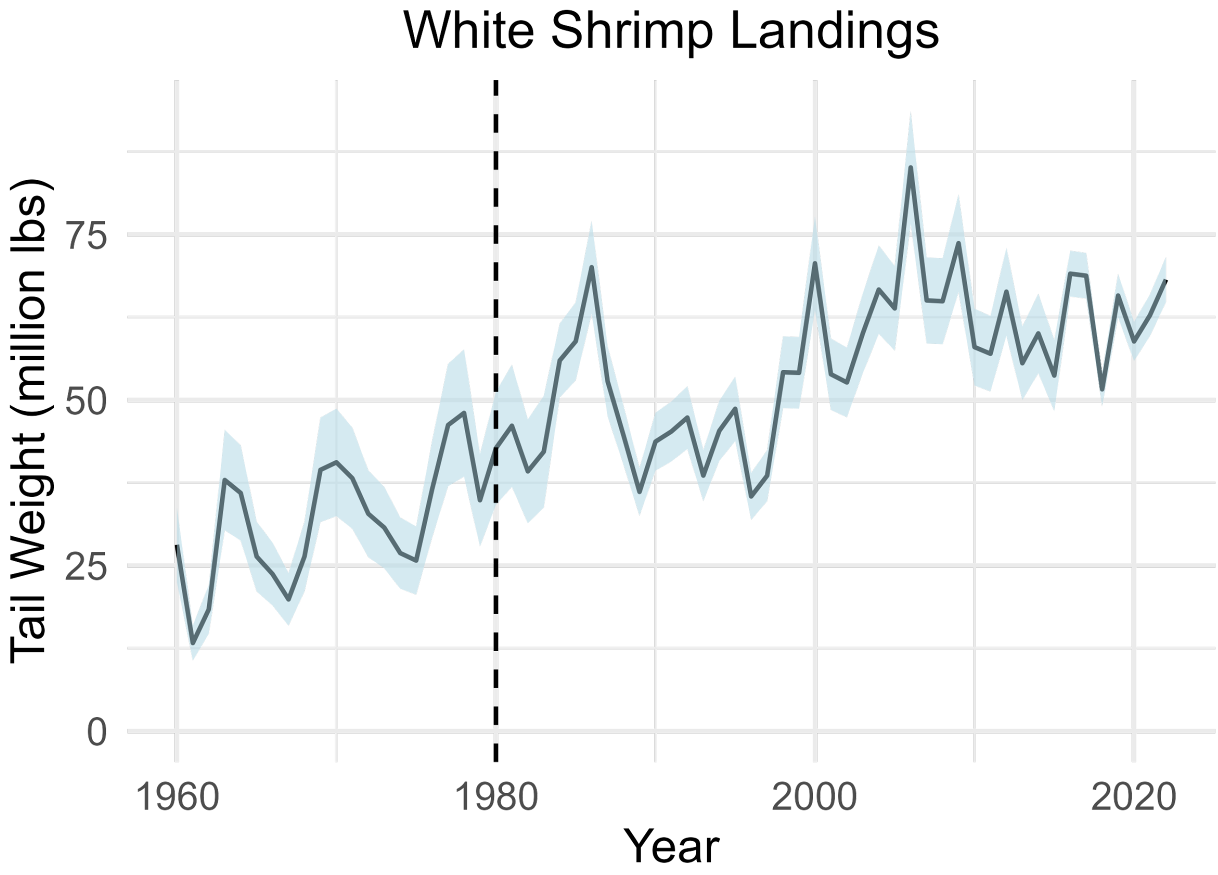


Figure 13: Final landings (blue line) and associated error (blue shading) input into JABBA. The dashed line indicates the start year of the index of relative abundance.

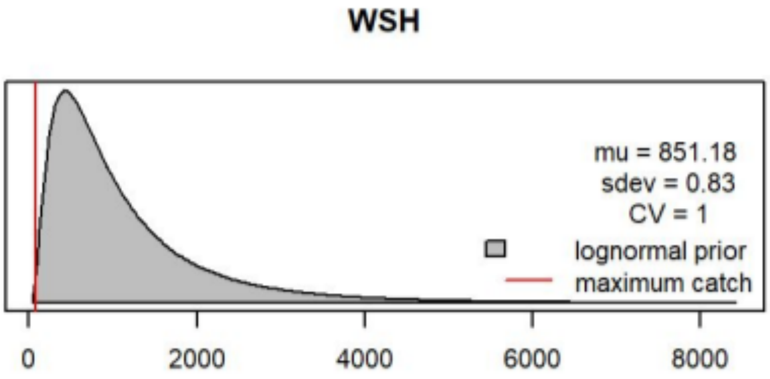


Figure 14: JABBA prior for carrying capacity, K, for all model configurations.

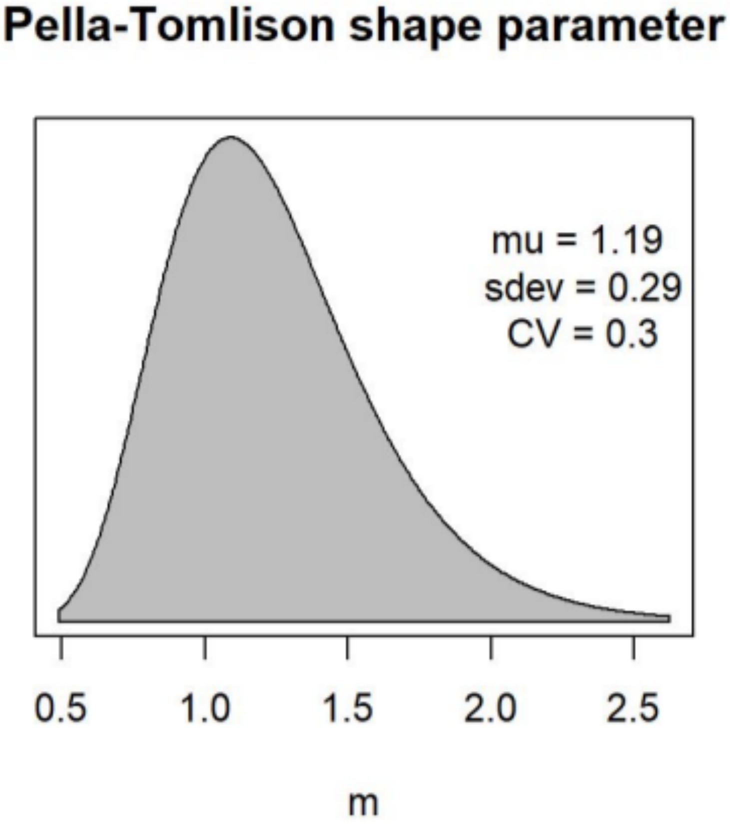


Figure 15: JABBA prior for Pella Tomlinson production function shape parameter, m, for all model configurations.

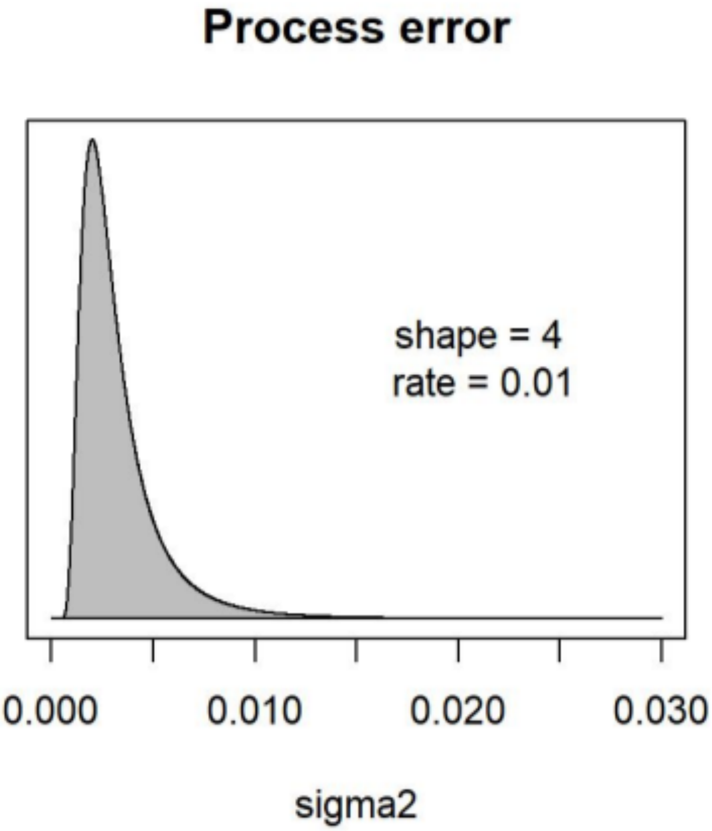


Figure 16: JABBA prior for process error for all model configurations.

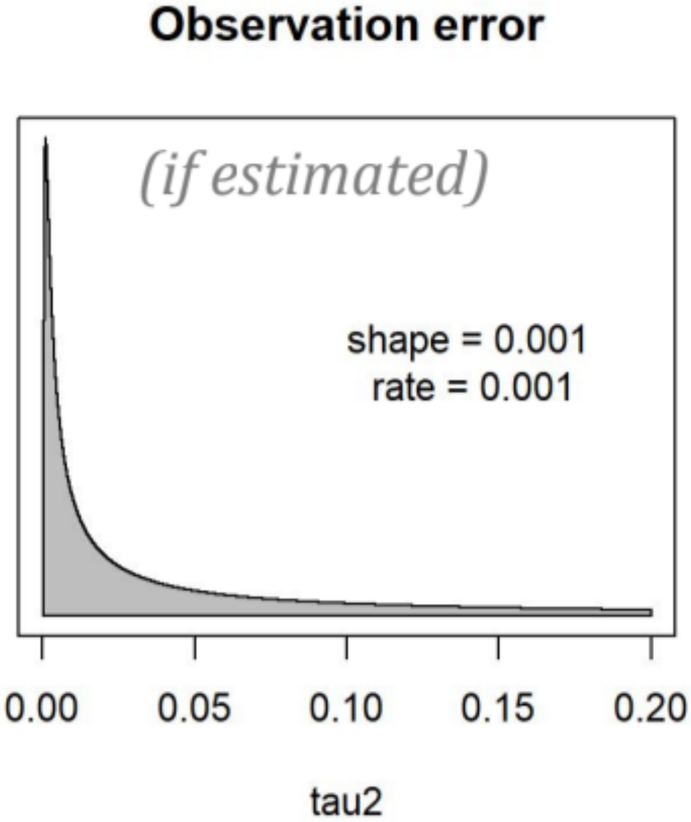


Figure 17: JABBA prior for observation error for all model configurations where estimated.

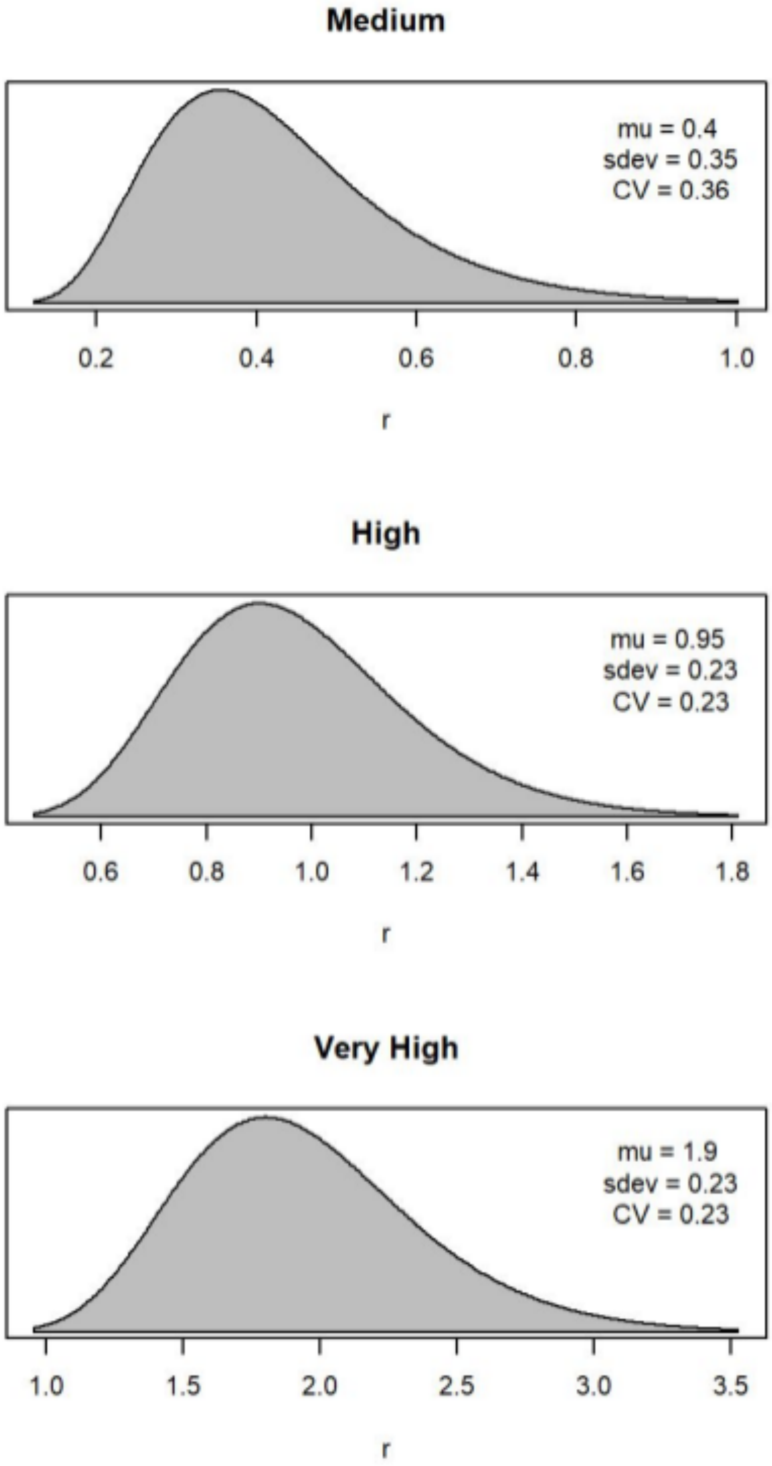
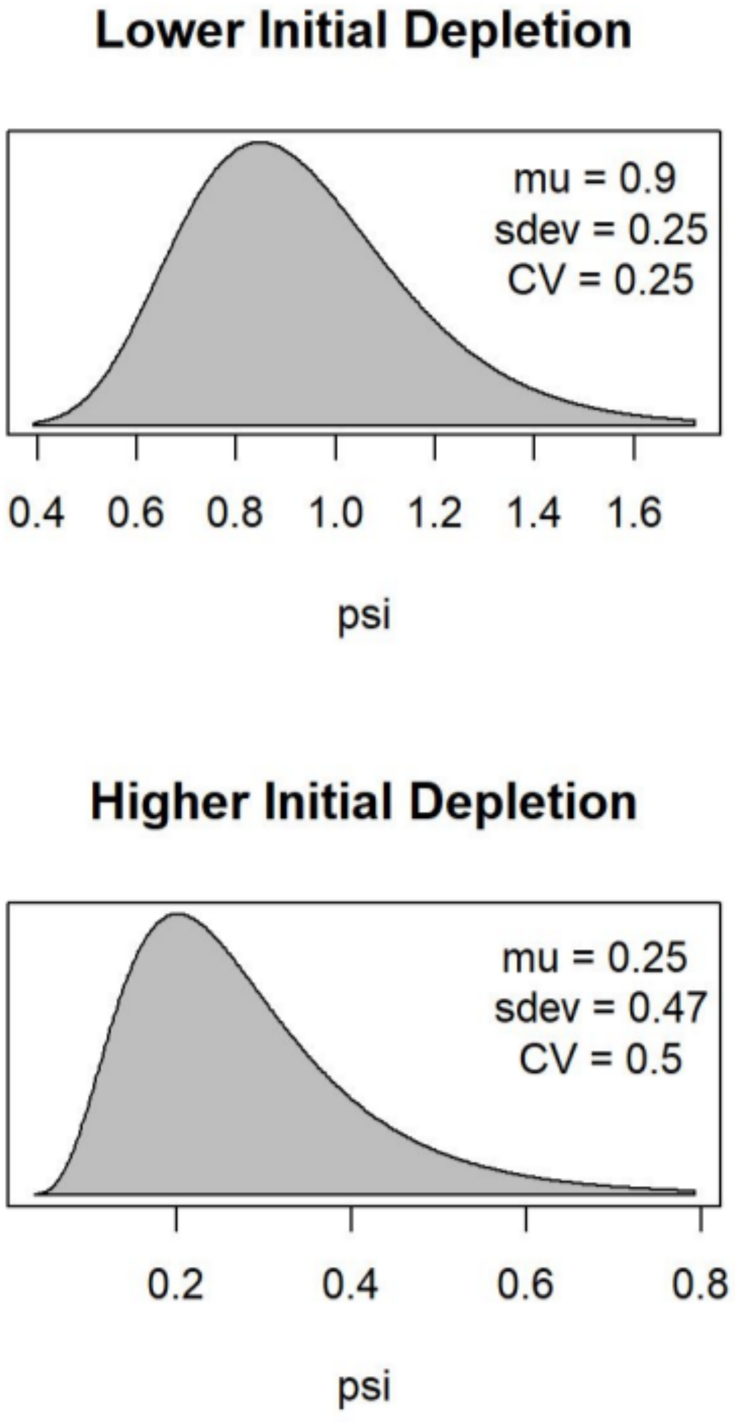


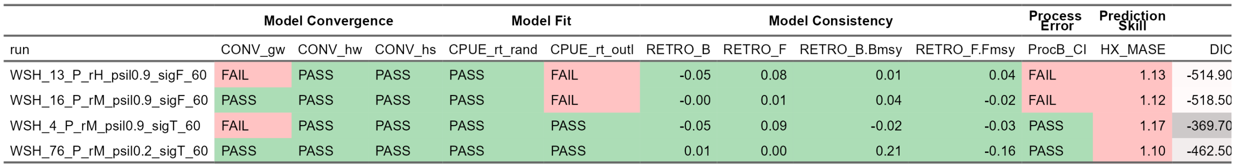
Figure 18: JABBA alternative prior assumptions for the intrinsic growth rate r.



Lower Initial Depletion

Higher Initial Depletion

Figure 19: JABBA alternative prior assumptions for the initial biomass depletion ratio psi.



	Model Convergence			Model Fit		Model Consistency				Process Error	Prediction Skill	
run	CONV_gw	CONV_hw	CONV_hs	CPUE_rt_rand	CPUE_rt_outl	RETRO_B	RETRO_F	RETRO_B.Bmsy	RETRO_F.Fmsy	ProcB_CI	HX_MASE	DIC
WSH_13_P_rH_psil0.9_sigF_60	FAIL	PASS	PASS	PASS	FAIL	-0.05	0.08	0.01	0.04	FAIL	1.13	-514.90
WSH_16_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.00	0.01	0.04	-0.02	FAIL	1.12	-518.50
WSH_4_P_rM_psil0.9_sigT_60	FAIL	PASS	PASS	PASS	PASS	-0.05	0.09	-0.02	-0.03	PASS	1.17	-369.70
WSH_76_P_rM_psil0.2_sigT_60	PASS	PASS	PASS	PASS	PASS	0.01	0.00	0.21	-0.16	PASS	1.10	-462.50

Figure 20: Diagnostic tests for top performing JABBA models, where Run 16 was the "best model" that passed the most diagnostic tests.

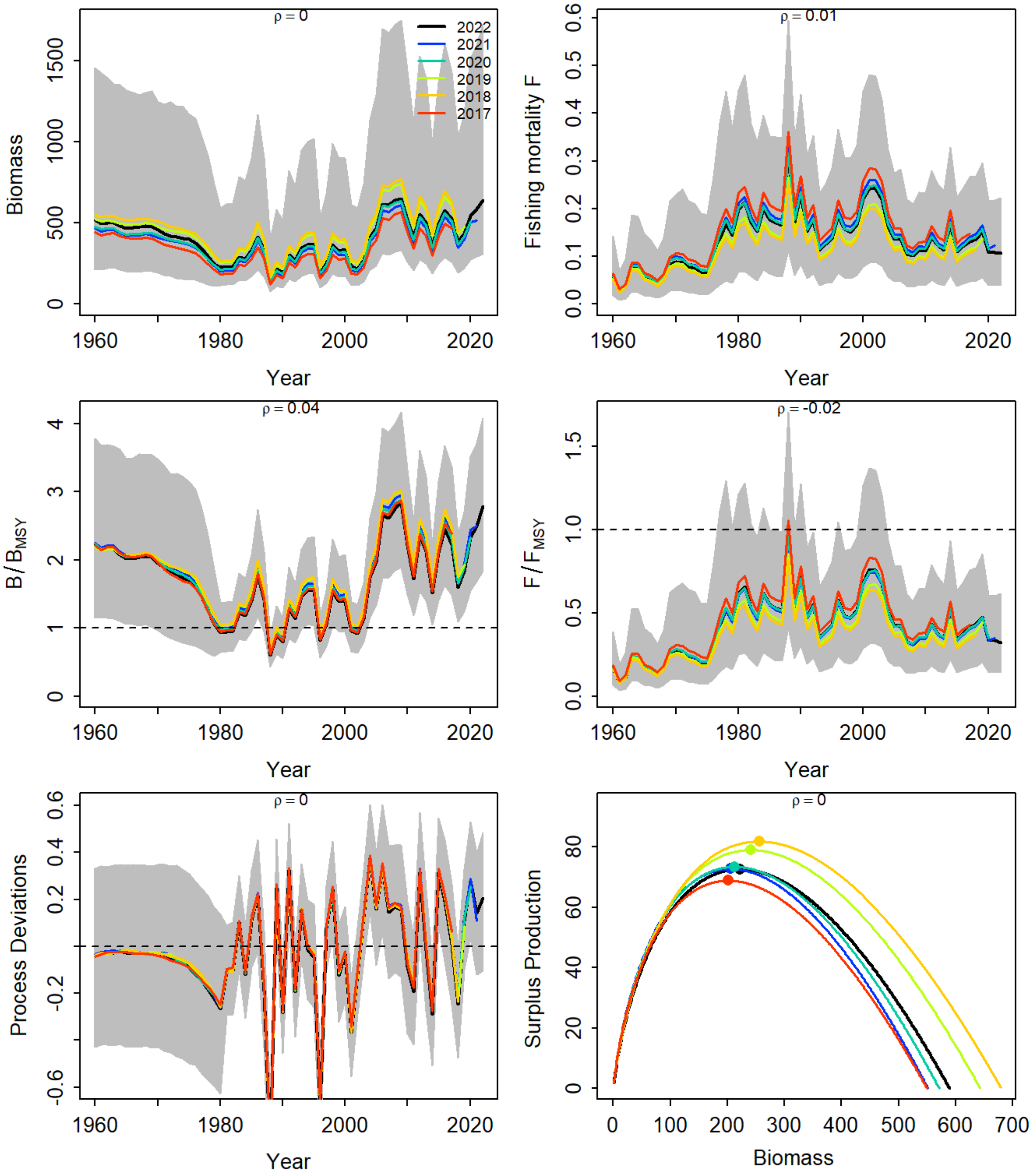


Figure 21: Retrospective analysis of key parameters and management quantities for top performing JABBA model run, with the line color corresponding to terminal years of data ranging from 2017:2022. Mohn's rho statistic (ρ) are denoted on top of the panels. Grey shaded areas are the 95% credible intervals from the reference model. Biomass and surplus production are reported in million lb tail weight.

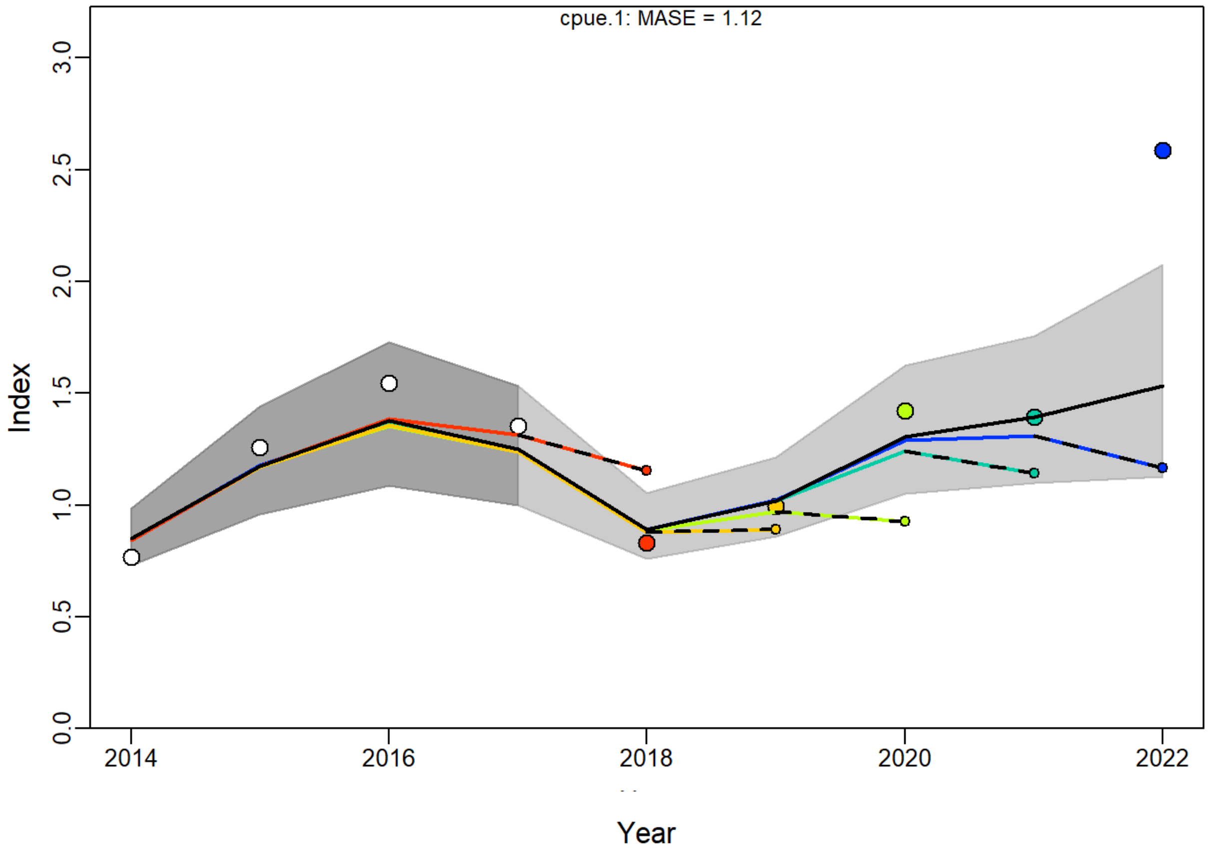


Figure 22: Hindcasting cross-validation (HCxval) results from CPUE fits, showing observed (large points), fitted (solid lines) and one-year ahead forecast values (small terminal points). HCxval was performed using one reference model (black line) and five hindcast model runs (colored lines with terminal years 2018 to 2022) relative to the expected CPUE. The mean absolute scaled error (MASE) score scales the mean absolute error (MAE) of forecasts (i.e., prediction residuals) to MAE of a naïve in-sample prediction (CPUE value this year = CPUE value from last year).

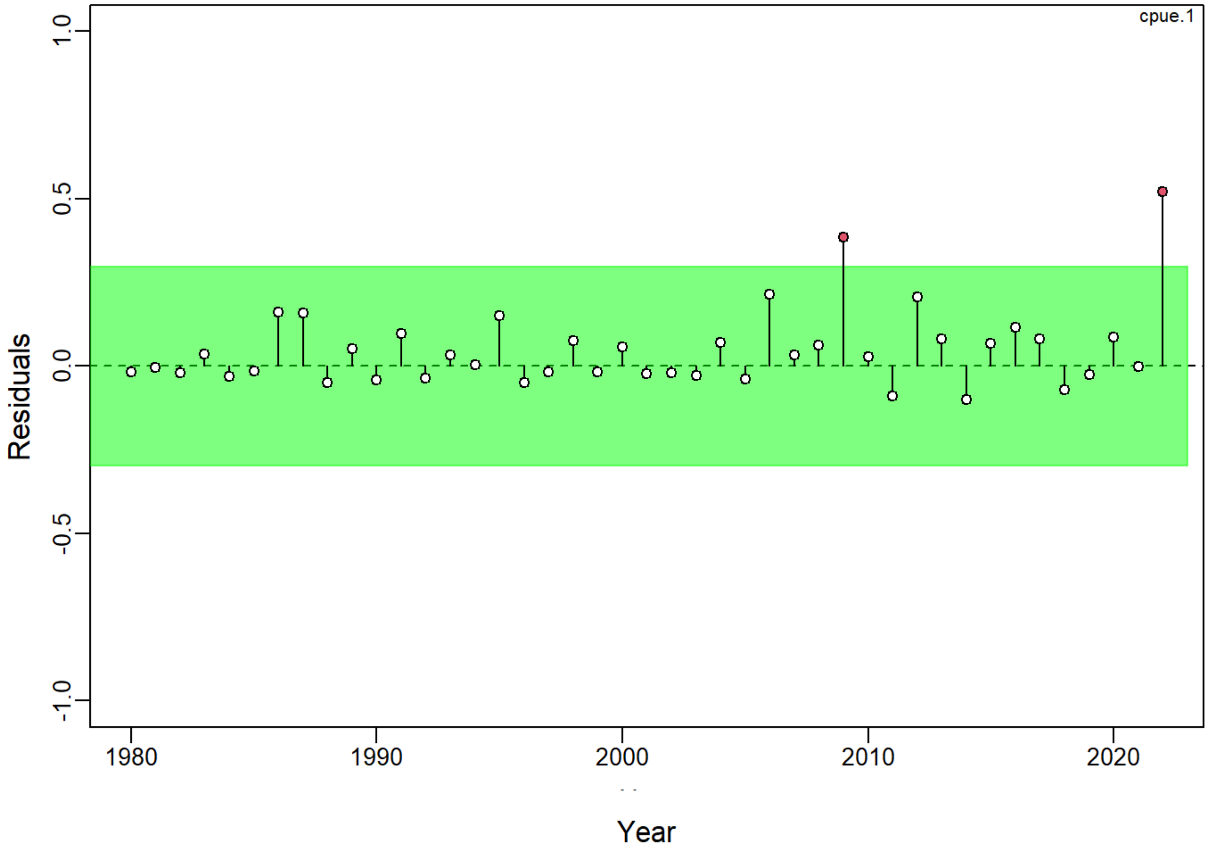


Figure 23: Residual runs test for top performing JABBA model. Green shading indicates no evidence ($p = 0.05$) and red shading evidence ($p < 0.05$) to reject the hypothesis of a randomly distributed time-series of residuals, respectively. The shaded (green/red) area spans three residual standard deviations to either side from zero, and the red points outside of the shading violate the 'three-sigma limit' for that series.

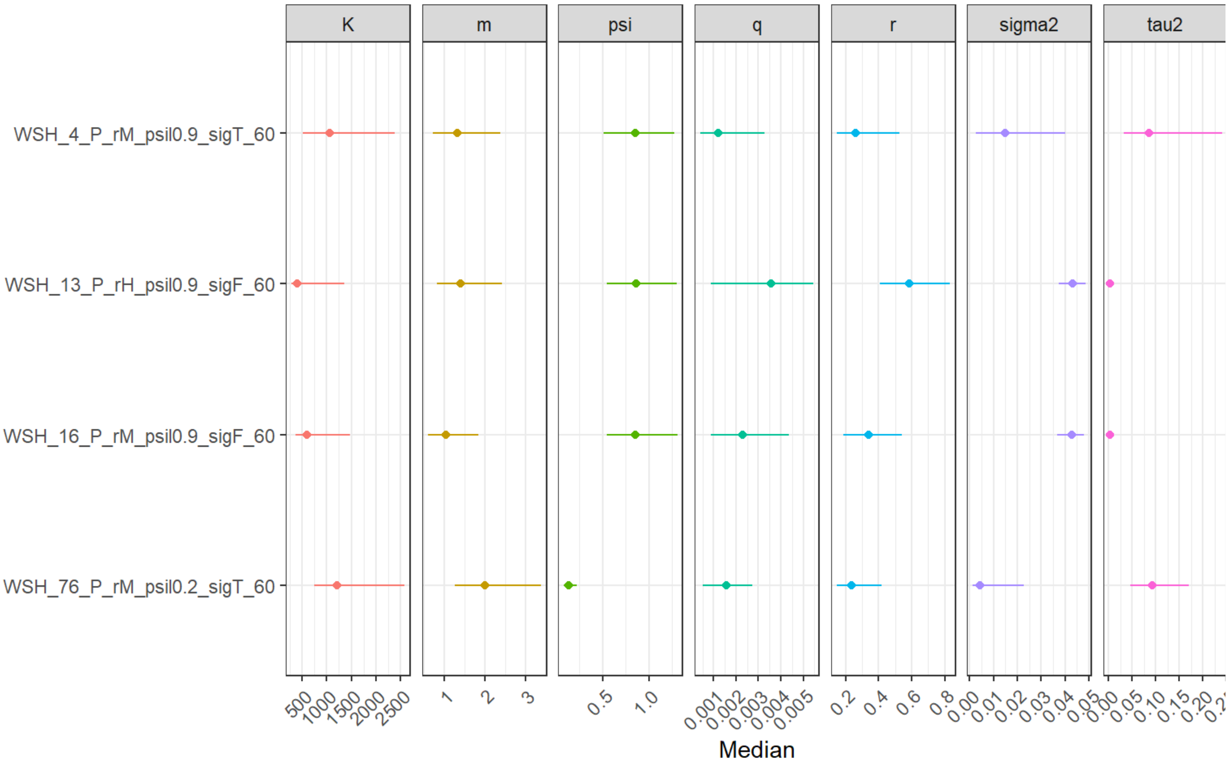


Figure 24: Parameter estimates and error for top performing JABBA models.

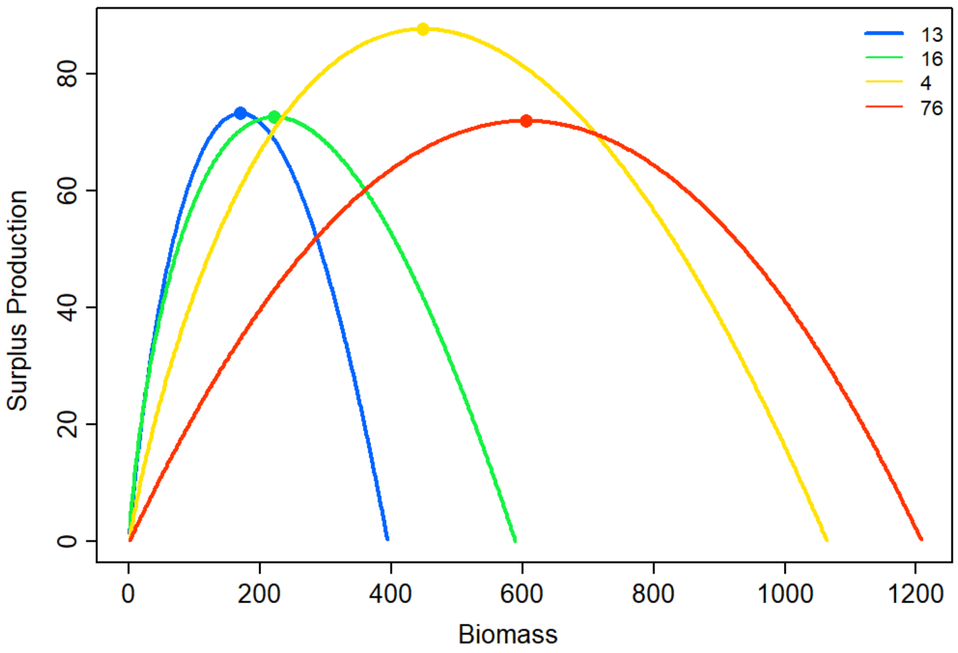


Figure 25: Surplus production and associated biomass estimated for all top performing models (in million lb tail weight).

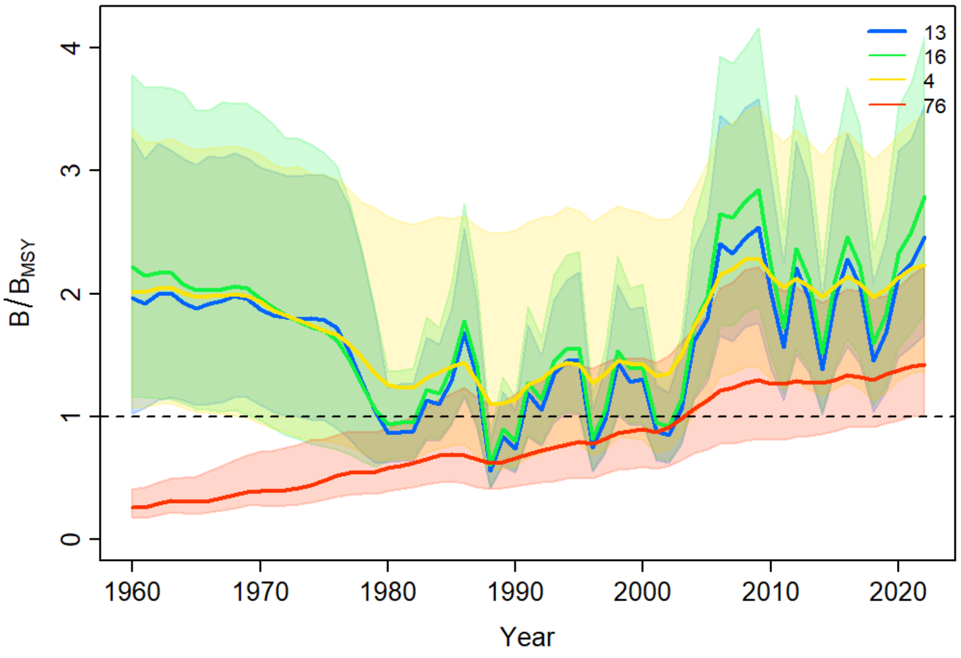


Figure 26: B/Bmsy trajectories for top performing JABBA models, where Run 16 (yellow) was the "best model" but did not pass diagnostic tests. Runs 4 and 13 (green and blue) did not converge.

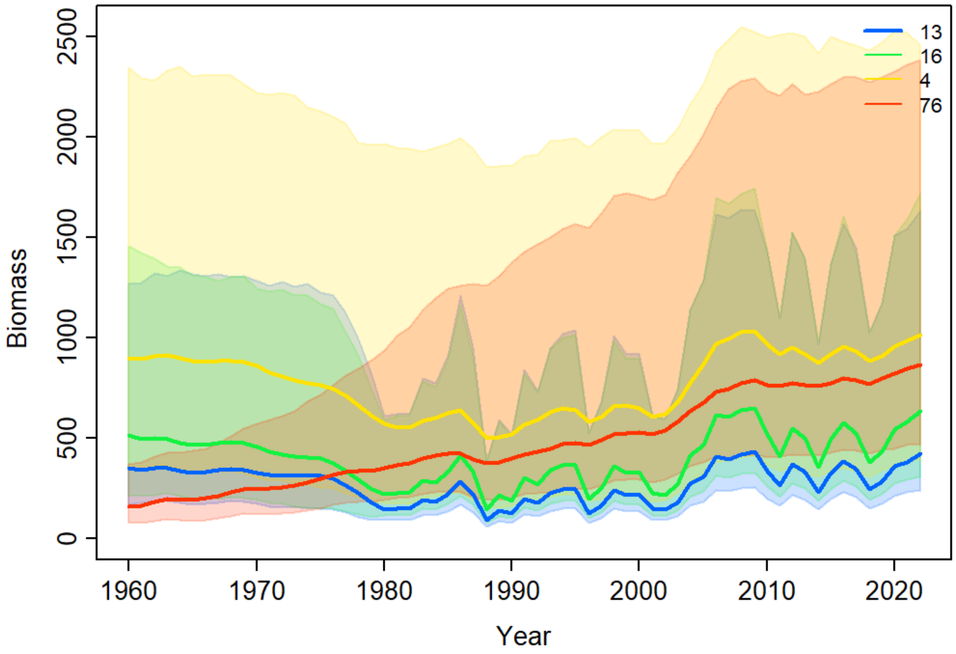


Figure 27: Biomass trajectories (in million lb tail weight) for top performing JABBA models, where Run 16 (yellow) was the "best model" but did not pass diagnostic tests.

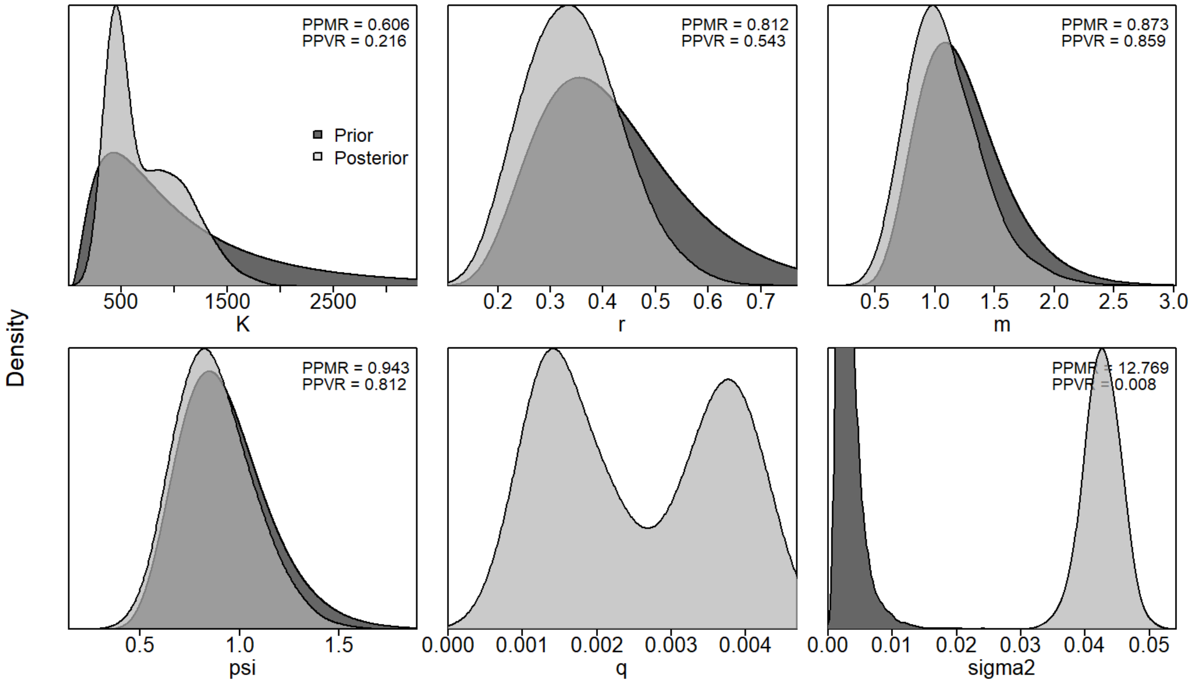


Figure 28: Posteriors for top JABBA model (did not pass diagnostic tests).

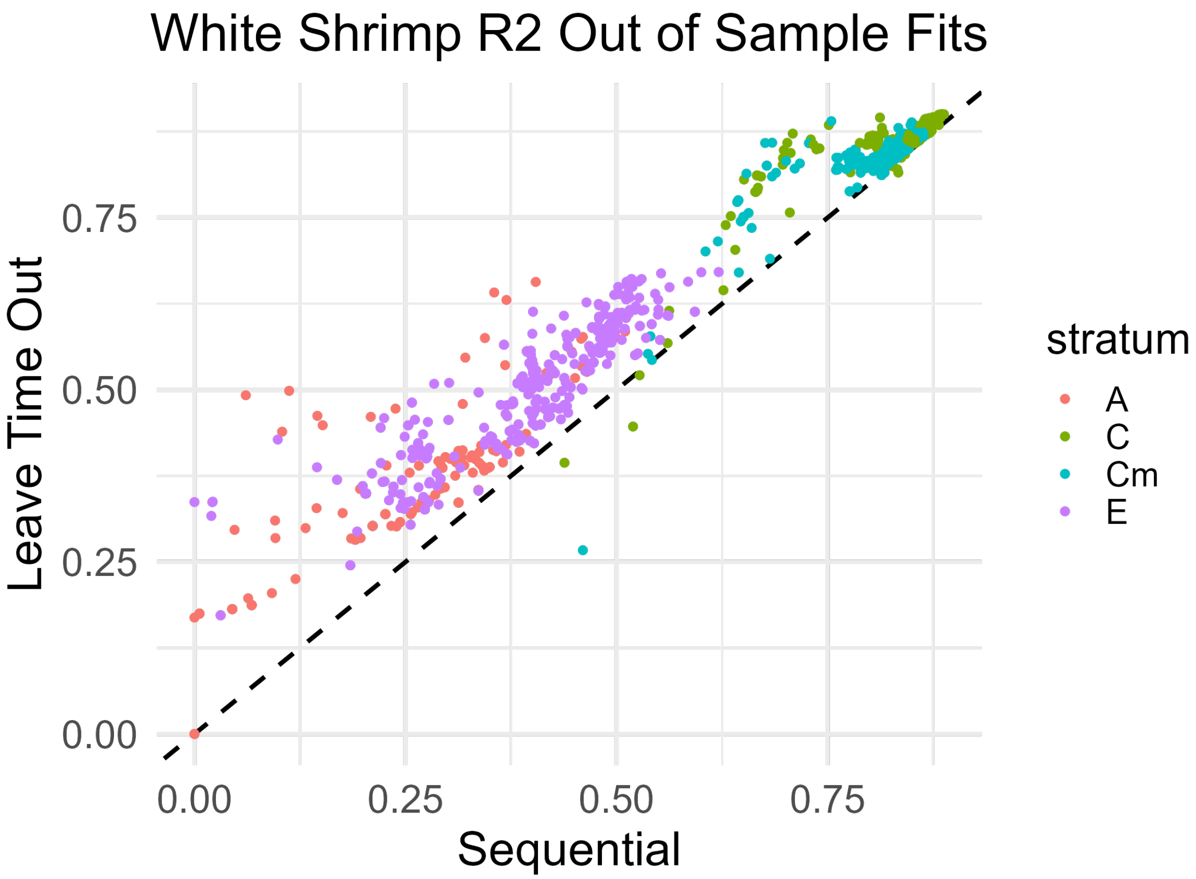


Figure 29: Out-of-sample R2 statistics for each model configuration using the 'leave time out' vs. the 'sequential' cross validation approach. While 'leave-time-out' obtains better model fits, the purpose here is to be able to project well into the future, which is better captured by the 'sequential' approach. Models are filtered based on the R2 statistics from the 'sequential' prediction method going forward.

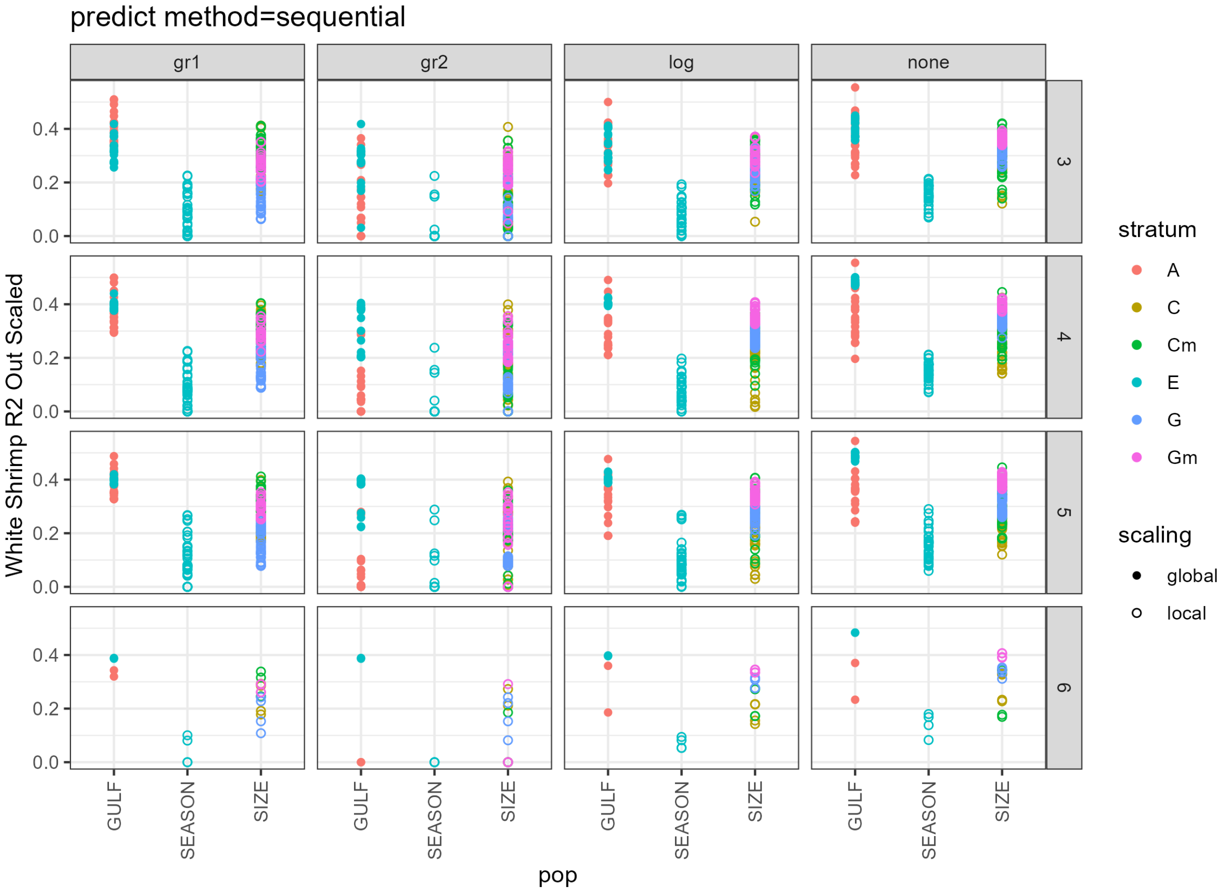


Figure 30: "Sequential" out-of-sample R2 fit statistic resulting from each model run. Facet columns show results based on different data transformations. Facet rows show results based on the embedding dimension. Within each facet, the x axis groups the models by the type of aggregation (spatial, size, season, or a combination).

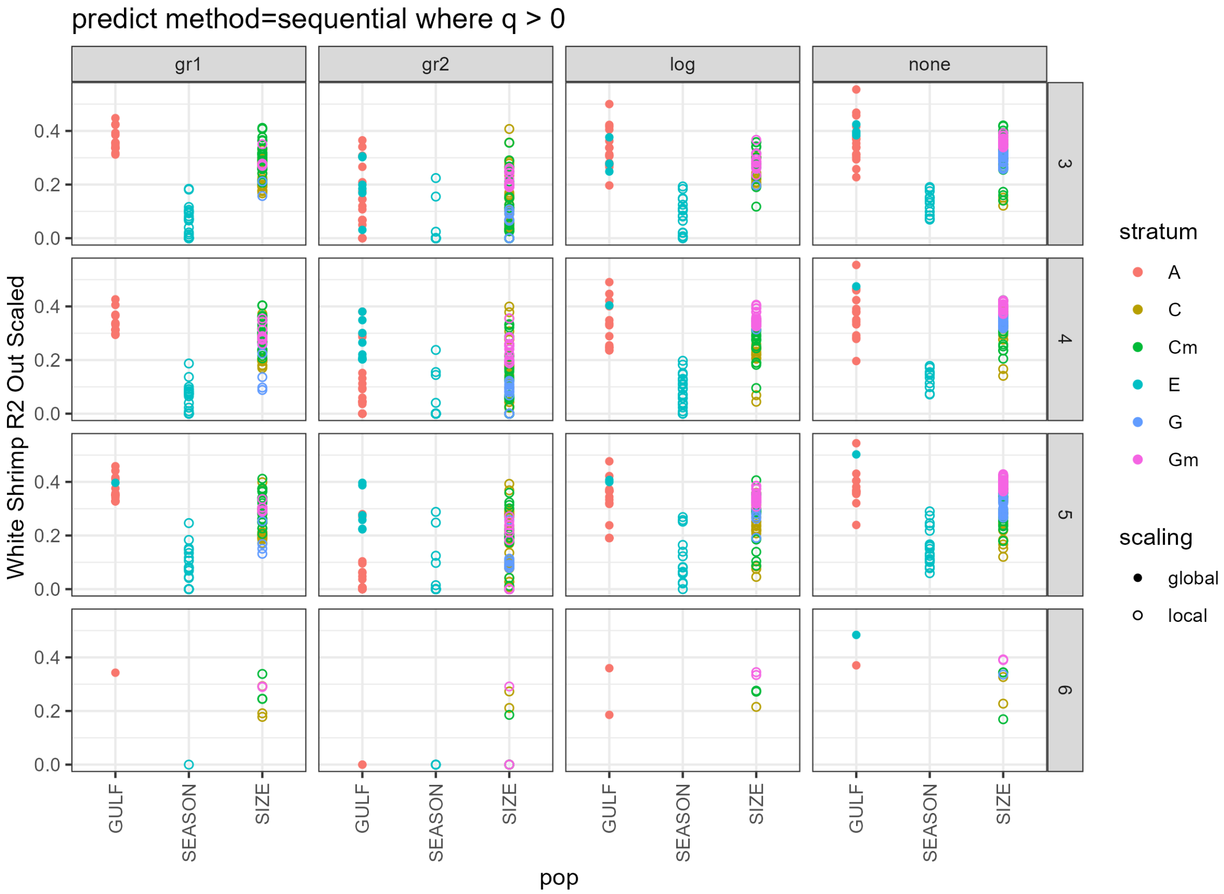


Figure 31: "Sequential" out-of-sample R2 fit statistic resulting from each model run with "local" scaling. Facet columns show results based on different data transformations. Facet rows show results based on the embedding dimension. Within each facet, the x axis groups the models by the type of aggregation (spatial, size, season, or a combination). Models that fit to the survey data and ignored landings (e.g. q=0) were removed from further consideration.

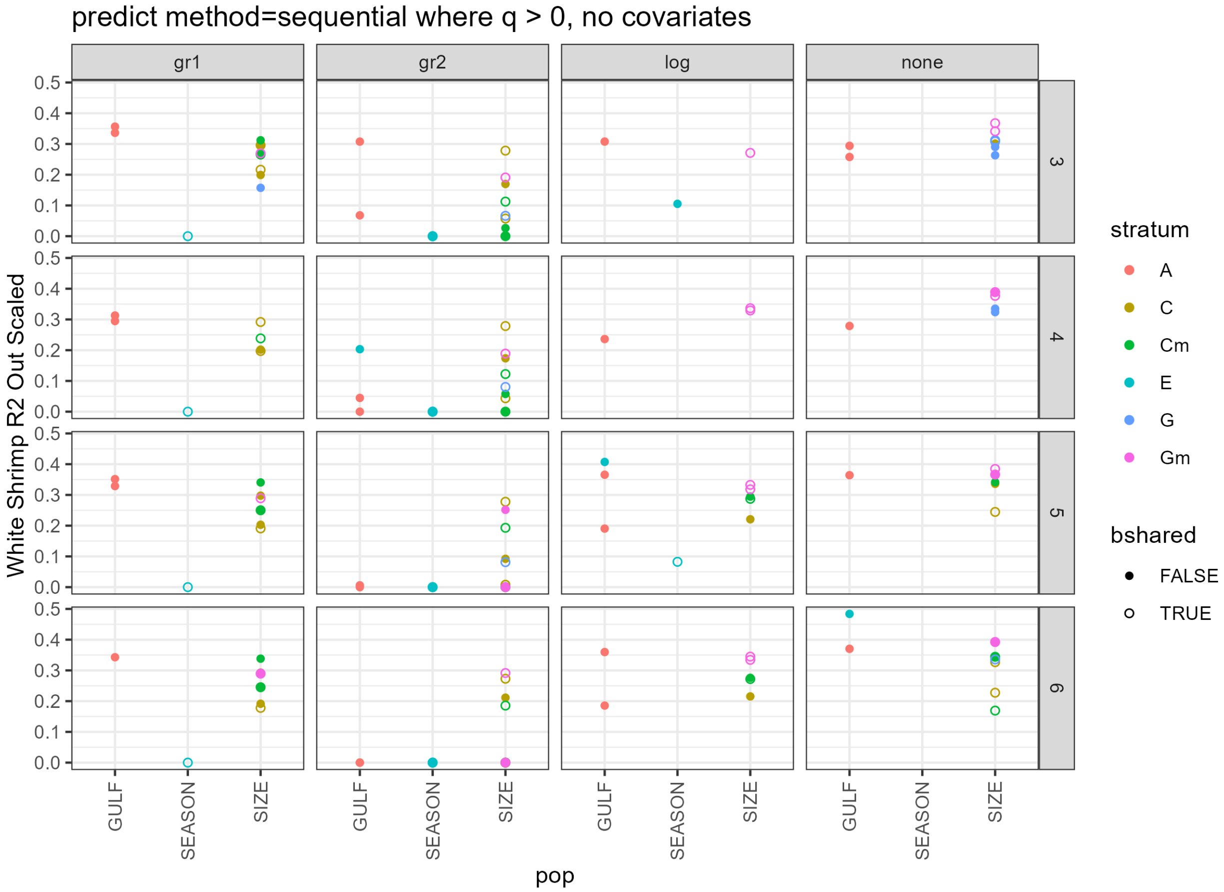


Figure 32: "Sequential" out-of-sample R2 fit statistic resulting from each model run with "local" scaling, q>0.001, and no covariates. Facet columns show results based on different data transformations. Facet rows show results based on the embedding dimension. Within each facet, the x axis groups the models by the type of aggregation (spatial, size, season, or a combination). In this figure, the shape fill was determined by whether or not the catchability parameter was shared among populations in the model (bshared = True / False, respectively).

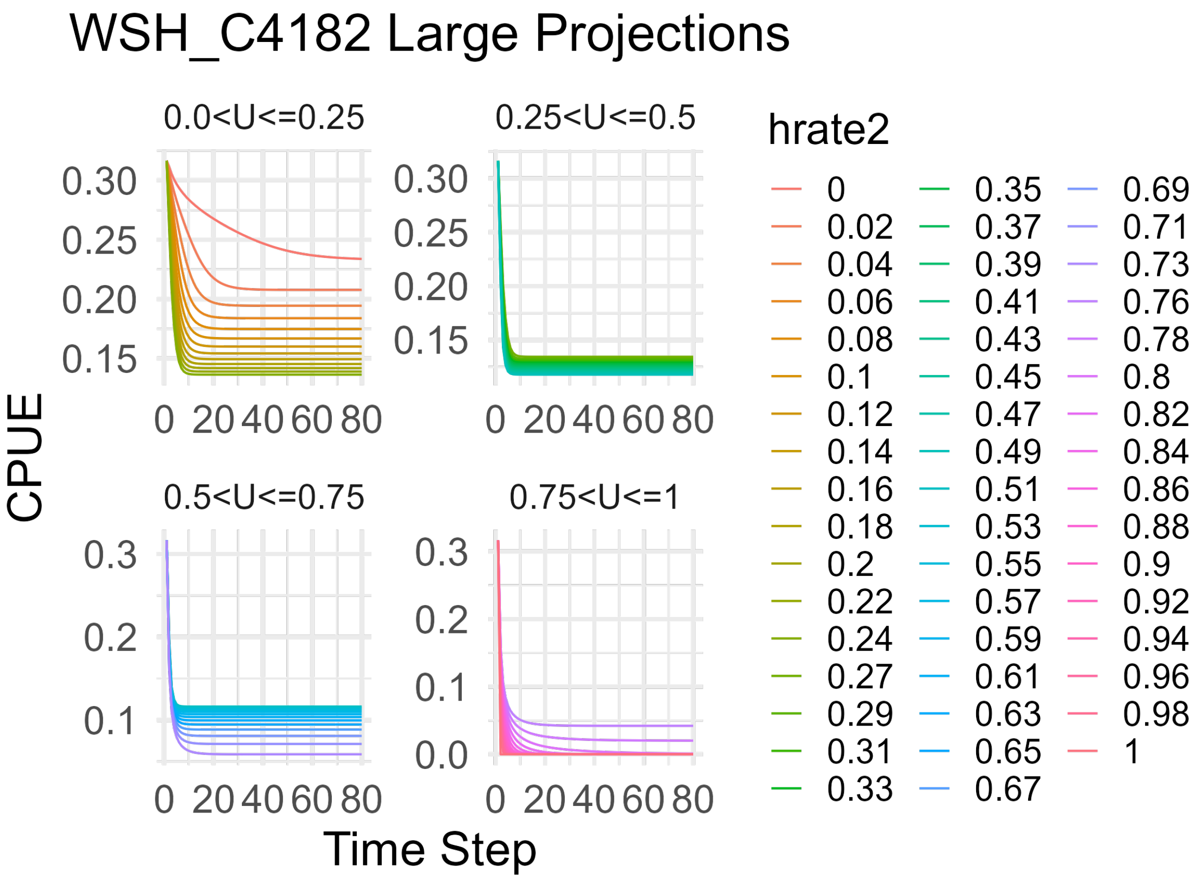


Figure 33: Variable harvest rate projections of CPUE from the best performing run for the Large shrimp population.

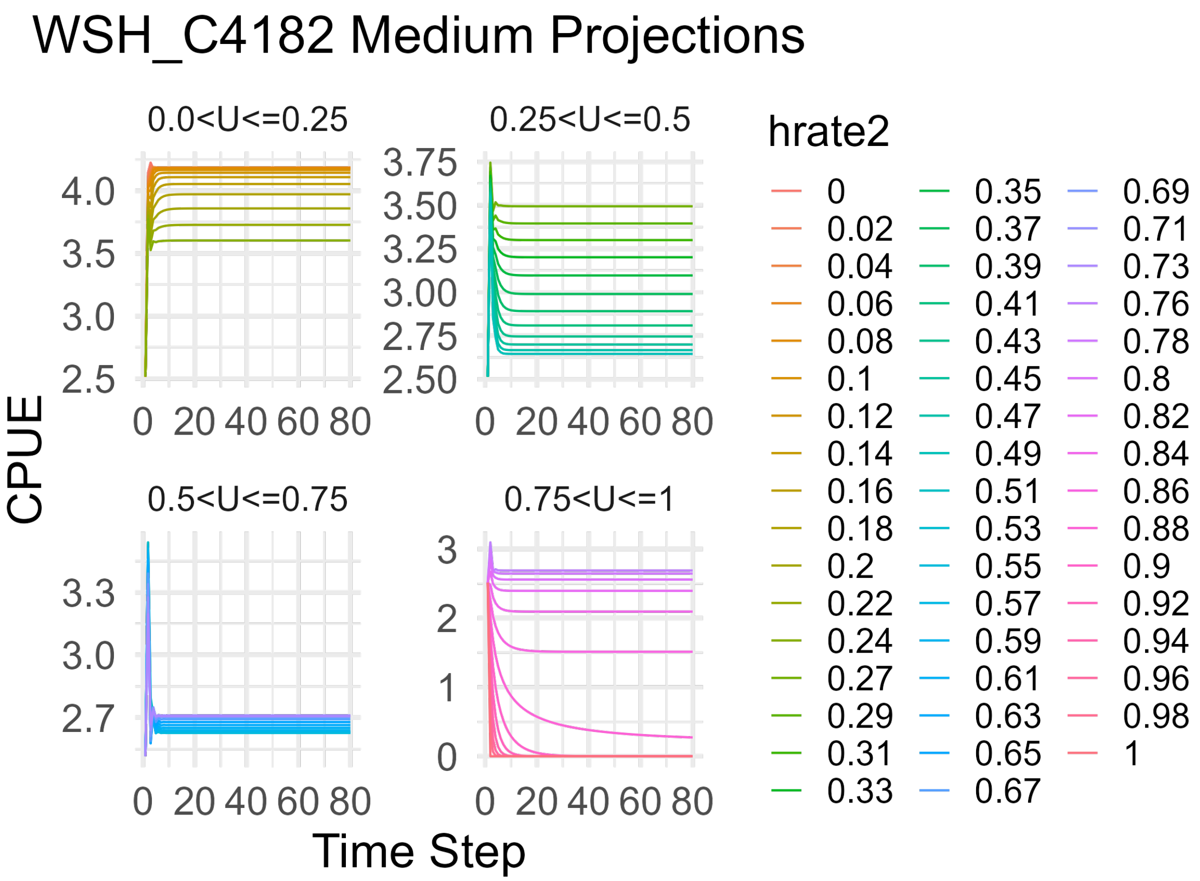


Figure 34: Variable harvest rate projections of CPUE from the best performing run for the Medium shrimp population.

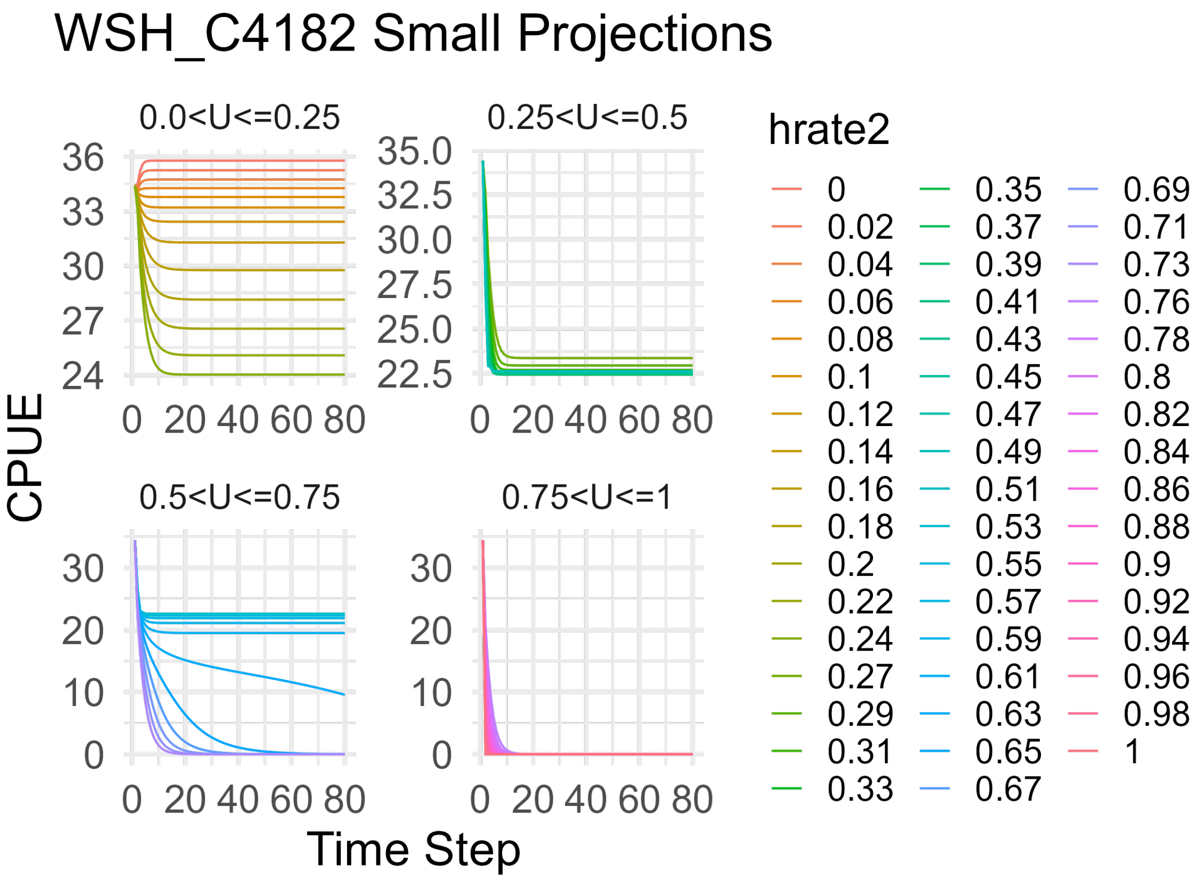


Figure 35: Variable harvest rate projections of CPUE from the best performing run for the Small shrimp population.

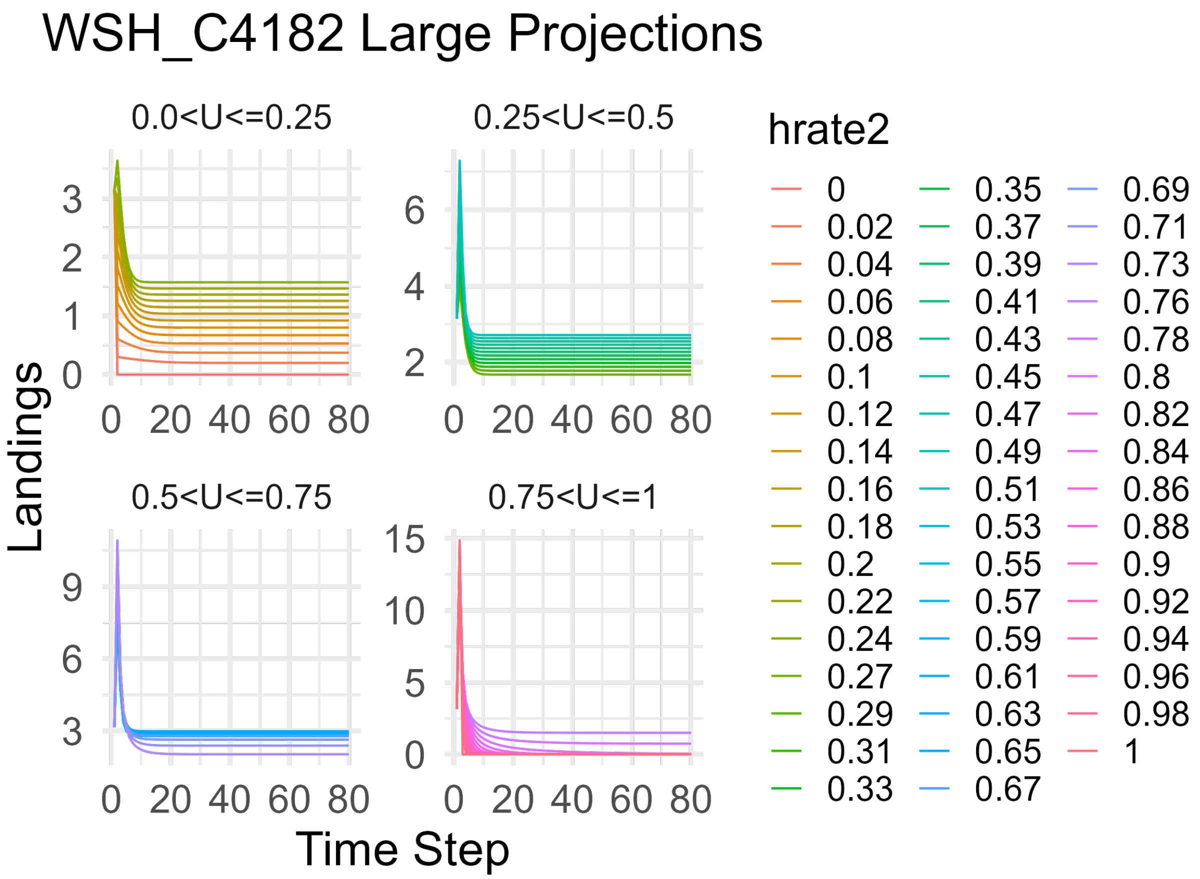


Figure 36: Variable harvest rate projections of landings from the best performing run for the Large shrimp population.

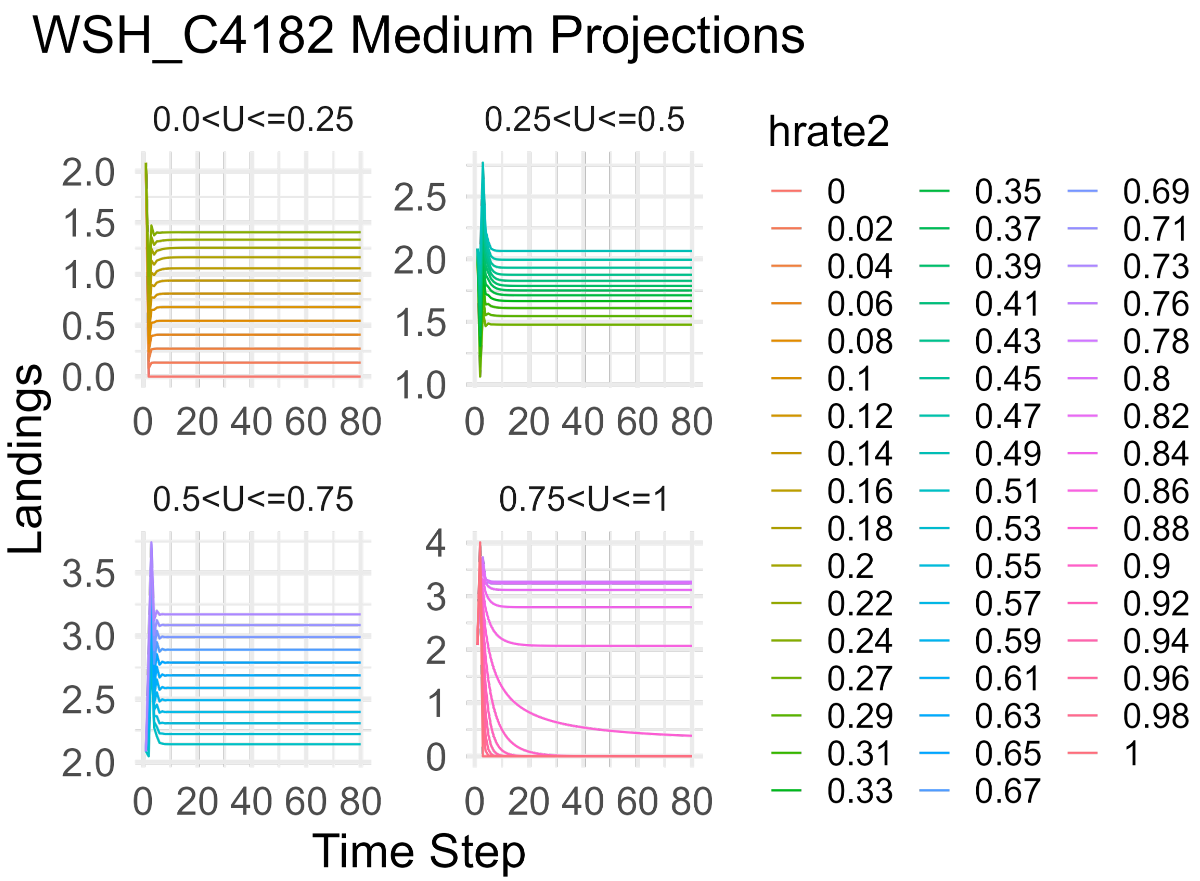


Figure 37: Variable harvest rate projections of landings from the best performing run for the Medium shrimp population.

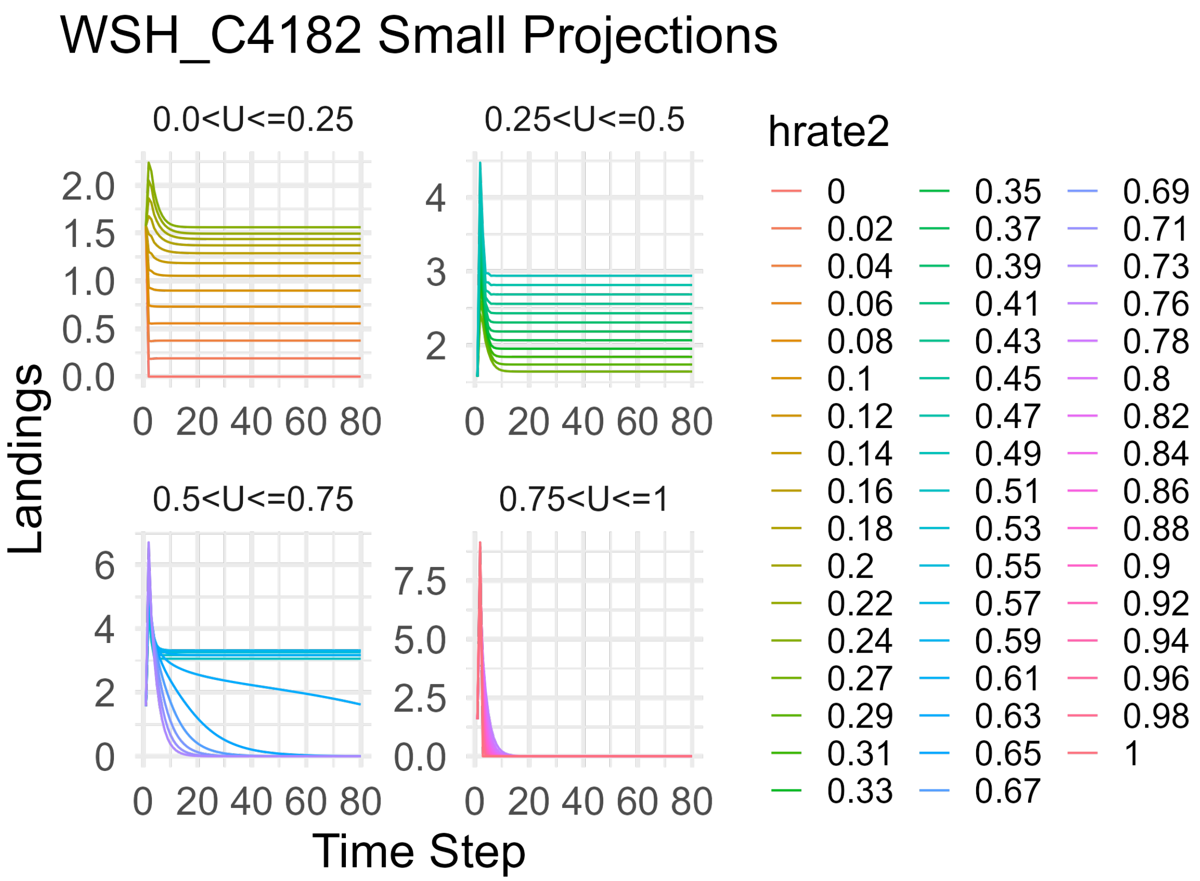


Figure 38: Variable harvest rate projections of landings from the best performing run for the Small shrimp population.

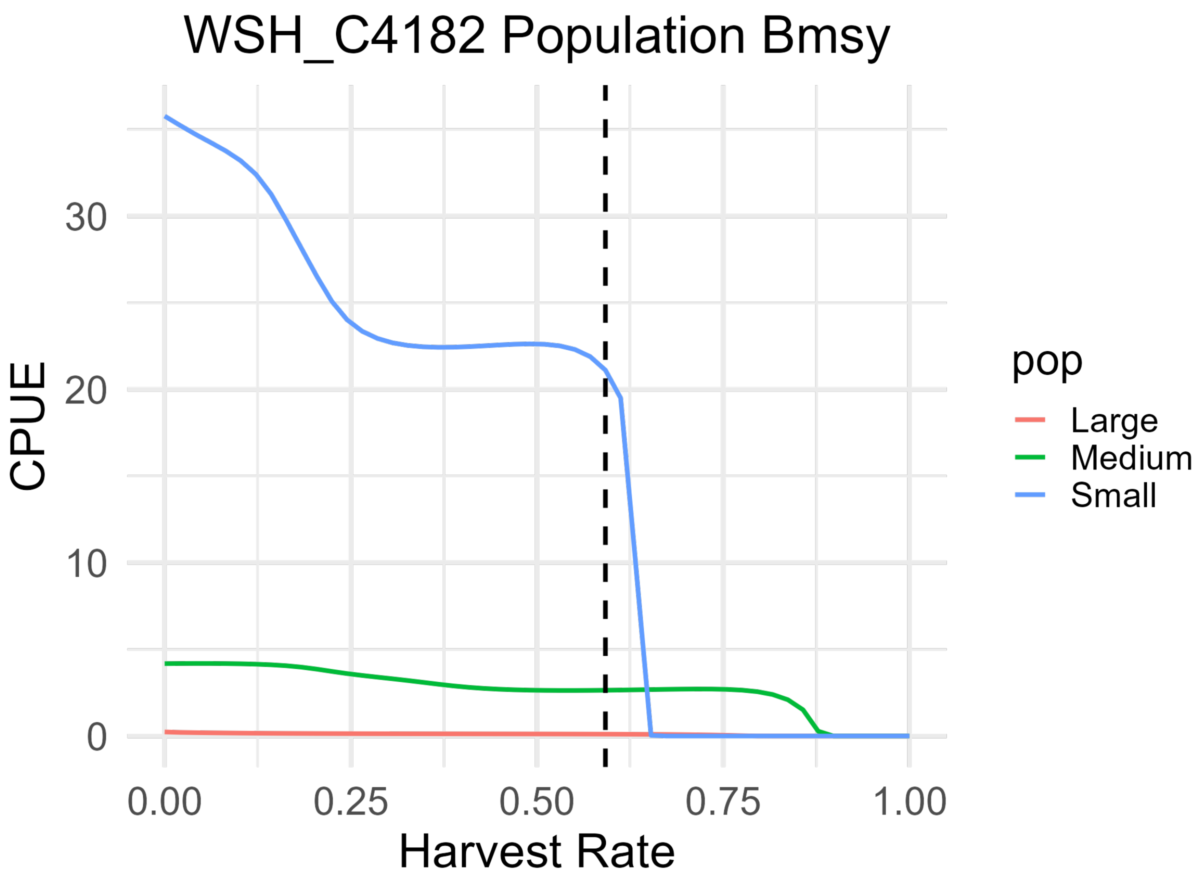


Figure 39: Average CPUE by harvest rate for individual populations for the best performing run. The dashed line indicates the annual harvest rate where MSY occurs, indicating population-wide Bmsy in units of CPUE for each population.

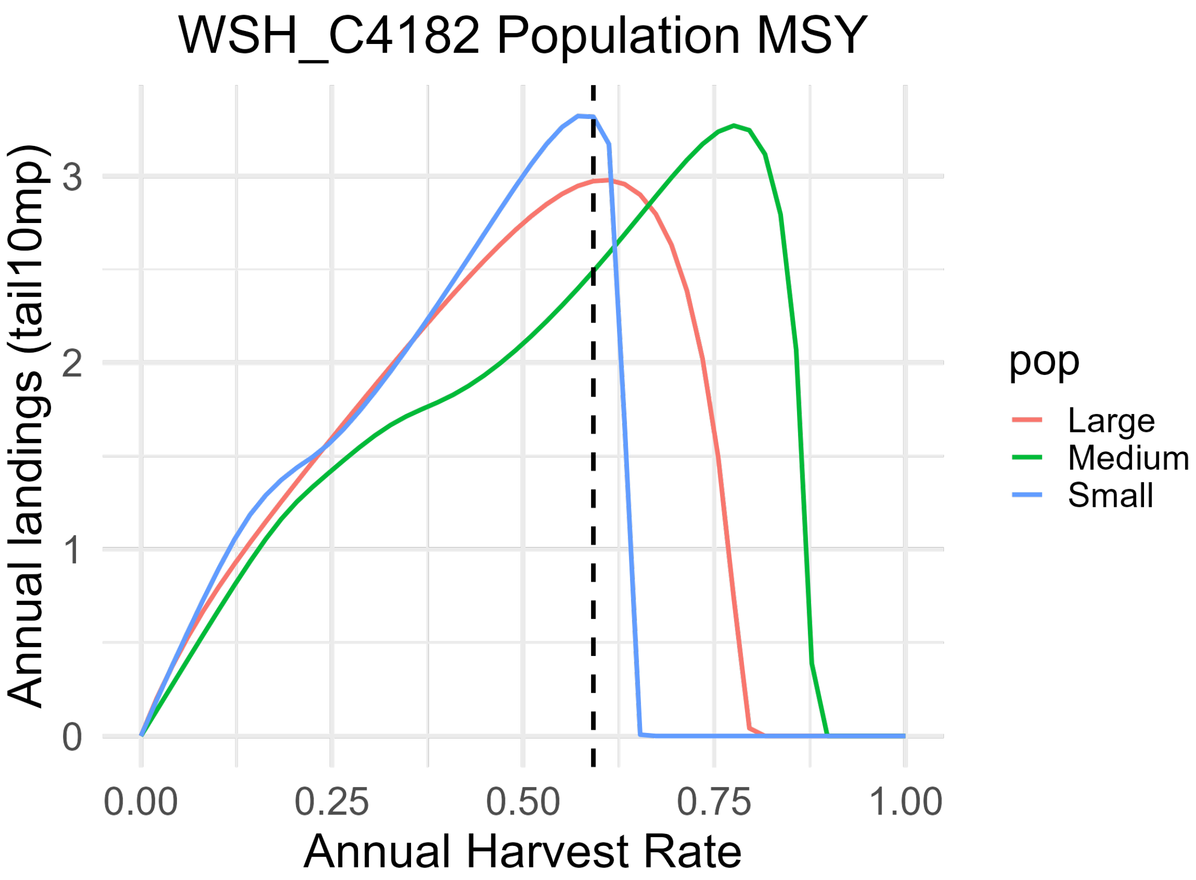


Figure 40: Average landings estimated under a range of annual harvest rates for the best performing run. The optimal annual harvest rate for all populations combined is shown in the dashed line. Individual populations see their landings maximized at slightly different harvest rates.

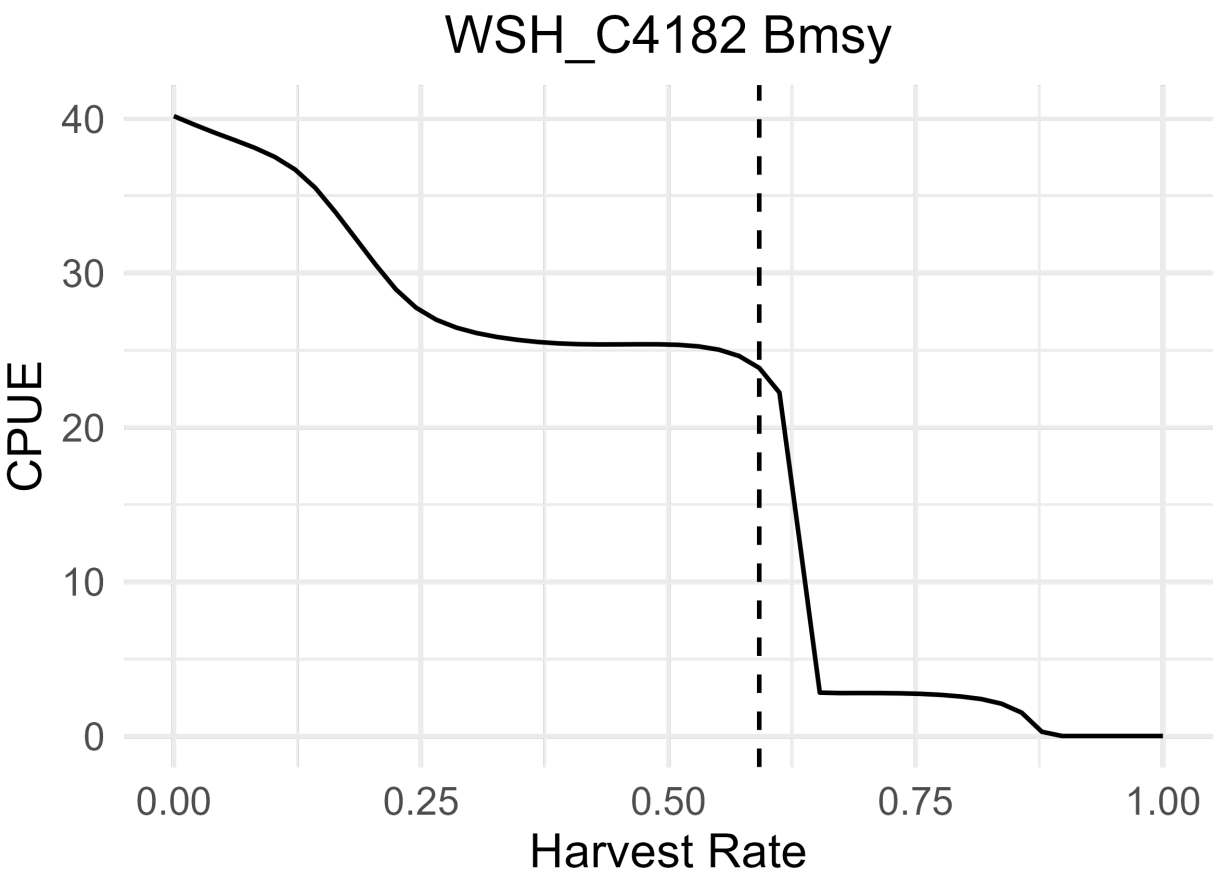


Figure 41: Average CPUE for all populations combined for the best performing run. The dashed line indicates the annual harvest rate where MSY occurs, indicating population-wide Bmsy in units of CPUE.

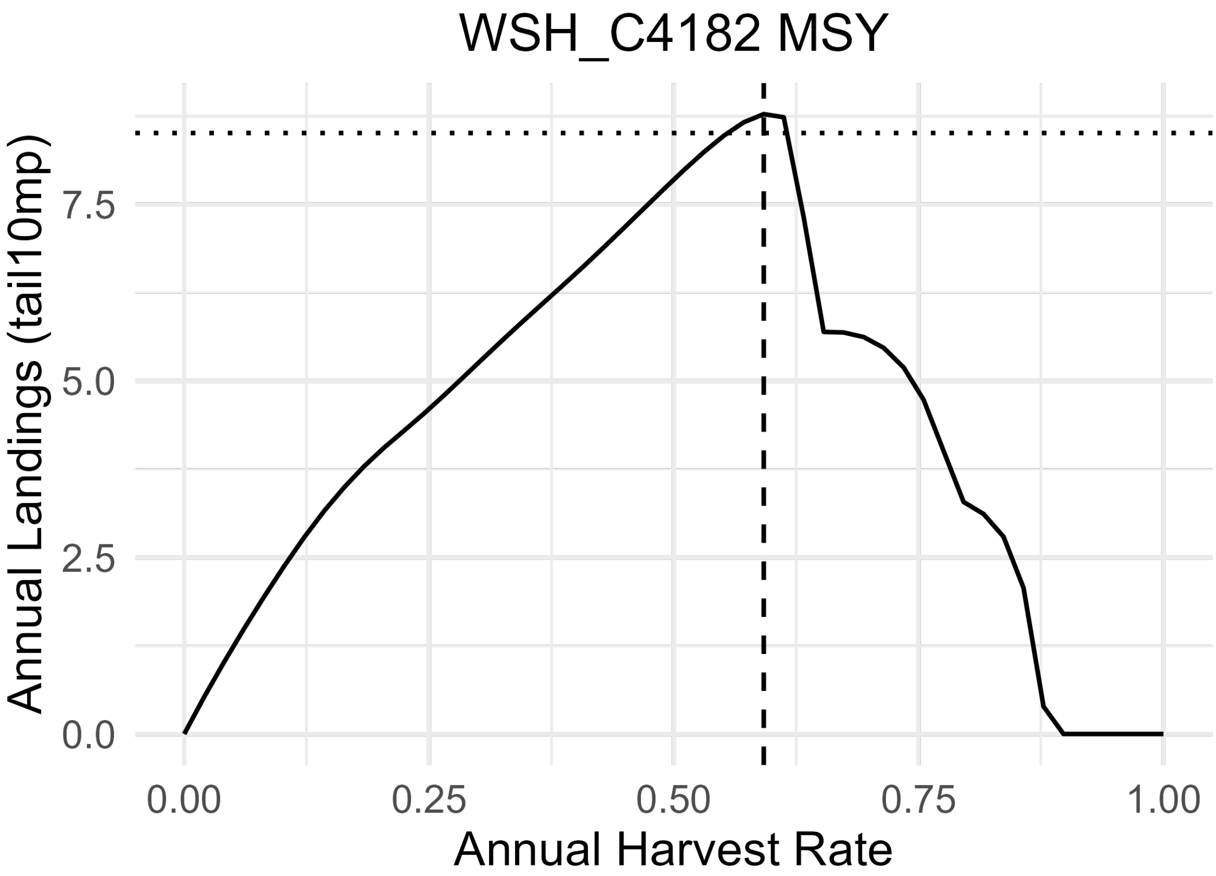


Figure 42: Average landings estimated under a range of annual harvest rates for the best performing run. The optimal annual harvest rate for all populations combined (MSY) is marked with a vertical dashed line. The maximum historical landings are marked with a horizontal dotted line, which is less than the estimated MSY.

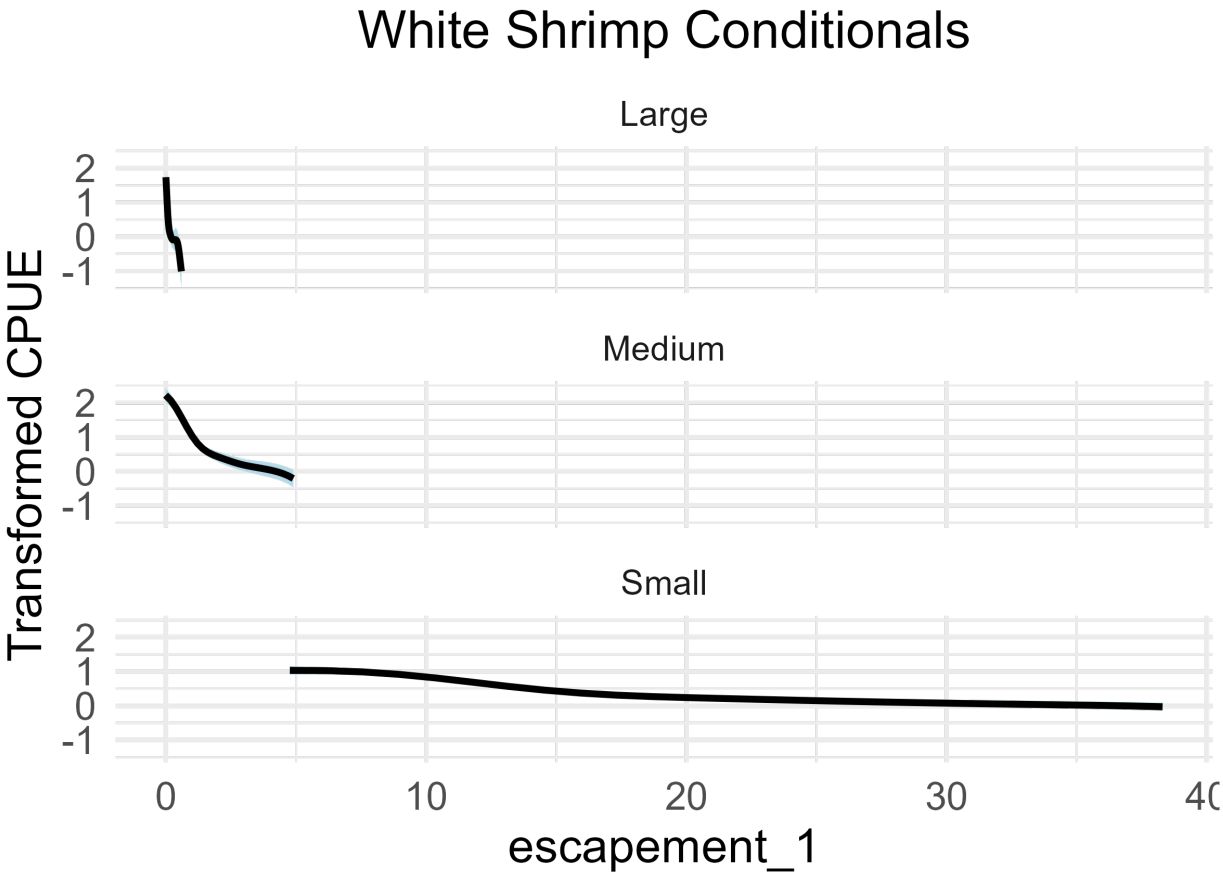


Figure 43: Length scale parameters for the 1st lag of abundance from the best performing model.

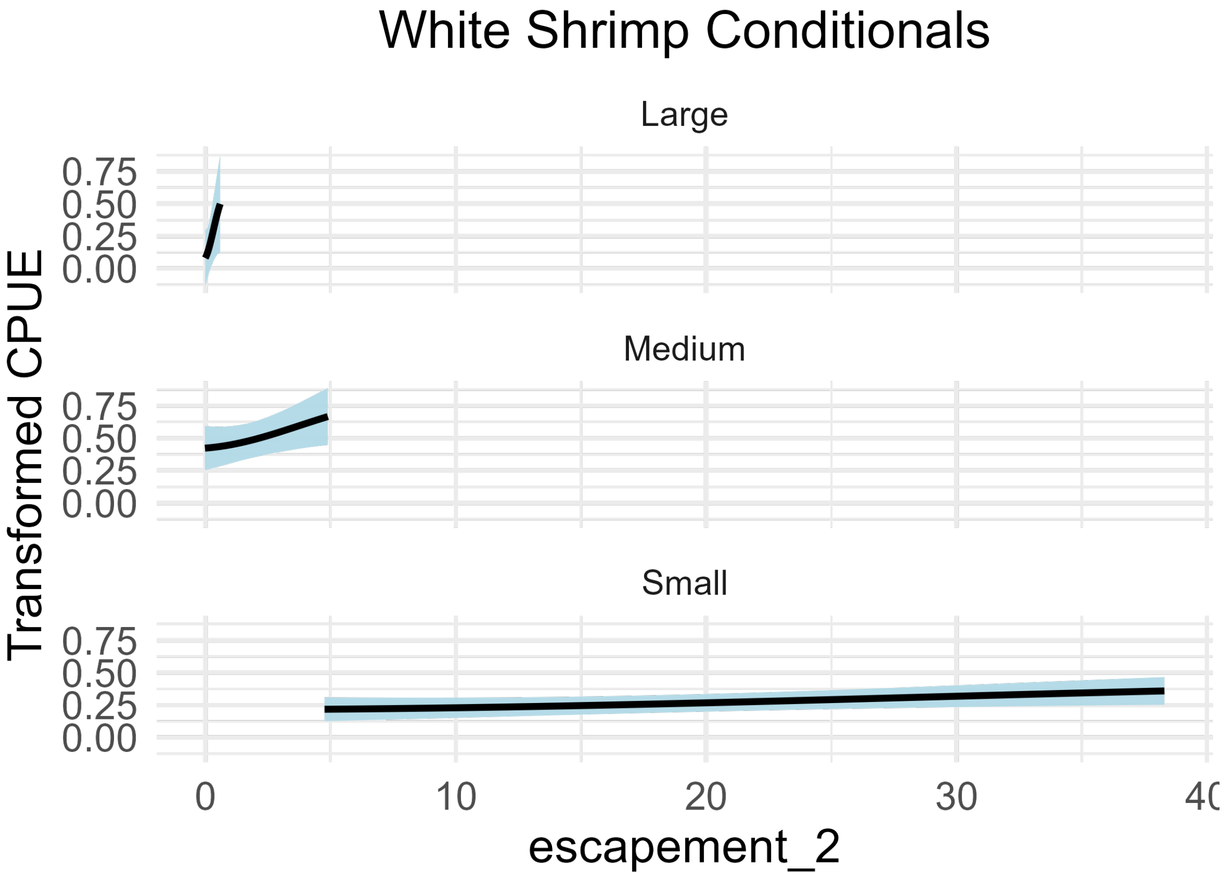


Figure 44: Length scale parameters for the 2nd lag of abundance from the best performing model.

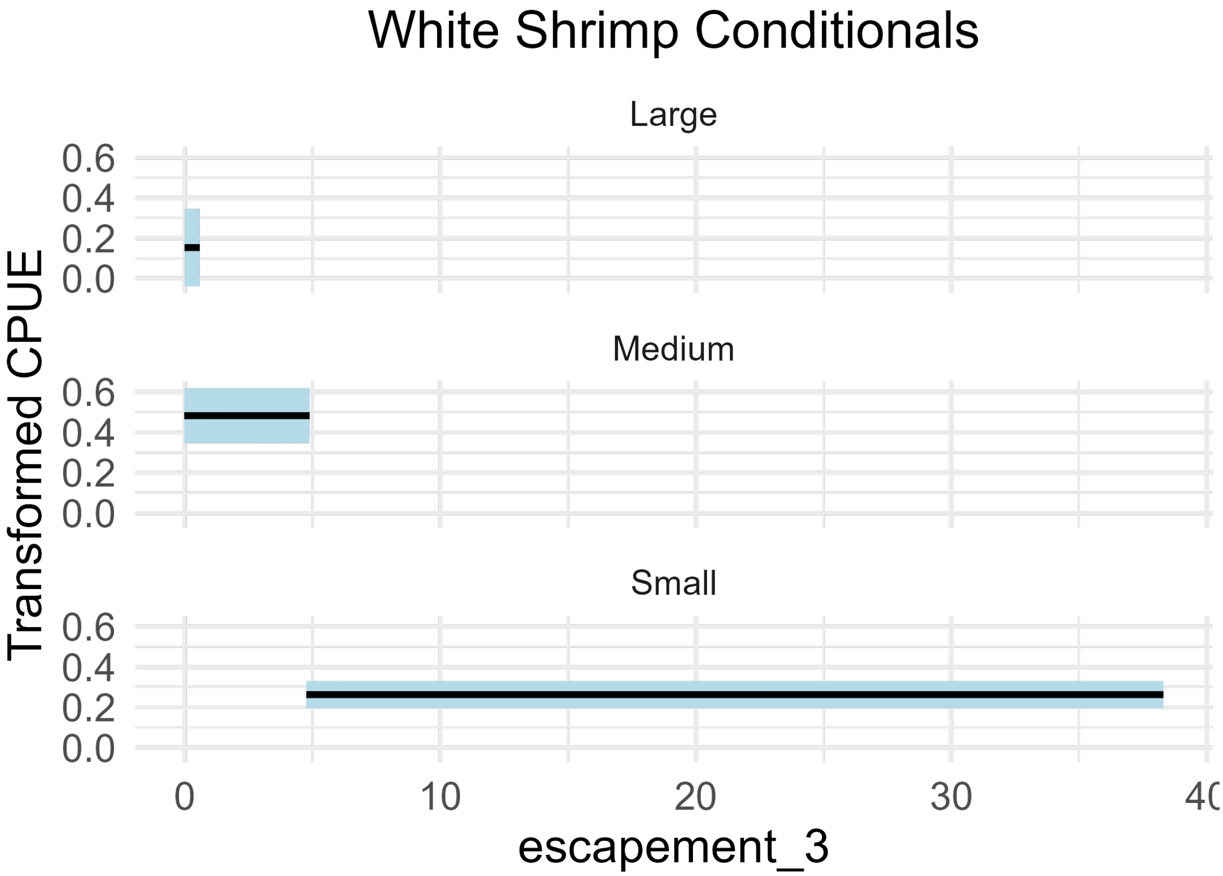


Figure 45: Length scale parameters for the 3rd lag of abundance from the best performing model.

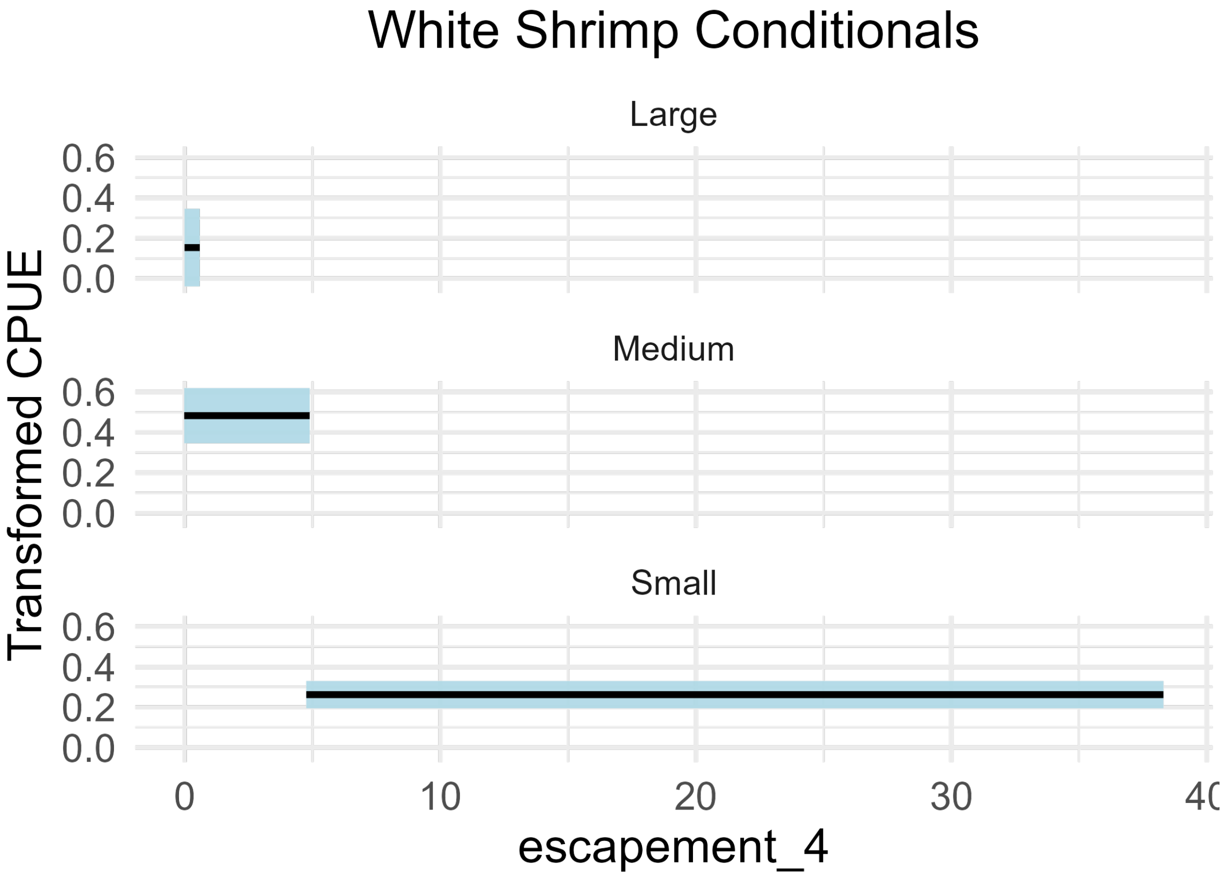


Figure 46: Length scale parameters for the 4th lag of abundance from the best performing model.

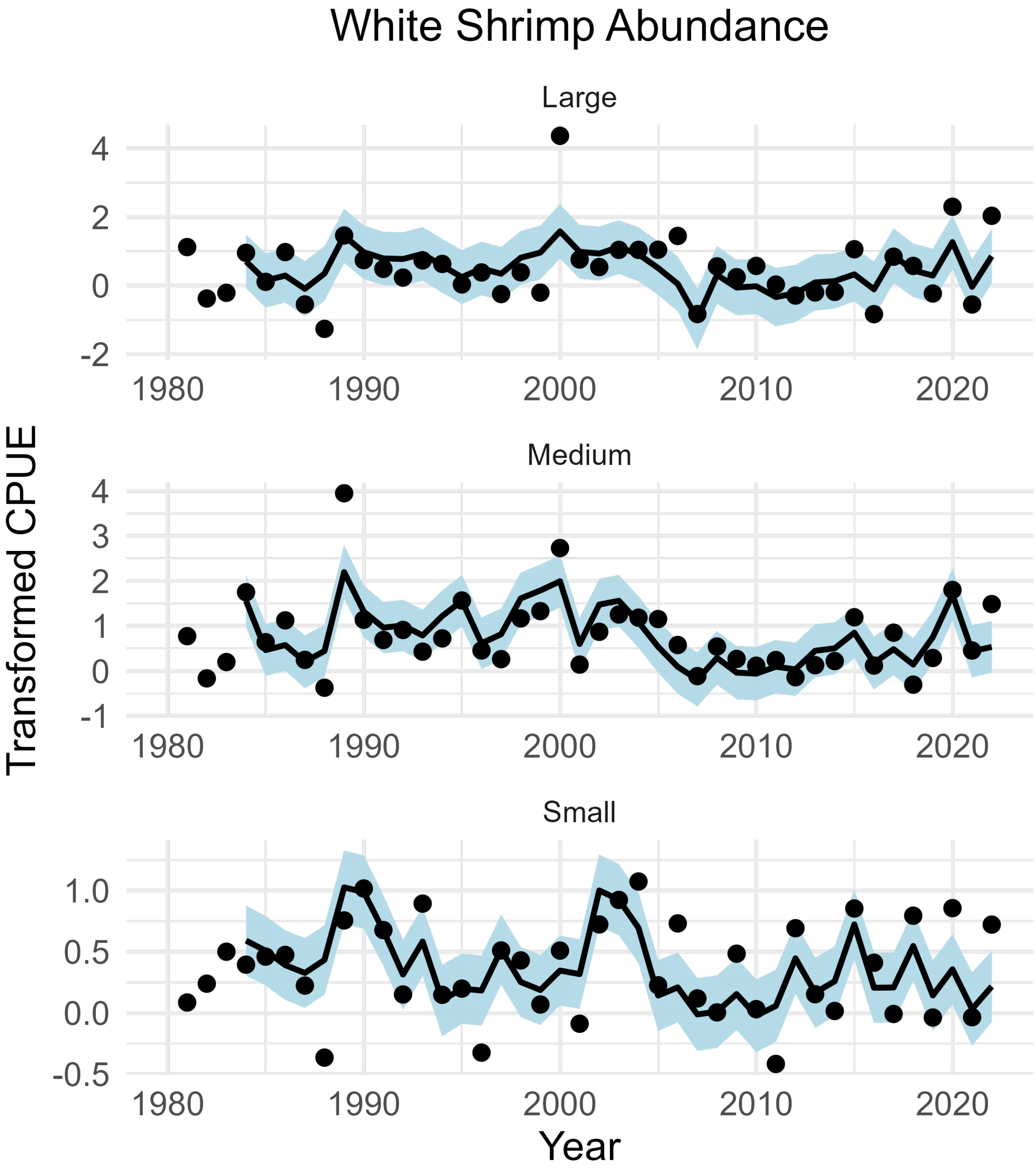


Figure 47: EDM model fits for the best performing run, transformed with error bars.

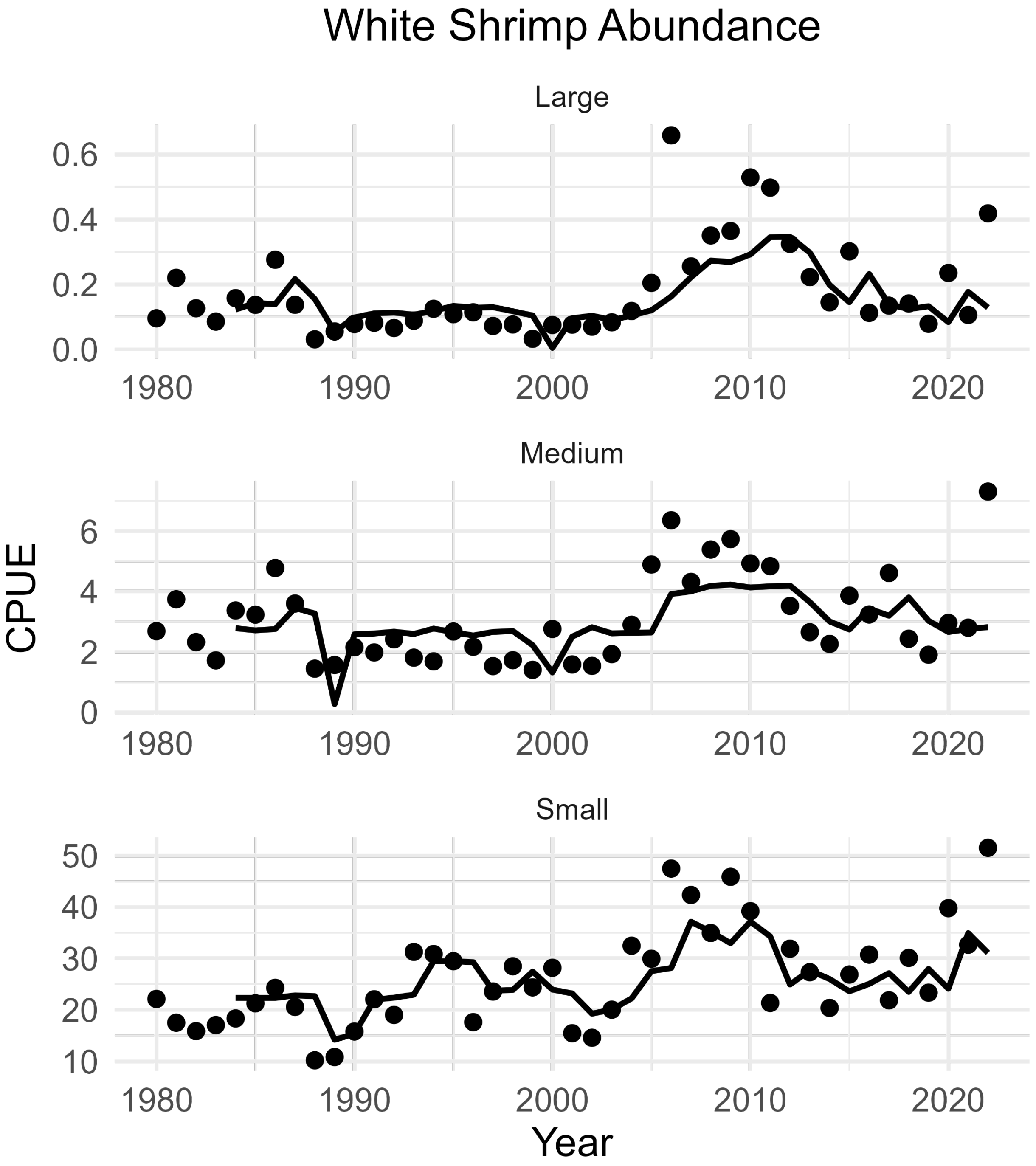


Figure 48: EDM model fits for the best performing run in raw units of LDWF CPUE.

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Gulf White, Pink, and Brown Shrimp

SECTION IV: Research Recommendations

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

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1. DATA WORKSHOP RESEARCH RECOMMENDATIONS

1.1 COMMERCIAL FISHERY STATISTICS RESEARCH RECOMMENDATIONS

- Continue investigations into the methodology of the GSS to better understand differences between GSS and STT programs where they overlap.
- Improve effort data collection for inshore shrimping trips.
- Develop a method to quantify under-reporting of landings in the shrimp fishery, perhaps through the use of separate socio-economic surveys.
- Quantify the prevalence of misidentification of “hopper” brown shrimp within each Gulf state.
- Continue investigations into estimation of species-specific effort.

1.2 ENVIRONMENTAL DRIVERS/INDUSTRY REPORT RESEARCH RECOMMENDATIONS

We highlight data gaps and research recommendations that will improve understanding of environmental impacts on shrimp.

Updated life history information – Much of the life history obtained for shrimp was conducted in the 1960-1970s. Given the short generation time of shrimp, high environmental influence on productivity, and nonstationary environmental dynamics, life history dynamics have likely changed, and these parameters should be updated (e.g., SEDAR87-DW-05).

Density dependence - The suggestion to prioritize environmental impacts on the estuarine stages of shrimp relies on the assumption that this is the region in which density dependence occurs. Expert guidance has suggested that there is no relationship between post larvae entering the estuary and the number of spawning adults in the population (J Nance). While previous efforts suggest that density dependence occurs during estuary residence (e.g., Galveston Bay sub-adult survey to predict brown fishery dynamics for the upcoming year), further research to support this assumption would further validate the assumptions made herein.

<u>Population connectivity models for brown and white shrimp</u> – Research linking spawning adults to their nursery estuary may provide guidance on which estuarine habitats are most productive. Priority could then be given to these most influential nursery habitats for research and conservation.

<u>Mechanistic environmental relationships</u> – Hypothesized environmental drivers presented in this report are correlative only and do not attempt to identify the mechanistic relationship underlying these correlations. Further research identifying the exact driver and the organismal and stock-wide response to these drivers would improve this effort. Updated environmental relationships should be generated or explored.

<u>State FIM data standardization</u> - Additional research should be conducted to standardize and calibrate state-by-state surveys.

<u>Role of shrimp as key forage species</u> - As forage species, shrimp play a key role in the ecosystem. Additional research may clarify linkages between shrimp and predator species and better clarify the extent of predator-induced mortality (e.g., Fujiwara et al. 2016). These linkages may inform how these interrelated species should be managed from an ecosystem-based perspective.

1.3 MEASURES OF POPULTAION ABUNDANCE RESEARCH RECOMMENDATIONS

- Explore survey / gear calibration studies among state and federal sampling programs
- Perform post hoc analysis to potentially account for habitat classification variables and on indices of abundance
- Examination of whether due to zeros, indices based on monthly data may best be structured to focus on core recruitment months or accommodate in model
- Exploration of indices of abundance utilizing combined data from AL, MS, and LA 16 ft state sampling programs, including potentially including a weighting factor to account for differences in area sampled (surface area, habitat area, etc.)

1.4 ECONOMICS AND SOCIAL SCIENCES

No research recommendations were provided.

2. ASSESSMENT PROCESS RESEARCH RECOMMENDATIONS

2.1 White Shrimp

The models provided in this report are sufficient to provide management advice for the stock. However, should future research funding become available, we have provided suggestions below.

Potential improvements to the modeling framework include accounting for removal of shrimp as it pertains to harvest rates that are optimized at varying size classes. Creating a feedback loop that appropriately represents the removal of larger shrimp that may not contribute to future generations as well as the removal of smaller shrimp that may not grow into large shrimp should be accounted for. Sensitivities of these potential feedback loops and their impact on estimating optimal harvest rates should be investigated in both directions (i.e. Large to Small and Small to Large impacts).

Additional research into covariates may also be investigated. Direct inclusion of covariates generally resulted in improved model fits and could likely improve forecasting efficiency for trends of abundance. To forecast MSY, covariates would need to be projected into the future. For environmental covariates, the cyclical nature of these trends would need to be captured. For economic covariates, the relationship with projected harvest rates would need to be explicitly defined.

Implications of the LDWF survey capturing mostly small shrimp in conjunction with the fishery capturing mostly large shrimp should be investigated as it pertains to catchability estimation and resulting estimates of escapement. It is suspected that this was the primary driver for a large process variance in the model.

2.2 Pink Shrimp

Additional research into covariates should be investigated. Direct inclusion of covariates resulted in improved model fits and could likely improve forecasting efficiency for trends of abundance. To forecast MSY, covariates would need to be projected into the future. For environmental covariates, the cyclical nature of these trends would need to be captured. For economic covariates, the relationship with projected harvest rates would need to be explicitly defined.

Potential improvements to the modeling framework include accounting for removal of shrimp as it pertains to harvest rates that are optimized at varying size classes. Creating a feedback loop that appropriately represents the removal of larger shrimp that may not contribute to future generations as well as the removal of smaller shrimp that may not grow into large shrimp should be accounted for. Sensitivities of these potential feedback loops and their impact on estimating optimal harvest rates should be investigated in both directions (i.e. Large to Small and Small to Large impacts).

As funding for scientific surveys is becoming increasingly sparse, implications of using an average of 2019/21 for missing summer 2020 SEAMAP data and resulting effects on model diagnostics should be investigated. EDM performs best on continuous, long time series of data, and quantifying implications of future gaps in survey data would be valuable.

2.3 Brown Shrimp

The models provided in this report are sufficient to provide management advice for the stock. However, should future research funding become available, we have provided suggestions below.

Potential improvements to the modeling framework include accounting for removal of shrimp as it pertains to harvest rates that are optimized at varying size classes. Creating a feedback loop that appropriately represents the removal of larger shrimp that may not contribute to future generations as well as the removal of smaller shrimp that may not grow into large shrimp should be accounted for. Sensitivities of these potential feedback loops and their impact on estimating optimal harvest rates should be investigated in both directions (i.e. Large to Small and Small to Large impacts).

Additional research into covariates may also be investigated. Direct inclusion of covariates generally resulted in improved model fits and could likely improve forecasting efficiency for trends of abundance. To forecast MSY, covariates would need to be projected into the future. For environmental covariates, the cyclical nature of these trends would need to be captured. For economic covariates, the relationship with projected harvest rates would need to be explicitly defined.

As funding for scientific surveys is becoming increasingly sparse, implications of using an average of 2019/21 for missing summer 2020 SEAMAP data and resulting effects on model diagnostics should be investigated. EDM performs best on continuous, long time series of data, and quantifying implications of future gaps in survey data would be valuable.

3. REVIEW PANEL RESEARCH RECOMMENDATIONS

The EDMs for brown and white shrimp evaluate many lag combinations across size and seasonal categories. Instead of reporting raw R^2 values, using an adjusted R^2 could improve model comparison by penalizing model complexity (e.g., number of embedding dimensions × size bins × seasons):

$$Adjusted\ R^2 = 1 - \left(\frac{(1-R^2)*(n-1)}{n-k-1}\right)$$

where k is the number of lags combined with any additional parameters used.

Track q and other metrics through the addition of each data point of escapement within EDM. It would be useful to visualize the sample size of escapement necessary for q (or other metrics) to stabilize.

It was difficult to know if data series were long enough to reliably fit EDM models despite some recommendations in the literature. It would be useful to fit EDM models to long simulated or real data sets sequentially eliminating the first point in the data set so that sequential model runs are based on shorter and shorter time series. The performance or stability of the model will probably degrade as the time series becomes too short. Such tests could be done routinely in real stock assessments or to develop general rules.

Can scale be estimated in EDM when survey data are flat or constitute a one-way trip? Such survey data patterns are problematic and degrade accuracy using traditional assessment models.

JABBA does not directly utilize environmental, economic or social data. However, a similar Bayesian surplus production model could be programmed locally to use such information.

Consider incorporating bay trawls from both Texas and Louisiana (with their accompanying environmental collections) to create a recruitment and adult index into the EDM model for Brown Shrimp.

If EDM can handle environmental data that has an unspecified probably nonlinear relationship with stock size, it seems possible that it might handle fishery CPUE as well. Fishery-dependent CPUE is meaningful to constituents but hard to handle in assessment models because it has a nonlinear relationship with biomass. It usually changes more slowly than biomass when stock size is high and more slowly than stock size when biomass is low. Moreover, CPUE is affected by changes in fishing technology, and vessel operations. One advantage of CPUE is that it can be standardized in models like VAST to account for differences among vessels, locations, etc. in the same way as survey data (although nonlinearity is not removed). CPUE data are usually less variable than survey data and may therefore show the direction, if not the magnitude, of changes in stock size clearly. The possibility of using CPUE in EDM should be investigated.

It might be possible to use fishery dependent data to a greater extent to improve short-term projections with EDM. EDM makes predictions based on lagged data which are “nearby” in time (e.g. 3-4 year lags). The emphasis on recent data may alleviate problems using fishery dependent data with properties that change slowly over time.One year of missing survey or other predictor data have a disproportionate effect on the length of time series in EDM models because each datum is used repeatedly in lags. One year of missing survey data for brown shrimp was imputed by averaging the previous and subsequent observation. Another imputation approach may be better, e.g., based on a nonlinear fit to data for the same spatial cell and population in years t-3 … t-1 and t+1 … t+3.

Use simulation, bootstrapping or some other approach to determine if the variances for EDM model results are realistic.

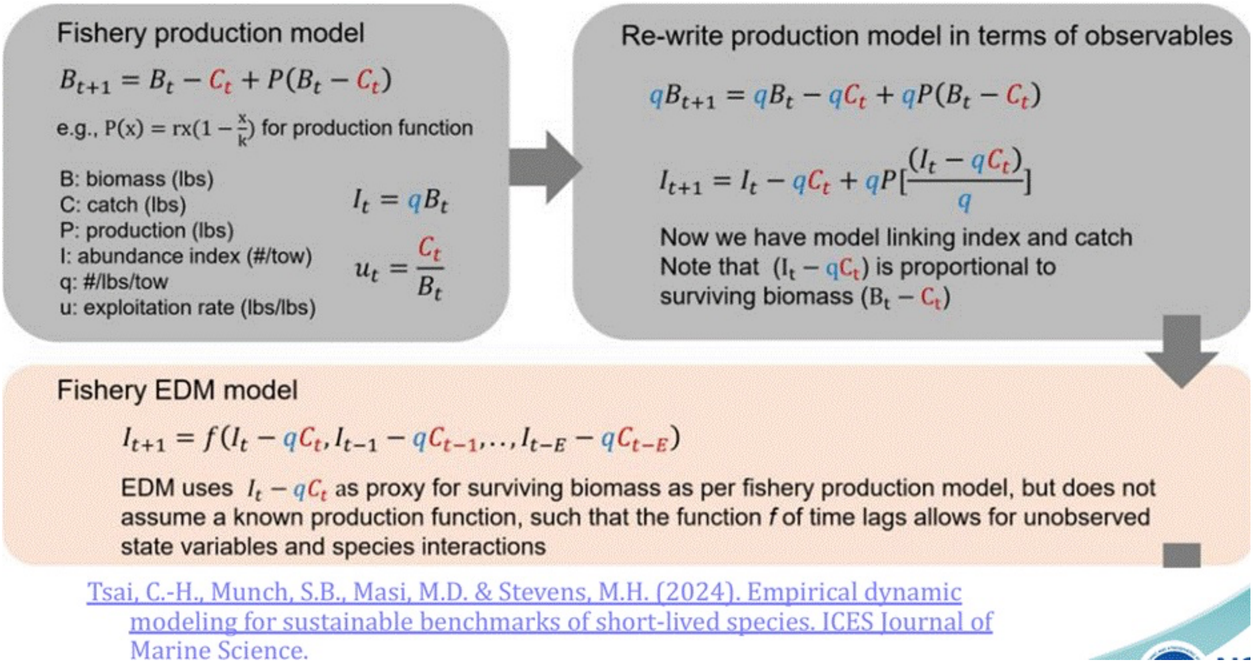
Determine if omitted predictor variables in EDM bias the scale of stock size estimates. According to Takens' theorem, the trend in EDM model estimates may be insensitive to missing predictor variables because the lagged survey data used in the model were influenced by and carry information about effects of missing predictors, particularly if predictor variables are correlated. However, it is not clear how or if Takens' theorem applies to scale.

Correlated predictor variables are a significant problem in traditional modeling (e.g., with linear regression). Evaluate effects of correlated predictors on EDM models. Would it be better to avoid correlated variables or use, for example, uncorrelated principal component scores that carry the same information as the original data? If correlated predictors cause problems and environmental variables are correlated with the survey data in the model, is it better to avoid using the environmental variables?

Determine how well EDM models can be used to estimate MSY reference points if data were collected while the stock was not near Bmsy or K. Is it possible to estimate these parameters in EDM for a lightly or chronically overfished stock? That is, can models be extrapolated into unsampled areas of the data space?

Clarify the interpretation of the q parameter in EDM. The parameter is estimated in the EDM model where it is used to put catch and survey data on the same scale, then to scale "escapement" into biomass units (see Fig. 1). The current EDM formulation is an algebraic reordering of terms in a crude, approximate surplus model that is most accurate under stable stock conditions when somatic growth (G) and mortality rates (Z) are low. However, G and Z are both high for shrimp and the approximation may be suboptimal.

The q parameter is used in EDM to relate biomass during a relatively short survey to biomass at the beginning of the current time step (It=qBt, see below). However, when applied to escapement (It-qCt), the parameter q converts catch in year t to a hypothetical quantity that adjusts biomass at the beginning of the year as though catch also occurred at the beginning of the year. However, shrimp catch occurs throughout the year while substantial growth and mortality occurs (it is possible that most of the catch biomass is due to growth in the current year). Thus, growth, mortality and the different time scales of the survey and fishery are ignored by the formulation in a manner that might affect model performance for stocks like shrimp with high growth and mortality rates. Other surplus production formulations are available that might serve better for shrimp.



Fishery production model

$B_{t+1} = B_t - C_t + P(B_t - C_t)$

e.g., $P(x) = rx(1 - \frac{x}{k})$ for production function

B: biomass (lbs)
C: catch (lbs)
P: production (lbs)
I: abundance index (#/tow)
q: #/lbs/tow
u: exploitation rate (lbs/lbs)

$I_t = qB_t$

$u_t = \frac{C_t}{B_t}$

Re-write production model in terms of observables

$qB_{t+1} = qB_t - qC_t + qP(B_t - C_t)$

$I_{t+1} = I_t - qC_t + qP[\frac{(I_t - qC_t)}{q}]$

Now we have model linking index and catch
Note that $(I_t - qC_t)$ is proportional to surviving biomass $(B_t - C_t)$

Fishery EDM model

$I_{t+1} = f(I_t - qC_t, I_{t-1} - qC_{t-1}, \ldots, I_{t-E} - qC_{t-E})$

EDM uses $I_t - qC_t$ as proxy for surviving biomass as per fishery production model, but does not assume a known production function, such that the function *f* of time lags allows for unobserved state variables and species interactions

Tsai, C.-H., Munch, S.B., Masi, M.D. & Stevens, M.H. (2024). Empirical dynamic modeling for sustainable benchmarks of short-lived species. ICES Journal of Marine Science.

Figure 1. Parameterized Fishery EDM for Gulf shrimps used for this assessment. Taken from Tsai, et al. (2024).

Clarify assumptions in the production model behind EDM. The current formulation (see above) appears to assume that production during year t is a function of biomass at the beginning of the same year Pt (Bt-Ct) with an adjustment for catch occurring later during the same year. The model subtracts catch in year t from biomass in the same year Bt-Ct again to account for reductions in biomass due to catch. Are we double counting the catch? Would it make sense to write the model as Bt+1=Bt+P(Bt)-Ct i.e., assuming production is a function of biomass at the beginning of the year which seems reasonable.

The transformations applied (log, gr1, gr2) could be clarified. If log and gr1 apply only to CPUE or X in the escapement equation, while gr2 transforms the entire escapement term, this distinction should be made explicit. All transformations appear appropriate, q would be estimated to convert catch units to whatever scale is chosen.

This assessment utilized novel approaches for estimating the management quantities of Bmsy, Bcurrent/Bmsy, Fmsy, Fcurrent/Fmsy for Gulf shrimp, and their trajectories of biomass and fishing rates over the past and projection into the future. While far removed from a "traditional" Research Track Assessment under typical SEDAR operations, these methods proved to be sound as well as robust, at least for brown and white shrimp. The caveat being despite the known relationships between Gulf shrimp species and environmental conditions in the estuaries during their post-larval, juvenile, and sub-adult stages (particularly water temperature in the spring when initial recruitment begins for brown shrimp), none of the environmental data was ultimately included in assessment. The same can be said for the socioeconomic factors that have been shown to drive much of the effort of the fleet (diesel price, consolidation of the fleet, massive recent influx of foreign imports and it's effect on dockside prices, etc.). An industry representative stated that "using fishery dependent data in modeling would tend to enhance industry confidence in results, despite difficulties in their use". The structure of EDM models may provide opportunities in this regard.

Long term predictions based on EDM models with environmental data may not be practical because of uncertainty about future environmental conditions. It may be feasible, however, to carry out short-term predictions. Environmental conditions may be relatively constant or predictable over shorter time periods so that environmental data are easier to predict with some accuracy. Moreover, environmental effects may be implicit in the survey data.

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Gulf White, Pink, and Brown Shrimp

SECTION V: Review Workshop Report

August 2025

SEDAR
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1. INTRODUCTION

1.1 WORKSHOP TIME AND PLACE

The SEDAR 87 Review Workshop was held in Tampa, Florida June 23-27, 2025.

1.2 TERMS OF REFERENCE

1. Evaluate the degree to which the terms of reference from the Data and Assessment processes were addressed.

2. Evaluate the data used in the assessment, including discussion of the strengths and weaknesses of data sources and decisions. Consider the following:
    - Are data decisions made by the Data and Assessment processes justified?
    - Are data uncertainties acknowledged, reported, and within normal or expected levels?
    - Is the appropriate model(s) applied properly to the available data?
    - Are input data series sufficient to support the assessment approach?

3. Evaluate and discuss the strengths and weaknesses of the methods used to assess the stock, given the available data. Consider the following:
    - Are methods scientifically sound and robust?
    - Are priority modeling issues clearly stated and addressed?
    - Are the methods appropriate for the available data?
    - Are assessment models configured properly and used in a manner consistent with standard practices?

4. Consider how uncertainties in the assessment, and their potential consequences, are addressed.
    - Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods.
    - Comment on the likely relationship of this variability with possible ecosystem or climate factors and possible mechanisms for including this into management reference points.

5. Provide, or comment on, recommendations to improve the assessment

  - Consider the research recommendations provided by the Data and Assessment processes in the context of overall improvement to the assessment, and make any additional research recommendations warranted.
  - If applicable, provide recommendations for improvement or for addressing any inadequacies identified in the data or assessment modeling. These recommendations should be described in sufficient detail for application, and should be practical for short-term implementation (e.g., achievable within ~6 months). Longer-term recommendations should instead be listed as research recommendations above.

6. Provide recommendations on possible ways to improve the Research Track Assessment process.

7. Prepare a Review Workshop Summary Report describing the Panel's evaluation of the Research Track stock assessment and addressing each Term of Reference.

1.3 LIST OF PARTICIPANTS

Review Panel

Jim Tolan (Chair)	GMFMC Appointee
Simon DeLestang	CIE Reviewer
Larry Jacobson	CIE Reviewer
Erik Lang	LDWF/GMFMC Appointee
Joe Powers	CIE Reviewer
Steven Saul	GMFMC SSC

Analytic Team

Lisa Ailloud	NMFS SEFSC
Molly Stevens	NMFS SEFSC
Katie Siegfried	NMFS SEFSC

Appointed Observers

Fernando Martinez-Andrade	TXPWD

Staff

Julie A Neer	SEDAR
Matt Freeman	GMFMC Staff
John Froeschke	GMFMC Staff
Ryan Rindone	GMFMC Staff
Charlotte Schiaffo	GMFMC Staff

Workshop Observers

Leann Bosarge	Industry

Workshop Observers via Webinar

Jason Adriance	LADWF
Jesse Buntin	NOAA
Peyton Cagle	LADWF

Judd Curtis	SAFMC Staff
Tricia Kimball	
Dominique Lazarre	SERO
Richard Malinowski	NOAA
Jessica Marchant	AL DCNR
Michelle Masi	SERO
Steve Munch	SWFSC
Emily Ott	SEDAR
Jason Saucier	MS DMR
Rebecca Smith	NOAA
John Walter	SEFSC

1.4 LIST OF REVIEW WORKSHOP WORKING PAPERS AND DOCUMENTS

Document #	Title	Authors	Date Submitted
Documents Prepared for the Review Workshop			
SEDAR87-RW-01	State Management History - Texas	Council & State Staff	28 May 2025
SEDAR87-RW-02	State Management History - Louisiana	Council & State Staff	28 May 2025
SEDAR87-RW-03	State Management History - Mississippi	Council & State Staff	28 May 2025
SEDAR87-RW-04	State Management History - Alabama	Council & State Staff	28 May 2025
SEDAR87-RW-05	State Management History - Florida	Council & State Staff	28 May 2025
SEDAR87-RW-06	Brown, White, and Pink Shrimp Life History in the Gulf: A Primer	Gulf Council Staff	18 June 2025
SEDAR87-RW-07	Public Comments Received During the Review Workshop		27 June 2025
Reference Documents			
SEDAR87-RD16	The Texas Shrimp Fishery	Texas Parks and Wildlife	

2. REVIEW PANEL REPORT

Executive Summary

The Gulf shrimp fishery has historically posed assessment challenges due to a disconnect between trends in abundance indices and landings over time, as well as limited data inputs. These factors make it difficult to fit integrated age and size-structured models, such as Stock Synthesis. In response, the analysts selected four modeling approaches that may better suited to the data that are available. The analysts did an excellent job of accounting for uncertainty in both data inputs and modeling parameterization. While the stock status results appear robust, there remains uncertainty in the scale of shrimp productivity.

Four main analytical approaches were used to assess the three stocks of shrimp: 1) Vector Autoregressive Spatiotemporal (VAST) model to construct a stock-wide index of abundance for each species; 2) fitting of the Pella-Tomlinson production model to the catch data and VAST index using the Bayesian state-space application of Just Another Bayesian Biomass Assessment (JABBA); and 3) using a Guassian Process to denoise index data that was the input into an application of Empirical Dynamic Modeling (EDM), using catch and survey data for each stock. The latter two approaches were used to estimate the management quantities of Bmsy, Bcurrent/Bmsy, Fmsy, Fcurrent/Fmsy and the trajectories of biomass and fishing rates over the past and projection into the future.

The analysts took the following measures to successfully manage both data and model uncertainty in this assessment: (1) using fishery-independent data to calculate indices of abundance; (2) using the tool VAST to standardize the indices by handling zero-inflated data and spatial autocorrelation; (3) applying two stock assessment modeling platforms that could best accommodate the life history of the three shrimp species; (4) incorporating environmental drivers and habitat covariates into the standardization of CPUE when appropriate; (5) applying a model ensemble approach by developing a matrix of different model configurations for JABBA and EDM to test different assumptions about the starting parameters and/or the input data; (6) applying a Bayesian model (JABBA) where key parameters can be informed by priors to reduce uncertainty; (7) using the EDM model which can accommodate lagged abundance data and incorporate environmental and economic covariates in the EDM models that help explain species and fishery dynamics to improve model fits.

Time series data inputs consisted of landings, catch per unit effort from the SEAMAP trawl survey (brown and pink shrimp), Texas Parks and Wildlife Department (TPWD) Gulf trawl survey (brown shrimp) and Louisiana Department of Wildlife and Fisheries (LDWF) trawl survey (white shrimp), environmental observations, and economic information. Commercial landings for Gulf shrimp were compiled from 1960 to 2022 using data from the Gulf Shrimp System (GSS) and State Trip Ticket (STT) data. A phased transition from GSS to STT was managed by switching to STT when considered reliable by each state.

While the assessment used two relatively novel models not previously used for Gulf shrimp (JABBA and EDM), the Analyst Team provided sufficient documentation and thorough explanations during the Workshop (see SEDAR87-RD13, SEDAR87-RD15, SEDAR87-RD16, and SEDAR87-RD18).

The EDM model is well equipped for populations like shrimp that have non-equilibrium dynamics and nonlinear state-dependent behavior. For brown shrimp, the EDM model was size structured (by three size categories) and provided stable estimates of MSY that were similar to one another across numerous model configurations (little variability). Using the mean and standard deviation of the MSY estimates from those model runs that passed the diagnostic tests for brown shrimp could help capture the variability and uncertainty around model configurations. For white shrimp, to capture variability in season and differences in shrimp size, three EDM model configurations were developed: a size class model, a seasonal size class model (which was not used), and one that used a natural log transformation of the CPUE index. The suite of EDM models examined for white shrimp also provided stable estimates of MSY that had little variability in their estimate of MSY across model configurations.

It was difficult for the Analyst Team to fit an EDM model for pink shrimp. This was largely because the SEAMAP index time series for this species did not have a trend (i.e. was flat) and was short, only representing 12 years of data. For these two reasons, the index did not adequately capture the population dynamics of this species. The index was shorter than that for brown shrimp because pink shrimp are predominantly distributed in the eastern half of the Gulf and the SEAMAP sampling program started sampling in the eastern Gulf more recently. None of the suite of EDM models that were developed for pink shrimp had predictive capability or passed all of the diagnostic selection criteria. The review panel supports the analysts' recommendations to not use the EDM or the JABBA model results for pink shrimp and supports the analyst recommendations to have the Council consider an index-based approach or data limited approach for this species.

For short lived species with large variation in recruitment strength, the utility of reference points are strongly linked to environmental conditions. Other factors that also impact reference points and their value to management include economic and social factors that affect fishing practices, fishery selectivity and choice of fishing grounds. Such data were used in some EDM test runs but not in EDM or JABBA model runs for reference point calculations because JABBA does not accommodate environmental data and future conditions for reference point projections in EDM are uncertain. In theory, lagged survey data used as predictor variables in EDM models carry some information about past environmental and economic effects. None of the final model configurations that were accepted (brown and white shrimp) explicitly included environmental covariates.

3. Terms of Reference

TOR1. Evaluate the degree to which the terms of reference from the Data and Assessment processes were addressed.

The selection of data sources was conducted via a thorough and comprehensive process that can be considered best practice and appropriate. A similar such process should be used for future assessments. All decisions were justified and reasonable given the TOR and the immediate goals of estimating historical stock conditions and estimating MSY reference points. Some minor questions and uncertainties are mentioned below under specific themes. Because the analytical approach used for this assessment was radically different from previous ones (Stock Synthesis Modeling platform), some terms of reference from the Data and Assessment processes are not applicable.

TOR2. Evaluate the data used in the assessment, including discussion of the strengths and weaknesses of data sources and decisions.

The appropriateness of all available data for use in the assessment was assessed using clear selection criteria associated with; Temporal range, Spatial range, Consistent survey design (e.g., fixed sampling sites, stratified random etc.), Standardized sampling methodology (e.g., gear, vessels, effort, etc.), and Ages and/or sizes represented.

Decisions about fishery independent surveys were important, particularly for EDM because survey data determine the years included in modeling. Missing years have a disproportionate effect on modeled years. A single missing survey observation from SEAMAP for summer 2020 brown shrimp was filled by averaging adjacent summer values but the efficacy of this approach was not evaluated. Preliminary examination by the review panel indicated using the relationship between summer and fall data may be a more accurate approach for estimating this value.

Identifying environment drivers of productivity from changes in catch rates, requires the composition of the catch to align with the correct time lag. In most months of the year there exist multiple cohorts of shrimp, with each cohort being derived from different period in the estuarine environment. A single cohort needs to be identified and modeled using VAST to examine environmental drivers of shrimp productivity.

The reference point procedure for EDM affected data decisions because long term projections are difficult when future conditions are unknown. JABBA is not programmed to accommodate environmental information. Consequently, reference point calculations did not involve environmental data.

Data potentially used in the stock assessment includes fishing effort, catch, depth, time, environmental drivers, potential abundance indices (CPUE and fishery independent surveys) and social and economic information. However, three fishery independent abundance indices and catch were the only data used in principal model runs.

Commercial fishing effort and CPUE data show gross trends that informed discussions but are difficult to interpret and were not used in modeling or reference point calculations. Difficulties include changes in fishery operations over time, nonlinear stock size relationships, recent low prices and a new procedure for calculating effort by species.

Catch data are collected by all five Gulf states using a variety of processes that have changed over time. The Data Workshop concluded that the accuracy of the data has changed and recommended a set of assumed CVs for landings data in JABBA assessment models (20% during 1960-1983, 10% during 1984-2015 and 5% during 2016-2022). The Review Panel noted that CVs <= 10% imply more accuracy than typically assumed. The Assessment Team suggested that the recommended values were based on expert discussions and capture the trend of increasing accuracy over time due to improvements in data collection systems. They suggested other uncertainties about the overall precision of the landings data would probably have little effect on assessment results. It was suggested by the Review Panel that a sensitivity analysis be conducted in which landings are perturbed to understand the sensitivity of the models to these assumptions.

Catch data was assumed accurate in Gaussian-Process EDM models although uncertainty in escapement (survey data minus catch) was assumed in model fitting. JABBA incorporates uncertainty in catch data (specification of a catch CV) and index data (specification of standard errors), while also allowing for the estimating or fixing of process variance and estimating additional observation variance.

All fishery index data used in the assessment (SEAMAP, Texas Gulf Survey, Louisiana Trawl Survey) is collected and recorded spatially. Furthermore, these data contain a relatively large proportion of zero values ~(70%, 40%, 80%) for brown, white and pink shrimp, respectively. Such data requires a unique model structure (e.g. delta-linear model) as provided by VAST which is spatial delta-generalized linear mixed model. This model structure can also incorporate habitat and catchability covariates which can lead to more precise estimates of abundance. This standardization method was used to produce a time-series of abundance for JABBA.

JABBA implements a Bayesian state-space surplus production model and is specifically designed for data-moderate stock assessments based on landings and an index of abundance. It offers a flexible framework for estimating stock status and generating reproducible results.

JABBA has been used successfully in other jurisdictions to conduct stock assessments on short-lived species including Penaeids.

EDM is new to most fisheries biologists and can accommodate environmental, economic and other types of data. MSY reference points from EDM were calculated by long term deterministic projections over a range of constant catch levels. EDM has been used to investigate stock dynamics in other fisheries, but not to the extent conducted by the assessment team.

The quality of the data (appropriate for shrimp, standardized, fishery-independent and spatially extensive) is appropriate. When sub-setted by species (spatial truncation), the data available for brown and white shrimp appear sufficient to support the assessment approach. The length of the time series for pink shrimp, however, currently seem too short to support the assessment approaches employed during this review.

TOR3. Evaluate and discuss the strengths and weaknesses of the methods used to assess the stock, given the available data

The VAST analyses are designed to standardize survey and index data by predicting density across space and year separately modeling encounter probability and positive catch rates using delta-models or zero-inflated binomial models. Unmeasured processes are approximated through spatial and spatio-temporal random effects (assuming two points in space are more strongly correlated if they are neighbors). In addition, VAST allows specification of either density or catchability covariates. VAST “controls for” catchability covariates when calculating an index (i.e., removes their estimated effect) while “conditioning on” density/habitat covariates when calculating an index (i.e., uses them to improve interpolated/extrapolated predictions of density). These are accounted for by fitting year as a fixed effect (separate intercept for each year), ensuring that estimates of abundance are independent for each modeled year.

Spatial variation is estimated as a random effect. Additionally, covariates may be included such as habitat covariates (e.g., depth, substrate, temperature and salinity) can be integrated as can catchability covariates (e.g. time of day, vessel) to explain changes in catchability over space and time. The resulting spatiotemporal index standardization can provide a more precise abundance index than the design-based estimator or other conventional standardization models by explaining spatial variation in densities.

A large number of modeling options were implemented and evaluated using multiple criteria. The resulting VAST indices were recommended to be carried forward in the assessment:
Brown Shrimp: use SEAMAP (summer and fall) + TPWD monthly surveys over the years 1987-2022. The recommended VAST model used Delta-lognormal numbers per tow with an effort

offset (fish time). Additionally, spatial and spatiotemporal random effects (anisotropy) and catchability covariates (time of day, survey and month) were included.

White Shrimp: use the LDWF survey over the years 1980-2022. The recommended VAST model used Delta-lognormal numbers per tow. Additionally, spatial and spatiotemporal random effects (anisotropy) and the catchability covariate (month) were included.

Pink Shrimp: use SEAMAP (summer and fall) survey over the years 2010-2022. The recommended VAST model used zero-inflated negative binomial numbers per tow. Additionally, spatial random effects (anisotropy) (no spatiotemporal RE) and the catchability covariate (time of day) were included.

The Pella-Tomlinson production model was implemented using the state-space formulation of JABBA; where Surplus Production_t=r/(m-1) B_t (1-(B_t/K)^(m-1)) where K is the carrying capacity and r and m are parameters. Most notable is the shape parameter, m, which defines the management quantity Bmsy/K=m^(1/(1-m)). In these JABBA implementations additional parameters were implemented: q the catchability coefficient associated with the VAST index; psi, the initial biomass depletion at the start of catch time series; the process variance (σ2; fixed or estimated); the observation variance (τ2; fixed or estimated): input observation error + year to year variation in catchability.

Prior distributions were assigned for key parameters which were common for all three stocks. These parameters were: K (mean 10x maximum catch, CV=1), Bmsy/K (mean 0.4, CV=0.3); process error variance (1/gamma(4,0.01)). Additionally, an uncertainty grid of priors was assigned for r [medium, high and very high priors (very high was used for brown shrimp, only)], psi [low (lognormal(mu=0.9, CV=0.25), high lognormal (mu=0.25, CV=0.5)] and additional index observation error [none versus 1/gamma(0.001,0.001)]. Model fits were conducted for all combinations of the uncertainty grid and the results evaluated using criteria for model convergence, model fit, model consistency and the DIC. Posterior distributions were estimated for the parameters and from these the management quantities and their posterior probability distributions were calculated.

The brown shrimp model selected was based upon the uncertainty grid of high r, low initial depletion and additional process error estimated (using catch time series starting in 1960). The white shrimp model selected was based upon the uncertainty grid of medium r, low initial depletion and no additional process error estimated (using catch time series starting in 1960). The pink shrimp model selected was based upon the uncertainty grid of medium r, high initial depletion and no additional process error estimated (using catch time series starting in 1960). However, in all three cases several alternative model structures provided similar results.

Empirical Dynamic Modeling uses lags of time series data to reconstruct the state-space of a system. This form of modeling is particularly useful for short-lived species with highly variable population dynamics where drivers are often not observed directly, yet the information is embedded within the time series of abundance. Lags of abundance indices are used to reconstruct the full dynamics of the system without needing data on variables impacting abundance or specifying model form. Gaussian Process EDM (GP-EDM) was used to fit the SEAMAP survey data aggregated at several defined levels. The inclusion of economic and environmental variables as covariates were tested as well.

In a broad sense and in the context of shrimp, EDM predicts an index of abundance based upon observations of the index in the previous year and an unknown function that incorporates unknown drivers. Takens' Theorem shows these drivers can be modeled through a series of index observations lagged over a number of years. The number of lagged years and covariate drivers define the embedded dimension of the system. Incorporation of catch data scaled by a catchability q converts the catch data into the index scale. Several options were evaluated to transform the index observations in the model no transformation, log(yt), log(yt/yt-1) and log(yt/(yt-1 – q*Ct-1)). The GP estimation process was used to denoise the observation index that was employed in EDM to estimate parameters defining the predicted index. Then imposing alternative harvest rates into a time series of predictions defines the relationship of abundance to fishing rates and, thus, management quantities Bmsy and Fmsy. These models (and their full description) were developed through a series of workshops and reports documented though SEDAR).

The shrimp data were stratified by area: Gulf fishing areas 1-10, 11-17, 18-21, size categories “Small”, “Medium”, “Large”; >67, 67-31, <=30 shrimp tails per pound; =167mm total length; seasonal categories: Winter (JFMA), Summer (MJJA), Fall (SOND); and years duration: 1987-2022. These were modeled as “populations” within a hierarchical model with options where populations were modeled independently with no shared parameters, with a degree to which the dynamics are correlated and quantifies the similarity of population responses across predictor space and hierarchical models with shared parameters. These were explored through a factorial design. All models were evaluated using multiple criteria.

The final selected brown shrimp model was size structured (Large, Medium, Small), with shared catchability, seasonal time steps, an embedded dimension of 5 and the transformation of the index observations, y, of log(yt/(yt-1 – qCt-1). It was felt that this provided a robust model that captured brown shrimp dynamics and provided stable estimates of maximum sustainable yield and management quantities.

The final selected white shrimp model was size structured (Large, Medium, Small), with separately estimated catchability, annual time steps, an imbedded dimension of 4 and the transformation of the index observations, y, of log(yt/(yt-1 - qCt). This parameterization was similar to the next best model, but had a smaller embedding dimension and fewer degrees of freedom. It was felt that this provided a robust model that captured white shrimp dynamics and provided stable estimates of maximum sustainable yield and management quantities.

No pink shrimp models passed the selection criteria and none were recommended for evaluation of management quantities.

The strengths and weaknesses of the methods used to assess the stock, given the available data were evaluated through the response to the following questions:

Are priority modeling issues clearly stated and addressed?

The priority modeling issues are clearly stated and addressed. The goal of the modeling was to provide estimates of shrimp productivity and biomass over past history and to estimate the management quantities of Bmsy, Fmsy, Bcurrent/Bmsy and Fcurrent/Fmsy. With the exception of pink shrimp this was done. Additionally, the goal was to incorporate environmental covariates or their surrogates into the production estimation models and evaluate their efficacy for inclusion in the models. This was done.

Are the methods appropriate for the available data?

The data was discussed in detail above. Essentially, these data were: catch histories by size class and survey data from SEAMAP and State surveys. Since shrimp productivity is quite volatile both in space and time, so too are the survey and catch data. The VAST standardization framework is designed to address the volatility, especially spatially. The modeling frameworks (JABBA, EDM) were chosen because of precisely those characteristics: high volatility, limited auxiliary data. So, yes, the methods are appropriate for the available data.

Are assessment models configured properly and used in a manner consistent with standard practices?

The VAST analyses were extensive, exploring a large number of model configurations and then evaluated through a suite of selection criteria. This process was well documented. The VAST modeling goes beyond standard practices in its detail.

The JABBA/Pella-Tomlinson model was configured in a manner consistent with standard practices established in Winker et al. (2018). However, the parameterization of Pella-Tomlinson used in Winker affects the interpretation of the parameter “r” when defining priors for r. Also, the structure of Pella-Tomlinson shifts when the parameter “m” is above or below 1. For that reason, alternative priors on m were explored at the meeting. Results indicated the sensitivity of that parameter.

EDM was configured consistently with standard practices established for EDM generally, but standard practices for fisheries applications have yet to be established. Nevertheless, the EDM analyses were rigorous in their construction and evaluation consistent with good scientific practices. However, because the methods are not as well-known as other approaches, continued effort is needed to show results in a manner consistent with standard assessment presentations and to compare results to more standard models.

Are methods scientifically sound and robust?

While this assessment used two relatively novel approaches not previously used for the assessment of Gulf shrimp (JABBA and EDM platforms), the Analyst Team provided sufficient documentation prior to the workshop for the Review Panel to familiarize themselves with these methods, in addition to answering any questions with insightful and thorough explanations during the Workshop. These methods appear justified and scientifically sound and robust.

TOR4. Consider how uncertainties in the assessment, and their potential consequences, are addressed.

The following CVs were used in JABBA to reflect uncertainty in landings based on changes in the sampling programs through time. 1960-1983: CV = 0.2, 1984-2015: CV = 0.1, 2016-2022: CV =0.05.

The Review Panel discussed possibly increasing the CV values to better represent uncertainty and allow the JABBA model more flexibility in fitting to the landings time series. However, fisheries models typically strongly assume that the catches are known with certainty. Therefore, a better way to explore how sensitive the model results may be to potential variability in the

landings could be to develop several sensitivity model runs with landings time series that are some percentage above and some percentage below the estimated landings data.
A catch per unit effort index of abundance was estimated for each of the three species. The SEAMAP trawl survey data was used to construct the index for brown and pink shrimp, while the LDFW shrimp survey was used to construct the index for white shrimp. A different data source was used for white shrimp because the LDFW shrimp survey is more spatially representative of the white shrimp population than the SEAMAP survey. The SEAMAP trawl survey is a fishery-independent survey which experimentally catches fish using the same fishing effort and gear configuration each year and at the same stations each year throughout the Gulf. The SEAMAP survey is general and meant to sample a wide variety of marine species across taxa including finfish, shellfish, shrimp, etc. that each have different life histories and habitat preferences. This, together with the fact that the SEAMAP survey data spatially covers the entire Gulf well beyond where brown and pink shrimp live, contributed many zero observations of shrimp catch to the data.

The Analyst Team used the VAST model to standardize the abundance indices, manage the high number of zero observations, and handle the spatial and spatial-temporal random effects of the three shrimp species. Shrimp population dynamics are responsive to environmental drivers, which was managed by incorporating environmental drivers into the VAST model index development. Results from the VAST modeling for brown and white shrimp had reasonable errors around the annual estimates and larger uncertainty around the annual estimates for pink shrimp. For pink shrimp, the proportion of positive observations from the SEAMAP data was very low (about 0.1) which can introduce uncertainty and bias to a final index, even when applying zero inflated approaches. The analysts could explore improving how they select SEAMAP data observations for inclusion into the VAST standardization for pink shrimp to try and increase the proportion of positive observations. In addition, the analysts could consider developing the index using only observations from tows that took place at night, when the shrimp are more active and out of their burrows.

Multiple VAST model configurations were developed and run by including or not including spatial and temporal random effects, and by considering isotropy and anisotropy. The time series trends for each species from these various runs are very similar to one another. The panel was comfortable moving forward with these indices and their associated uncertainty.

Some JABBA model runs returned with reasonable diagnostics for brown and white shrimp, but not for pink shrimp, where none of the model run diagnostics passed. JABBA model runs to present to the panel were selected by the analysts as the best fit runs based on model diagnostics. For brown shrimp, the estimated time series of biomass relative to biomass at MSY from these model runs followed the same general trends across the time series for most years with substantial uncertainty around the estimates. For white shrimp selected model runs, the estimated time series of biomass relative to the biomass at MSY were inconsistent and with substantial uncertainty. Fits to the indices of abundance were reasonable for both brown and white shrimp. For pink shrimp, none of the JABBA model runs passed the diagnostic tests.

The review panel was generally comfortable with the methods the analysts used to manage uncertainty in this assessment. To help the Gulf Council, and other end users of the assessment output best interpret the results, the review panel recommends that the analysts develop plots that are similar to the figures that come out of a more typical assessment model such as a time series of fishing mortality (with reference line), time series of biomass (with reference line), Kobe plot for status determination, as well as others.

TOR5. Provide, or comment on, recommendations to improve the assessment.

The EDMs for brown and white shrimp evaluate many lag combinations across size and seasonal categories. Instead of reporting raw R^2 values, using an adjusted R^2 could improve model comparison by penalizing model complexity (e.g., number of embedding dimensions × size bins × seasons):

$$Adjusted\ R^2 = 1 - \left(\frac{(1-R^2)*(n-1)}{n-k-1}\right)$$

where k is the number of lags combined with any additional parameters used.

Track q and other metrics through the addition of each data point of escapement within EDM. It would be useful to visualize the sample size of escapement necessary for q (or other metrics) to stabilize.

It was difficult to know if data series were long enough to reliably fit EDM models despite some recommendations in the literature. It would be useful to fit EDM models to long simulated or real data sets sequentially eliminating the first point in the data set so that sequential model runs are based on shorter and shorter time series. The performance or stability of the model will probably degrade as the time series becomes too short. Such tests could be done routinely in real stock assessments or to develop general rules.

Can scale be estimated in EDM when survey data are flat or constitute a one-way trip? Such survey data patterns are problematic and degrade accuracy using traditional assessment models.

JABBA does not directly utilize environmental, economic or social data. However, a similar Bayesian surplus production model could be programmed locally to use such information.

Consider incorporating bay trawls from both Texas and Louisiana (with their accompanying environmental collections) to create a recruitment and adult index into the EDM model for Brown Shrimp.

If EDM can handle environmental data that has an unspecified probably nonlinear relationship with stock size, it seems possible that it might handle fishery CPUE as well. Fishery-dependent CPUE is meaningful to constituents but hard to handle in assessment models because it has a nonlinear relationship with biomass. It usually changes more slowly than biomass when stock size is high and more slowly than stock size when biomass is low. Moreover, CPUE is affected by changes in fishing technology, and vessel operations. One advantage of CPUE is that it can be standardized in models like VAST to account for differences among vessels, locations, etc. in the same way as survey data (although nonlinearity is not removed). CPUE data are usually less variable than survey data and may therefore show the direction, if not the magnitude, of changes in stock size clearly. The possibility of using CPUE in EDM should be investigated.

It might be possible to use fishery dependent data to a greater extent to improve short-term projections with EDM. EDM makes predictions based on lagged data which are “nearby” in time (e.g. 3-4 year lags). The emphasis on recent data may alleviate problems using fishery dependent data with properties that change slowly over time.One year of missing survey or other predictor data have a disproportionate effect on the length of time series in EDM models because each datum is used repeatedly in lags. One year of missing survey data for brown shrimp was imputed by averaging the previous and subsequent observation. Another imputation approach may be better, e.g., based on a nonlinear fit to data for the same spatial cell and population in years t-3 … t-1 and t+1 … t+3.

Use simulation, bootstrapping or some other approach to determine if the variances for EDM model results are realistic.

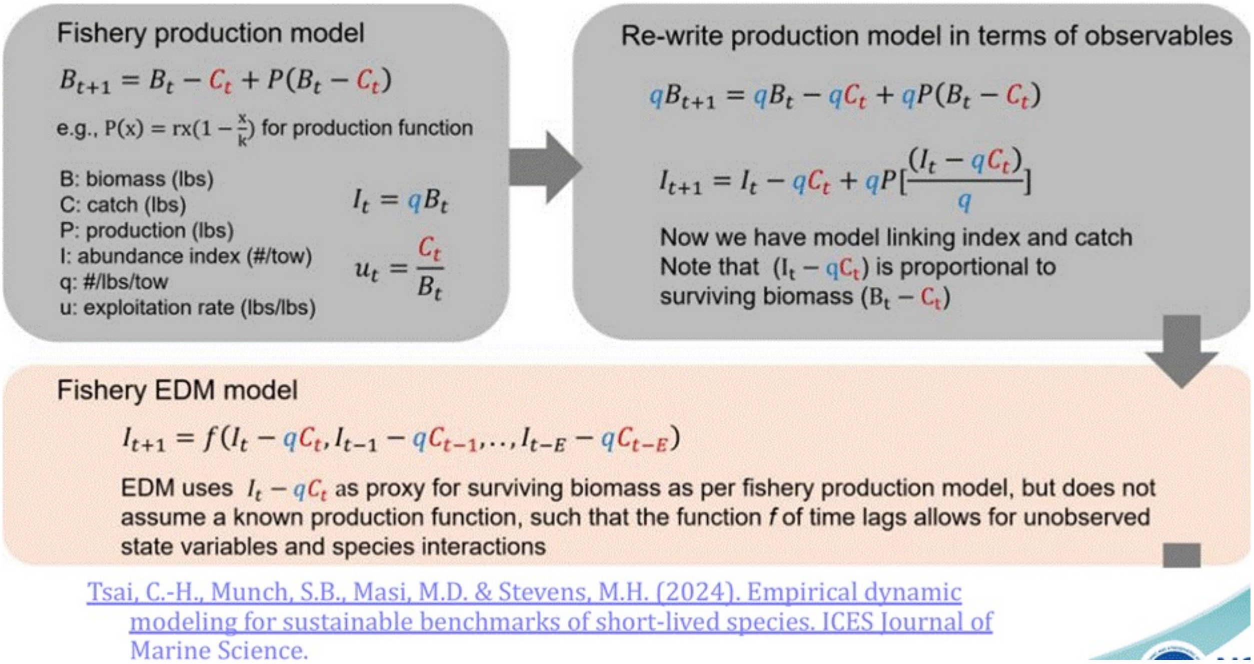
Determine if omitted predictor variables in EDM bias the scale of stock size estimates. According to Takens' theorem, the trend in EDM model estimates may be insensitive to missing predictor variables because the lagged survey data used in the model were influenced by and carry information about effects of missing predictors, particularly if predictor variables are correlated. However, it is not clear how or if Takens' theorem applies to scale.

Correlated predictor variables are a significant problem in traditional modeling (e.g., with linear regression). Evaluate effects of correlated predictors on EDM models. Would it be better to avoid correlated variables or use, for example, uncorrelated principal component scores that carry the same information as the original data? If correlated predictors cause problems and environmental variables are correlated with the survey data in the model, is it better to avoid using the environmental variables?

Determine how well EDM models can be used to estimate MSY reference points if data were collected while the stock was not near Bmsy or K. Is it possible to estimate these parameters in EDM for a lightly or chronically overfished stock? That is, can models be extrapolated into unsampled areas of the data space?

Clarify the interpretation of the q parameter in EDM. The parameter is estimated in the EDM model where it is used to put catch and survey data on the same scale, then to scale "escapement" into biomass units (see Fig. 1). The current EDM formulation is an algebraic reordering of terms in a crude, approximate surplus model that is most accurate under stable stock conditions when somatic growth (G) and mortality rates (Z) are low. However, G and Z are both high for shrimp and the approximation may be suboptimal.

The q parameter is used in EDM to relate biomass during a relatively short survey to biomass at the beginning of the current time step (It=qBt, see below). However, when applied to escapement (It-qCt), the parameter q converts catch in year t to a hypothetical quantity that adjusts biomass at the beginning of the year as though catch also occurred at the beginning of the year. However, shrimp catch occurs throughout the year while substantial growth and mortality occurs (it is possible that most of the catch biomass is due to growth in the current year). Thus, growth, mortality and the different time scales of the survey and fishery are ignored by the formulation in a manner that might affect model performance for stocks like shrimp with high growth and mortality rates. Other surplus production formulations are available that might serve better for shrimp.



Fishery production model

$$B_{t+1} = B_t - C_t + P(B_t - C_t)$$

e.g., $P(x) = rx(1 - \frac{x}{k})$ for production function

B: biomass (lbs)
C: catch (lbs)
P: production (lbs)
I: abundance index (#/tow)
q: #/lbs/tow
u: exploitation rate (lbs/lbs)

$$I_t = qB_t$$

$$u_t = \frac{C_t}{B_t}$$

Re-write production model in terms of observables

$$qB_{t+1} = qB_t - qC_t + qP(B_t - C_t)$$

$$I_{t+1} = I_t - qC_t + qP[\frac{(I_t - qC_t)}{q}]$$

Now we have model linking index and catch
Note that $(I_t - qC_t)$ is proportional to surviving biomass $(B_t - C_t)$

Fishery EDM model

$$I_{t+1} = f(I_t - qC_t, I_{t-1} - qC_{t-1}, .., I_{t-E} - qC_{t-E})$$

EDM uses $I_t - qC_t$ as proxy for surviving biomass as per fishery production model, but does not assume a known production function, such that the function *f* of time lags allows for unobserved state variables and species interactions

Tsai, C.-H., Munch, S.B., Masi, M.D. & Stevens, M.H. (2024). Empirical dynamic modeling for sustainable benchmarks of short-lived species. ICES Journal of Marine Science.

Figure 1. Parameterized Fishery EDM for Gulf shrimps used for this assessment. Taken from Tsai, et al. (2024).

Clarify assumptions in the production model behind EDM. The current formulation (see above) appears to assume that production during year t is a function of biomass at the beginning of the same year Pt (Bt-Ct) with an adjustment for catch occurring later during the same year. The model subtracts catch in year t from biomass in the same year Bt-Ct again to account for reductions in biomass due to catch. Are we double counting the catch? Would it make sense to write the model as Bt+1=Bt+P(Bt)-Ct i.e., assuming production is a function of biomass at the beginning of the year which seems reasonable.

The transformations applied (log, gr1, gr2) could be clarified. If log and gr1 apply only to CPUE or X in the escapement equation, while gr2 transforms the entire escapement term, this distinction should be made explicit. All transformations appear appropriate, q would be estimated to convert catch units to whatever scale is chosen.

TOR6. Provide recommendations on possible ways to improve the Research Track Assessment process.

This assessment utilized novel approaches for estimating the management quantities of Bmsy, Bcurrent/Bmsy, Fmsy, Fcurrent/Fmsy for Gulf shrimp, and their trajectories of biomass and fishing rates over the past and projection into the future. While far removed from a "traditional" Research Track Assessment under typical SEDAR operations, these methods proved to be sound as well as robust, at least for brown and white shrimp. The caveat being despite the known relationships between Gulf shrimp species and environmental conditions in the estuaries during their post-larval, juvenile, and sub-adult stages (particularly water temperature in the spring when initial recruitment begins for brown shrimp), none of the environmental data was ultimately included in assessment. The same can be said for the socioeconomic factors that have been shown to drive much of the effort of the fleet (diesel price, consolidation of the fleet, massive recent influx of foreign imports and it's effect on dockside prices, etc.). An industry representative stated that "using fishery dependent data in modeling would tend to enhance industry confidence in results, despite difficulties in their use". The structure of EDM models may provide opportunities in this regard.

Long term predictions based on EDM models with environmental data may not be practical because of uncertainty about future environmental conditions. It may be feasible, however, to carry out short-term predictions. Environmental conditions may be relatively constant or predictable over shorter time periods so that environmental data are easier to predict with some accuracy. Moreover, environmental effects may be implicit in the survey data.

TOR7. Prepare a Review Workshop Summary Report describing the Panel's evaluation of the Research Track stock assessment and addressing each Term of Reference

This Report documents the Panel's evaluation SEDAR87-Gulf shrimp stock assessment, and addresses each of the Terms of Reference.

SEDAR

Southeast Data, Assessment, and Review

SEDAR 87

Gulf White, Pink, and Brown Shrimp

SECTION VI: Addenda and Post-Review Workshop Documentation

July 2025

SEDAR
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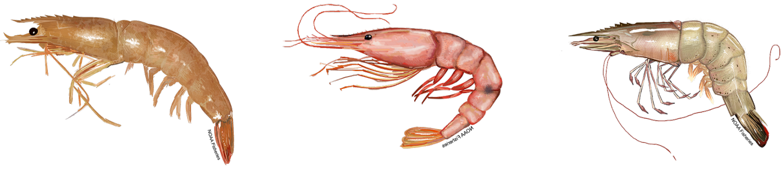

SEDAR87 Gulf Shrimp Post-Review Workshop Addendum

Gulf Fisheries Branch
Sustainable Fisheries Division
NOAA Fisheries - Southeast Fisheries Science Center

July 2025

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1. Introduction

The SEDAR 87 Review Workshop (RW) for Gulf Brown, Pink, and White Shrimp took place June 23-27, 2025 in Tampa, FL. During the RW, the SEDAR 87 RW Panel revisited discussions and decisions made during the Data Workshop (DW) and Assessment Process (AP) Webinars and requested additional details or analyses from the analytical team. Below is a summary of those requests.

2. VAST

2.1 Comparing Brown Shrimp nominal CPUE in the SEAMAP vs TPWD datasets

The review panel was interested in comparing trends in the nominal CPUE data from the SEAMAP vs. TPWD Gulf surveys used to produce the Brown Shrimp VAST index. Analysts produced a plot of the Brown Shrimp SEAMAP nominal CPUE data plotted against the TPWD nominal CPUE data (average numbers per hour across hauls in each year standardized to a mean of 1; *Figure 1*). They noted that the trends were different, with TPWD exhibiting a flatter and more variable trend through time compared with SEAMAP, whose index follows a steady increase starting in the early 2000s. This could be due to a couple of factors. First, the bulk of the SEAMAP survey operates farther offshore than the TPWD Gulf survey and covers a larger geographical extent overall. As such, the TPWD data are only capturing a portion of the exploitable stock that SEAMAP is tracking. Second, the increase observed in the SEAMAP survey post-2000 may be related to an increase in shrimp production originating from the Louisiana nursery grounds given that the increase is also observed in the White Shrimp LDWF data (see *Section 2.2*).

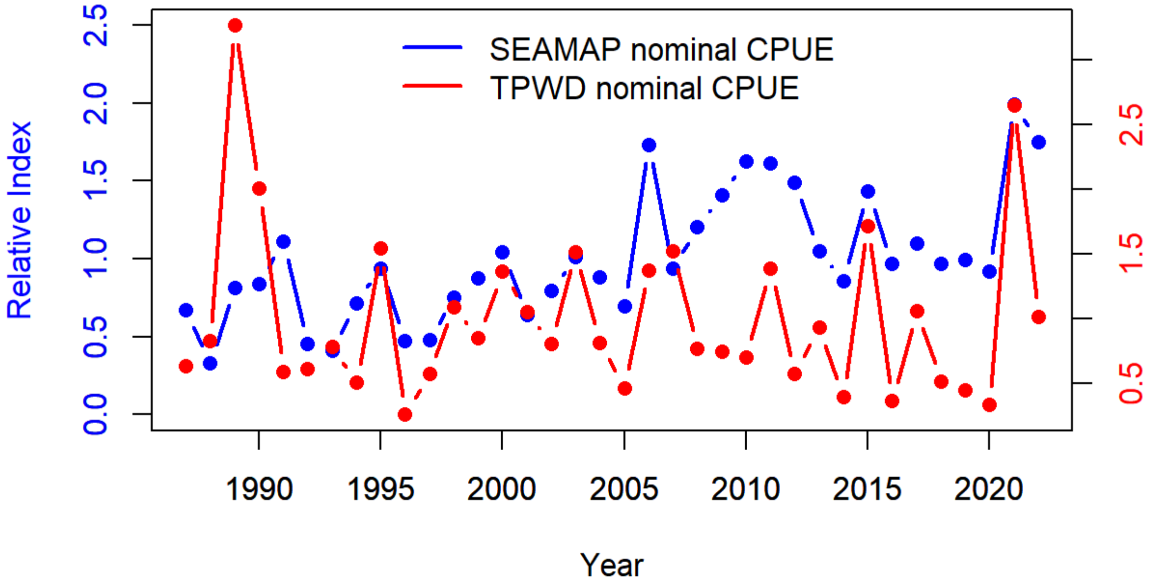


Figure 1: Brown Shrimp SEAMAP nominal CPUE vs. TPWD nominal CPUE.

2.2 Comparing the Brown and White Shrimp index trends

The review panel was interested in directly comparing the trends in the VAST indices of relative abundance for Brown and White Shrimp. The analysts provided a plot showing the Brown and White Shrimp VAST indices standardized to a mean of 1 and plotted against one another (*Figure 2*). They noted the striking similarity between the two trends and stated that this might suggest an environmentally driven change in abundance through time, given that Brown and White Shrimp landings have followed very different trajectories since the early 2000s, and yet the trends in abundance appear quite similar.

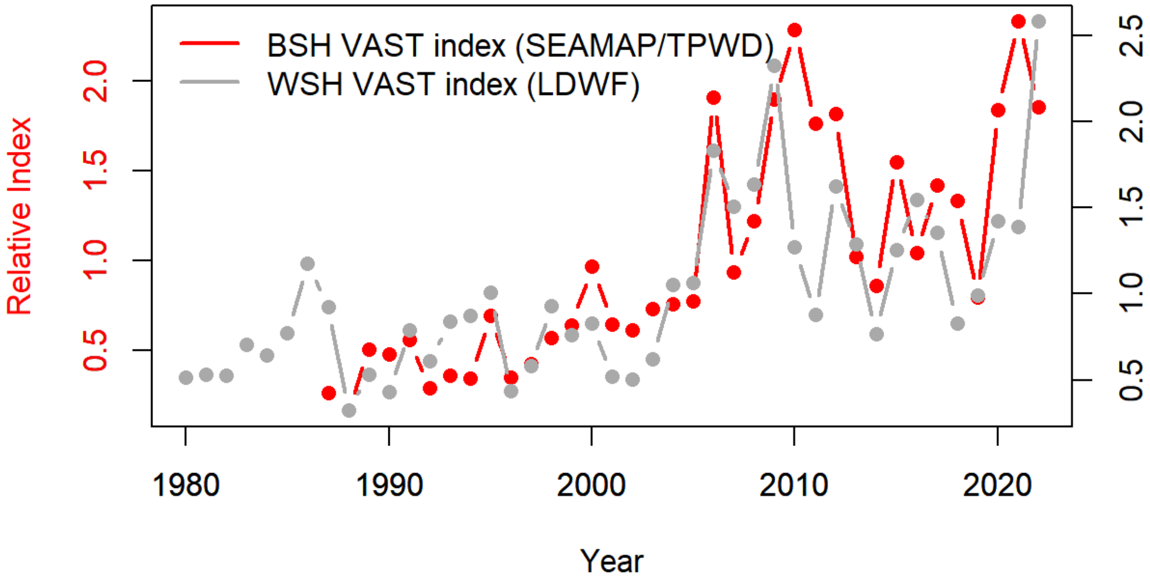


Figure 2: Brown Shrimp VAST index plotted against White Shrimp VAST index.

2.3 Numbers per hour vs weight per hour

The review panel questioned the use of numbers instead of weights when building the SEAMAP indices (given that landings are in weight). The analysts responded that the SEAMAP survey group recommended numbers to develop indices and showed that the trends in the two quantities were quite similar (*Figures 3* - *5*). The analysts also provided background on the SEAMAP data collection process for numbers vs. weights:

"At the end of each tow, the catch was emptied onto the deck, where a total weight was taken. All commercial shrimp species (brown, pink and white shrimp) were removed from the catch and then counted and weighed. During the summer survey, up until 2018, 200 individual shrimp of each species were then measured (total length in mm), sexed, and weighed. Under the current protocols, up to 50 individual shrimp are measured, sexed, and weighed. This change was made in an effort to increase efficiency and allow for the completion of additional stations. Analysis showed no differences in the length distribution collected when measuring 50 versus 200 individuals. During the fall survey, up to 20 individual shrimp of each species were measured, with every fifth individual being weighed and sexed." (Pollack et al. 2023)

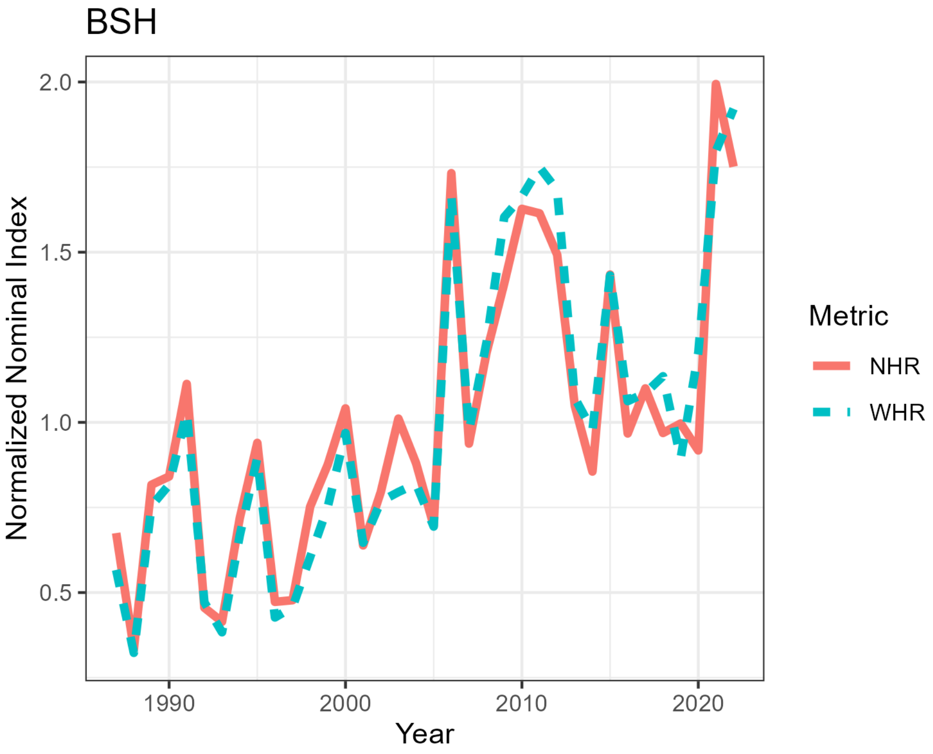


Figure 3: Brown Shrimp CPUE in numbers vs weights.

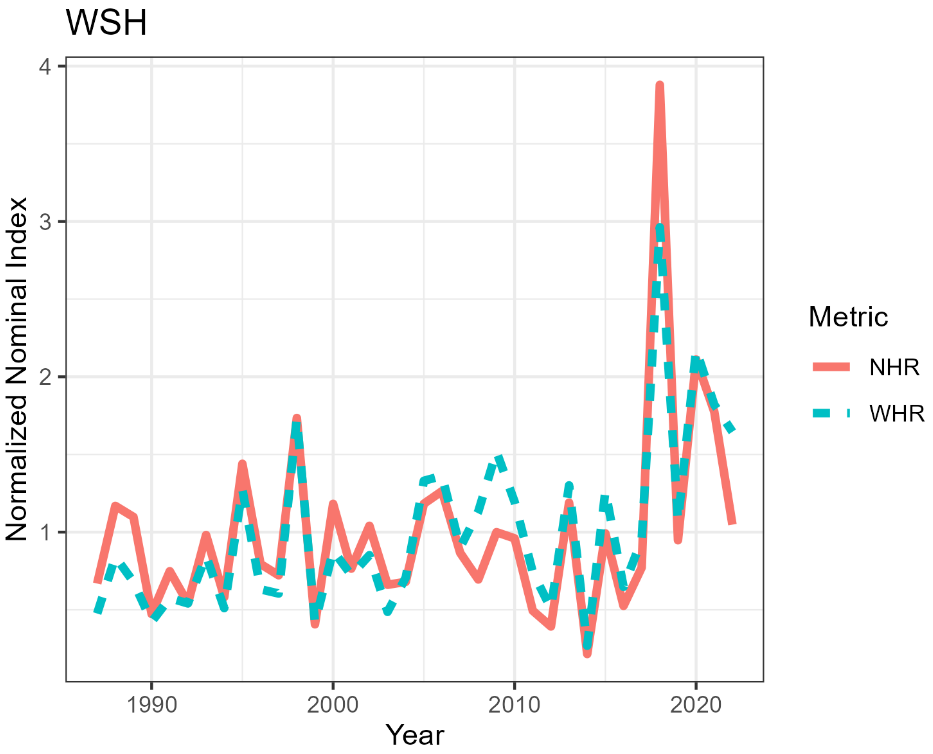


Figure 4: White Shrimp CPUE in numbers vs weights.

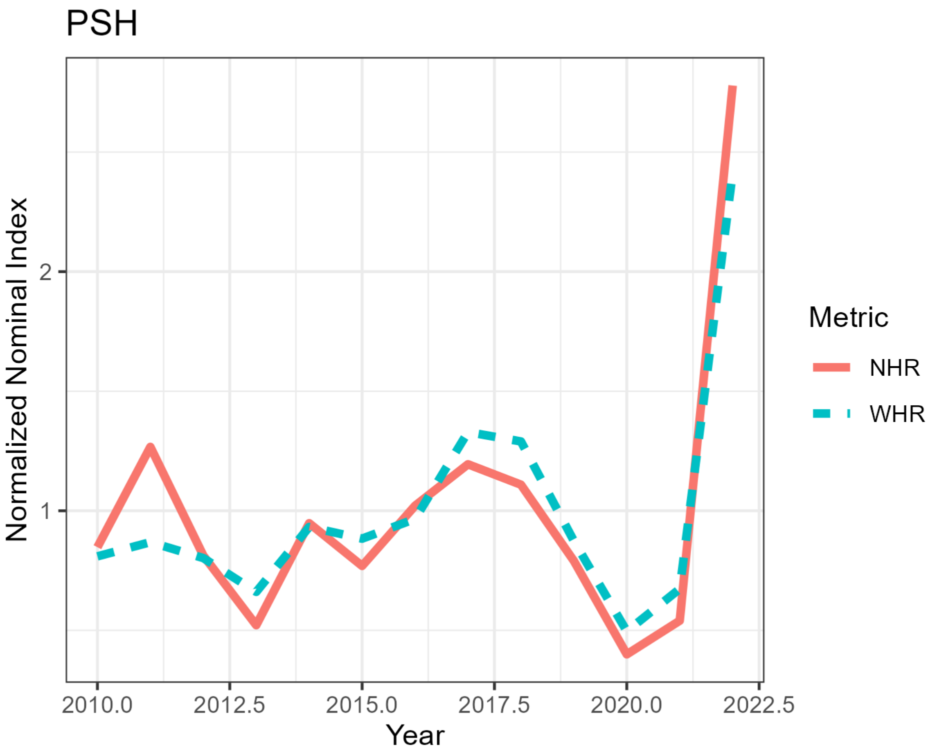


Figure 5: Pink Shrimp CPUE in numbers vs weights.

2.4 Timing of Pink Shrimp fishery vs. SEAMAP survey

The review panel asked to inspect the timing and geographical extent of the SEAMAP survey vs. the Pink Shrimp fishery. They thought that a mismatch between the two might help explain why both the abundance index and the landings follow the same increasing trend. The analysts showed a map produced by the SEAMAP team that shows the spatial overlap between the fishery (based on Electronic Logbook tows) and SEAMAP (see Figures 14 and 15 in Pollack et al. (2023)). SEAMAP appears to cover most of the fishery's extent except for the southern portion of the fishing effort (Dry Tortugas fishing grounds) and extends into deeper offshore waters than where the fishery operates. The analysts indicated that the bulk of the landings, in recent years, come from the Dry Tortugas fishing grounds, and that the bulk of the recruits contributing to those fishing grounds are believed to originate from Florida Bay. Therefore, there might be some level of mismatch there, however, no survey data were made available for Florida Bay or the Tortugas fishing grounds at the SEDAR 87 Data Workshop. To explore the temporal overlap between the survey and the fishing effort, analysts created a plot of the monthly landings against the monthly SEAMAP effort and mean monthly CPUE (*Figure 6*). SEAMAP operates over two distinct seasons (~June and ~October) while the bulk of the fishery occurs over the winter months. Unlike Brown and White Shrimp, however, Pink Shrimp are seen exiting the estuaries and entering the fishing grounds throughout the year, rather than through strong, temporally defined pulses.

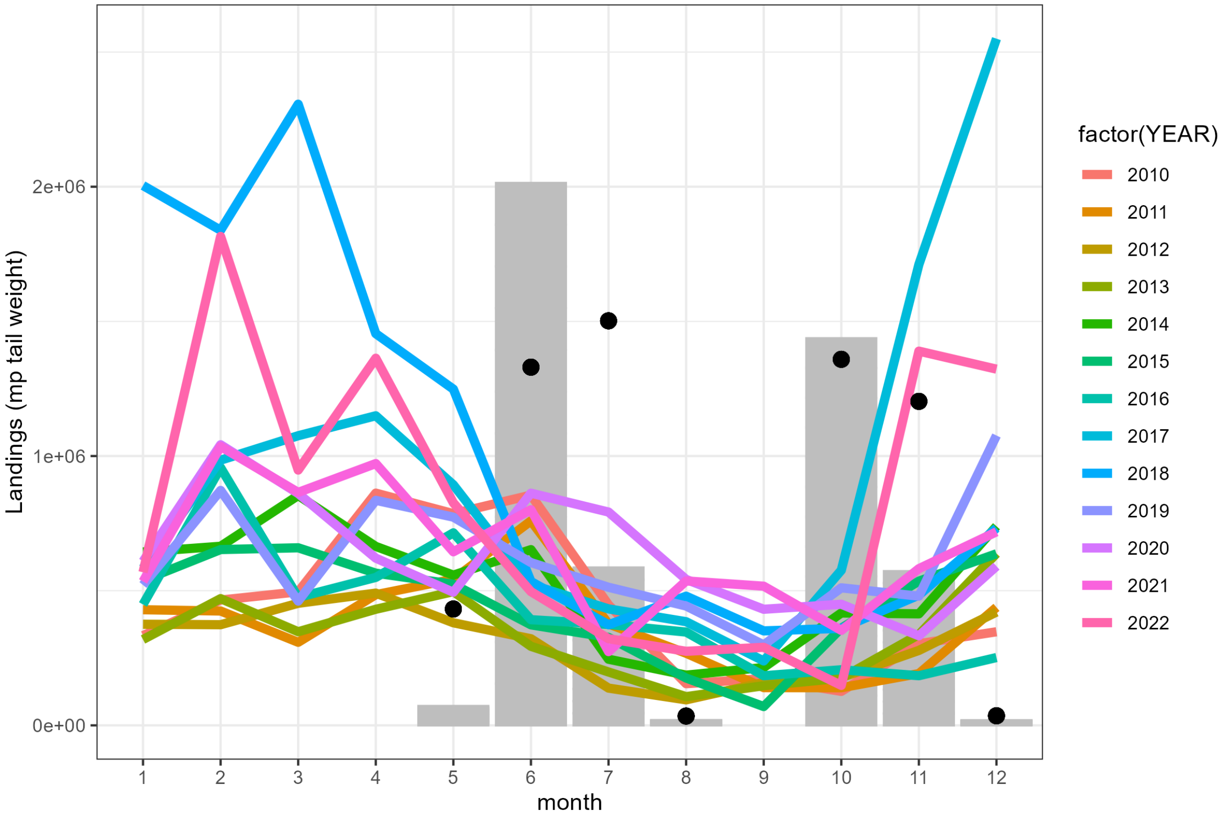


Figure 6: Monthly trends in Pink Shrimp landings (solid colored lines) overlaid on top of the relative monthly effort of the SEAMAP survey across all years (grey histogram) and relative monthly mean nominal SEAMAP CPUE (black points).

2.5 High percentage of zeros in the SEAMAP dataset for Pink Shrimp

Reviewers were concerned with the high instance of zeros in the Pink Shrimp SEAMAP dataset used to create a standardized index of relative abundance for Pink Shrimp. They asked the analysts to investigate whether the percent positive tows could be increased by removing daytime tows (since Pink Shrimp burrow during the day) and/or removing a section of the SEAMAP extent (if zeros were concentrated in specific areas).

Re-running the analysis removing daytime tows was straightforward and increased the percent positive tows from 11% to 23%. The request to investigate removing certain areas from the prediction grid, however, was more challenging because zeros were apparent throughout the entire area (*Figure 7*), even after daytime tows were removed (*Figure 8*). There did appear to be a higher concentration of zeros on the western edge of the SEAMAP extent where deeper depths are surveyed. A maximum depth cut off could be explored as a potential way to further increase to proportion positive. However, this could not be done within the time frame of the review workshop and was suggested as a research recommendation for future analyses. In the context of

VAST, the spatial random effects appropriately captured and accounted for this spatial pattern of low abundance/high presence of zeros in the deeper depth when calculating the final index.

The VAST index standardization procedure was re-run during the assessment workshop using night-only tows. The number of knots was left unchanged from the previous analysis (700) but the distribution type was re-evaluated given the reduced dataset and shift in the proportion zeros. The negative binomial model did not converge. Between the delta-lognormal (AIC=9750) and the Poisson-link (AIC=10094), the delta-lognormal resulted in the lowest AIC (*Δ*AIC=344). Both spatial and spatio-temporal random effects brought significant improvements to the index (*Table 1*, *Figure 9*), unlike the original index which did not find spatio-temporal random effects to significantly improve the fit. A month catchability covariate was tested but did not improve the fit (*Table 2*, *Figure 10*). The final index included both spatial and spatiotemporal random effects assuming anisotropy and including no covariates (*Figure 11*). This index (based on night only tows) was deemed superior to the previous index (based on day and night tows) due to the ability to detect spatio-temporal variations in abundance and proportion positive tows and the final index having a lower variance (*Figure 12*).

Table 1: Marginal standard deviation of spatial (ω) and spatiotemporal (ϵ) terms and AIC across runs with different specifications for the spatial and spatiotemporal random effects and associated Matérn covariance function. The run with the lowest AIC is bolded. RE: random effects; iso : isotropic Matérn covariance function; aniso: anisotropic Matérn covariance function.

Run Description	$\sigma_{\omega 1}$	$\sigma_{\omega 2}$	$\sigma_{\varepsilon 1}$	$\sigma_{\varepsilon 2}$	AIC	ΔAIC
No RE					9,750	789
Spatial RE (iso)	2.30	1.12			8,968	7
Spatial (iso) & spatiotemporal REs	2.27	1.10	0.29	-0.29	8,970	10
Spatial (aniso) & spatiotemporal REs	**2.30**	**1.08**	**0.27**	**0.42**	**8,961**	**0**

Table 2: Marginal standard deviation of spatial (ω) and spatiotemporal (ϵ) terms and AIC across runs with and without the month catchability covariate. The run with the lowest AIC is bolded.

Run Description	$\sigma_{\omega 1}$	$\sigma_{\omega 2}$	$\sigma_{\varepsilon 1}$	$\sigma_{\varepsilon 2}$	AIC	ΔAIC
Null model	**2.30**	**1.08**	**0.27**	**0.42**	**8,961**	**0**
Null model + month	2.31	1.08	0.33	0.40	8,967	6

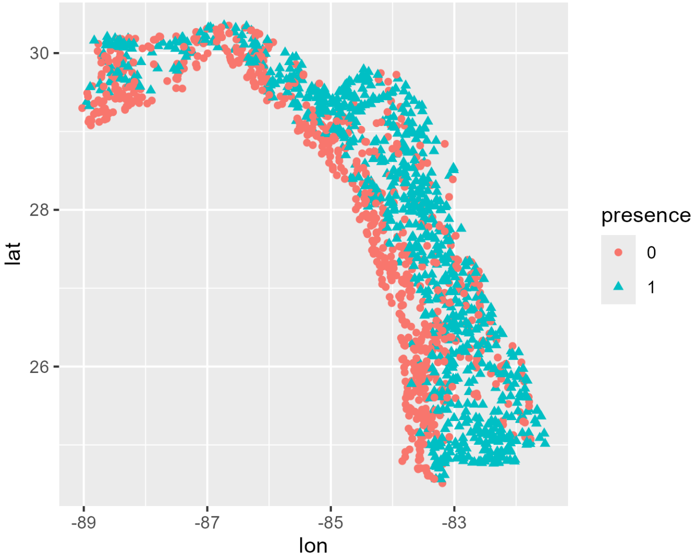


Figure 7: Location of presence (1) / absence (0) SEAMAP tows across all years using the full (day & night) dataset.

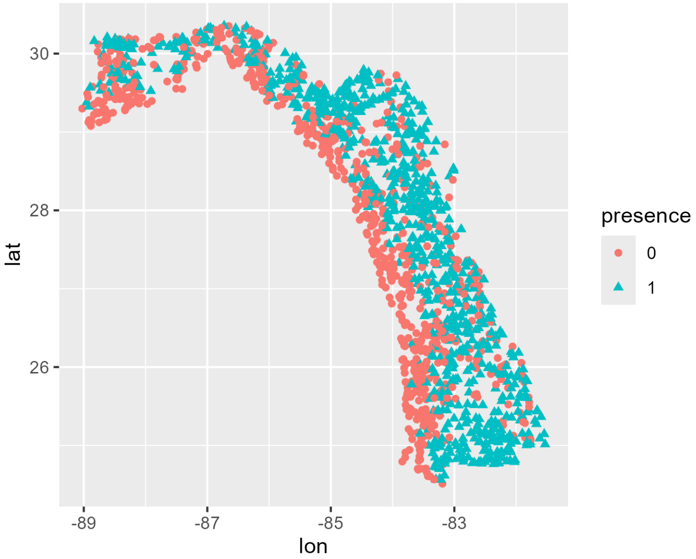


Figure 8: Location of presence (1) / absence (0) SEAMAP tows across all years using the partial (night only tows) dataset.

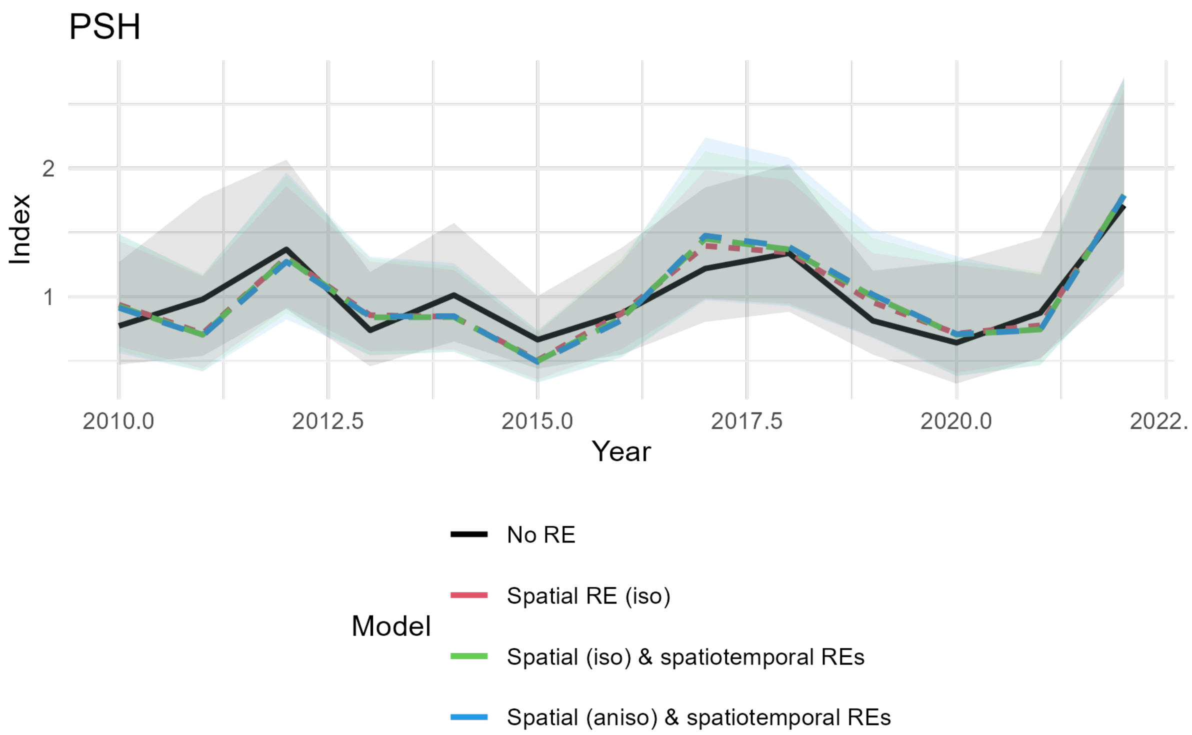


Figure 9: Comparing index estimates and associated confidence intervals across runs with different spatial and spatiotemporal random effects (RE) specifications. iso: isotropic Matérn covariance function; aniso: anisotropic Matérn covariance function.

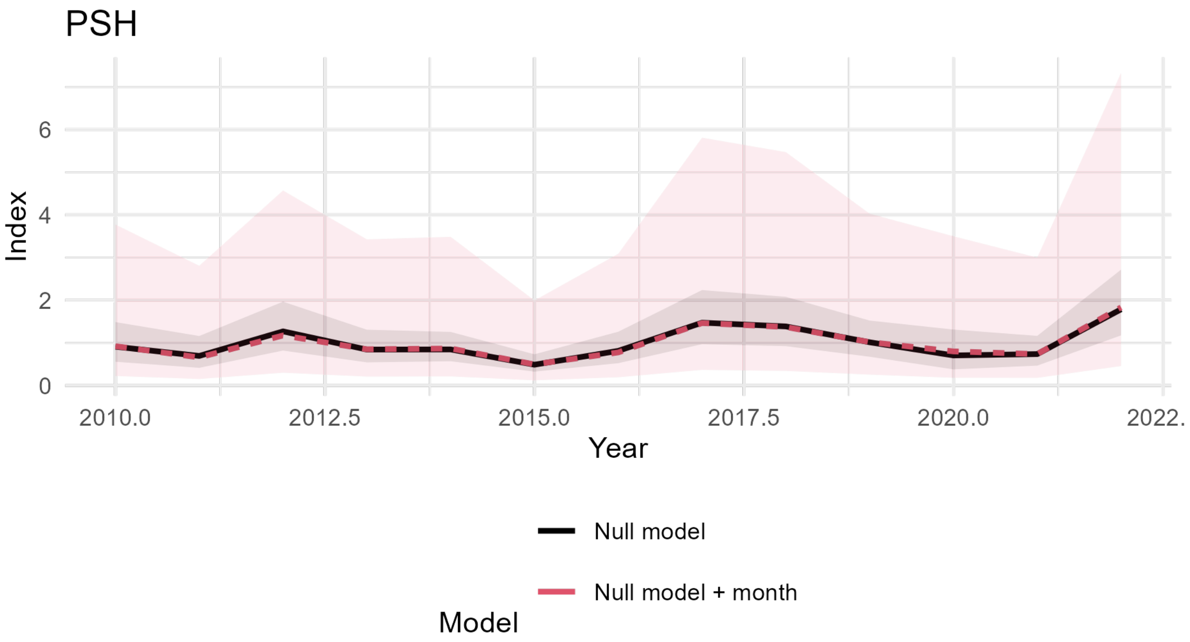


Figure 10: Comparing index estimates and associated confidence intervals across runs with or without the month catchability covariate. The Null model is a model with spatial and spatio-temporal random effects included in both the 1st and 2nd linear predictors and assuming geometric anisotropy but with no catchability covariates included.

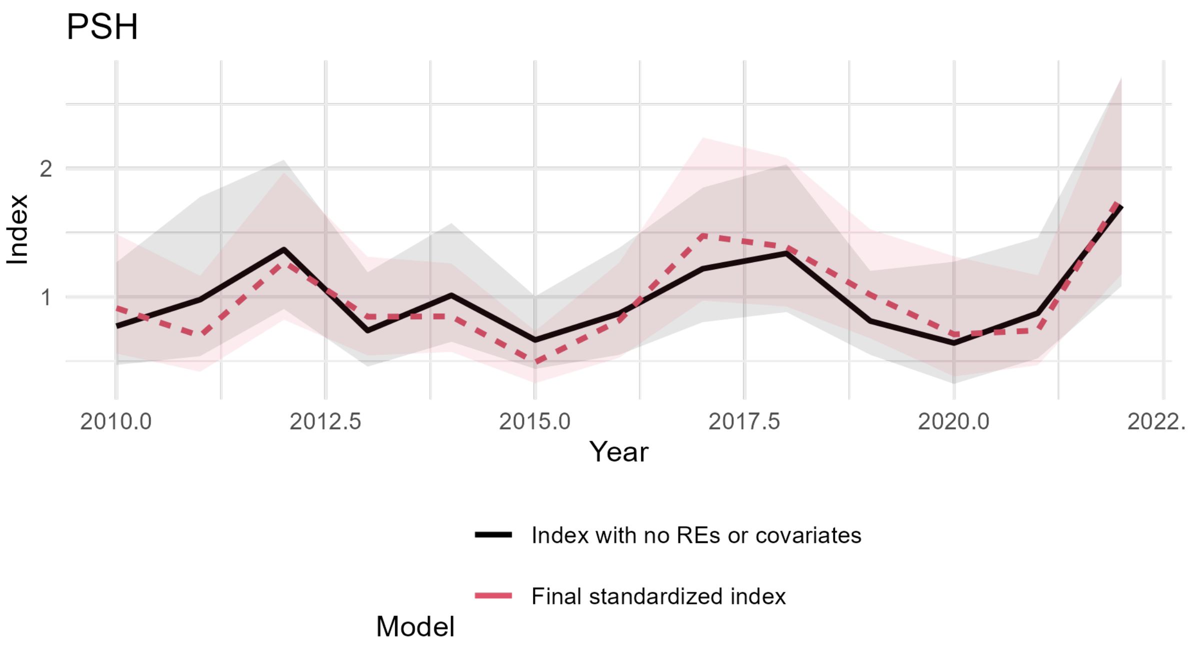


Figure 11: Comparing index estimates and associated confidence intervals for the final model (red) with the preliminary unstandardized index (black). The final index includes spatial and spatio-temporal random effects assuming geometric anisotropy.

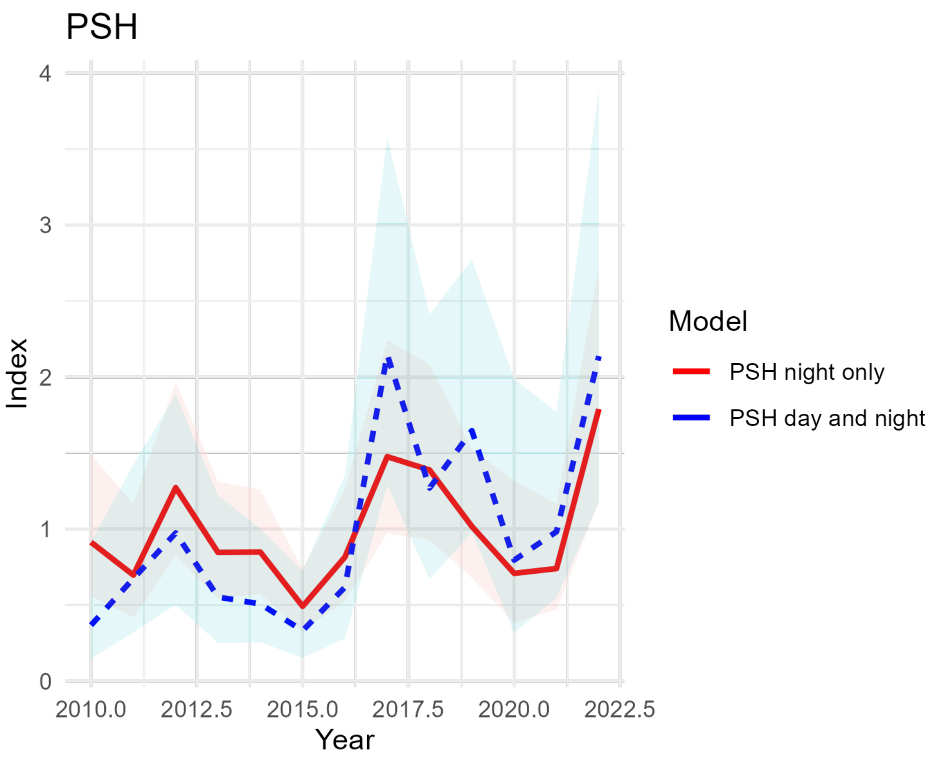


Figure 12: Old (day and night tows) vs. new (night only tows) Pink Shrimp VAST index.

3. JABBA

3.1 Exploring the impact of the shape parameter *m*

The review panel was concerned about the interaction between the *r* and *m* priors given that the two parameters are inherently linked in the generalized Pella-Tomlinson formulation. They therefore asked for JABBA to be re-run to explore the impact of alternative priors on *m*, the shape parameter that determines the *B/K* ratio at which maximum surplus production is attained. The default *m* prior used for the assessment centered the *B/K* ratio around 0.4 (*m*~1.2). The analysts had explored an alternative prior of .5 (*m*~2) and observed only minor differences. However, the reviewers pointed out that *m* was likely less than 1 for shrimp and suggested exploring two alternative priors: centering *B/K* around .25 (*m*~.5) and .15 (*m*~.23) (*Figure 13*).

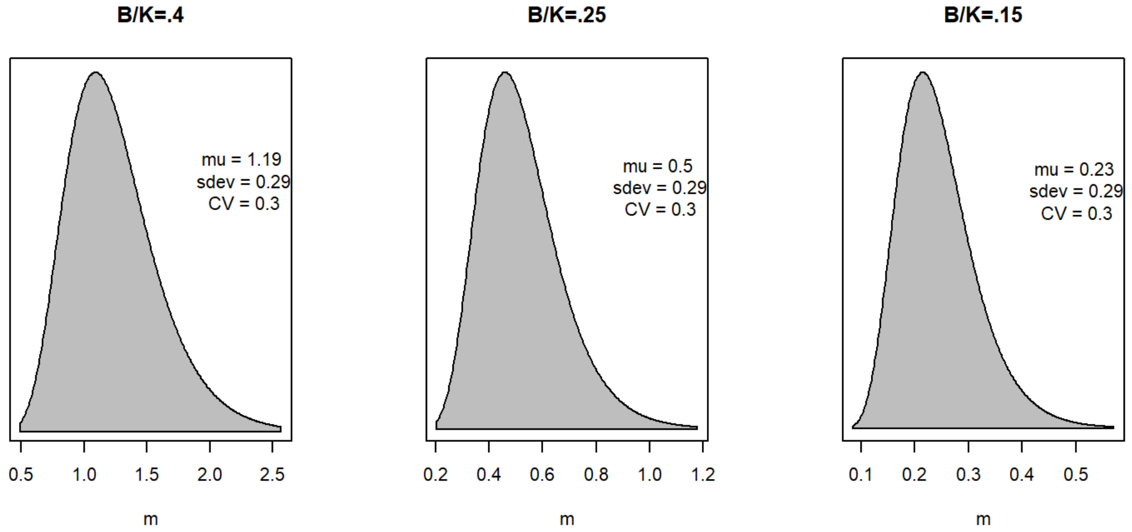


Figure 13: m prior for the base case (far left) and alternative m priors run.

Results are presented here for all three prior types: assuming *B/K*~.40 (ID run numbers <1000), *B/K*~.25 (ID run numbers in the 1000s) and *B/K*~.15 (ID run numbers in the 2000s).

3.1.1 Brown Shrimp

For Brown Shrimp, decreasing *B/K* decreased the overall size of the population (*Figure 14*) and resulted in steeper changes in stock status through time (*Figure 15*). Lower *B/K* ratios resulted in a more optimistic stock status in the terminal year. However, it did not change the overall trends in *B/Bmsy* (*Figure 15*) and *F/Fmsy* (*Figure 16*), with all runs showing Brown Shrimp as likely overfished and undergoing overfishing in the late 1980s/early 1990s. MSY was fairly consistent across all runs (*Figure 17*).

Runs with lower *B/K* ratios performed slightly better overall with improved diagnostics compared with the base runs (assuming *B/K*~.4) (*Figure 18*), particularly in terms of the fit to the index and predictability skill. *Figure 19* and *Figure 20* show the results of the hindcasting and retrospective analysis diagnostic tests side by side for three example runs (73, 1073, 2073) that only differ in their treatment of *m*. Posterior distributions for these runs are shown in *Figure 21*. Run 1073 very slightly outperforms run 2073 overall for this example run (*Figure 18*).

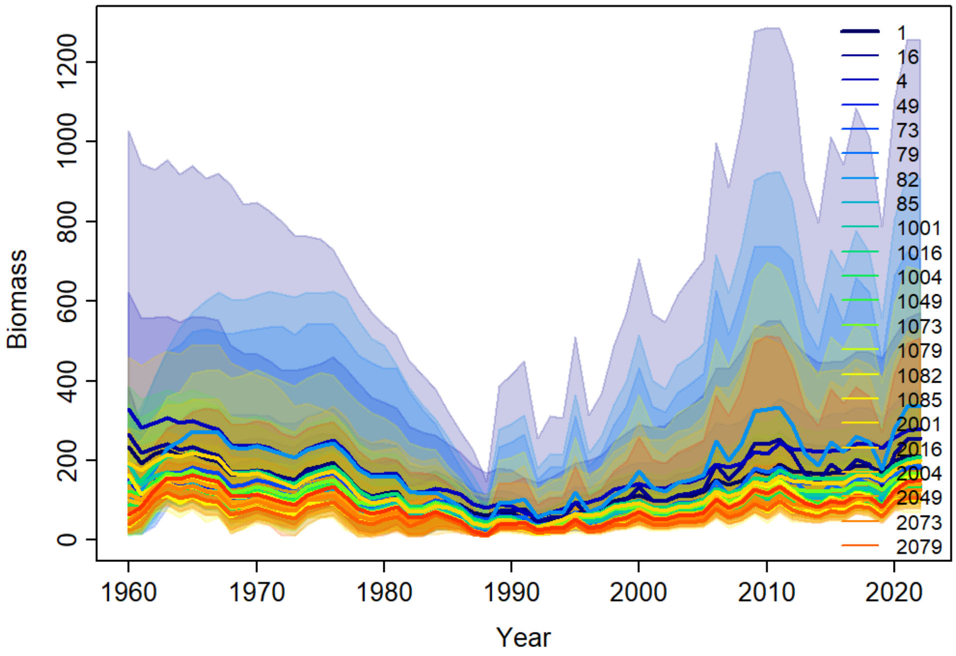


Figure 14: Biomass estimates in million pounds of tail weight for Brown Shrimp across runs.

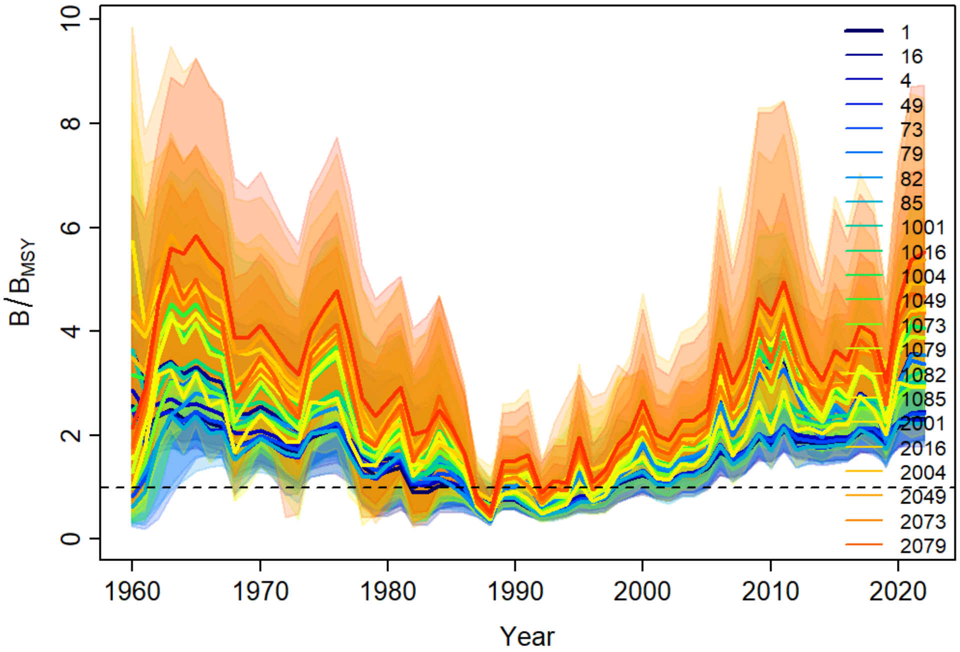


Figure 15: B/Bmsy estimates for Brown Shrimp across runs.

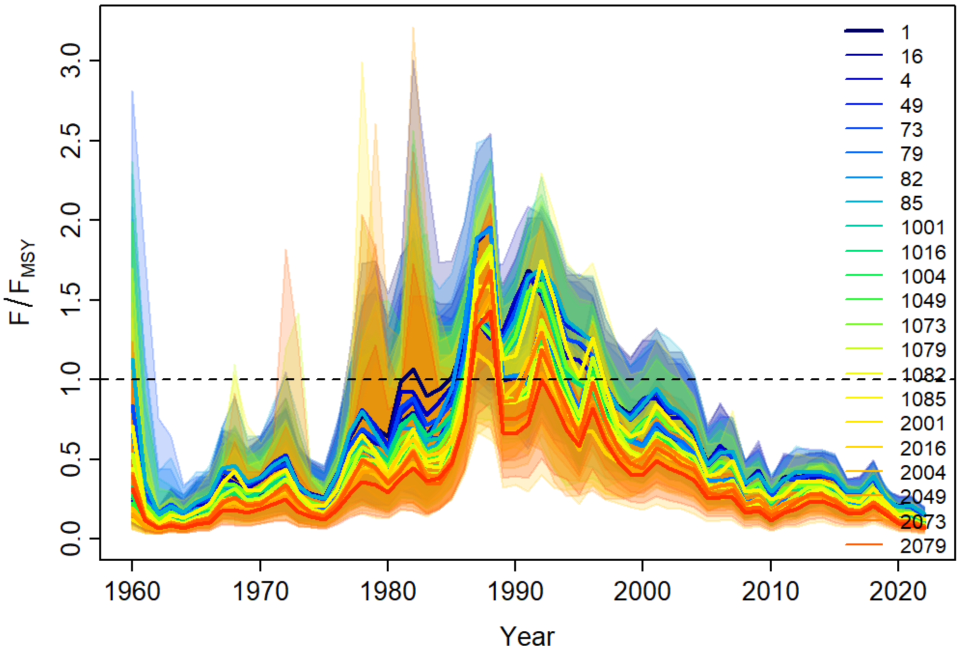


Figure 16: F/Fmsy estimates for Brown Shrimp across runs.

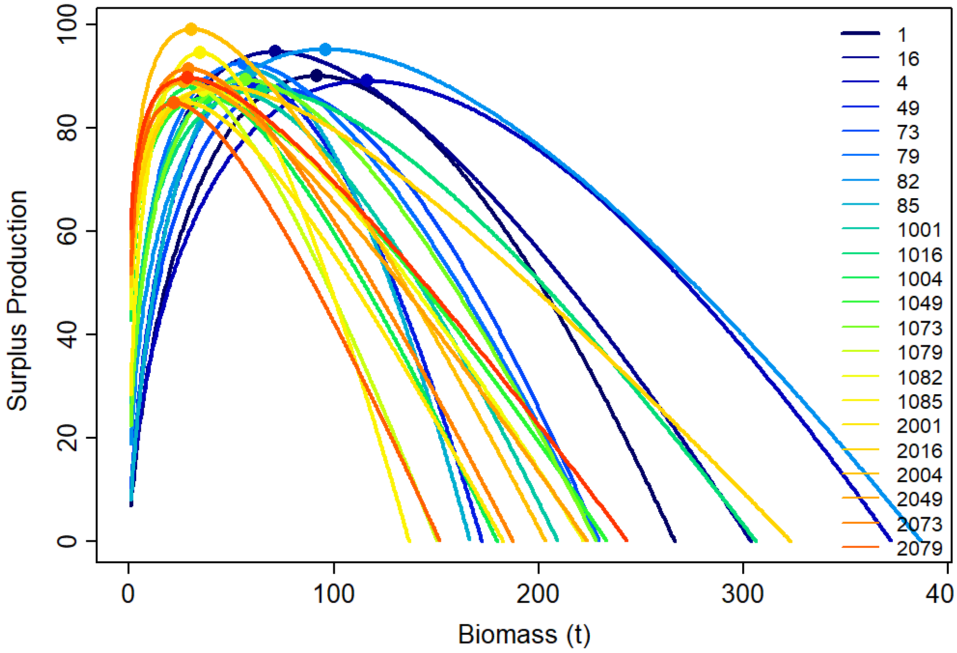
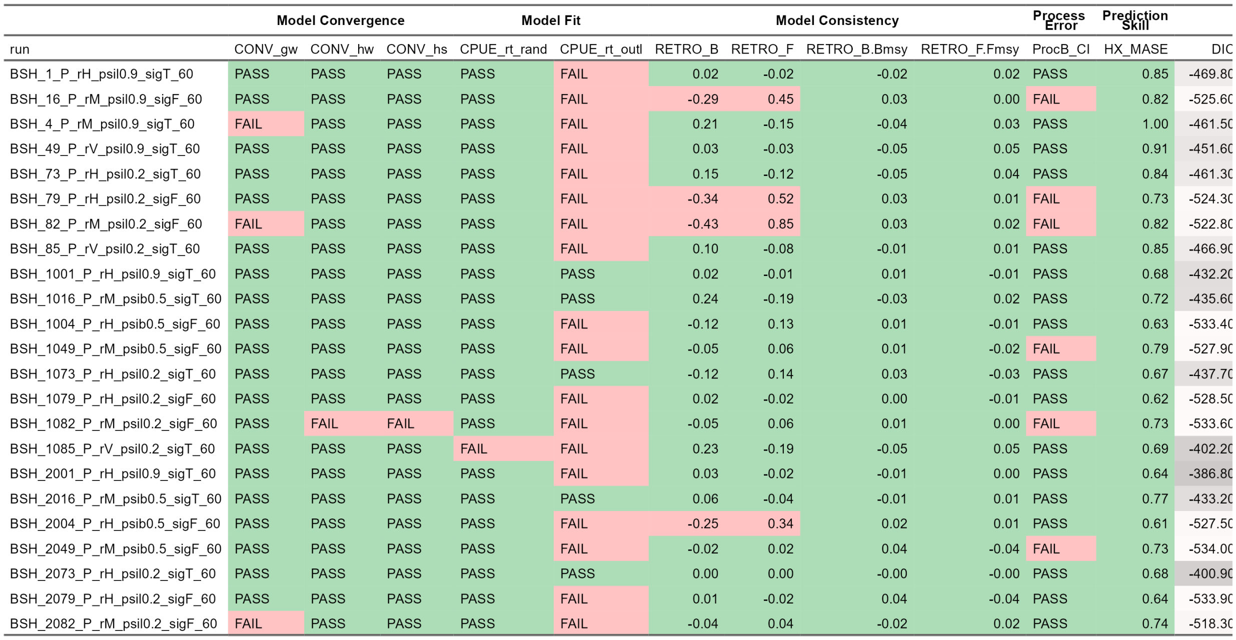


Figure 17: Surplus production curve estimated for Brown Shrimp across runs. Solid points indicate MSY. Surplus production and biomass are both in million pounds of tail weight.



	Model Convergence			Model Fit		Model Consistency				Process Error	Prediction Skill	
run	CONV_gw	CONV_hw	CONV_hs	CPUE_rt_rand	CPUE_rt_outl	RETRO_B	RETRO_F	RETRO_B.Bmsy	RETRO_F.Fmsy	ProcB_CI	HX_MASE	DIC
BSH_1_P_rH_psil0.9_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.02	-0.02	-0.02	0.02	PASS	0.85	-469.80
BSH_16_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.29	0.45	0.03	0.00	FAIL	0.82	-525.60
BSH_4_P_rM_psil0.9_sigT_60	FAIL	PASS	PASS	PASS	FAIL	0.21	-0.15	-0.04	0.03	PASS	1.00	-461.50
BSH_49_P_rV_psil0.9_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.03	-0.03	-0.05	0.05	PASS	0.91	-451.60
BSH_73_P_rH_psil0.2_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.15	-0.12	-0.05	0.04	PASS	0.84	-461.30
BSH_79_P_rH_psil0.2_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.34	0.52	0.03	0.01	FAIL	0.73	-524.30
BSH_82_P_rM_psil0.2_sigF_60	FAIL	PASS	PASS	PASS	FAIL	-0.43	0.85	0.03	0.02	FAIL	0.82	-522.80
BSH_85_P_rV_psil0.2_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.10	-0.08	-0.01	0.01	PASS	0.85	-466.90
BSH_1001_P_rH_psil0.9_sigT_60	PASS	PASS	PASS	PASS	PASS	0.02	-0.01	0.01	-0.01	PASS	0.68	-432.20
BSH_1016_P_rM_psib0.5_sigT_60	PASS	PASS	PASS	PASS	PASS	0.24	-0.19	-0.03	0.02	PASS	0.72	-435.60
BSH_1004_P_rH_psib0.5_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.12	0.13	0.01	-0.01	PASS	0.63	-533.40
BSH_1049_P_rM_psib0.5_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.05	0.06	0.01	-0.02	FAIL	0.79	-527.90
BSH_1073_P_rH_psil0.2_sigT_60	PASS	PASS	PASS	PASS	PASS	-0.12	0.14	0.03	-0.03	PASS	0.67	-437.70
BSH_1079_P_rH_psil0.2_sigF_60	PASS	PASS	PASS	PASS	FAIL	0.02	-0.02	0.00	-0.01	PASS	0.62	-528.50
BSH_1082_P_rM_psil0.2_sigF_60	PASS	FAIL	FAIL	PASS	FAIL	-0.05	0.06	0.01	0.00	FAIL	0.73	-533.60
BSH_1085_P_rV_psil0.2_sigT_60	PASS	PASS	PASS	FAIL	FAIL	0.23	-0.19	-0.05	0.05	PASS	0.69	-402.20
BSH_2001_P_rH_psil0.9_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.03	-0.02	-0.01	0.00	PASS	0.64	-386.80
BSH_2016_P_rM_psib0.5_sigT_60	PASS	PASS	PASS	PASS	PASS	0.06	-0.04	-0.01	0.01	PASS	0.77	-433.20
BSH_2004_P_rH_psib0.5_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.25	0.34	0.02	0.01	PASS	0.61	-527.50
BSH_2049_P_rM_psib0.5_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.02	0.02	0.04	-0.04	FAIL	0.73	-534.00
BSH_2073_P_rH_psil0.2_sigT_60	PASS	PASS	PASS	PASS	PASS	0.00	0.00	-0.00	-0.00	PASS	0.68	-400.90
BSH_2079_P_rH_psil0.2_sigF_60	PASS	PASS	PASS	PASS	FAIL	0.01	-0.02	0.04	-0.04	PASS	0.64	-533.90
BSH_2082_P_rM_psil0.2_sigF_60	FAIL	PASS	PASS	PASS	FAIL	-0.04	0.04	-0.02	0.02	PASS	0.74	-518.30

Figure 18: Summary of diagnostics for each run for Brown Shrimp.

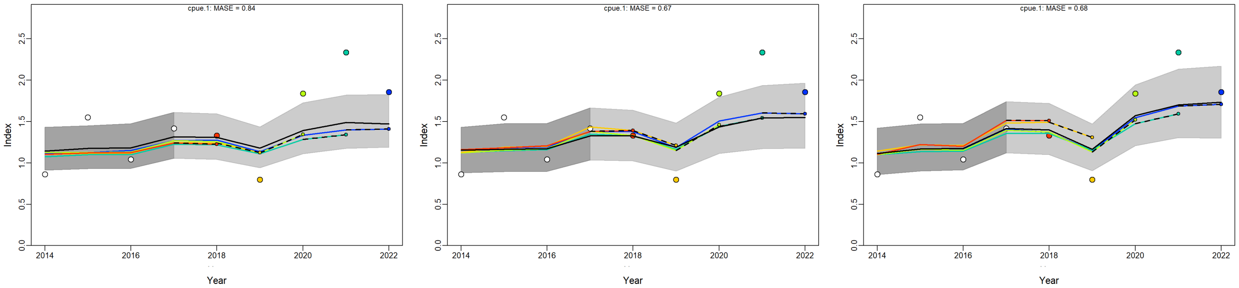


Figure 19: Comparing prediction skill using an example run (73) with varying priors on m (left to right decreasing B/K runs 73, 1073, 2073)

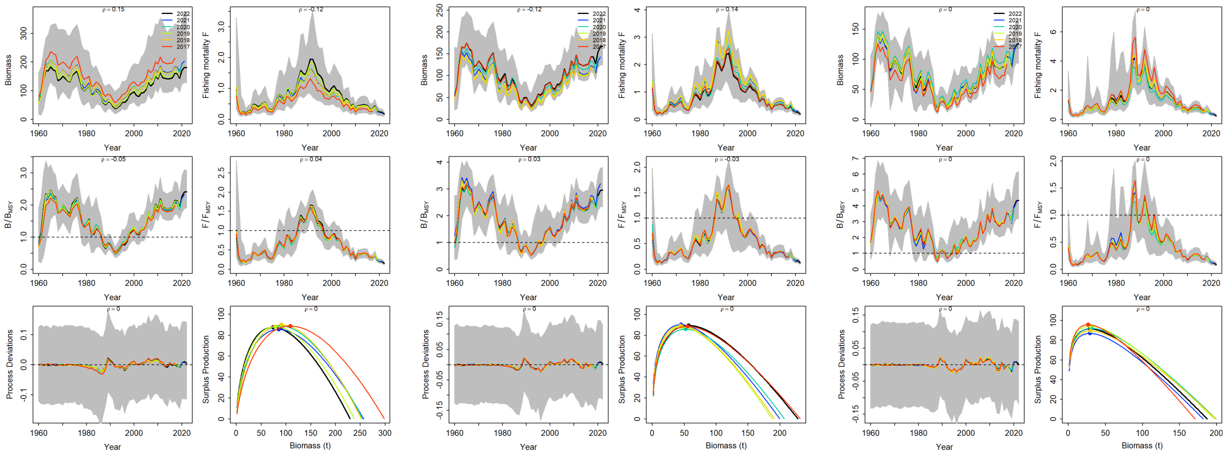


Figure 20: Comparing retrospective patterns using an example run (73) with varying priors on m (left to right decreasing B/K runs 73, 1073, 2073)

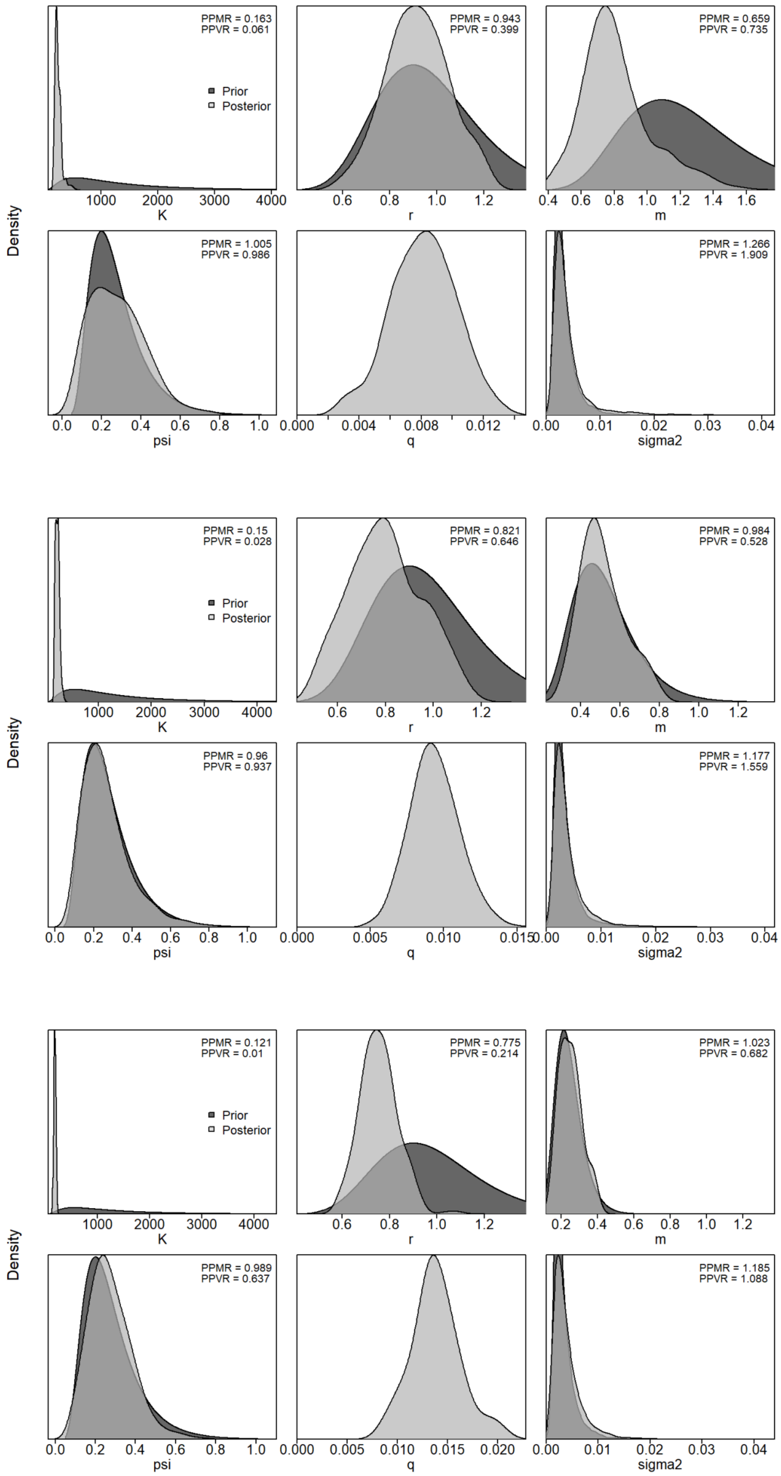


Figure 21: Comparing posterior distributions using an example run (73) with varying priors on m (top to bottom decreasing B/K runs 73, 1073, 2073)

3.1.2 White Shrimp

For White Shrimp, decreasing *B/K* had a large impact on the results (*Figure 22* - *25*) but did not markedly improve model performance (*Figure 26*). Lower *B/K* ratios resulted in more optimistic stock status and lower estimates of exploitation rates across the entire time series (*Figures 23* - *24*). MSY was not consistent across runs (*Figure 25*). None of the new runs were considered adequate based on diagnostics (*Figure 26*).

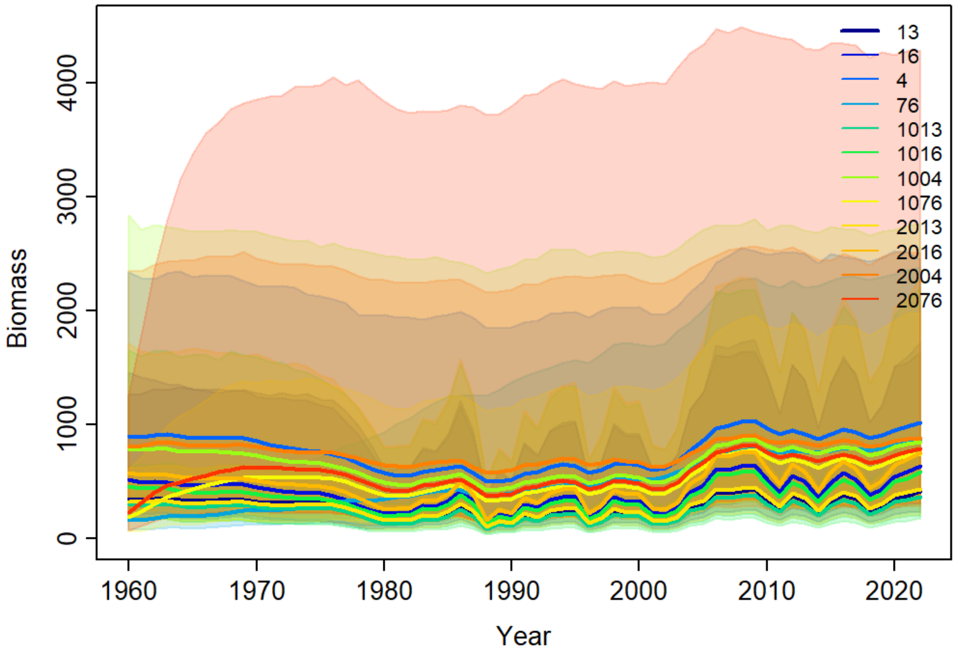


Figure 22: Biomass estimates in million pounds of tail weight for White Shrimp across runs.

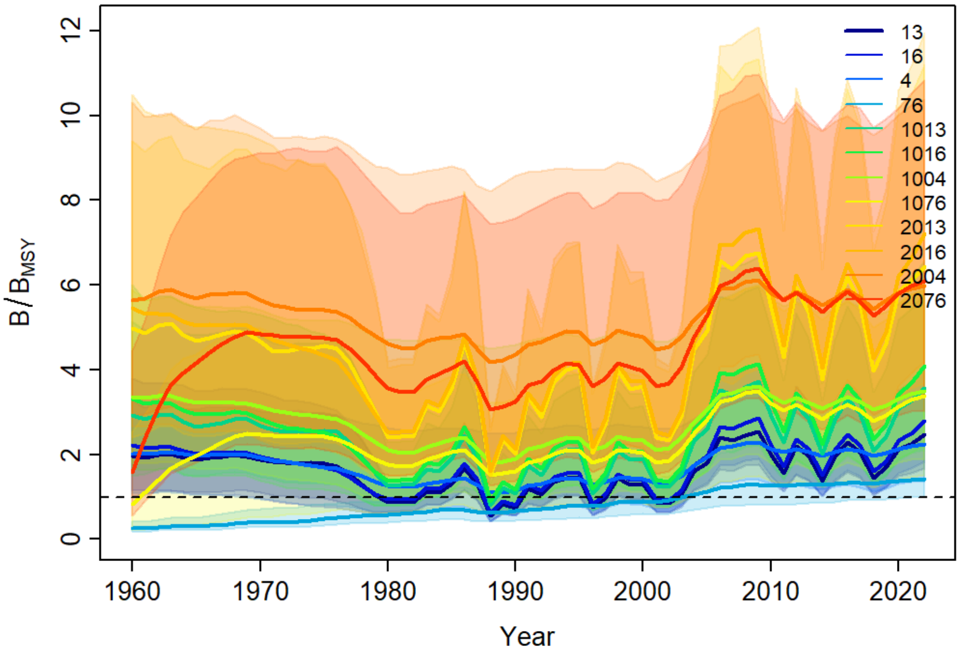


Figure 23: B/Bmsy estimates for White Shrimp across runs.

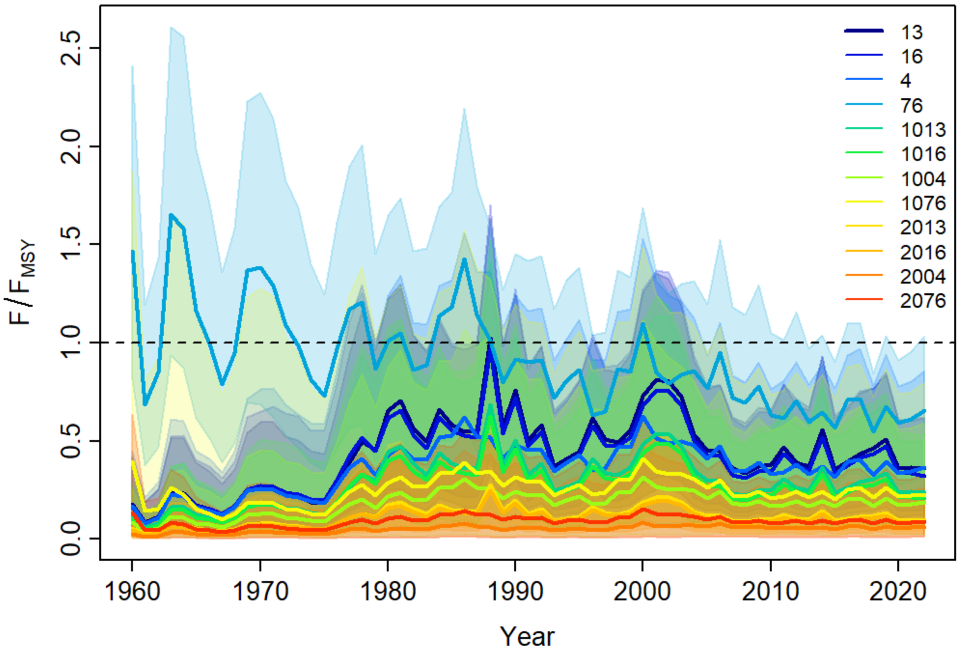


Figure 24: F/Fmsy estimates for White Shrimp across runs.

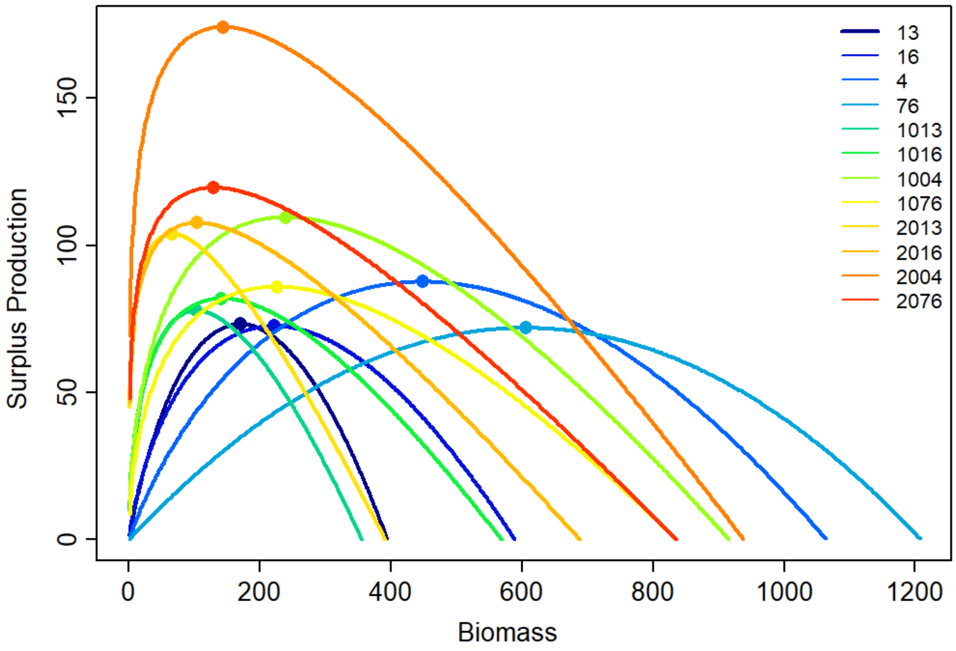
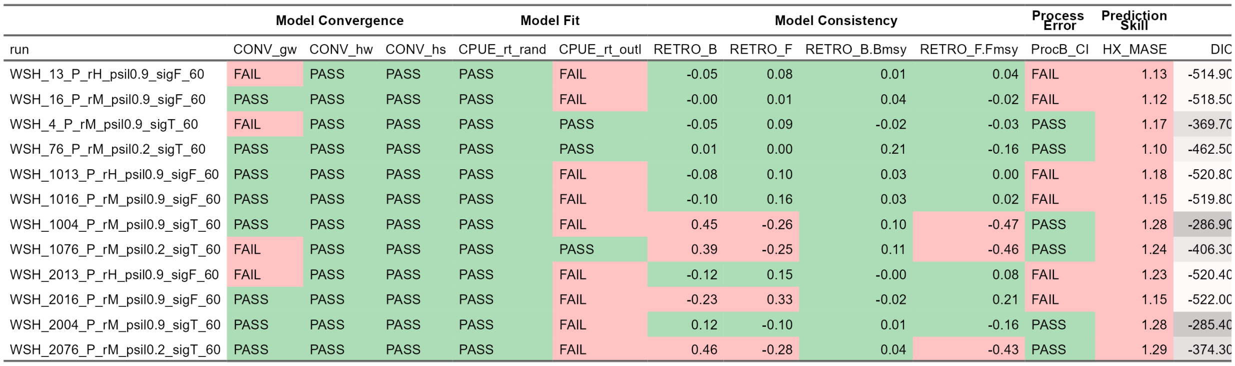


Figure 25: Surplus production curve estimated for White Shrimp across runs. Solid points indicate MSY. Surplus production and biomass are both in million pounds of tail weight.



	Model Convergence			Model Fit		Model Consistency				Process Error	Prediction Skill	
run	CONV_gw	CONV_hw	CONV_hs	CPUE_rt_rand	CPUE_rt_outl	RETRO_B	RETRO_F	RETRO_B.Bmsy	RETRO_F.Fmsy	ProcB_CI	HX_MASE	DIC
WSH_13_P_rH_psil0.9_sigF_60	FAIL	PASS	PASS	PASS	FAIL	-0.05	0.08	0.01	0.04	FAIL	1.13	-514.90
WSH_16_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.00	0.01	0.04	-0.02	FAIL	1.12	-518.50
WSH_4_P_rM_psil0.9_sigT_60	FAIL	PASS	PASS	PASS	PASS	-0.05	0.09	-0.02	-0.03	PASS	1.17	-369.70
WSH_76_P_rM_psil0.2_sigT_60	PASS	PASS	PASS	PASS	PASS	0.01	0.00	0.21	-0.16	PASS	1.10	-462.50
WSH_1013_P_rH_psil0.9_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.08	0.10	0.03	0.00	FAIL	1.18	-520.80
WSH_1016_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.10	0.16	0.03	0.02	FAIL	1.15	-519.80
WSH_1004_P_rM_psil0.9_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.45	-0.26	0.10	-0.47	PASS	1.28	-286.90
WSH_1076_P_rM_psil0.2_sigT_60	FAIL	PASS	PASS	PASS	PASS	0.39	-0.25	0.11	-0.46	PASS	1.24	-406.30
WSH_2013_P_rH_psil0.9_sigF_60	FAIL	PASS	PASS	PASS	FAIL	-0.12	0.15	-0.00	0.08	FAIL	1.23	-520.40
WSH_2016_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	FAIL	-0.23	0.33	-0.02	0.21	FAIL	1.15	-522.00
WSH_2004_P_rM_psil0.9_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.12	-0.10	0.01	-0.16	PASS	1.28	-285.40
WSH_2076_P_rM_psil0.2_sigT_60	PASS	PASS	PASS	PASS	FAIL	0.46	-0.28	0.04	-0.43	PASS	1.29	-374.30

Figure 26: Summary of diagnostics for each run for White Shrimp.

3.1.3 Pink Shrimp

For Pink Shrimp, similar to what was observed for White Shrimp, decreasing *B/K* had a large impact on the results (*Figures 27* - *30*) but did not sufficiently improve model performance (*Figure 31*). Lower *B/K* ratios resulted in more optimistic stock status and lower estimates of exploitation rates across the entire time series (*Figures 28* - *29*). MSY was not consistent across runs (*Figure 30*). None of the new runs were considered adequate based on diagnostics (*Figure 31*).

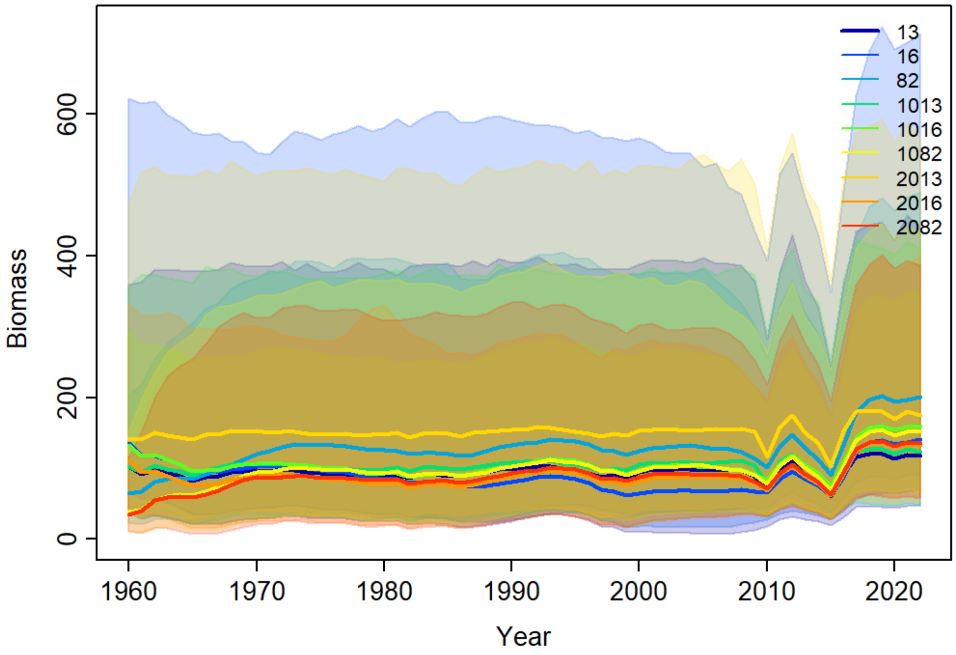


Figure 27: Biomass estimates in million pounds of tail weight for Pink Shrimp across runs.

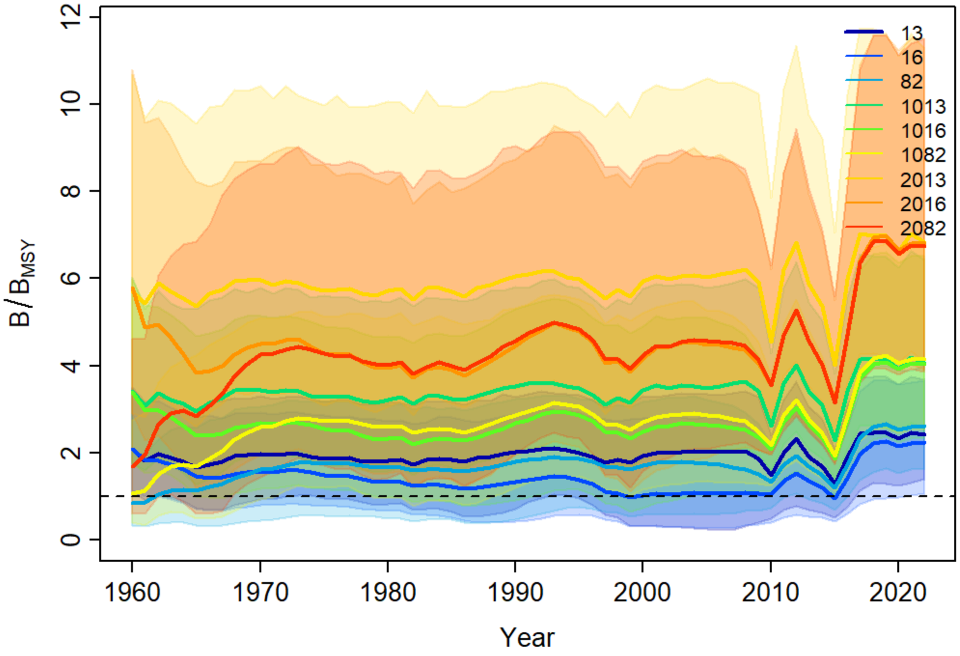


Figure 28: B/Bmsy estimates for Pink Shrimp across runs.

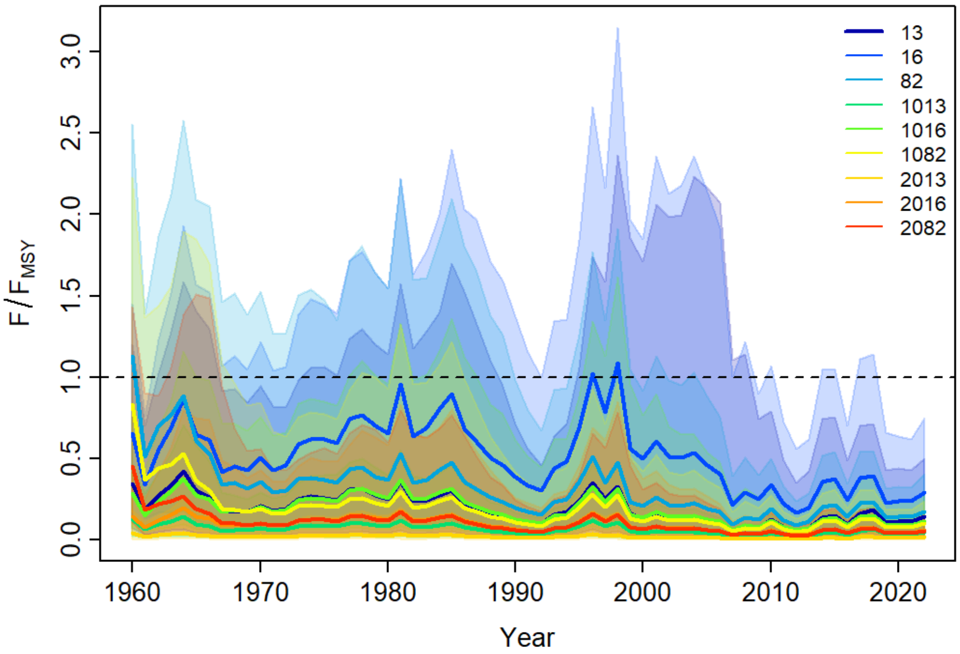


Figure 29: F/Fmsy estimates for Pink Shrimp across runs.

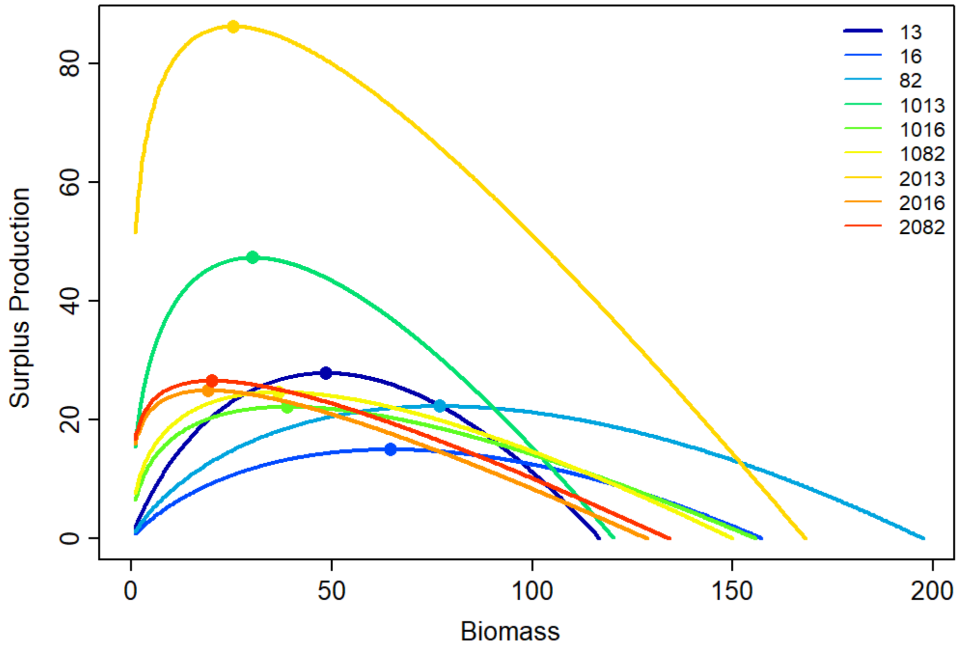
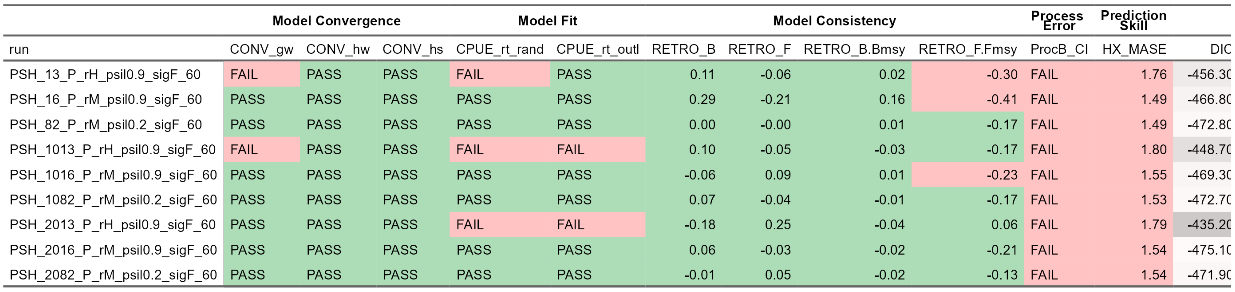


Figure 30: Surplus production curve estimated for Pink Shrimp across runs. Solid points indicate MSY. Surplus production and biomass are both in million pounds of tail weight.



	Model Convergence			Model Fit		Model Consistency				Process Error	Prediction Skill	
run	CONV_gw	CONV_hw	CONV_hs	CPUE_rt_rand	CPUE_rt_outl	RETRO_B	RETRO_F	RETRO_B.Bmsy	RETRO_F.Fmsy	ProcB_CI	HX_MASE	DIC
PSH_13_P_rH_psil0.9_sigF_60	FAIL	PASS	PASS	FAIL	PASS	0.11	-0.06	0.02	-0.30	FAIL	1.76	-456.30
PSH_16_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	PASS	0.29	-0.21	0.16	-0.41	FAIL	1.49	-466.80
PSH_82_P_rM_psil0.2_sigF_60	PASS	PASS	PASS	PASS	PASS	0.00	-0.00	0.01	-0.17	FAIL	1.49	-472.80
PSH_1013_P_rH_psil0.9_sigF_60	FAIL	PASS	PASS	FAIL	FAIL	0.10	-0.05	-0.03	-0.17	FAIL	1.80	-448.70
PSH_1016_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	PASS	-0.06	0.09	0.01	-0.23	FAIL	1.55	-469.30
PSH_1082_P_rM_psil0.2_sigF_60	PASS	PASS	PASS	PASS	PASS	0.07	-0.04	-0.01	-0.17	FAIL	1.53	-472.70
PSH_2013_P_rH_psil0.9_sigF_60	PASS	PASS	PASS	FAIL	FAIL	-0.18	0.25	-0.04	0.06	FAIL	1.79	-435.20
PSH_2016_P_rM_psil0.9_sigF_60	PASS	PASS	PASS	PASS	PASS	0.06	-0.03	-0.02	-0.21	FAIL	1.54	-475.10
PSH_2082_P_rM_psil0.2_sigF_60	PASS	PASS	PASS	PASS	PASS	-0.01	0.05	-0.02	-0.13	FAIL	1.54	-471.90

Figure 31: Summary of diagnostics for each run for Pink Shrimp.

4. Empirical Dynamic Modeling (EDM)

Empirical Dynamic Modeling (EDM) is a flexible modeling framework that operates in a unitless functional space, and reviewers primarily requested plots and analyses regarding the scale used to generate management benchmarks. We used the scale of the fishery landings to ground the trends of relative abundance to a measurable value for application to fishery management and monitoring. Requests from the Review Panel digging into this concept and others are detailed below.

4.1 Clarifying catchability

EDM models are fit to escapement ($X_t - qC_t$), where X_t is abundance at time t in survey units, C_t is landings from the same time step t in biomass units and q is a scalar. q is referred to in the GP-EDM literature as a "catchability" parameter, which generated some confusion in the Review Panel since, in the EDM context, it does not define the efficiency of the survey in capturing shrimp. Instead, it is used as a scalar to account for removal of landings within the GP-EDM formulation to translate fishery landings to units of the survey. Inversely, the scalar is used to translate the final estimates of abundance in survey units into units of fishery landings.

Because a familiar word in fishery science was used to define a different concept, this generated some confusion, and additional examples were provided below to more explicitly define the catchability parameter q estimated in GP-EDM (*GP-EDM*, version 0.0.0.9010). The function fitGP_fish in GP-EDM finds the parameter q by maximizing the marginal posterior likelihood (details in next section). As described in the Assessment Workshop Report in more detail, q can be estimated as distinct or shared among populations within a hierarchical model, and its units as reported can be interpreted as units of the survey per unit of landings (e.g. shrimp per trawl hour / million pounds of tails).

The top performing Brown Shrimp model estimated a shared catchability parameter $q = 0.402$ to translate units of landings to units of the survey. The inverse of the catchability scalar q was used to translate estimates of abundance and benchmarks including B_{MSY} from units of the survey (shrimp per trawl hour) to units of landings (million pounds of tails).

Population	Metric	Equation	Result
Large	B_{MSY}	25.18 shrimp/hr / 0.402	62.67 tailmp
Medium	B_{MSY}	63.12 shrimp/hr / 0.402	157.10 tailmp

Population	**Metric**	**Equation**	**Result**
Small	B_{MSY}	74.58 shrimp/hr / 0.402	185.63 tailmp
————	————	———————-	————-
Total	B_{MSY}		405.39 tailmp

White Shrimp estimated distinct catchability parameters to translate population size classes between units of the LDWF survey (shrimp per 10 min tow) and units of the landings (10million pounds of tails). This required scaling each population by their respective catchability parameter before summing them up for a population-wide B_{MSY} (e.g. whole population was not scaled up by the same parameter).

Population	**Metric**	**Equation**	**Result**
Large	B_{MSY}	0.1069 shrimp/10min / 0.0213	5.023 tail10mp
Medium	B_{MSY}	2.640 shrimp/10min / 0.627	4.208 tail10mp
Small	B_{MSY}	21.112 shrimp/10min / 3.77	5.605 tail10mp
————	————	————————	————
Total	B_{MSY}		14.835 tail10mp

4.2 Calculating fishery escapement and predicting abundance

Clarification was requested for the order of operations for calculating escapement, performing transformations on y, and fitting the model, as well as how exactly the model was fitting and projecting into the future. An exact formulation of the log difference transformation on escapement (ytrans=gr2) is provided below to explicitly define this for one of the cases.

$$ln[y_t/(y_{t-1} - qC_{t-1})] = f(y_{t-1} - qC_{t-1}, \dots, y_{t-E} - qC_{t-E})$$

Escapement from the previous year $(t-1)$ up to the embedding dimension $t-E$ is calculated and is used to predict growth rate, $ln[y_t/(y_{t-1} - qC_{t-1})]$ in this case. It is in this space that the fitting procedure occurs (estimation of GP hyperparameters using the R-prop gradient descent algorithm). The GP model is iteratively fit with different fixed values of parameter q, and the value of q is selected that maximizes the marginal posterior likelihood. The golden section optimization method is used for models with a single q, the Nelder-Mead method for hierarchical models with multiple q values. The bounds on q were 0 and q_{max}, where q_{max} is the largest value of q that keeps escapement non-negative (i.e. $y - qC > 0$ implies $q < y/C$, so $q_{max} = min(y/C)$). The predicted growth rate is then transformed back to a survey abundance estimate, y_t. [Note: models with $q < 0.001$ were dropped from consideration, but this value was not used as a bound for estimating q.] Prediction accuracy (used for model selection among different model configurations) is evaluated on the back-transformed abundance estimates.

The fitting and updating procedure for GP-EDM includes a 2-stage approach that leverages the flexibility of GP regression. The first stage involves integrating the function f out of the marginal likelihood for abundance y to estimate hyperparameters from the marginal posterior. The posterior distribution for f is also a GP, allowing for 1-step ahead forecasts by directly setting the estimated y as y_{T+1} (where T is the time series length) and continuing to replace the lags of data for predictions and projections. Detailed mathematical formulations of this process are available in Appendix B of Munch et al. (2017).

The fitted model can produce step-ahead predictions given any past values of abundance and catch, so it can predict and be iterated forward in time from any starting state. For iteration, the next predicted abundance and catch (given a fixed harvest rate) is used to compute the next escapement, which is used to predict the next growth rate, which is transformed to the next abundance, and so on.

The relationship between abundance and escapement is shown in *Figure 32* and *Figure 33* for Brown Shrimp and White Shrimp, respectively. These populations, particularly Brown Shrimp, have a high rate of escapement from the fishery, which aligns with how we understand the population and fishery distribution. White Shrimp are packed closer to shore and are more available to harvest compared to Brown Shrimp, which are spread out throughout depth gradients of the Gulf along approximately the same shoreline.

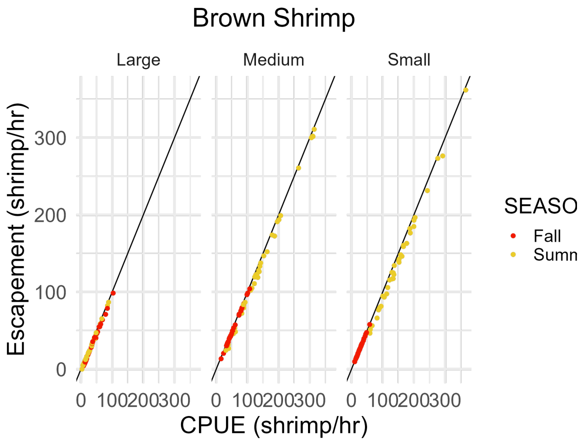
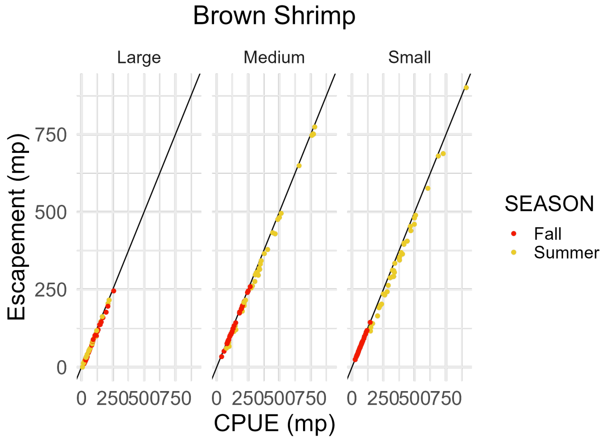


Figure 32: Brown Shrimp, CPUE units



Brown Shrimp, landings units

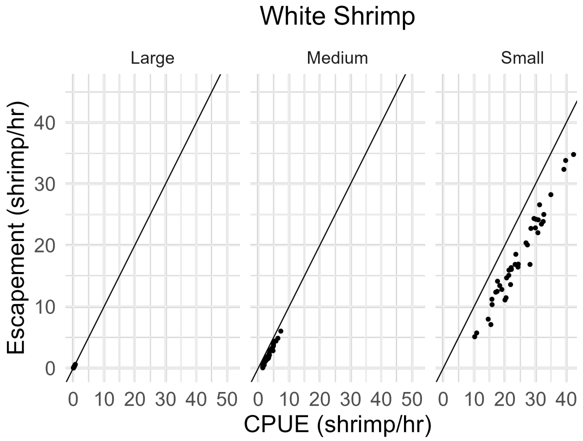
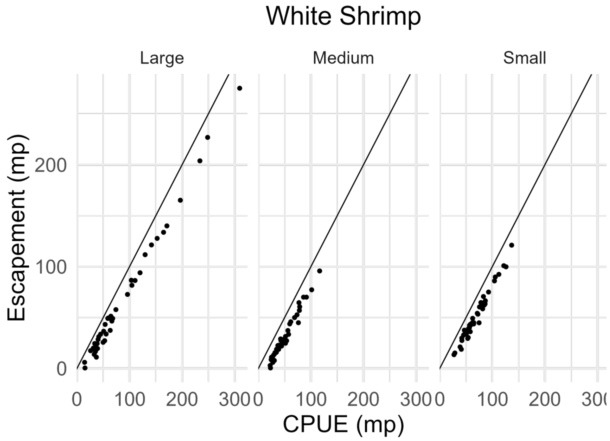


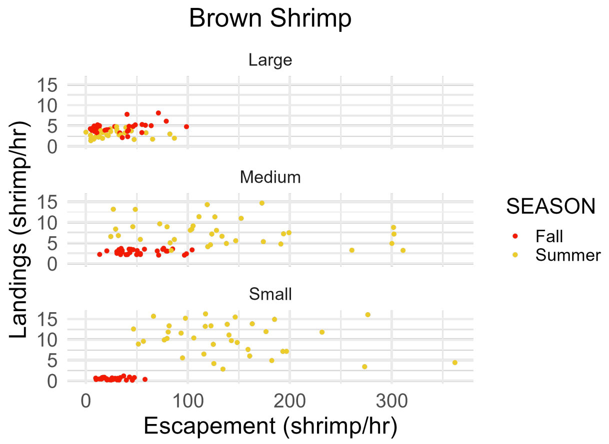
Figure 33: White Shrimp, CPUE units



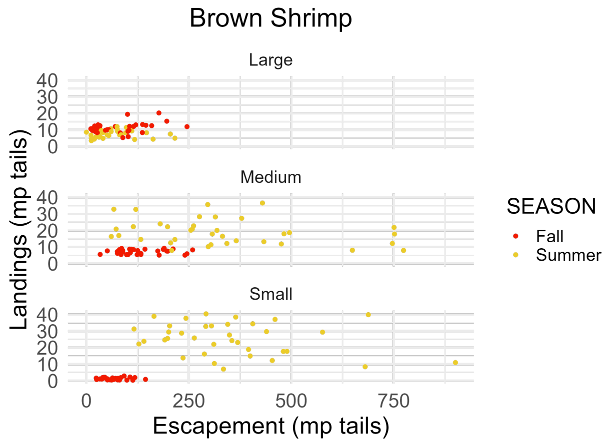
White Shrimp, landings units

1:1 line shown on Figures above, with points to the right of the line indicating a lower rate of escapement from the fishery (or a higher harvest rate).

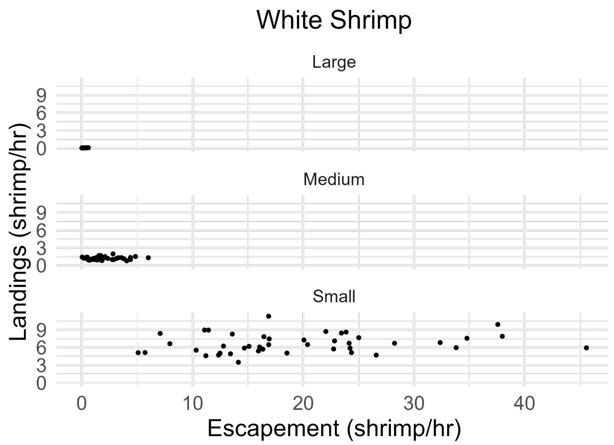
The Review Panel also requested to see landings plotted against model escapement. These are provided below, and color-coding is applied to seasonal data to distinguish the generally low Fall landings from the higher Summer landings for Brown Shrimp, which was a seasonal model.



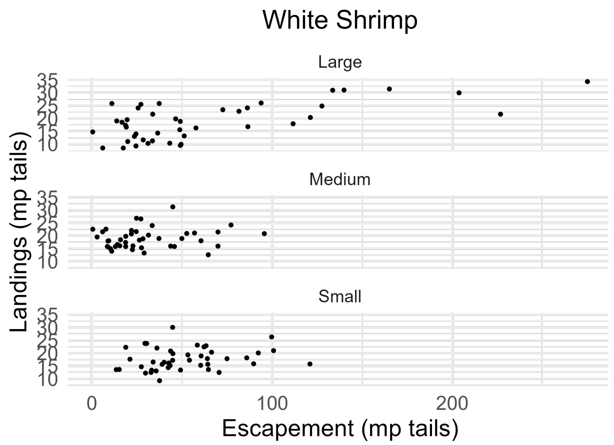
Brown Shrimp, CPUE units



Brown Shrimp, landings units



White Shrimp, CPUE units



White Shrimp, landings units

4.3 Influence of embedding dimension on fit statistics

The reviewers raised concerns over comparing the various fit statistics from different model configurations and the influence some of those configurations may have on the relative fits. Throughout the development of these models and workflow, the GP-EDM developers added an additional fit statistic to better capture cross-model comparisons for hierarchical models with local scaling, R^2_{scaled}. The reviewers suggested an additional standardization to better compare models with different embedding dimensions, E. Embedding dimension is inherently linked to time series length in the model and used to generate fit statistics, which will influence the results. In the future, all model results will be truncated to include the same years as the maximum embedding dimension E when calculating fit statistics in order to more appropriately compare apples to apples when comparing models with different embedding dimensions.

4.4 Management benchmarks

Kobe plots were requested for Brown and White Shrimp at the Review Workshop and are shown in *Figure 34* and *Figure 35*, respectively. Neither population has undergone overfishing ($F/F_{MSY} > 1$) throughout the time series of abundance. Brown Shrimp was estimated as overfished ($B/B_{MSY} < 1$) only in 1988, a year that the White Shrimp population was also estimated to be overfished. This shows support for the anecdotal evidence of poor environmental conditions in the region, since these are two species (with similar life histories and fisheries) surveyed by two different methods, obtaining the same low population estimate. White Shrimp population oscillates into overfished status periodically, but this is not a cause for concern due to the nature of EDM-based MSY estimation for an annual species as described in the Assessment Workshop Report.

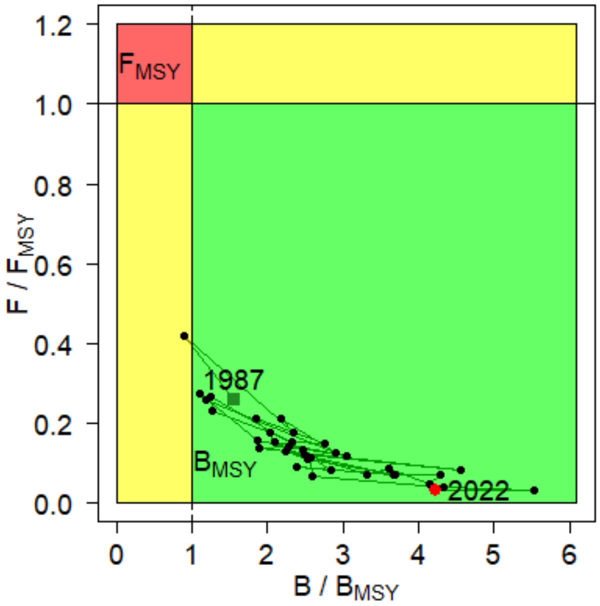


Figure 34: Brown Shrimp Kobe plot, 1987-2022.

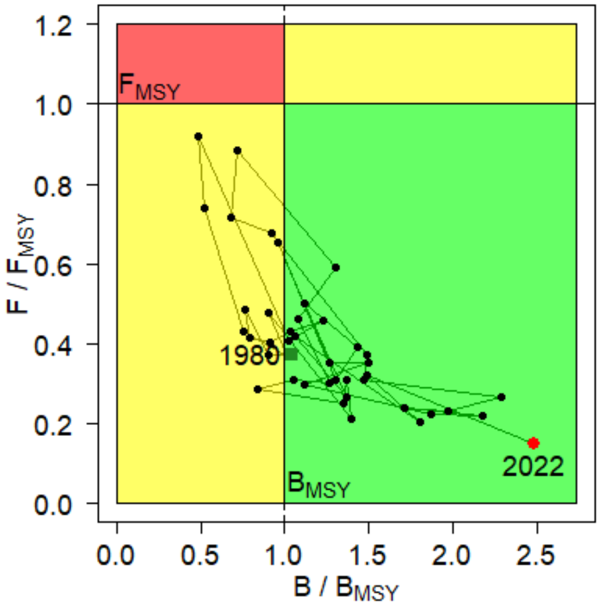


Figure 35: White Shrimp Kobe plot, 1980-2022.

This section focused on questions and figures that dig into the inputs and how the model handled scale and fitting procedures. Plots in *Section 5* show how these estimates compare to other modeling frameworks considered here.

5. Summary

The Review Panel requested plots and analyses to ground truth the scale of the assessment results. EDM estimates for MSY exceeded anything the fishery has landed in the past, drawing scrutiny to the scale of these models. Landings biomass by species is shown in *Figure 36*, where total landings have been stable or declining over the last decade.

Results of sensitivity analyses presented in *Section 3* indicated that under a surplus production model form, the peak of the production function is skewed to the left (m=0.15-0.25). This indicates that MSY occurs at a relatively lower stock size, and is plausible that the fleet has never realized MSY even under its full development in the 1980s.

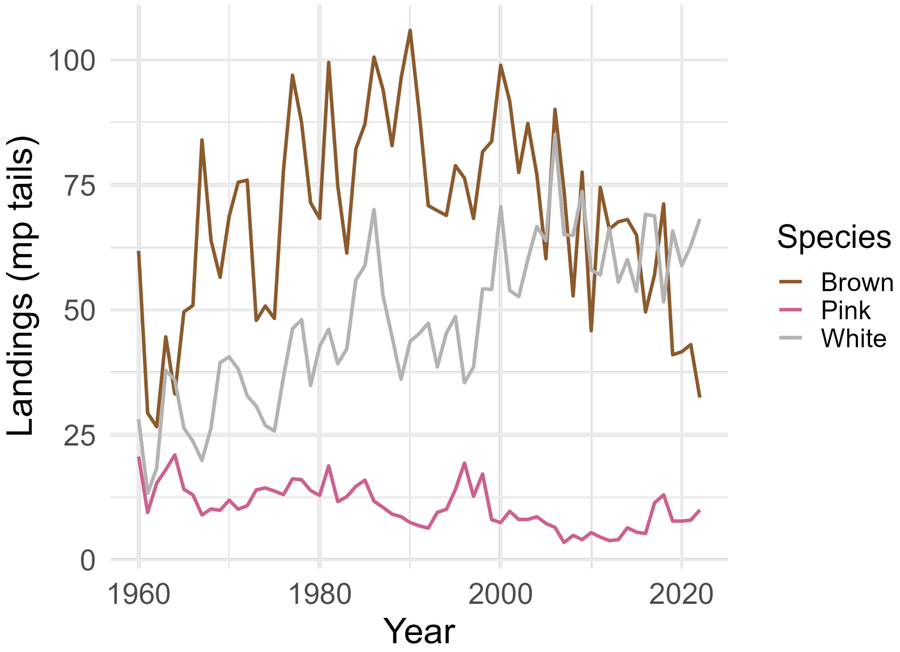


Figure 36: Brown, White, and Pink Shrimp landings, 1960-2022.

Relative abundance, fishing mortality rates, and management benchmarks were plotted to more effectively compare all surveys and methods across species. These results are presented first by species, then aggregated on the same plots to provide context to the Gulf-wide scale.

5.1 Brown Shrimp

Requests from the RW Panel for Brown Shrimp are summarized and presented below. The estimate of abundance from EDM was translated to million pounds of tails using the inverse of the catchability parameter presented in *Section 4*. The estimated abundance index from VAST and biomass estimates from EDM and JABBA were standardized to 1 and plotted together in *Figure 37* to show the relative trends of the various models utilized here.

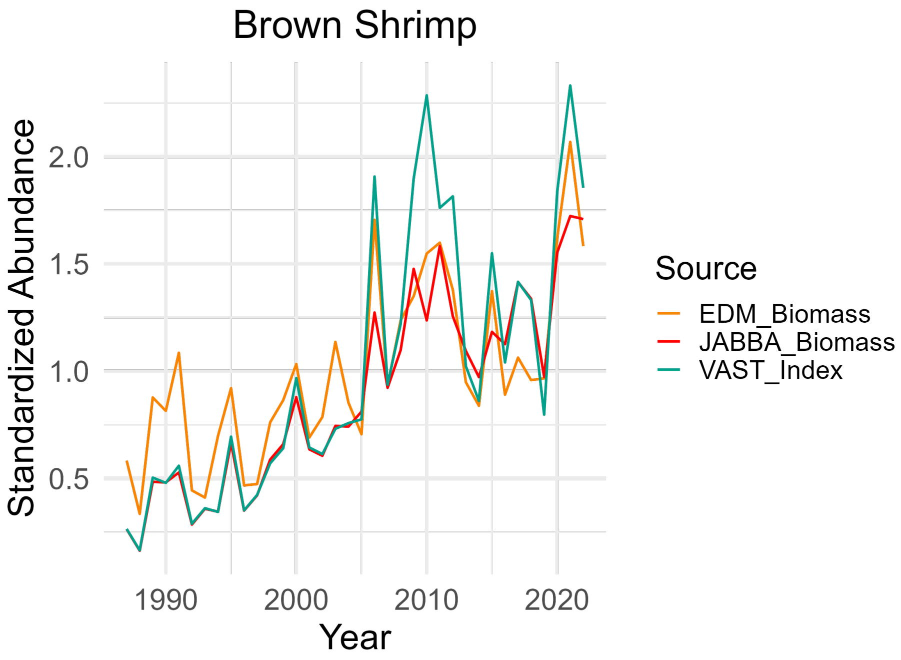


Figure 37: Brown Shrimp abundance indices standardized to 1.

Fishing mortality rate estimates from EDM and JABBA were also normalized and plotted together in *Figure 38* to highlight any areas where the trend differs.

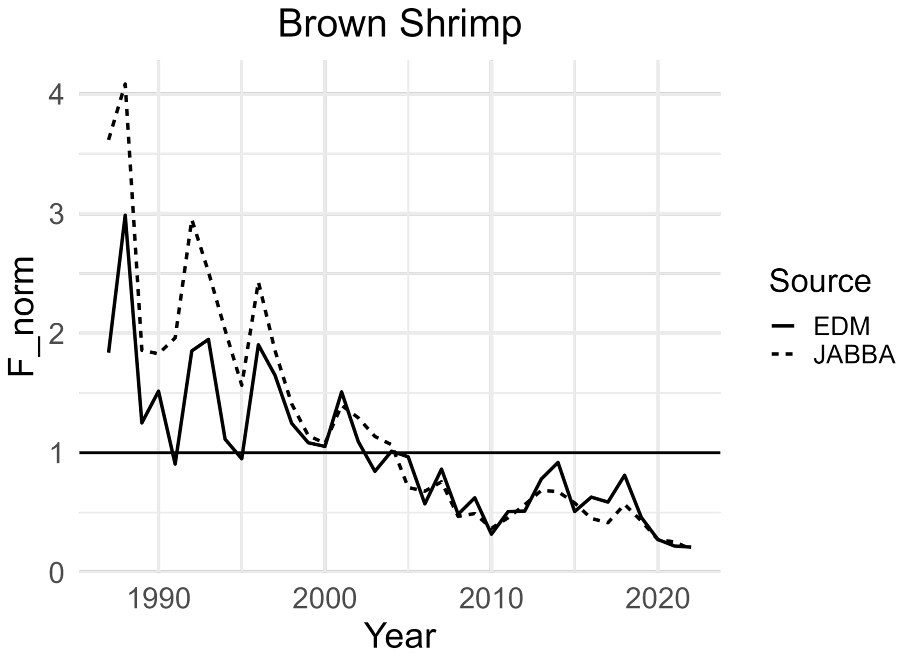


Figure 38: Brown Shrimp fishing mortality rate estimates from EDM and JABBA standardized to 1.

Fishery landings divided by the raw survey data can be used as a rough approximation for fishing mortality rate. This is shown for Brown Shrimp in *Figure 39* and matches the general trend shown above in *Figure 38*.

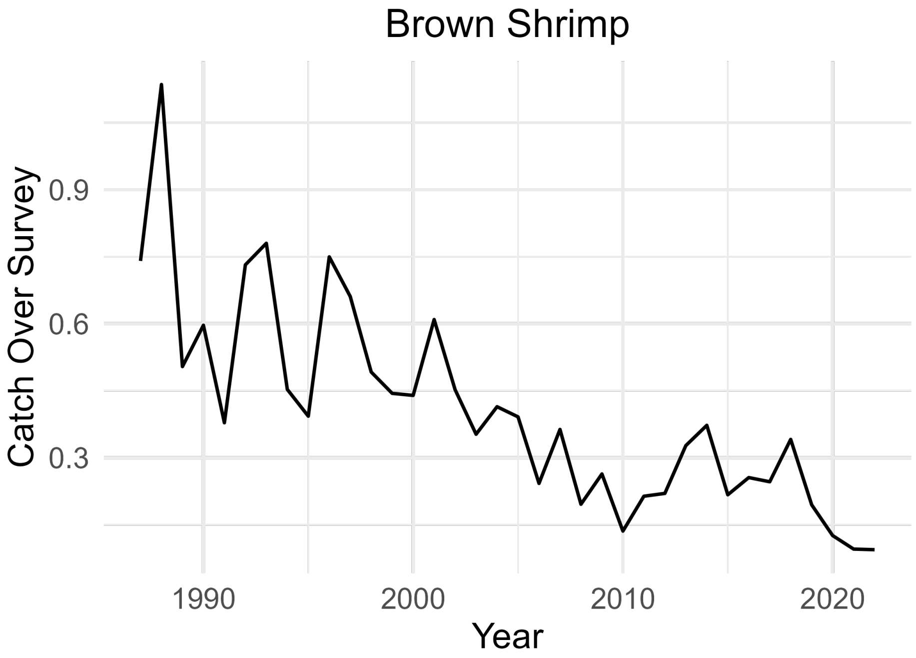


Figure 39: Brown Shrimp landings divided by SEAMAP survey, an approximation for fishing mortality rate.

Brown shrimp estimated biomass B was shown through time relative to biomass at MSY, the management benchmark B/B_{MSY}, for the duration of the model outputs in *Figure 40*. EDM and JABBA resulted in fairly similar estimates of B/B_{MSY} for the years they overlap, with JABBA estimating a longer enduring overfished status, $B/B_{MSY} < 1$.

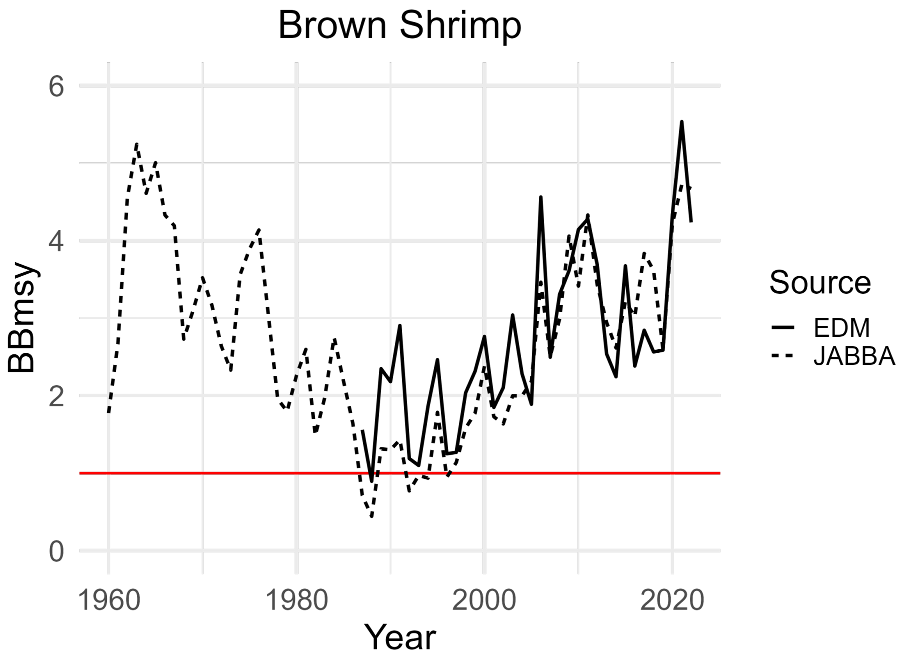


Figure 40: Brown Shrimp B/Bmsy for EDM and JABBA.

The estimated fishing mortality rate F relative to the F at MSY is shown in *Figure 41* for the duration of the model outputs for EDM and JABBA. When the index time series comes into JABBA in 1987, the model estimates a very large F relative to F_{MSY}, seemingly pushing any excess mortality into the F term. EDM estimates of F/F_{MSY} are more similar to the scale of the JABBA estimates prior to the incorporation of the index of abundance.

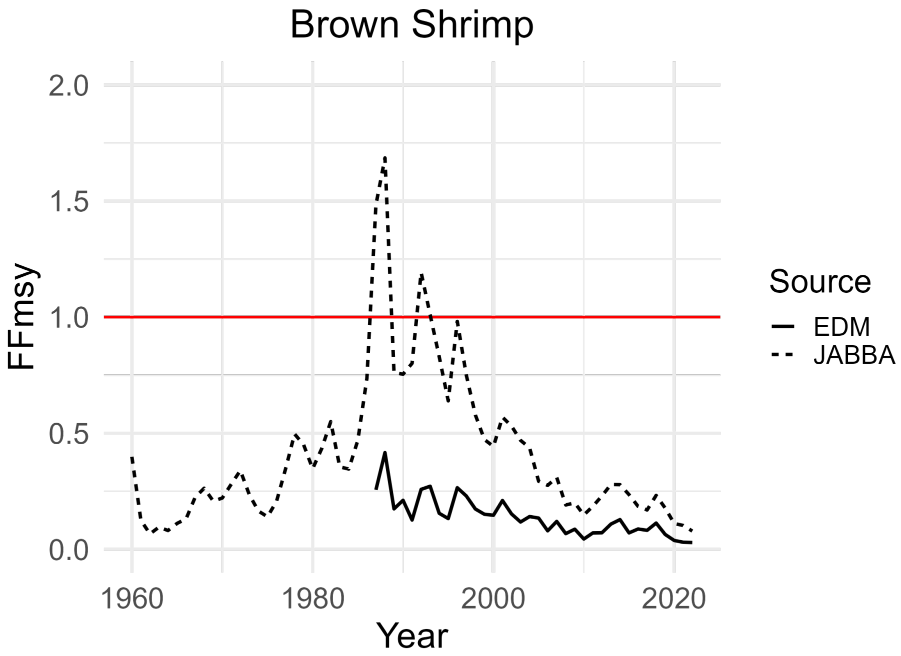


Figure 41: Brown Shrimp F/Fmsy for EDM and JABBA.

5.2 White Shrimp

The estimate of abundance from EDM was translated to 10 million pounds of tails using the inverse of the catchability parameters presented in *Section 4*. The estimated abundance index from VAST and biomass estimates from EDM and JABBA were standardized to 1 and plotted together in *Figure 42* to show the relative trends of the various models utilized here.

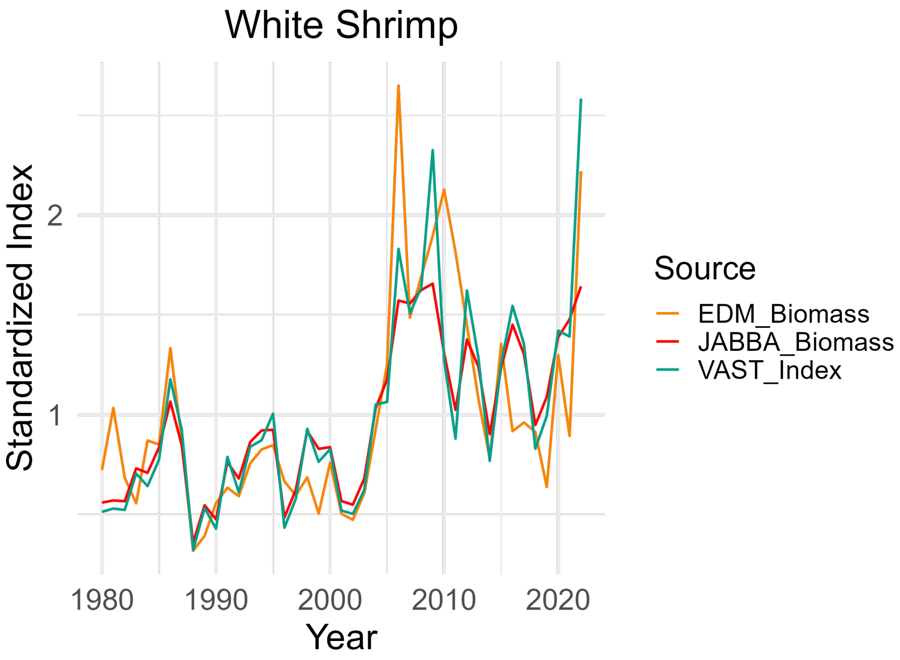


Figure 42: White Shrimp abundance indices standardized to 1.

Fishing mortality estimates from EDM and JABBA for White Shrimp are standardized to 1 and shown in *Figure 43*.

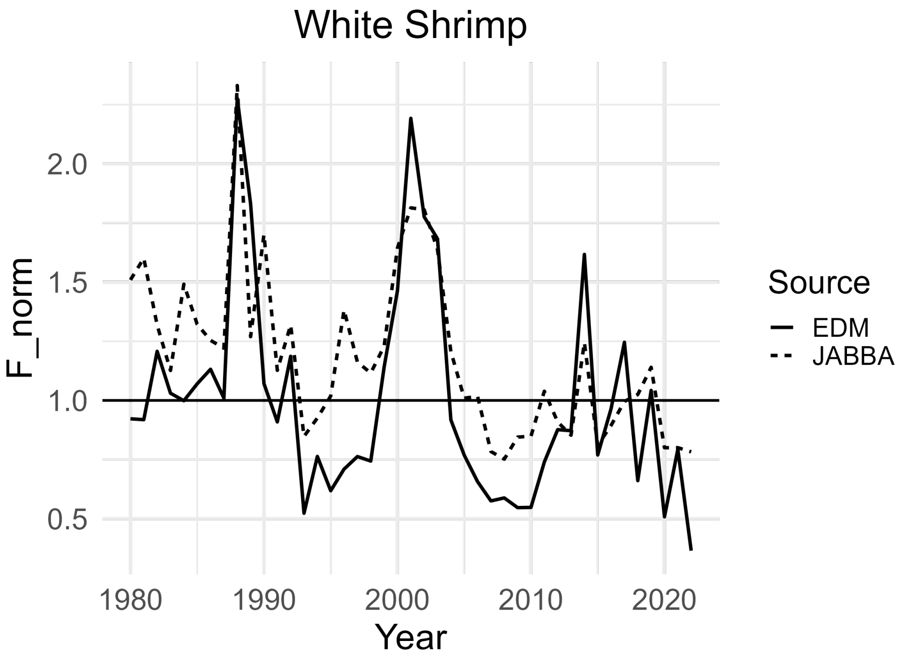


Figure 43: White Shrimp fishing mortality rate estimates from EDM and JABBA standardized to 1.

The White Shrimp landings are divided by the LDWF raw survey index for a rough approximation for fishing mortality rate in *Figure 44* and approximately matches the trends shown in *Figure 43*.

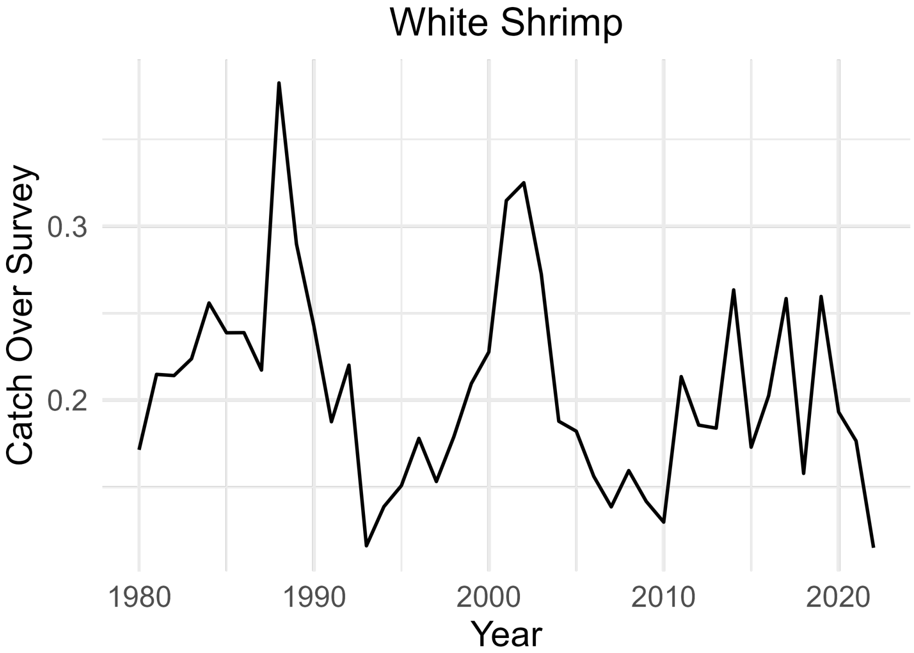


Figure 44: White Shrimp landings divided by LDWF survey raw index, an approximation for fishing mortality rate.

White shrimp estimated biomass B was shown through time relative to biomass at MSY, the management benchmark B/B_{MSY}, for the duration of the model outputs in *Figure 45*. EDM and JABBA resulted in fairly similar estimates of B/B_{MSY} for the years they overlap, with JABBA benchmark estimates trending above EDM. The White Shrimp JABBA models were not recommended for use due to failed diagnostic tests. The model shown here had slightly better diagnostics under a lower B_{MSY}/K estimate, but the relative scale of the result was very sensitive to the shape parameter m (e.g. the B/B_{MSY} trend shifted up and down markedly from changing this parameter).

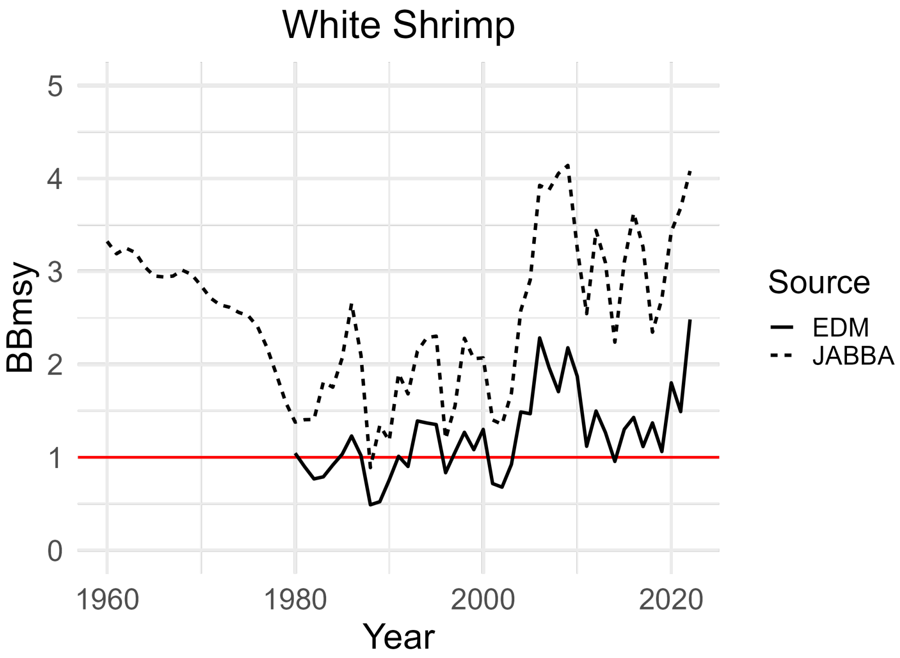


Figure 45: White Shrimp B/Bmsy for EDM and JABBA (not recommended for use).

The estimated fishing mortality rate F relative to the F at MSY is shown in *Figure 46* for the duration of the model outputs for EDM and JABBA. EDM and JABBA estimates of F/F_{MSY} follow similar trends, with EDM capturing more drastic shifts in this benchmark through time. Neither model estimates the population to have ever been undergoing overfishing (defined as $F/F_{MSY} > 1$).

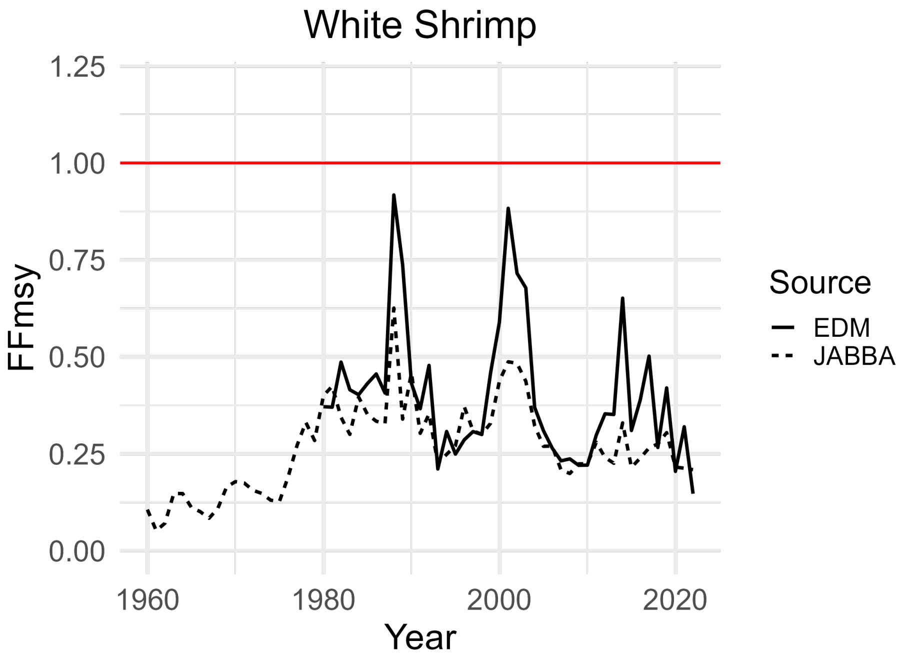


Figure 46: White Shrimp F/Fmsy for EDM and JABBA.

5.3 Pink Shrimp

Pink Shrimp had a shorter available time series for the index of abundance, and none of the models were recommended for use. The estimated abundance index from VAST and biomass estimates from EDM and JABBA were standardized to 1 and plotted together in *Figure 47* to show the relative trends of the various models utilized here. These indices were not very stable and did not follow the same trends among models when different survey seasons were used.

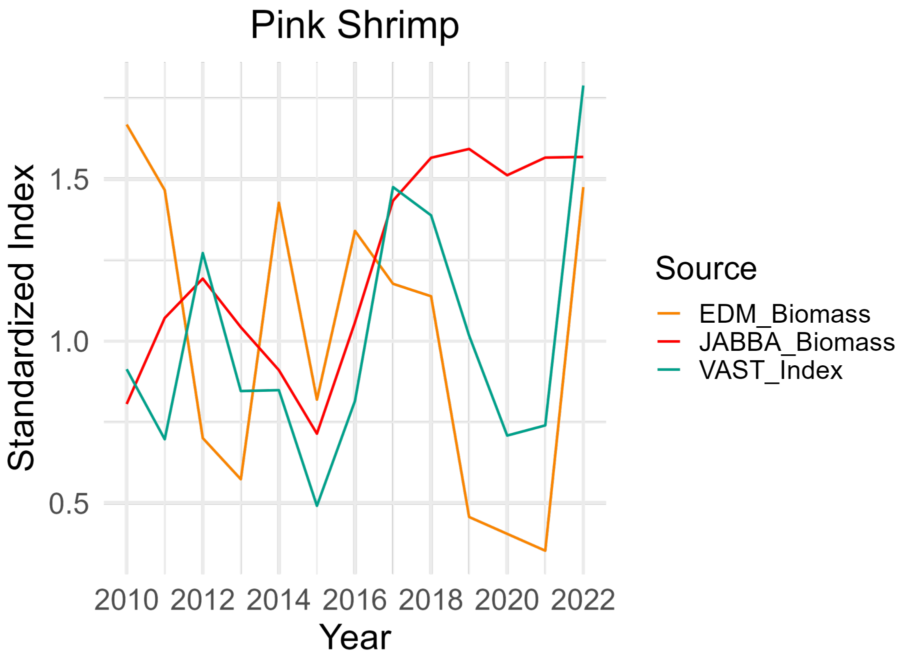


Figure 47: Pink Shrimp abundance indices standardized to 1.

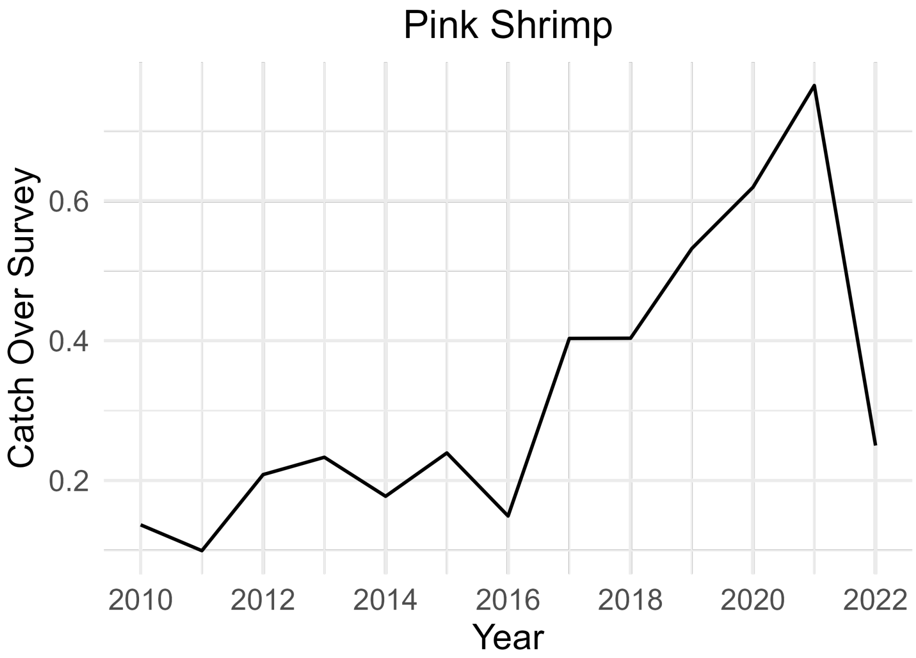


Figure 48: Pink Shrimp landings divided by SEAMAP survey, an approximation for fishing mortality rate.

Because the Pink Shrimp EDM model shown here solved MSY on a bound at a harvest rate $U = 1$, this translated to an infinite fishing mortality rate $F_{MSY} = -ln(0)$. Therefore, the benchmark $F/F_{MSY} = 0$ for all years and wasn't attempted to show here, since these models had very poor diagnostics.

Pink Shrimp estimated biomass B was shown through time relative to biomass at MSY, the management benchmark B/B_{MSY}, for the duration of the model outputs in *Figure 49*. EDM and JABBA resulted in very different estimates of B/B_{MSY} for the years they overlap. Neither the JABBA nor EDM models were recommended for Pink Shrimp due to failed diagnostic tests.

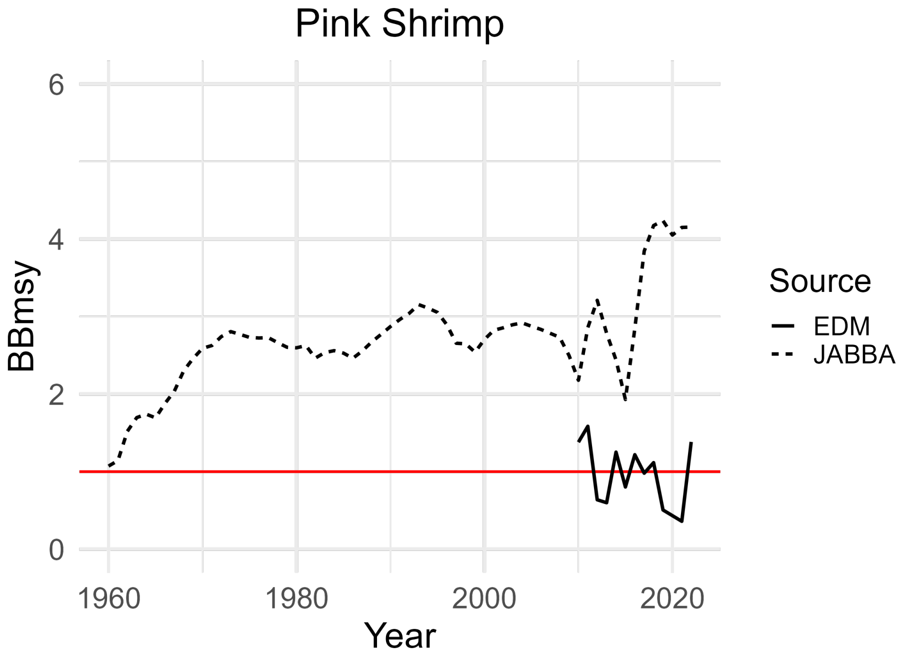


Figure 49: Pink Shrimp B/Bmsy for EDM and JABBA, neither of which were recommended for use.

5.4 Benchmark Comparisons

The scales of Brown Shrimp abundance and MSY estimates between EDM and JABBA were initially a cause of concern for the RW Panel. In *Figure 50*, Brown and White Shrimp estimates of biomass in million pounds of tails from EDM and JABBA are plotted together. This figure shows EDM Brown Shrimp estimates far exceeding JABBA Brown Shrimp results, but the EDM Brown Shrimp scale relative to EDM White Shrimp makes more intuitive sense than the JABBA outputs. Brown Shrimp are found in a broader depth range throughout the Gulf, implying there would likely be more Brown Shrimp in the water compared to White Shrimp, which are more compressed along the shoreline. Furthermore, it is intuitive that White Shrimp would be more susceptible to a higher fishing mortality rate compared to Brown Shrimp because all size classes are available for harvest in shallow water, in closer proximity to the fleet. The results for relative fishing mortality rates between species in EDM align with this concept in *Figure 51*, where White Shrimp F exceeds Brown Shrimp F.

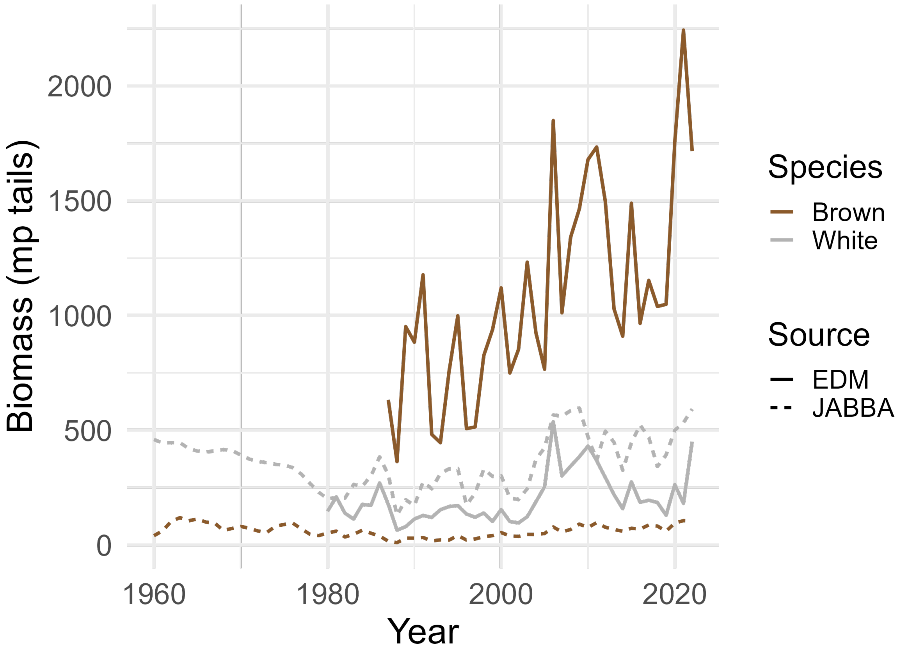


Figure 50: Estimates of total population biomass in million pounds of tails from EDM and JABBA for Brown and White Shrimp.

JABBA Brown Shrimp model estimated a very high fishing mortality rate, particularly at the start of the index of abundance in 1987 (*Figure 51*). Surplus production models like JABBA are very rigid in how mortality estimates and carrying capacity are defined. For penaeid shrimp species in the Gulf, it is likely that their carrying capacity increases and decreases due to environmental conditions. In 1988, there was a hard freeze (anecdotal) that resulted in poor conditions for shrimp throughout the Gulf. This was the only year that all surveys and models estimated all species (other than Pink Shrimp) to be less than their respective B_{MSY}. Estimated fishing mortality rates for Brown and White Shrimp from EDM appear more feasible and in line with how we would expect the relative magnitudes to align.

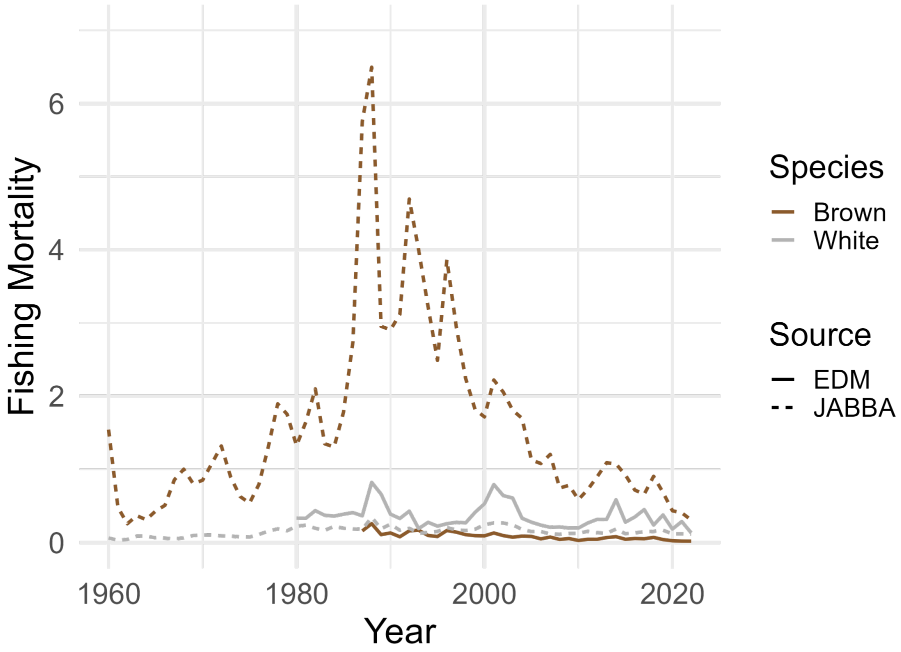


Figure 51: Fishing mortality rate estimates for Brown and White Shrimp from EDM (solid line) and JABBA (dashed line).

EDM model results for biomass, fishing mortality, and the respective benchmarks appear to be robust for Brown and White Shrimp. They also align with our understanding of the relative distribution of these species throughout the Gulf.

5.5 Biomass Estimate from SEAMAP Estimate

The Review Panel asked the analysts to convert the SEAMAP Brown Shrimp index into an absolute measure of biomass using the "swept area method" to compare with JABBA and EDM results.

The calculations were done as follows:

Total biomass = mean weight of catch per hour * total trawlable area / area swept in km^2 per hour

Area Swept was calculated by multiplying vessel speed with fishing time and the net opening
Area swept in km^2 per hour = speed in km per hr * 1 hour fishing time * net opening in km

Target speed assumed was 3 knots (5.556 km/hr) and the net opening was 31 ft (0.0094488 km), resulting in an area swept of 0.05249753 km^2 per hour.

Assuming a SEAMAP trawlable area for shrimp statistical zones 11 through 21 of 113,013 km^2 (estimate obtained from the SEAMAP survey team) results in the annual estimates of total biomass presented in *Table 3*.

The analysts pointed out to the Review Panel that these figures assume a catchability of 1 and a two dimensional space, when in reality shrimp are found above and below the net and catchability should not be expected to be close to 1. In addition, the total trawlable area covered by SEAMAP in SSZ 11-21 does not cover the entire fishing grounds over which Brown Shrimp are found. These estimates should therefore be treated as minimum bounds on biomass. These biomass estimates hover around 1-2% of the biomass estimates coming out of EDM and 10-40% of the biomass estimates obtained in JABBA (assuming *B/K*~.25).

Table 3: Brown Shrimp biomass estimates obtained using the "swept area method"

Year	Total biomass (mp whole weight)
2022	31.33
2021	29.31
2020	19.65
2019	14.58
2018	18.52
2017	17.72
2016	17.33
2015	23.35
2014	15.92
2013	17.47
2012	27.44
2011	28.54
2010	27.13
2009	26.15
2008	20.16
2007	15.90
2006	27.20
2005	11.32
2004	13.36
2003	12.97
2002	12.52
2001	10.54

Table 3 continued: Brown Shrimp biomass estimates obtained using the "swept area method"

Year	Total biomass (mp whole weight)
2000	15.80
1999	12.28
1998	9.87
1997	7.46
1996	6.96
1995	14.61
1994	10.87
1993	6.25
1992	7.69
1991	16.79
1990	13.32
1989	12.31
1988	5.27
1987	9.24

6. References

Munch, S. B., V. Poynor, and J. L. Arriaza. 2017. *Circumventing structural uncertainty: A Bayesian perspective on nonlinear forecasting for ecology*. Ecological Complexity 32:134–143.

Pollack, A., M. Masi, D. Hanisko, K. Craig, J. Williams, M. Smith, S. Munch, B. Gallaway, J. Nance, D. Gregory, J. Rester, C. Somerset, and L. Bosarge. 2023. *SEAMAP trawl shrimp data and index estimation work group report*. Page 119pp. SEDAR, SEDAR87-RD-01, North Charleston, SC.