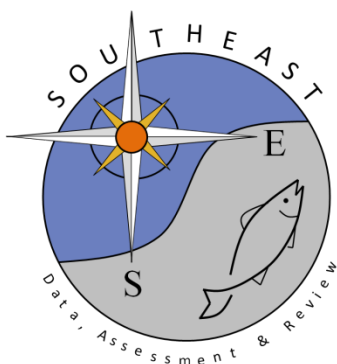


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SEDAR100-DW-22

12 December 2025



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Please cite this document as:

Peterson, Cheston T., Carly Daiek, Kyle Dettloff, Steve G. Smith, and Sarina Atkinson 2025. Estimation of Gray Triggerfish Bycatch from Gulf of America Shrimp Trawls. SEDAR100-DW-22. SEDAR, North Charleston, SC. 23 pp.

SEDAR 100 Working Paper

Estimation of Gray Triggerfish Bycatch from Gulf of America Shrimp Trawls

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September 2025

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Introduction

Bycatch of non-target species in Gulf of America (formerly Gulf of Mexico) shrimp trawls has been a pressing management concern for several decades. Procedures for estimating bycatch from shrimp fleet landings and effort, and catch-effort data from observer and SEAMAP sampling, were developed in the 2000s (Nichols 2004a,b) and routinely applied for stock assessments of bycatch species (e.g., Isely 2017). Prompted by concerns about the reliability of shrimp bycatch estimates, NOAA SEFSC (Southeast Fisheries Science Center) formed a project team in 2021 to investigate the bycatch input data sources, data processing procedures, and estimation methods. This research culminated in a revised methodology (Smith et al. 2023), that was reviewed by the Council of Independent Experts (CIE). The CIE reviewers found the revised bycatch methodology to be scientifically and statistically sound and agreed with the bycatch project team's conclusion that remaining reliability concerns pertained to issues with input data sources, specifically commercial shrimp landings and effort. This revised bycatch methodology was applied to Red Snapper for SEDAR 98 for the full observer time period, 2007-2023. A hindcast methodology was developed for the pre-observer time period using an updated time-series of commercial shrimp fleet landings (Atkinson et al. 2024) and effort (Dettloff 2024) as key data inputs and a modified hindcasting procedure developed for reef fish discards (Smith et al. 2019) to estimate historical strata CPUEs for Red Snapper (Smith et al. 2025).

Gray Triggerfish present a unique problem for shrimp bycatch estimation because they were not among the species for which data have been recorded in the observer program since mandatory coverage began in 2007. Shrimp bycatch of Gray Triggerfish is known to occur based on a set of full characterization observer trips that occurred from December 2001 to August 2002 (Scott-Denton et al. 2012). Previously, bycatch estimation was done using a WinBUGS Bayesian modeling approach developed by Nichols (2004a, 2004b, 2006) using several historical trawl observer and experimental studies, supplemented heavily with the SEAMAP trawl survey data (Zhang, 2020). Because the SEAMAP survey samples habitats outside of the areas of operation of the commercial shrimp fleet, shrimp bycatch estimates derived from those data were thought to be potentially biased. Additionally, the bycatch estimation methods used for Red Snapper in SEDAR 98 (Smith et al. 2025) could not be applied directly to Gray Triggerfish due to their absence in the observer data. Instead, bycatch estimation was applied to proxy species for Gray Triggerfish based on a co-occurrence analysis of SEAMAP data, which were filtered to reflect commercial shrimping grounds/habitat as accurately as possible. Annual bycatch estimates (1984-2023) were then calculated using the same methodology applied to Red Snapper in SEDAR 98 and calibrated based on catch-per-unit-effort (CPUE) ratios of Gray Triggerfish and the proxy species in the filtered SEAMAP dataset. This working paper describes the filtering process applied to the SEAMAP dataset, the co-occurrence analysis used to determine proxy species for Gray Triggerfish, and estimates of shrimp trawl bycatch for Gray Triggerfish using the calibrated estimates using the methodology applied to Red Snapper in SEDAR 98.

Methods

Estimation of Gray Triggerfish shrimp trawl bycatch consisted of three phases: **1)** filtering the SEAMAP data to best represent shrimp habitat; **2)** conducting a stratified co-occurrence analysis of Gray Triggerfish and species tracked by the shrimp observer program to determine proxy species using the filtered SEAMAP data; **3)** estimation of shrimp bycatch of proxy species using the methods in Smith et al. (2025) and calibration to Gray Triggerfish based on CPUE ratios from the filtered SEAMAP data. In addition to bycatch estimation, analyses of

the complete bycatch characterization observer data – including comparisons with standard trips and co-occurrence analysis are presented in Appendices 1 and 2, respectively.

Filtering SEAMAP data

The overall workflow for processing SEAMAP data involved two main steps: initial data cleaning and habitat-based filtering. Data were cleaned following instruction from SEFSC staff and subset to include only tows matching standard shrimp trawls (gear size 40, gear type "ST", mesh size 1.63 inches, and operation type 'W' or NA) from 1983-2023. These filtered inventory records were then joined with station and cruise records. A further filter was applied to retain only data from Fall and Summer Groundfish Surveys, excluding Texas (TX) trawls.

Habitat filtering consisted of a series of flags to each tow based on biological and spatial characteristics to further refine the dataset to shrimp habitat. The data removal rates associated with these flags are detailed in Table 1 and are visually represented in Figure 1. The final SEAMAP tows used for analysis can be seen in Figure 2. There were four habitat filters applied:

- 1. Known Reef Habitat Intersection (Figure 1a):** Tow tracks were constructed using start and end coordinates. If end coordinates were unavailable, start coordinates were used to create point features. Station geometries were then spatially intersected with a 500m UTM grid shapefile containing known reef habitat data from observer surveys. Tows were removed if any part of their track intersected a reef cell.
- 2. Hard Bottom Indicator Species (Figure 1b):** Stations were removed if their associated biological records contained any pre-identified 'hard bottom indicator species' (e.g., octocorals). The list of these 52 species was compiled from external references (Cairns et al. 2009, Chiappone et al. 2018, Etnoyer 2009, Enoyer et al. 2022, Giammona 1978, Jordán-Dahlgren 2022, Sánchez et al. 2005, Sánchez et al. 2019).
- 3. Commercial Shrimp Effort Area Overlap (Figure 1c):** Tow track geometries were spatially intersected with a shapefile representing commercial shrimp effort areas. Tows were removed if they did not intersect with these designated effort areas.
- 4. Penaeid Shrimp Catch (Figure 1d):** The total count of three specific Penaeid shrimp species (*Penaeus setiferus*, *P. duorarum*, and *P. aztecus*) was calculated for each tow, serving as a biological indicator of soft-bottom habitat. Tows with zero Penaeid shrimp count were removed.

Co-Occurrence Analysis of filtered SEAMAP data

A blocked co-occurrence analysis (Mackenzie et al. 2006, Smith et al. 2021) using area-season-depth strata was applied to the filtered SEAMAP dataset to identify proxy species from the pool of species tracked by the shrimp observer program. The co-occurrence species interaction factor (SIF) was calculated to evaluate the association between Gray Triggerfish and other species in the SEAMAP catch that are also tracked by the shrimp observer program. The SIF was the ratio of the observed co-occurrence of species A (Gray Triggerfish) and species B (potential proxy species) to the expected co-occurrence,

$$SIF = \frac{\text{observed co-occurrence}}{\text{expected co-occurrence}} = \frac{p(A, B)}{p(A)p(B)}$$

The observed co-occurrence $p(A, B)$ was estimated as the proportion of sample units capturing

both species, while the expected co-occurrence was estimated as the proportion of sample units capturing species A, $p(A)$, multiplied by the proportion of sample units capturing species B, $p(B)$. A value of SIF equal to 1 indicates the species were caught together by chance, SIF values greater than 1 indicate a positive association, and values less than 1 indicate a negative association. A chi-square test for the null hypothesis that $SIF=1$ was computed from a 2x2 contingency table consisting of sample units with neither species, both species, and only one of the two species (Smith et al. 2021). Standard sample sizes guidelines of $n \geq 5$ for each cell of the contingency table. If the chi-square test was unbalanced a Fisher's exact test was run instead. The co-occurrence analysis used a stratification, or blocking, scheme to allow for spatio-temporal flexibility in species associations and therefore multiple proxy species if necessary. This stratification scheme followed previous work in the Gulf (Smith et al. 2025) by using an Area-Season-Depth stratification consisting of four areas (Figure 3), three seasons, and two depth zones (≤ 10 fathoms and > 10 fathoms). Due to limited data availability, depth zones were pooled in Area 1.

Bycatch estimation of proxy species

Bycatch estimation was conducted on proxy species following the methods of Smith et al. (2023, 2025). The general approach to estimating bycatch involves two catch rate expansions: one estimating total fleet effort and one estimating total fleet catch/bycatch. Fleet effort for the observer time period (2007-2023) was estimated using shrimp catch and effort data for a subset of vessels equipped with GPS tracklog (ELB) devices (Smith et al. 2025, Dettloff 2023). Fleet catch of non-target species (discarded as bycatch) was estimated in the second expansion using onboard observer catch and effort data for a subset of vessel trips and the estimated fleet effort (Atkinson et al. 2024, Smith et al. 2025). GLM analysis of stratification variables confirmed that season, area, and depth were important variables for partitioning mean and variance of penaeid shrimp and non-target species catch rates.

Bycatch estimation for the pre-observer time period (1984-2006) entailed: development of a time-series of historical shrimp fleet landings for the three penaeid species (Atkinson et al. 2024), development of a time-series of historical shrimp fleet effort (Dettloff 2024, Atkinson et al. 2025), and modification of a hindcasting procedure developed for reef fish discards (Smith et al. 2019) to estimate historical strata CPUEs for non-target species. The hindcasting procedure used observer data for 2007-2013 to estimate the stratum-specific ratio of non-target species CPUE to penaeid shrimp CPUE. This ratio was applied to historical penaeid strata CPUEs from captain interviews to estimate historical strata CPUEs of non-target species. These were multiplied by strata fleet effort to obtain strata bycatch. A mandatory requirement to install bycatch reduction devices (BRDs) on shrimp nets was implemented in 1998. GLM analysis of paired-net experiments (with and without BRDs) conducted by the Shrimp Observer Program was used to adjust strata CPUE estimates of non-target species for the pre-BRD time period.

To calibrate bycatch estimates of proxy species to Gray Triggerfish, conversion factors were calculated for each strata based on catch rates of each species in the filtered SEAMAP dataset. The conversion ratio was calculated as

$$Conversion\ ratio = \frac{CPUE_{SEAMAP}^{GT}}{CPUE_{SEAMAP}^{ProxySp}} \times \hat{C}_{OBS}^{ProxySp}$$

To account for potential changes in the associations of Gray Triggerfish and proxy species through time, time-varying conversion ratios were applied using 3 eras: 1) 1987-2006, 2) 2007-2013, and 3) 2014-2023.

Bycatch Length Composition

Bycatch length compositions of Gray Triggerfish were derived from the filtered SEAMAP data set. First, bycatch length compositions of Red Snapper were developed from observer catch-at-length data and estimates of bycatch. Length data were pooled within season-area-depth strata across years corresponding to time periods used for bycatch estimation. Stratum bycatch was multiplied by the stratum proportion of length L to obtain stratum bycatch at length, summed over all strata to obtain the zone total at each length, and then converted to relative proportion at length (Smith et al. 2025). These length compositions were compared to the same frequencies in the filtered SEAMAP dataset to confirm the assumption that observed length compositions were similar to those in the SEAMAP catch.

Results

Proportions of SEAMAP tows removed with each of the four habitat filters applied are shown in Table 1. Ultimately, 36.94% of SEAMAP tows from 1983-2023 were removed. The zero shrimp catch filter removed the largest percentage of the original amount of tows (21.67%), but the change in cumulative percentage removed once this filter was applied following the others was less than 10% (Table 1). Maps showing the removed stations for each habitat filter are shown in Figure 1 and the final set of retained SEAMAP tows are shown in Figure 2.

Results of the co-occurrence analysis indicated Lane Snapper (*Lutjanus synagris*) were positively associated with Gray Triggerfish across nearly all strata (Table 2). Red Snapper (*L. campechanus*) were also positively associated with Gray Triggerfish and had a higher SIF value (i.e. association) in lower depths in Area 2. For some strata statistics could not be run due to sample size limitations but SIF values were greater than 1 (Table 2). Time of day was included in the co-occurrence analysis, but associations were found to be stable over the diel cycle. Lane Snapper were chosen as the proxy species for all strata except in the lower depth zone of Area 2 in all seasons (Table 3).

Estimates of Gray Triggerfish bycatch from commercial shrimp trawls for East, West, and Gulf-wide regions for 1984-2023 are provided in Table 4 and presented in Figures 4 and 5. Gray Triggerfish bycatch was substantially higher in the West Gulf compared to the East subregion (Fig. 4). Gulf-wide Gray Triggerfish bycatch peaked in the late 1980s at over 3.5 million fish, and has been below 1 million fish since 2010 (Fig. 5). These estimates were higher in most year than previous bycatch estimates provided for SEDAR 62 using the previous methodology, but past estimates were more volatile and achieved higher maximums (Fig. 5).

Bycatch length compositions were also provided for this assessment. Shrimp Observer and filtered SEAMAP Red Snapper length distributions were compared and found to be similar within area-depth-season strata (Fig. 6). Therefore, filtered SEAMAP length frequencies were considered representative of bycatch length frequencies and calculated based on the estimates of bycatch for both the East/West Gulf regions and Gulf-wide. The length range was 1.5 to 52.0 cm fork length, with 99.5% of the observations below the minimum legal size of 35.6 cm (Fig. 7).

Discussion

Regional and Gulf-wide shrimp trawl bycatch estimates of Gray Triggerfish were developed for SEDAR 100 by applying the methodology developed by Smith et al. (2025) to proxy species (Lane and Red Snapper) determined through stratified co-occurrence analysis of filtered SEAMAP trawl survey data. These estimates were dependent on recent estimates of shrimp fleet effort and commercial shrimp fleet landings (Dettloff 2024, Atkinson et al. 2025), and the general decline in bycatch over the time-series reflects the corresponding decline in fleet effort, similar to Red Snapper bycatch estimates in SEDAR 98 (Smith et al. 2025). Present estimates did not achieve the same highs and were generally less volatile as estimates provided in SEDAR 62, which used unfiltered SEAMAP data and a Bayesian modeling approach (Zhang 2020). Analysis of limited full-characterization observer data corroborated the co-occurrence results using filtered SEAMAP data and indicated Gray Triggerfish bycatch in Gulf shrimp trawls is non-zero (Scott-Denton et al. 2012).

The approach applied to here was intended as a stop-gap measure given the lack of commercial shrimp observer data for Gray Triggerfish. Future estimates of bycatch would be improved with consistent fleet observer data for Gray Triggerfish, and this should be considered for assessments of taxa not currently mandatorily quantified in the observer program. Addressing potential bias in SEAMAP sampling was effective for this application, but additional research would be needed to calibrate SEAMAP trawl survey data to commercial shrimp catch for all species. Moving forward, the SEFSC is in the process of improving bycatch estimation by 1) outfitting the commercial shrimp fleet with modern, tamper-proof GPS tracklog devices; 2) applying electronic technologies to enable observers to collect size information on all fish species captured in fish trawls; 3) modifying the allocation of observer sampling effort to better incorporate net configuration and diurnal period; and 4) scoping of field experiments for calibrating SEAMAP and commercial shrimp trawls.

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Table 1. Filters applied to SEAMAP Gulf summer and fall trawl survey data, number of tows removed, and percent removed.

Filter	Tows Removed (from original)	Percent Removed (from original)	Tows Removed (cumulative)	Percent Removed (cumulative)
<i>Intersected reef</i>	1189	4.87	1189	4.87
<i>Had indicator species</i>	1998	8.19	3153	12.92
<i>Fell outside effort</i>	4557	18.75	6802	27.87
<i>Had no shrimp catch</i>	5289	21.67	9017	36.94

Table 2. Results of co-occurrence analysis of Gray Triggerfish and potential proxy species, Red Snapper (*L. campechanus*) and Lane Snapper (*L. synagris*).

Area-Season-Depth	Proxy Species	Assoc.	SIF	Test Method	Statistic	p-value	Odds Ratio
1-2-x	<i>Lutjanus campechanus</i>	Positive	1.04	NA	NA	NA	NA
1-3-x	<i>Lutjanus campechanus</i>	Positive	1.34	chisq test	2.59	0.11	NA
2-2-1	<i>Lutjanus campechanus</i>	Positive	1.84	NA	NA	NA	NA
2-2-2	<i>Lutjanus campechanus</i>	Negative	0.71	NA	NA	NA	NA
2-3-1	<i>Lutjanus campechanus</i>	Positive	3.29	NA	NA	NA	NA
2-3-2	<i>Lutjanus campechanus</i>	Positive	1.29	chisq test	6.71	0.01	NA
3-2-1	<i>Lutjanus campechanus</i>	Positive	2.33	chisq test	11.01	<0.01	NA
3-2-2	<i>Lutjanus campechanus</i>	Positive	1.79	chisq test	134.28	<0.01	NA
3-3-1	<i>Lutjanus campechanus</i>	Positive	3.04	chisq test	54.02	<0.01	NA
3-3-2	<i>Lutjanus campechanus</i>	Positive	1.39	chisq test	242.78	<0.01	NA
4-2-1	<i>Lutjanus campechanus</i>	Positive	2.11	chisq test	32.13	<0.01	NA
4-2-2	<i>Lutjanus campechanus</i>	Positive	1.36	chisq test	41.96	<0.01	NA
4-3-1	<i>Lutjanus campechanus</i>	Positive	2.42	chisq test	16.97	<0.01	NA
4-3-2	<i>Lutjanus campechanus</i>	Positive	1.14	chisq test	89.01	<0.01	NA
1-2-x	<i>Lutjanus synagris</i>	Positive	1.12	NA	NA	NA	NA
1-3-x	<i>Lutjanus synagris</i>	Positive	1.04	chisq test	0.20	0.65	NA
2-2-1	<i>Lutjanus synagris</i>	Neutral	0.00	NA	NA	NA	NA
2-2-2	<i>Lutjanus synagris</i>	Positive	3.82	NA	NA	NA	NA
2-3-1	<i>Lutjanus synagris</i>	Positive	2.37	NA	NA	NA	NA
2-3-2	<i>Lutjanus synagris</i>	Positive	2.36	chisq test	27.51	<0.01	NA
3-2-1	<i>Lutjanus synagris</i>	Positive	2.36	Fisher test	NA	0.02	2.95
3-2-2	<i>Lutjanus synagris</i>	Positive	2.63	chisq test	210.75	<0.01	NA
3-3-1	<i>Lutjanus synagris</i>	Positive	2.57	chisq test	20.74	<0.01	NA
3-3-2	<i>Lutjanus synagris</i>	Positive	1.85	chisq test	350.86	<0.01	NA
4-2-1	<i>Lutjanus synagris</i>	Positive	3.42	Fisher test	NA	<0.01	9.96
4-2-2	<i>Lutjanus synagris</i>	Positive	2.03	chisq test	33.09	<0.01	NA
4-3-1	<i>Lutjanus synagris</i>	Positive	3.83	Fisher test	NA	<0.01	7.74
4-3-2	<i>Lutjanus synagris</i>	Positive	1.49	chisq test	120.91	<0.01	NA

Table 3. Proxy species used for each strata for bycatch estimation.

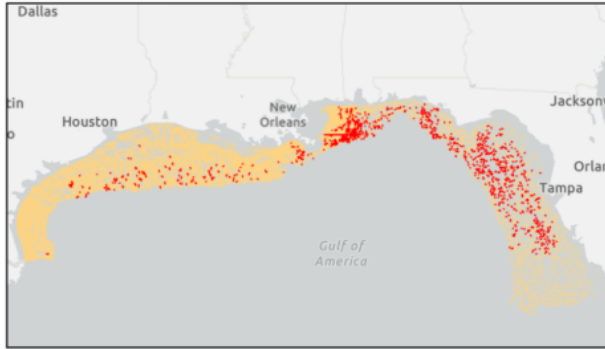
Area-Season-Depth	Proxy Species
1-1-x	<i>Lutjanus synagris</i>
1-2-x	<i>Lutjanus synagris</i>
1-3-x	<i>Lutjanus synagris</i>
2-1-1	<i>Lutjanus campechanus</i>
2-1-2	<i>Lutjanus synagris</i>
2-2-1	<i>Lutjanus campechanus</i>
2-2-2	<i>Lutjanus synagris</i>
2-3-1	<i>Lutjanus campechanus</i>
2-3-2	<i>Lutjanus synagris</i>
3-1-1	<i>Lutjanus synagris</i>
3-1-2	<i>Lutjanus synagris</i>
3-2-1	<i>Lutjanus synagris</i>
3-2-2	<i>Lutjanus synagris</i>
3-3-1	<i>Lutjanus synagris</i>
3-3-2	<i>Lutjanus synagris</i>
4-1-1	<i>Lutjanus synagris</i>
4-1-2	<i>Lutjanus synagris</i>
4-2-1	<i>Lutjanus synagris</i>
4-2-2	<i>Lutjanus synagris</i>
4-3-1	<i>Lutjanus synagris</i>
4-3-2	<i>Lutjanus synagris</i>

Table 4. Time-series (1984-2023) of annual Gray Triggerfish bycatch estimates and associated standard error for the West/East Gulf subregions and Gulf-wide.

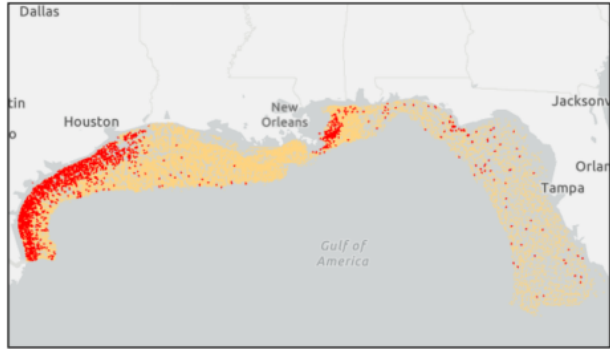
Year	East		West		Gulf	
	Bycatch	SE	Bycatch	SE	Bycatch	SE
1984	348,883	51,039	2,181,785	300,991	602,379	148,033
1985	390,068	54,298	2,397,973	329,808	670,997	178,256
1986	300,785	43,757	2,804,911	391,953	966,090	119,242
1987	430,966	65,524	3,206,838	459,509	540,201	50,701
1988	306,332	55,086	2,875,992	414,721	758,124	77,499
1989	298,776	51,267	2,751,088	385,031	704,027	94,371
1990	327,404	46,174	2,627,805	364,406	484,904	68,151
1991	267,675	42,356	2,714,367	392,295	660,309	55,952
1992	260,878	65,109	2,776,928	395,517	463,600	52,897
1993	275,399	41,411	2,694,047	391,001	437,446	51,893
1994	301,546	46,205	1,909,226	257,363	477,767	53,190
1995	456,167	77,144	1,589,749	223,185	424,302	40,706
1996	472,803	83,880	1,827,673	256,193	387,097	32,528
1997	445,693	93,359	2,218,890	321,520	368,221	31,366
1998	355,665	60,117	1,836,106	257,270	392,766	37,086
1999	249,506	38,249	1,891,162	278,825	257,934	19,562
2000	197,805	27,370	1,791,133	258,747	250,215	26,764
2001	201,124	28,334	1,411,184	219,230	2,530,668	307,430
2002	151,989	23,847	1,637,802	243,661	2,788,041	314,337
2003	139,340	26,969	1,237,157	186,654	3,105,696	349,112
2004	116,536	20,076	1,087,187	160,080	3,637,803	426,309
2005	83,861	14,885	854,585	121,871	3,182,324	427,100
2006	62,639	10,647	779,094	109,951	3,049,864	394,229
2007	140,290	39,430	462,089	114,883	2,955,209	317,663
2008	119,350	37,832	551,647	70,224	2,982,042	348,475
2009	102,596	16,604	863,494	110,293	3,037,806	579,787
2010	54,197	6,727	486,003	66,845	2,969,446	334,731
2011	69,321	9,912	688,803	82,488	2,210,772	274,235
2012	79,113	14,384	624,914	77,892	2,045,915	291,909
2013	35,973	7,615	448,932	67,211	2,300,476	349,643
2014	54,108	5,911	606,201	75,176	2,664,584	454,956
2015	34,799	2,926	428,801	172,639	2,191,771	296,618
2016	29,894	2,481	407,552	177,957	2,140,668	245,028
2017	33,993	2,629	443,774	218,757	1,988,938	202,757
2018	41,274	3,345	383,028	164,065	1,612,308	177,561
2019	36,419	2,818	350,678	126,095	1,789,791	202,955
2020	41,930	3,165	326,291	131,559	1,376,498	193,858
2021	36,414	2,996	356,352	142,460	1,203,723	150,714
2022	25,060	1,813	232,874	79,936	938,446	119,082
2023	22,525	1,907	227,690	102,109	841,732	101,584

Figure 1. Tows removed from SEAMAP summer and fall trawl survey data by filter type.

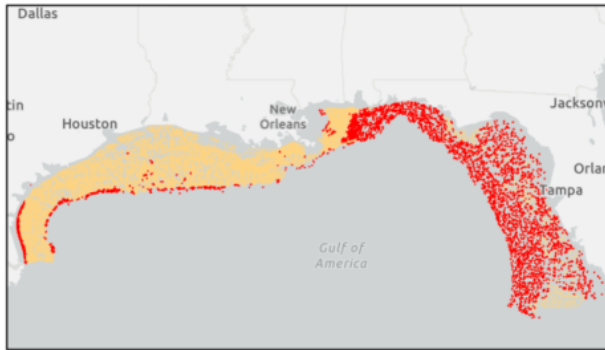
a.) Tows crossing into known reef habitat



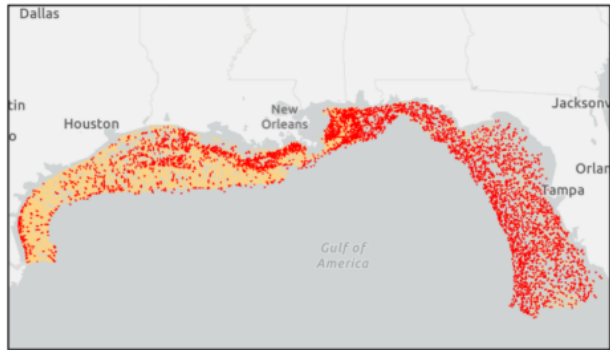
b.) Tows with indicator species catch



c.) Tows outside of known effort

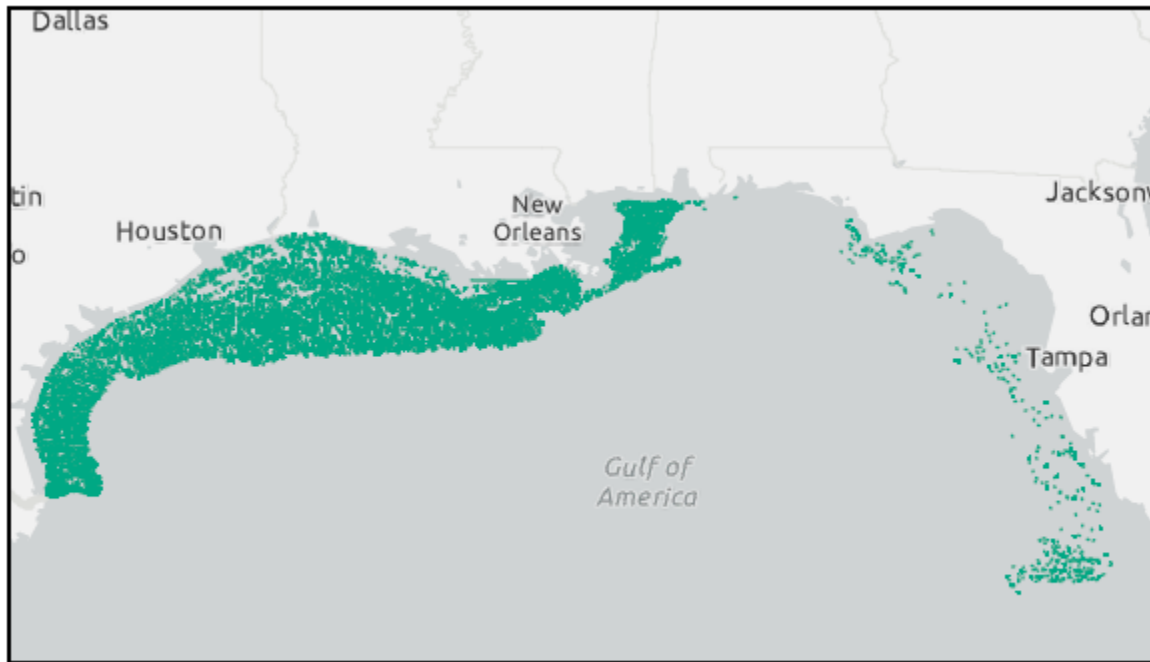


d.) Tows without shrimp catch



CONANP, Esri, TomTom, Garmin, FAO,
NOAA, USGS, EPA

Figure 2. Tows removed from SEAMAP summer and fall trawl survey data for analysis (i.e. the ‘filtered SEAMAP’ tows).



CONANP, Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA

Figure 3. Gulf of America subregions. Subregions correspond to Areas in the analysis. (Area 1 - East, Area 2 - Central, Area 3 - West LA, Area 4 - West TX. Figure from Atkinson et al. (2025).

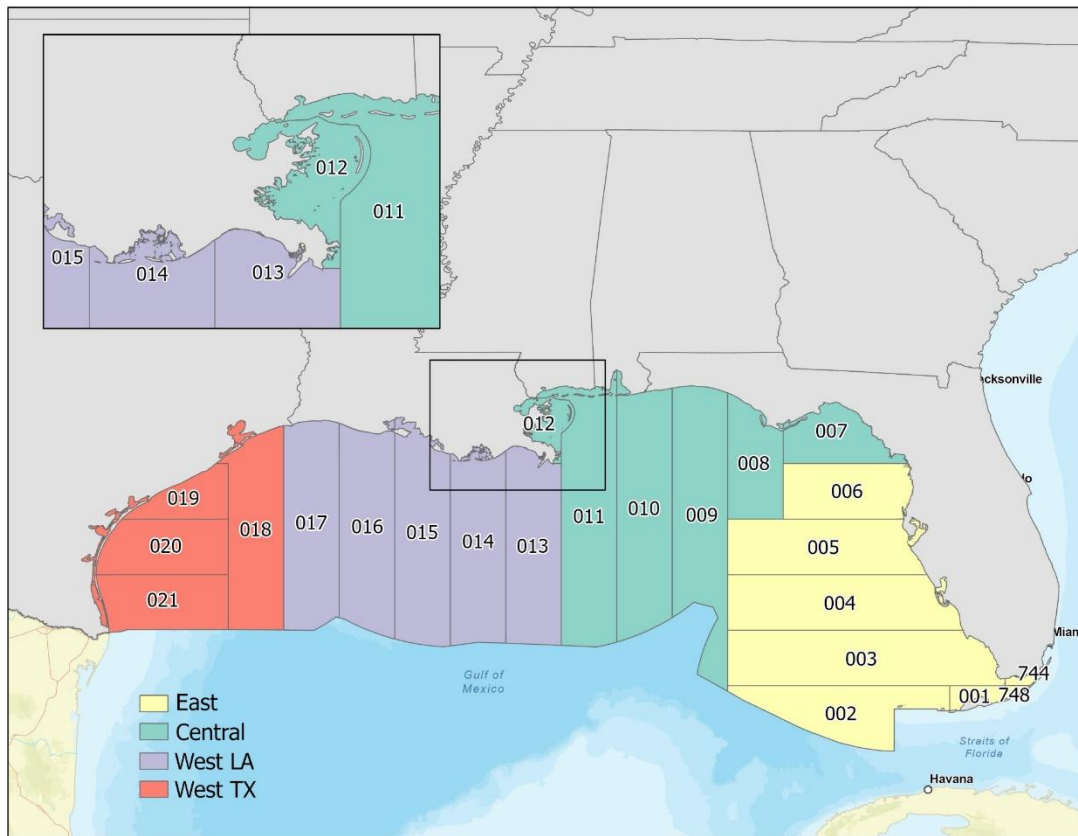


Figure 4. Gray Triggerfish bycatch time-series (1984-2023) and associated standard errors for West and East Gulf subregions.

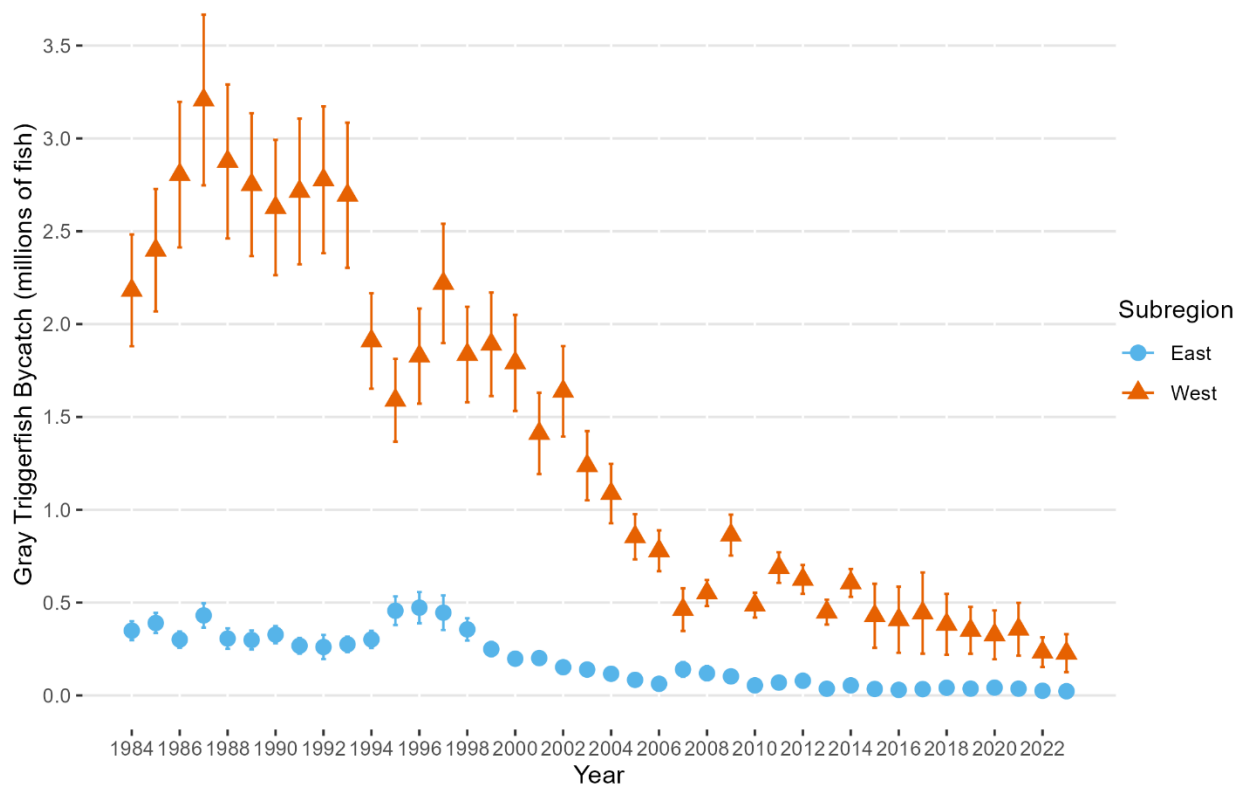


Figure 5. Gulf-wide Gray Triggerfish bycatch time-series (1984-2023) and associated standard errors compared to SEDAR 62 (Zhang 2020).

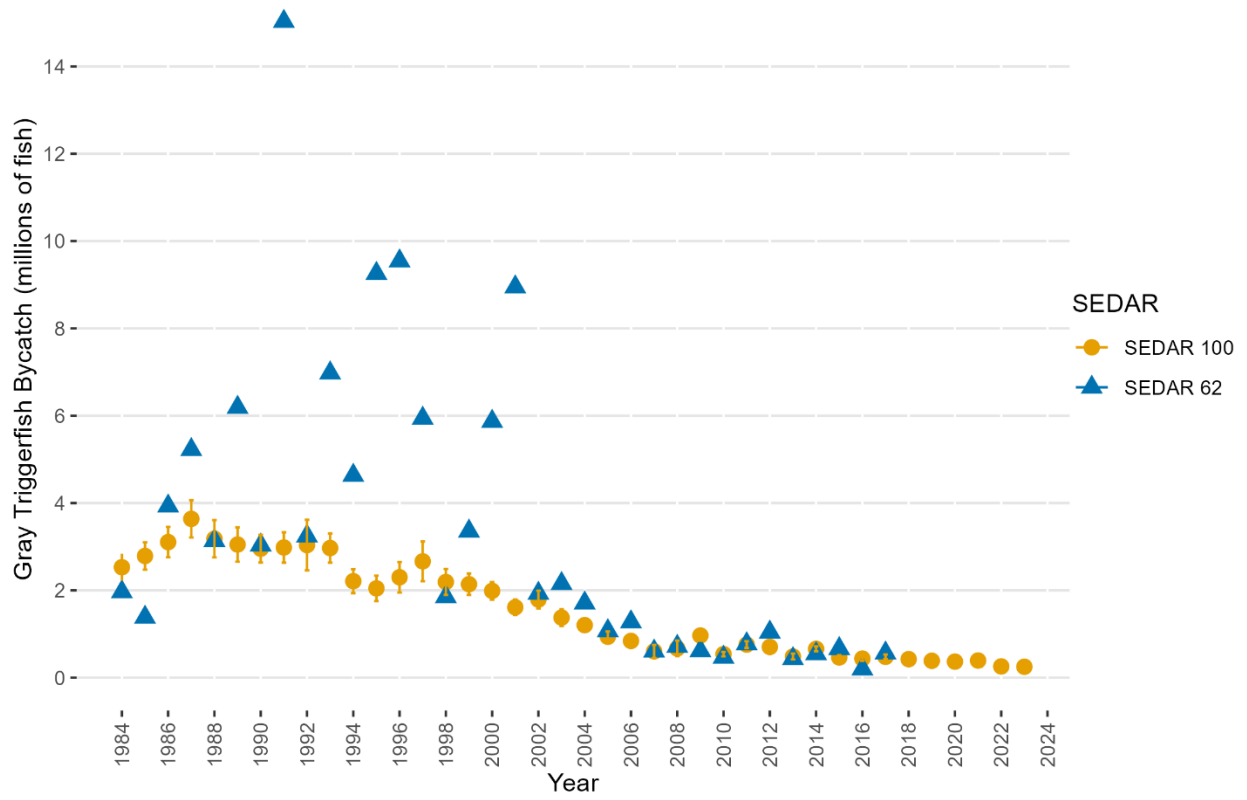


Figure 6. Example regional comparisons of Shrimp Observer and filtered SEAMAP Red Snapper length distributions: **(a)** Area 3, Depth zone 2, season 3 (Sep-Dec). **(b)** Area 4, Depth zone 2, season 3.

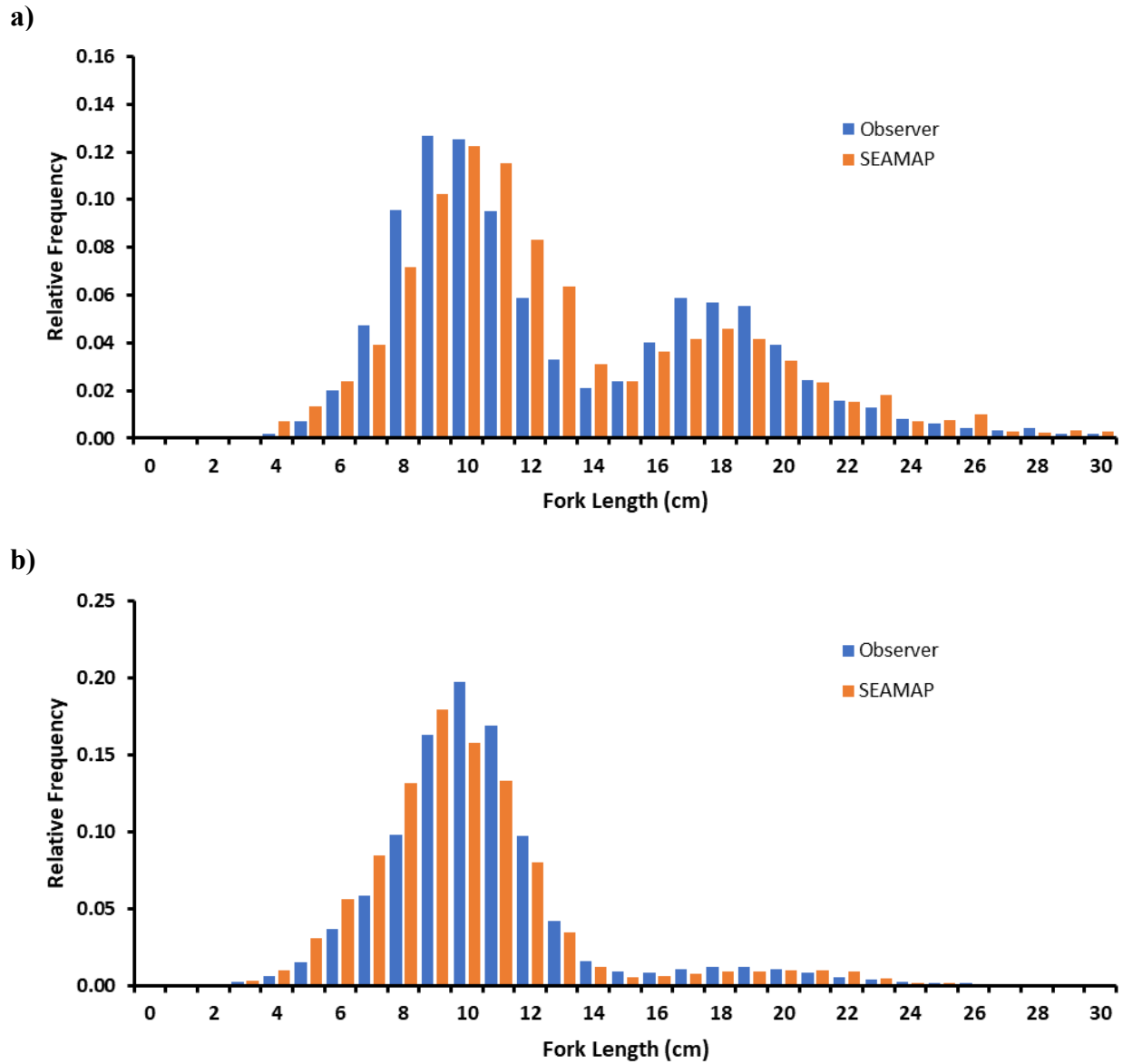
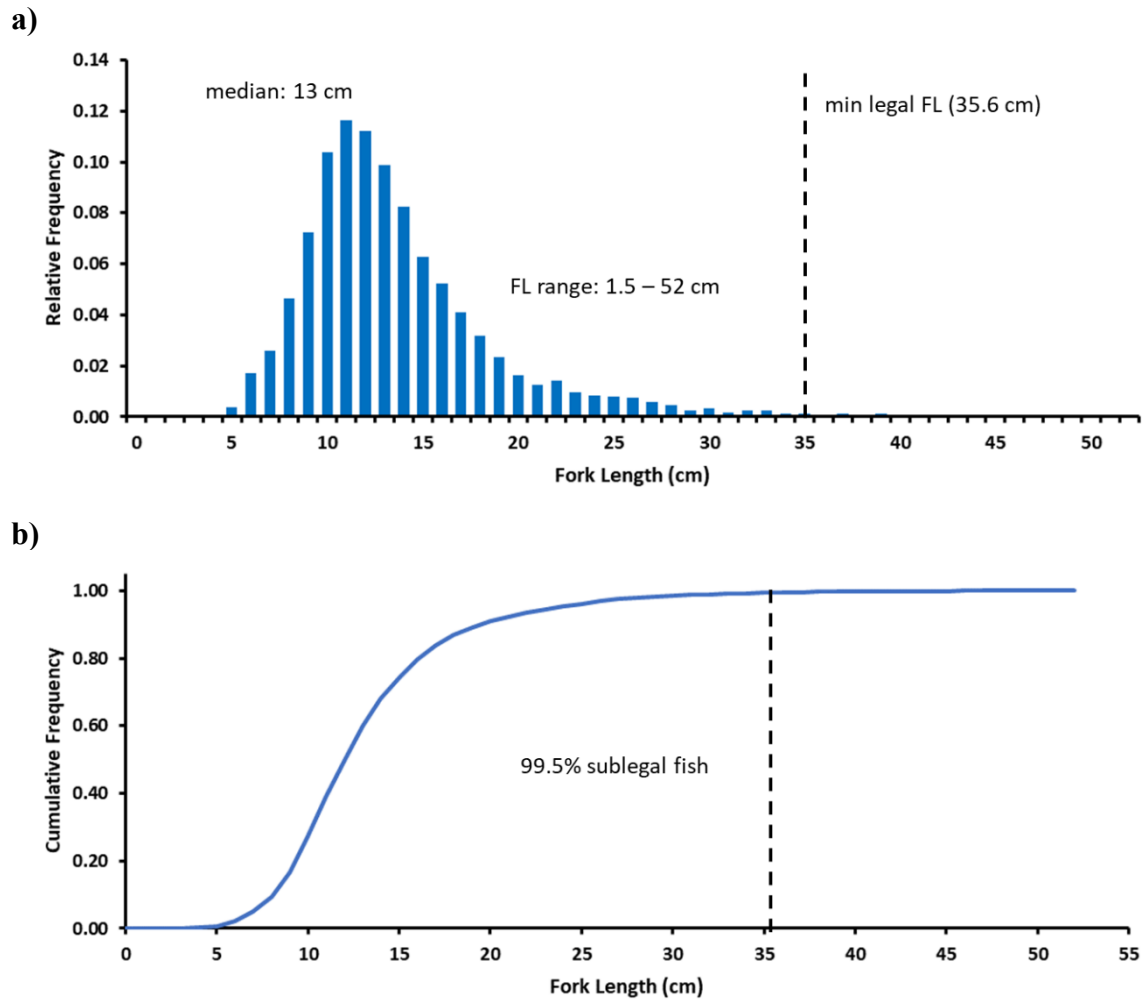


Figure 7. Observer sampling (2007-2023) Red Snapper bycatch length composition: **(a)** relative frequency; **(b)** cumulative frequency.



Appendix 1. Comparison of commercial shrimp full characterization observer trips to standard trips using GLMM

Between December 2001 and August 2002, complete species characterization of bycatch from commercial shrimp tows was performed on select observer trips spanning GoA statistical zones 1-8. A total of 511 tows from 23 trips and 11 vessels were included in this study. Tow times ranged from 1 to 11.9 hours (mean 3.9 hours), and all vessels towed four nets. 507 of the 511 tows occurred during nighttime hours (midpoint between 6:30pm and 6:30am). Sampling of nets was done fractionally and scaled up to the tow level based on total weight of the catch vs. sampled weight. Gray triggerfish were recorded on 36 of the complete characterization tows with positive catches in all seasons (Figures A1 and A2).

A zero-inflated negative binomial (with quadratic mean-variance relationship) generalized linear mixed model (GLMM) was fit using restricted maximum likelihood to the number of gray triggerfish reported at the set level on Gulf shrimp observer trips (including both complete characterization and standard trips (2001-2024) on which triggerfish were not required to be recorded) using R package glmmTMB (Brooks et al. 2017). Fixed effects for the count component included trip type (standard vs. complete characterization) and depth zone (≤ 10 ftm, >10 ftm), with a random intercept for trip ID and an offset for the natural log of nets sampled. Hours towed was included as a predictor in the zero component. Scaled quantile residuals indicated model assumptions were sufficiently met. Catch per unit effort (CPUE) estimates were calculated for each factor level combination of the fixed effects (2 trip types x 2 depth zones; `ggeffects::predict_response(margin = "empirical")`) and standardized to number per 24 trawling hours based on mean tow time and mean number of nets towed within each depth zone (Table A1).

There was no evidence of a difference between gray triggerfish CPUE based on standard observer (non-complete characterization trips) between the eastern (stat zones 1-9) and western (stat zones 10-21) Gulf ($p = 0.67$). Accounting for trip type, there was weak evidence of statistical differences between depth zones, with higher CPUE occurring in >10 ftm depths ($p = 0.064$); there were no apparent differences by season ($p = 0.77$). Overall, gray triggerfish CPUE was estimated to be 296 times higher on completely characterized vs. standard shrimp observer trips (95% CI: 57x-1526x, $p < 0.0001$).

Table A1. Model-predicted gray triggerfish catch per unit effort by observer trip type and depth zone for the Gulf shrimp fleet.

Characterization	Depth Zone	Positive Tows	Observed Tows	Predicted CPUE (number per 24 trawling hours)
Complete	<=10 ftm	2	257	18.4
Complete	>10 ftm	34	254	40.0
Standard	<=10 ftm	4	15,978	0.06
Standard	>10 ftm	52	24,809	0.14

Figure A1. Recorded gray triggerfish capture locations overlaid on shrimp fishery effort. “R” denotes standard shrimp observer trips (2001-2024, gray triggerfish not required to be recorded) and “C” denotes complete bycatch characterization trips (Dec 2001-Aug 2002).

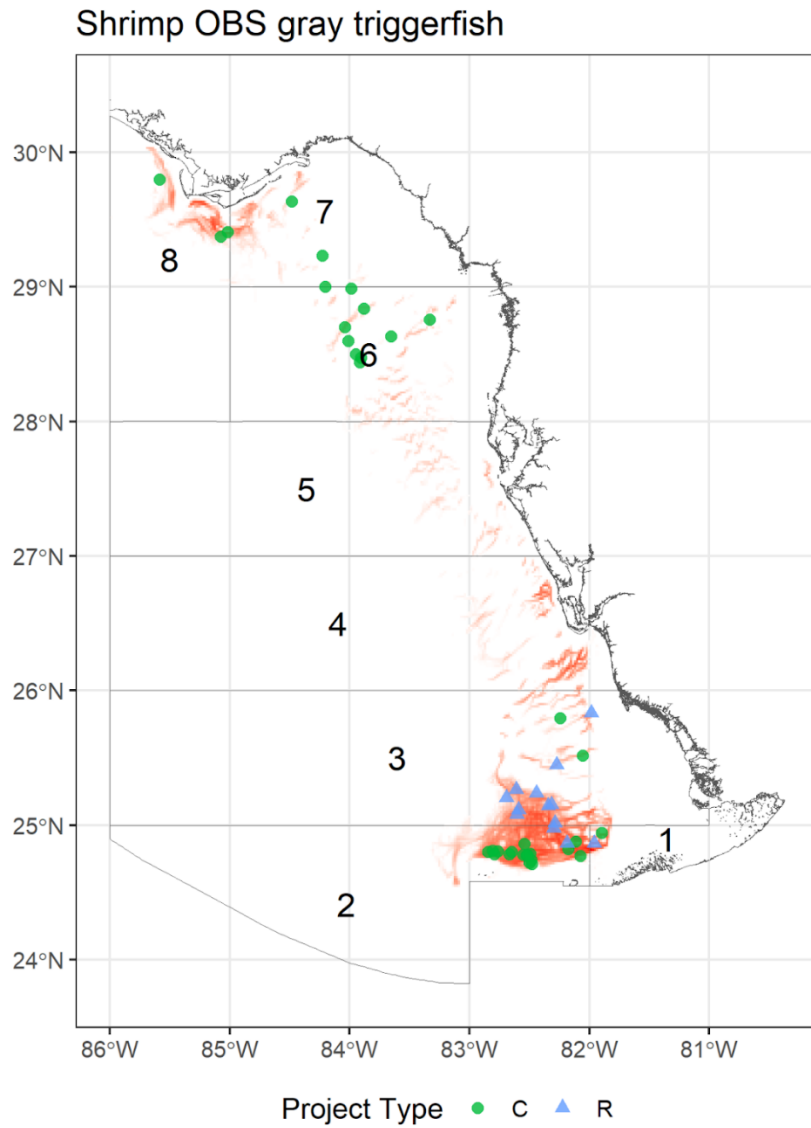
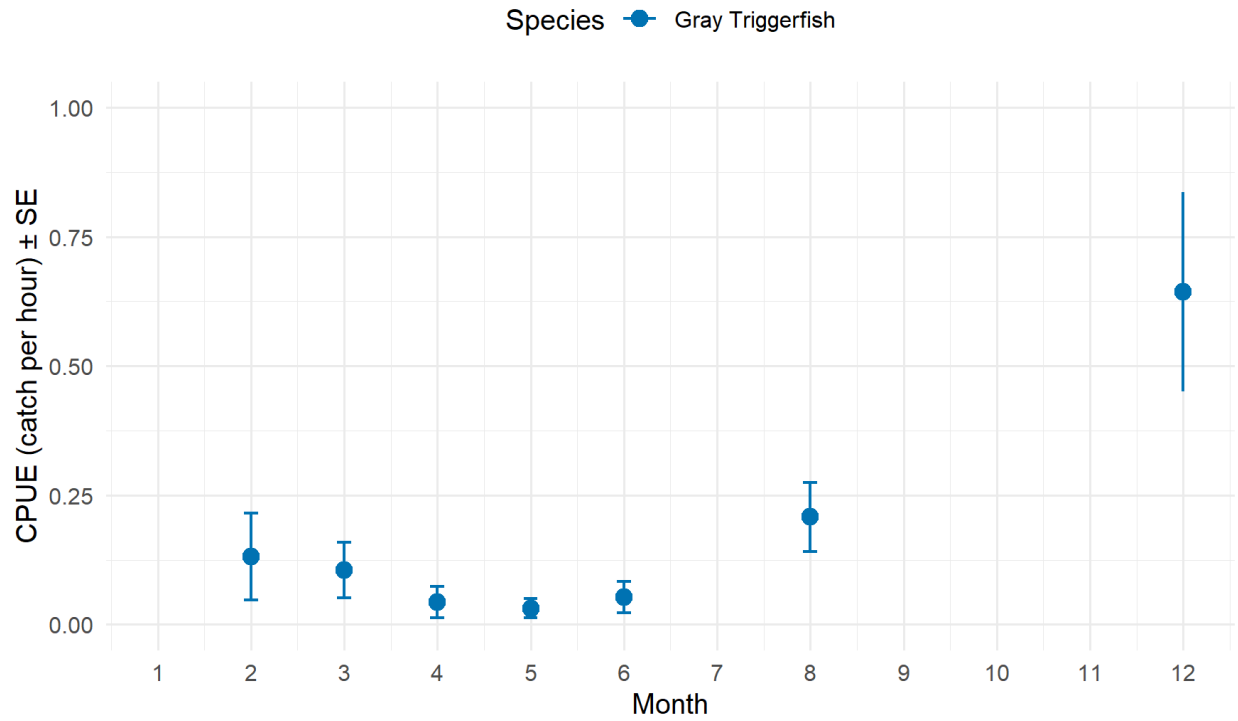


Figure A2. Catch per hour of Gray Triggerfish (scaled by total number of nets fished) in complete bycatch characterization shrimp observer trips across sampled months from December 2001 to August 2002 (i.e. no sampling occurred from September through November).



Appendix 2. Co-occurrence analysis of Gray Triggerfish, Lane Snapper, and Red Snapper in complete bycatch characterization shrimp observer trips

A co-occurrence analysis using identical methods to those described above was conducted on the complete bycatch characterization shrimp observer trips conducted briefly from 2001 to 2002. As data were limited and mainly collected in Area 1 (n = 428) with some sampling in Area 2 (n = 81), only an Area-Season stratification scheme was used. Due to low sample sizes statistics could not be run in most cases, however species interaction factors (SIFs) could still be calculated (Table A2). Despite the low sample sizes, these results corroborate our results and use of Lane Snapper as a proxy species for Area 1 and parts of Area 2.

Table A2. Results of co-occurrence analysis of Gray Triggerfish and potential proxy species, Red Snapper (*L. campechanus*) and Lane Snapper (*L. synagris*), using complete bycatch characterization shrimp observer trips.

Area-Season-Depth	Proxy Species	Assoc.	SIF	Test Method	Statistic	p-value	Odds Ratio
1-1	<i>Lutjanus campechanus</i>		NA	NA	NA	NA	NA
1-2	<i>Lutjanus campechanus</i>		NA	NA	NA	NA	NA
1-3	<i>Lutjanus campechanus</i>		NA	NA	NA	NA	NA
2-1	<i>Lutjanus campechanus</i>		NA	NA	NA	NA	NA
2-2	<i>Lutjanus campechanus</i>	Neutral	0.00	NA	NA	NA	NA
2-3	<i>Lutjanus campechanus</i>		NA	NA	NA	NA	NA
1-1	<i>Lutjanus synagris</i>	Positive	1.47	Fisher test	NA	0.31	NA
1-2	<i>Lutjanus synagris</i>	Positive	1.67	NA	NA	NA	NA
1-3	<i>Lutjanus synagris</i>		NA	NA	NA	NA	NA
2-1	<i>Lutjanus synagris</i>		NA	NA	NA	NA	NA
2-2	<i>Lutjanus synagris</i>	Neutral	0.00	NA	NA	NA	NA
2-3	<i>Lutjanus synagris</i>	Positive	1.25	NA	NA	NA	NA