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SEDAR 98 Working Paper

Estimation of Red Snapper Bycatch from Gulf of America Shrimp Trawls

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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. During the 1990s, devices installed on shrimp nets to limit bycatch of fishes and protected species (bycatch reduction devices, turtle excluder devices) were developed and implemented fleet-wide. 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 2004ab) and routinely applied for stock assessments of Red Snapper and other 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. The team focused on the 2014-2020 time period in which data from the key input sources were deemed most reliable: commercial shrimp landings from state trip-ticket program, GPS tracklog (ELB, electronic logbook) effort from federal vessels, and bycatch data from the mandatory SEFSC Shrimp Observer Program implemented in 2007. The team was able to substantially improve the bycatch estimation process as measured by a newly-developed verification procedure that provided a gauge for bycatch estimate reliability. This research culminated in a revised methodology, provided for SEDAR 98 as a Reference Document (S.G. 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 also 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.

For SEDAR 98, the challenge for the bycatch team was to estimate Red Snapper bycatch for the full observer time period, 2007-2023, and then extend this time series to pre-observer years as far back as practicable. This entailed developing an accurate time-series of commercial shrimp fleet landings and effort as key data inputs. Serendipitously, an SEFSC team had already begun work on these shrimp catch-effort time series for SEDAR 87 Gulf penaeid shrimp (brown, pink, and white). The two teams joined forces, incorporated CIE reviewer suggestions for rectifying remaining bias issues, and produced updated time series for commercial fleet shrimp landings (Atkinson et al. 2024) and effort (Dettloff 2024). This working paper describes modifications and extensions to the S.G. Smith et al. (2023) methodology for estimating bycatch of Red Snapper from Gulf shrimp trawls.

Methods

General Approach

The general approach for estimating bycatch entails two catch rate expansion estimates, one to estimate total fleet effort (f) and one to estimate total fleet catch/bycatch (C). For the initial analysis time frame 2014-2020, fleet effort was estimated using shrimp catch and effort data for a subset of vessels equipped with GPS tracklog (ELB) devices, assuming representativeness with shrimp fleet catch and effort,

$$\frac{c_{ELB}}{f_{ELB}} = \frac{c_{fleet}}{f_{fleet}} \quad . \qquad (1)$$

This relationship was then used to estimate shrimp fleet effort (tow hours),

$$\hat{f}_{fleet} = \frac{c_{fleet} \times f_{ELB}}{c_{ELB}} \quad , \qquad (2)$$

where the respective fleet and ELB catches are obtained from reported shrimp landings. Although referred to as an ‘electronic logbook’, the ELB device only records location at specified time intervals (i.e., in essence a GPS tracklog) and does not obtain the usual gear, catch, etc., information associated with commercial fleet logbooks. Fleet catch of non-target species (discarded as bycatch) was estimated using onboard observer catch and effort data for a subset of vessel trips, again assuming representativeness with fleet catch and effort,

$$\frac{c_{obs}}{f_{obs}} = \frac{c_{fleet}}{f_{fleet}} \quad . \qquad (3)$$

Fleet effort from Eq. (2) was used to estimate fleet bycatch,

$$\hat{C}_{fleet} = \frac{c_{obs} \times \hat{f}_{fleet}}{f_{obs}} \quad . \qquad (4)$$

Historical estimation procedures employed a space-time stratification scheme within years: geographical area, depth, and season (Nichols 2004ab, Isely 2017). The project team re-evaluated these stratification variables, as described below.

Summary of Methodology Reviewed by CIE

Key refinements to the bycatch estimation methodology described in S.G. Smith et al. (2023) are summarized as follows:

(i) Refinement and modernization of observer data processing

Fundamental refinements to legacy code and processing procedures included missing value coding and correction, data filtering to only include observer trips that conducted normal shrimp fishing operations, imputation of species weight when the subsampled catch was less than 0.1 kg, and streamlined procedures for incorporating valid zero catch observations at the species level.

(ii) Cross-checks for observer effort and catch

Cross-check procedures were developed to investigate observer effort and catch at the level of individual trips. Matched trips by observers on vessels with ELB units showed no systematic bias in observer trip effort compared with ELB-estimated effort. Likewise, matched observer-trip ticket trips showed no systematic bias in observer-estimated trip penaeid catch compared with trip ticket penaeid landings.

(iii) Observer catch-per-unit-effort (CPUE) estimation

Bycatch estimation using observer catch rates (Eq. 4) was carried out using a Horvitz-Thompson ratio-of-means estimator for a stratified sample frame (Lohr 2022), which accommodated varying levels of fishing effort among observer samples. Computational details are provided in S.G. Smith et al. (2023).

(iv) GLM analysis of stratification variables

General linear regression analysis was used to evaluate relationships between catch and effort and between CPUE and potential stratification variables. Regression models were developed of the general form,

$$Catch = f(effort, addtl.covariates) + \varepsilon \quad .$$

Results confirmed that season, geographical area, and depth were important variables for partitioning mean and variance of penaeid shrimp and Red Snapper catch rates. This analysis also identified two additional variables, trawl configuration (2-nets or 4-nets) and diurnal period (daytime, nighttime), that further improved estimation of mean and variance of CPUE. Combinations of trawl configuration and diurnal period were used to designate gear types: D2, daytime 2-net trawls; D4, daytime 4-net trawls; N2, nighttime 2-net trawls; and N4, nighttime 4-net trawls.

(v) Annual Landings and Gear survey data

A previously unused database, the SEFSC Annual Landings and Gear (ALG) mail survey of the commercial shrimp fleet (R. Smith et al. 2023), enabled incorporation of net configuration (2-net, 4-net) in the bycatch methodology. ALG data were used to delineate shrimp fleet catch and effort input data by nets per vessel.

(vi) Sparse sampling procedures

Commercial shrimp trips sampled by observers in a given year included most season-area-depth-gear strata, but not all. Stratification analysis of interannual variability showed that combining data across years for the same trawl configuration and diurnal period within area-depth-season strata did not introduce any systematic bias in CPUE estimates. Year strata were subsequently grouped into time periods of years to mitigate observer sampling issues. Variance of mean CPUE was computed using the average annual stratum sample size to avoid inflating the precision (i.e., treating the combined years as a single survey). A GLM imputation procedure was developed for remaining sparsely-sampled gear types (N2, N4, D2, D4) within specific season-area-depth strata, which accounted for 11% of fleet effort.

(vii) Verification procedure

A verification procedure was developed as a measure of reliability of bycatch estimates. This procedure applied the bycatch estimation methodology to estimate the annual landings of penaeid shrimp (brown, pink, white), the primary target of the shrimp fleet, and then comparing the estimated landings with the reported fleet landings.

Refinements and Extensions for SEDAR 98

For SEDAR 98, the above methodology was applied to the full observer time period 2007-2023. Area strata were configured to match Red Snapper West, Central, and East Gulf zones. Annual data for a given season-area-depth-gear stratum were grouped into two time periods, 2007-2013 and 2014-2023, corresponding with changes in ELB effort sampling (Dettloff 2024, Atkinson et al. 2025). GLM analysis was used to re-estimate mean catch-per-net for gear main effects (N2, N4, D2, D4) for shrimp species (brown, pink, white) and Red Snapper. These results were used for sparse sampling imputation, and to facilitate delineation of historical shrimp fleet landings and effort by the four gear types (Atkinson et al. 2024, 2025).

Bycatch estimation for the pre-observer time period 1984-2006 entailed: (1) development of a time-series of historical shrimp fleet landings for the three penaeid species (Atkinson et al. 2024); (2) development of a time-series of historical shrimp fleet effort (Dettloff 2024, Atkinson et al. 2025); and (3) modification of a hindcasting procedure developed for reef fish discards (Smith et al. 2019) to estimate historical strata CPUEs for Red Snapper. Historical shrimp landings and effort were obtained from federal port agent interviews of shrimp vessel captains (landings and effort) and shrimp seafood dealers (landings only). Starting in 1984, SEFSC port agent interviews of vessel captains recorded species-specific shrimp catch and effort by net configuration and diurnal period. Shrimp fleet landings transitioned from port agent interviews to dealer-reported state trip-tickets from 2000-2015 (depending on the state). Likewise, shrimp fleet effort transitioned from port agent captain interviews to ELB sampling in 2006. The hindcasting procedure used observer data for 2007-2013 to estimate the stratum-specific ratio of Red Snapper CPUE to penaeid shrimp CPUE. This ratio was applied to historical penaeid strata CPUEs from captain interviews to estimate historical Red Snapper strata CPUEs. These were multiplied by strata fleet effort to obtain strata bycatch (Eq.4). 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 Red Snapper strata CPUE estimates for the pre-BRD time period (1984-1997). To mitigate sparse annual sampling of strata for port agent captain interviews, years were combined into three time periods corresponding to changes in fleet effort and BRD requirements:

1984-1990: moderate fleet effort, no BRD requirement
1991-1997: high fleet effort, no BRD requirement
1998-2006: decreasing fleet effort, BRD requirement

Bycatch Length Composition

Bycatch length compositions for Red Snapper were developed from observer catch-at-length data and estimates of bycatch (Eq. 4). Analyses showed that Red Snapper length compositions generally differed with respect to season, area, and depth strata, but were similar for gear types (N2, N4, D2, D4) within strata. Length data were subsequently pooled within season-area-depth strata across gears and also across years corresponding to time periods used for bycatch estimation. Stratum bycatch $\hat{C}$ was multiplied by the stratum proportion of length L to obtain stratum bycatch at length,

$$\hat{C}(L)_h = \hat{C}_h \times p(L)_h \quad .$$

These were summed over all strata to obtain the Gulf zone total $\hat{C}$ at each length L

$$\hat{C}(L)_{zone} = \sum_h \hat{C}(L)_h \quad ,$$

and then converted to relative proportion of length L,

$$p(L)_{zone} = \frac{\hat{C}(L)_{zone}}{\sum_h \hat{C}_h} \quad . \qquad (5)$$

Results

Observer sample sizes by Gulf subregion for 2007-2023 are provided in **Table 1**. Plots of GLM-predicted catch by gear are illustrated for two shrimp species in **Fig. 1** and for Red Snapper in **Fig. 2**. Predicted catches differed with respect to net configuration and diurnal period for each species, and also among species. For Red Snapper, mean catch per net tow was over 5 times greater (i.e., 500%) for the nighttime 4-net gear compared to the daytime 2-net gear. Red Snapper mean catch per tow was 7.1% higher for nets without a BRD (**Table 2**). This difference was used to adjust bycatch observations for the pre-BRD time period of 1984-1997 in the hindcasting procedure.

Annual observer-predicted catches of penaeid shrimp (3 species) were compared with reported landings for 2007-2023 as a verification step for estimating bycatch (**Fig. 3**). Refinements in time-series of commercial fleet shrimp landings (Atkinson et al. 2024) and trawl effort (Atkinson et al. 2025), as well as modifications to bycatch data and estimation procedures, improved the correspondence of observer-predicted and reported penaeid landings for 2014-2020 over the initial verification estimates of Smith et al. (2023). Observer-predicted landings were generally lower than reported for the periods 2008-2013 and 2022-2023, coinciding with differing methods of collecting shrimp effort data compared to 2014-2020 (Atkinson et al. 2025).

Estimates of Red Snapper bycatch from commercial shrimp trawls for West, Central, and East Gulf regions for 1984-2023 are provided in **Table 3** and graphed in **Fig. 4**. Red Snapper bycatch was substantially higher in the West Gulf compared to the Central and East subregions. Gulf-wide Red Snapper bycatch peaked in the late 1990s at over 20 million fish, and has been at or below 10 million fish for the past decade (**Fig. 5**). Bycatch estimates provided for SEDAR 52 using the previous methodology showed similar patterns of increases and decreases over time, but were generally more volatile in terms of magnitude compared to estimates using the new methodology.

Bycatch length compositions were also provided for this assessment. Observers obtained 336,228 length observations for Red Snapper during 2007-2023. The length range was 1.5 to 88.5 cm fork length, but 99.2% of the observations were below the minimum legal size of 30.5 cm fork length (**Fig. 6**). An example comparison of cumulative length frequencies for 2007 (first observer year) and 2023 (last observer year) in the West Gulf shows slightly larger fish on average for 2007 (**Fig. 7**); however, annual differences in regional length compositions are likely driven by differences in fleet effort with respect to season, depth, and gear given that bycatch estimates and length compositions (eq. 5) were based on data pooled over periods of years (e.g., 2007-2013, 2014-2023).

Discussion

For SEDAR 98, the methodology of Smith et al. (2023) was refined and extended to estimate Red Snapper bycatch for the full observer time period, 2007-2023. Concurrent research provided key input time-series of commercial shrimp fleet landings (Atkinson et al. 2024) and effort (Dettloff 2024, Atkinson et al. 2025). The verification procedure comparing observer-predicted vs. reported penaeid landings showed improvement in the reliability of bycatch estimates using the refined methodology and input data streams compared to Smith et al. (2023), which was in turn a substantial improvement in reliability from the methodology used in SEDAR 52 and prior. These improvements can be attributed to three main factors: (i) incorporation of trawl configuration (2-nets, 4-nets) and diurnal period (daytime, nighttime) as additional stratification variables to area-season-depth; (ii) development of strata-specific time-series of shrimp landings; and (iii) development of strata-specific time-series of shrimp effort.

A hindcasting procedure was developed for estimating bycatch for the pre-observer years 1984-2006 using observer data for 2007-2013 and the improved time-series of shrimp landings and effort for 1984-2006. The key assumption was a stable relationship between strata-specific shrimp and Red Snapper catch rates. The resulting bycatch estimates for 1984-2006 generally tracked changes in shrimp fleet effort, and were less volatile in terms of magnitude compared to the estimates produced for SEDAR 52, which relied on SEAMAP trawl data as a proxy for commercial shrimp trawls. The analyses of catch rates by commercial gear types (**Figs. 1** & **2**) showing differences of over 500% depending on species, net configuration, and diurnal period indicated that equating SEAMAP trawls to commercial shrimp trawls might not be scientifically valid.

Bycatch of Red Snapper was 10 or more times higher in the West Gulf compared to the Central and East Gulf. The peak of bycatch in the late 1990s corresponded with the peak in shrimp fleet effort, and the historically lower bycatch of Red Snapper in the past decade matched with historically lower effort during this time. Length compositions showed that bycatch is focused on sublegal sizes of Red Snapper.

Looking to the future, SEFSC is in the process of improving bycatch estimation based on recommendations by CIE reviewers and the findings of this study. These improvements include:

- outfitting the commercial shrimp fleet with modern, tamper-proof GPS tracklog devices;
- applying electronic technologies to enable observers to collect size information on all fish species captured in fish trawls;
- modifying the allocation of observer sampling effort to better incorporate net configuration and diurnal period;
- scoping of field experiments for calibrating SEAMAP and commercial shrimp trawls.

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Table 1. Annual observer sampled tows and nets by Gulf subregion.

	West		Central		East	
Year	n_tows	n_nets	n_tows	n_nets	n_tows	n_nets
2007	646	1,134	17	22	--	--
2008	859	1,484	61	97	193	348
2009	734	1,150	128	191	269	509
2010	540	825	150	248	338	572
2011	732	1,059	95	134	226	402
2012	712	1,131	88	166	181	315
2013	988	1,468	173	281	154	278
2014	1,166	1,880	477	768	171	308
2015	650	1,027	302	498	289	525
2016	660	1,113	529	873	396	730
2017	1,151	1,917	544	902	278	504
2018	725	1,229	362	615	223	394
2019	370	569	294	489	208	385
2020	229	375	303	525	68	126
2021	1,310	2,130	367	566	448	808
2022	825	1,165	481	795	524	929
2023	678	1,105	381	584	291	525
Total	12,975	20,761	4,752	7,754	4,257	7,658

Table 2. GLM analysis results used to adjust Red Snapper bycatch estimates for the pre-BRD time period (1984-1997).

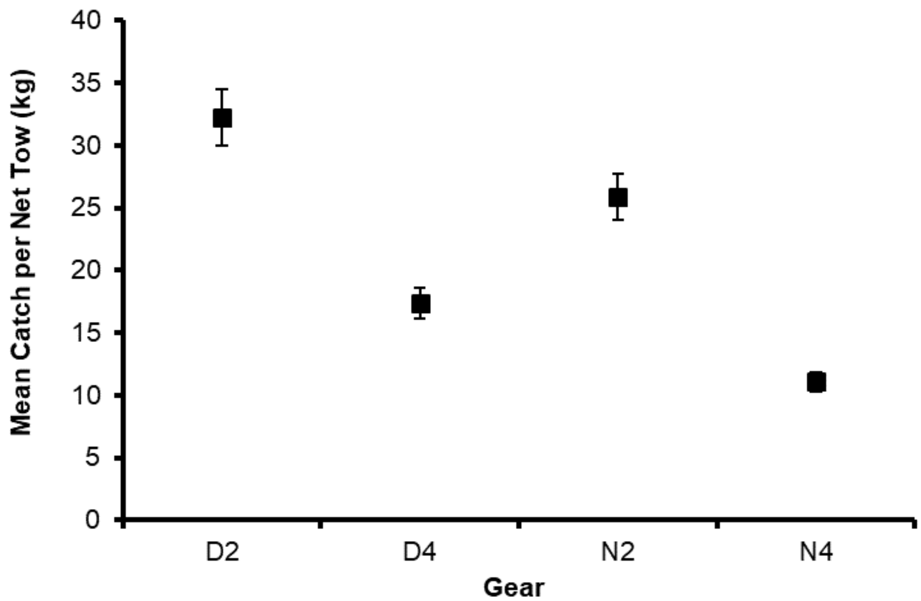
		GLM Estimates	
Paired-Net Tows	Net Type	Mean Catch	SE
830	No BRD	25.6	0.64
	BRD	23.9	0.64

Table 3. Time-series (1984-2023) of annual Red Snapper bycatch in numbers and associated CVs for the West, Central, and East Gulf subregions.

	West		Central		East	
Year	**Bycatch**	**CV**	**Bycatch**	**CV**	**Bycatch**	**CV**
1984	11,094,823	0.081	1,172,015	0.442	221,140	0.164
1985	12,380,165	0.076	1,087,535	0.439	234,456	0.163
1986	14,318,632	0.071	1,241,663	0.417	181,489	0.172
1987	16,356,390	0.074	1,387,341	0.440	229,635	0.169
1988	15,074,918	0.073	1,260,973	0.447	182,609	0.177
1989	14,585,967	0.074	1,287,579	0.430	185,504	0.183
1990	14,562,641	0.072	1,441,690	0.427	198,253	0.173
1991	14,347,129	0.073	1,292,179	0.448	157,281	0.173
1992	15,164,075	0.072	1,410,090	0.447	159,532	0.181
1993	15,363,625	0.073	1,133,612	0.502	158,781	0.172
1994	11,276,199	0.072	397,458	0.324	207,428	0.184
1995	9,863,335	0.071	373,284	0.294	257,754	0.176
1996	11,272,566	0.069	579,141	0.315	288,297	0.176
1997	13,251,104	0.068	792,867	0.326	258,454	0.180
1998	22,193,429	0.069	1,618,651	0.335	361,226	0.178
1999	21,650,136	0.070	1,633,375	0.361	242,205	0.180
2000	21,069,990	0.068	1,367,943	0.372	195,230	0.181
2001	15,592,406	0.070	1,539,984	0.421	225,587	0.185
2002	18,822,591	0.069	1,564,845	0.404	147,518	0.179
2003	14,157,819	0.070	1,263,123	0.388	127,370	0.178
2004	12,714,229	0.069	942,860	0.385	119,479	0.183
2005	10,298,769	0.068	587,795	0.319	85,795	0.182
2006	9,114,180	0.068	518,089	0.362	65,282	0.182
2007	10,312,639	0.076	238,017	0.238	147,096	0.180
2008	7,790,722	0.083	442,839	0.313	72,784	0.193
2009	11,080,587	0.072	521,565	0.302	111,793	0.192
2010	6,138,575	0.079	260,347	0.298	53,795	0.181
2011	9,400,457	0.068	232,999	0.230	68,894	0.177
2012	7,629,641	0.072	203,434	0.224	66,727	0.181
2013	4,040,861	0.127	796,414	0.441	41,013	0.257
2014	9,446,938	0.083	1,021,709	0.602	100,525	0.145
2015	9,477,171	0.180	663,237	0.138	178,944	0.126
2016	9,009,690	0.167	519,427	0.138	183,612	0.121
2017	8,669,013	0.174	531,606	0.131	213,362	0.133
2018	8,067,892	0.174	586,996	0.158	267,189	0.120
2019	7,117,805	0.164	491,851	0.146	232,380	0.131
2020	6,617,452	0.163	674,810	0.145	233,697	0.117
2021	7,725,846	0.173	566,370	0.160	223,163	0.114
2022	4,867,097	0.197	386,734	0.135	195,031	0.116
2023	4,648,856	0.196	424,468	0.155	112,167	0.109

Figure 1. Plots of model-predicted mean catch by gear for (A) White and (B) Pink Shrimp.

(A) White



(B) Pink

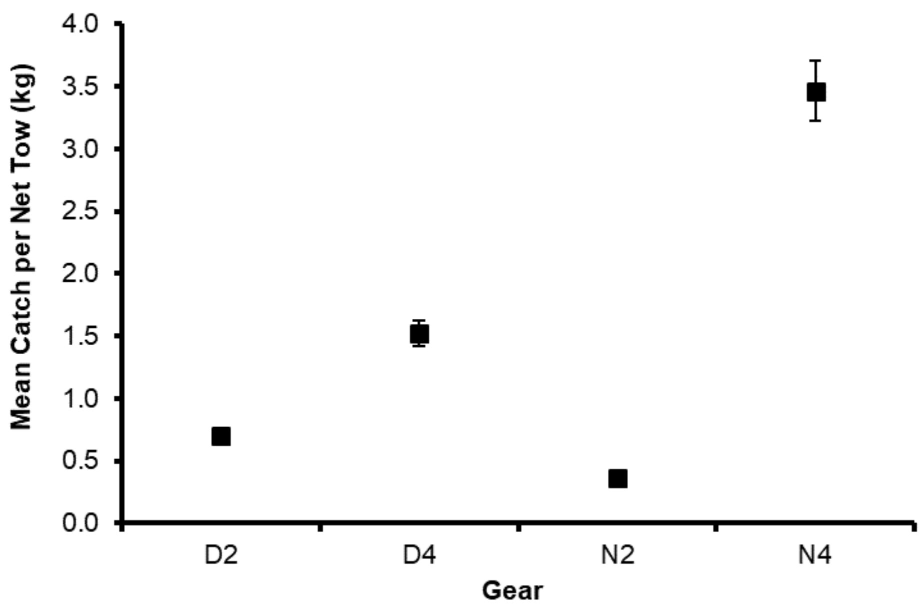


Figure 2. Plot of model-predicted mean catch by gear for Red Snapper.

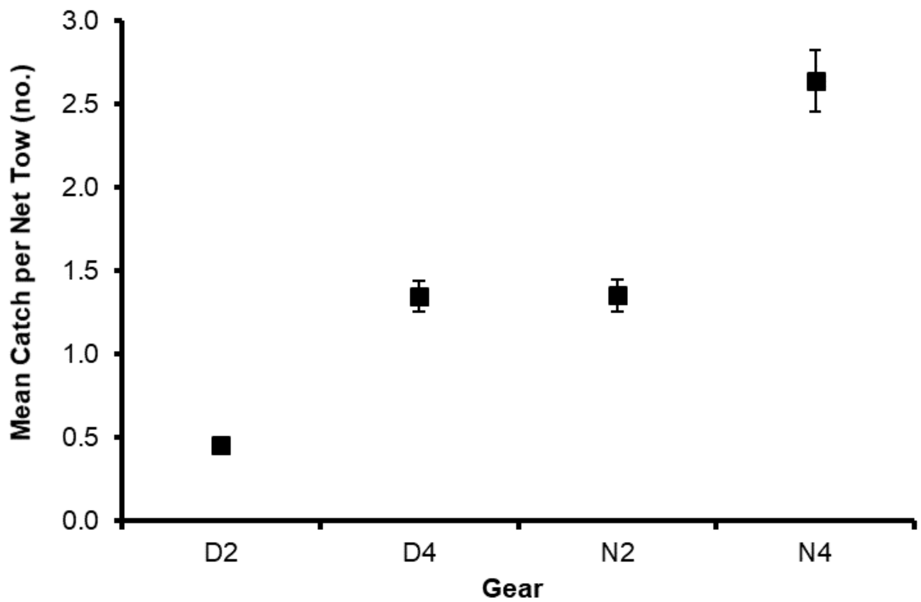


Figure 3. Comparison of reported penaeid shrimp landings (solid dots, line) with observer-predicted landings (open squares, ±SE), 2007-2023.

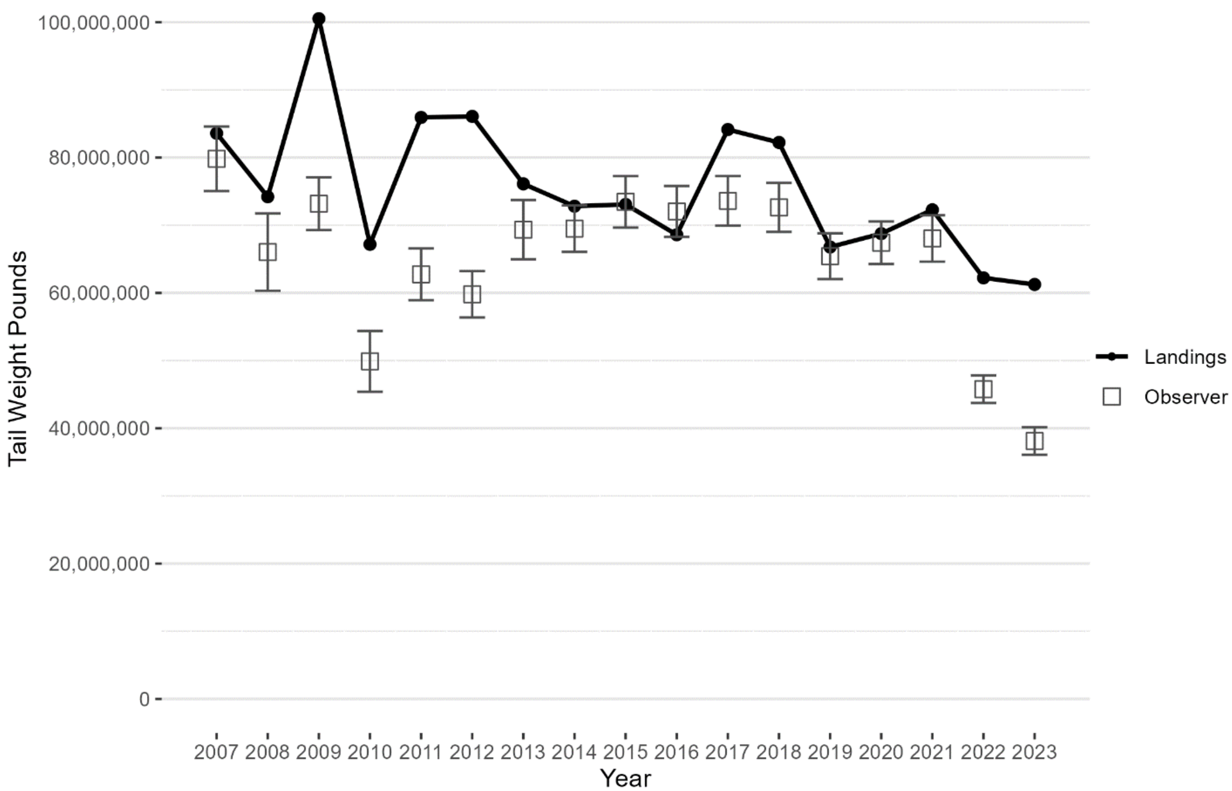


Figure 4. Red Snapper bycatch time-series (1984-2023) and associated standard errors for West, Central, and East Gulf subregions.

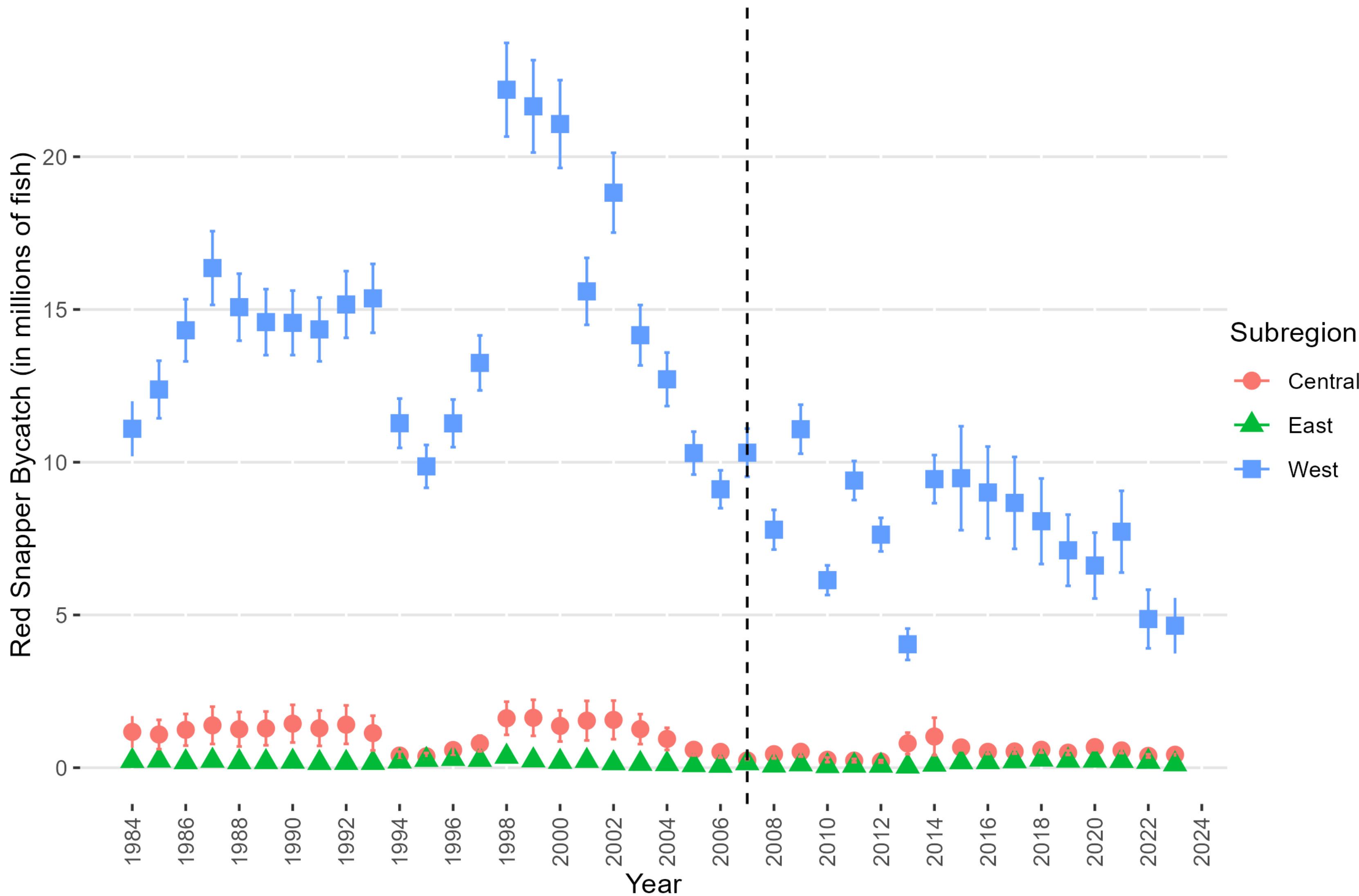


Figure 5. Comparison of Gulf-wide Red Snapper bycatch time-series for SEDAR 98 (triangles) and SEDAR 52 (circles).

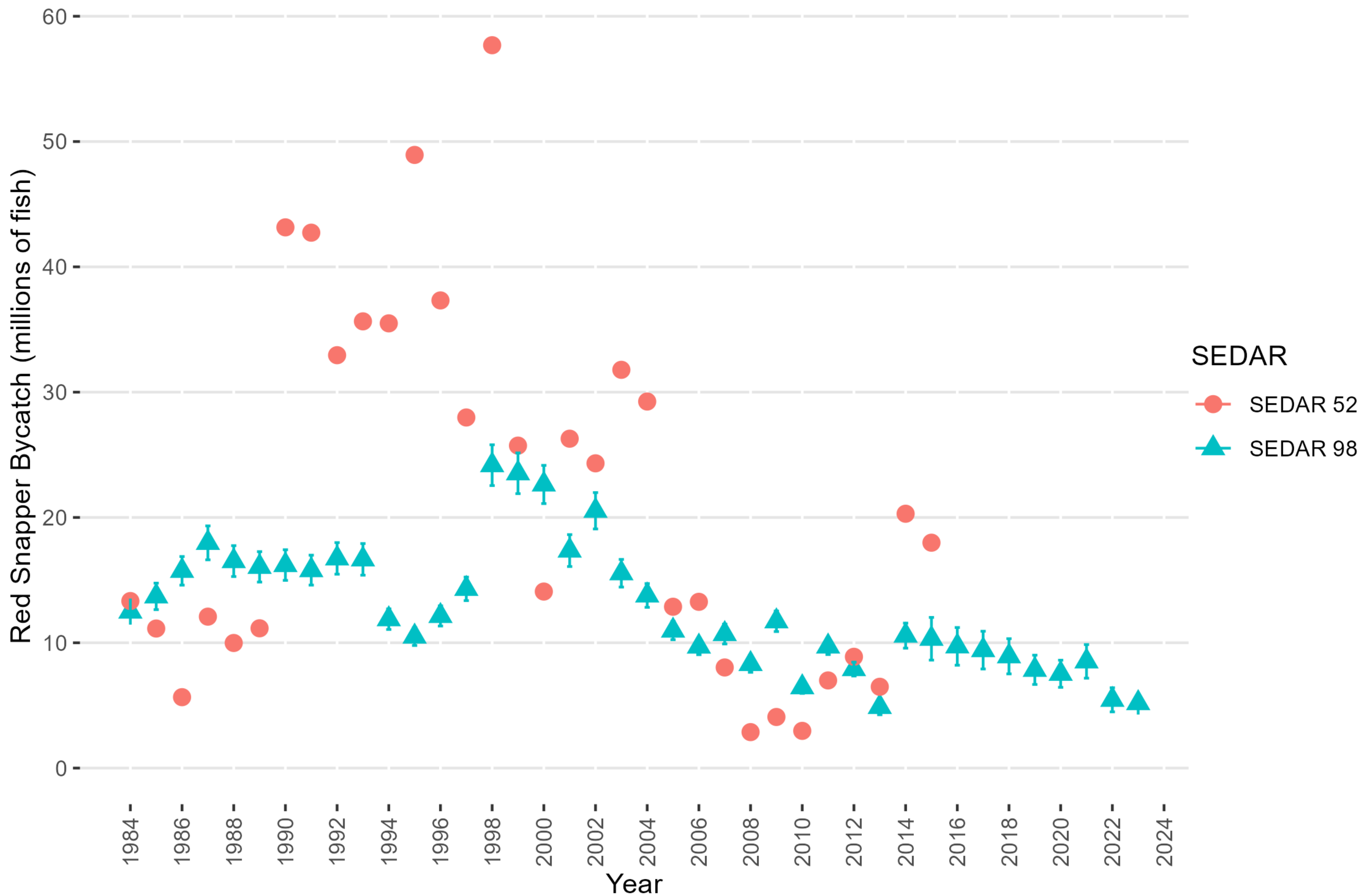
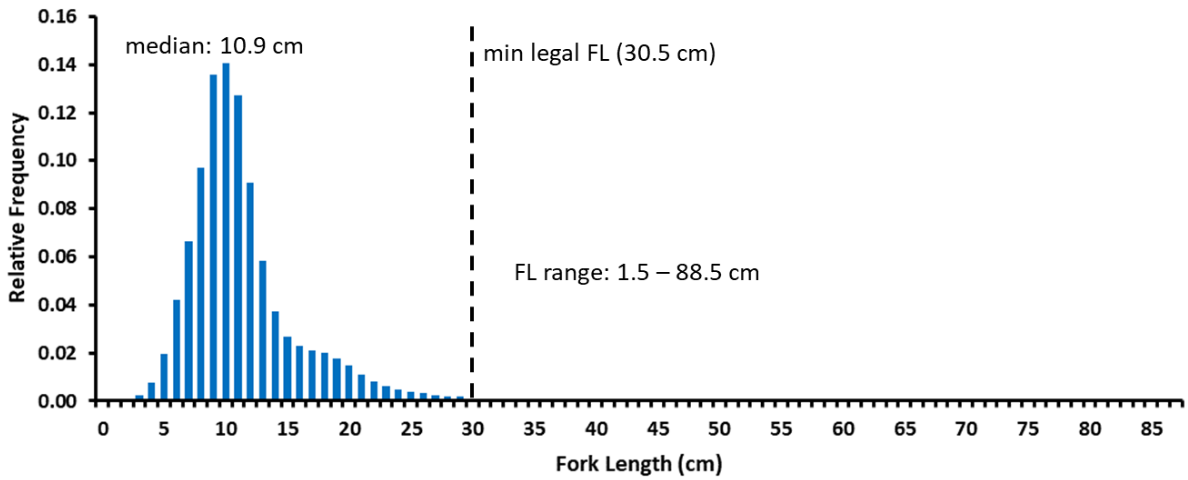


Figure 6. Observer sampling (2007-2023) Red Snapper bycatch length composition: (A) relative frequency; (B) cumulative frequency.

(A)



(B)

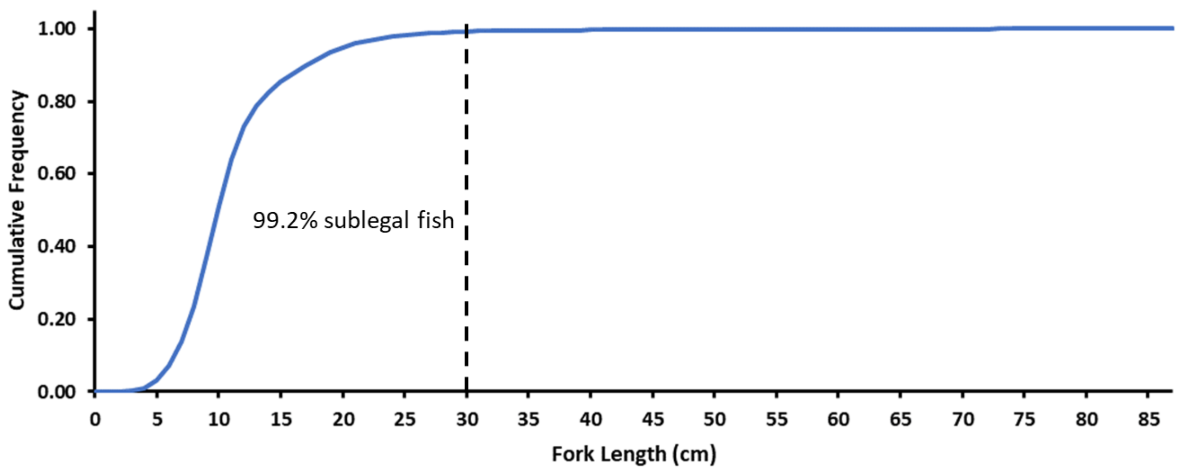


Figure 7. Observer program cumulative length frequencies of Red Snapper bycatch in the western Gulf for two example years, 2007 and 2023.