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Estimation of Commercial Shrimp Effort in the Gulf of Mexico from 1984-2023

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31 January 2025
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† Updated to include a table and additional results for calculating a calibration factor to adjust captain interview effort to electronic logbook and observer effort units.

Introduction

Penaeid shrimp effort in the Gulf of Mexico has non-universal coverage of the fleet. Therefore, trawling effort must be estimated from a sample of the fleet and scaled up to total effort using the landings. An improved method to estimate total shrimp effort was presented for SEDAR 87 (Dettloff 2024). This method was specifically focused on streamlining and simplifying the effort estimation procedure using cellular electronic logbook (cELB) data from 2014 to present. For shrimp bycatch of Red Snapper, total trawling effort of the shrimp fleet is needed from 1984-2023. The data collection of shrimp effort has changed over time and broken into three main time periods (Lowther 2023).

1. Captain interviews collected by NMFS port agents (1958-2014)
2. Electronic logbook positional data collected by LGL Ecological Research Associates (2006-2013)
3. Electronic logbook positional data collected by NMFS Southeast Fisheries Science Center (SEFSC) (2014-present)

Additionally, total trawling effort is needed with additional stratification variables not previously provided such as trawl configuration (two nets vs. 4 nets). This was the impetus to re-evaluate how total effort is calculated using port agent interview data and electronic logbook (ELB) data collected by LGL.

Due to the nature of the data collected over time (interviews vs. electronic logbook), the methods to estimate total effort slightly differ depending on the data available. Where possible, methods were standardized following the procedures presented by Dettloff (2024). Additional proportions were calculated to distribute effort across the necessary strata for shrimp bycatch. From

2007-2014, port agents were still conducting interviews and electronic logbooks were recording positional data for select vessels. These years were used to 1) adjust the interview reported hours trawled to more closely align with hours of trawling calculated from positional data and 2) compare total effort estimates from each source and method to produce a single time series.

Data Sources

Port agent interviews

Port agents assigned to specific ports along the Gulf of Mexico are responsible for collecting shrimp statistics from seafood dealers and fishermen. Data collected by the dealers are considered a census of shrimp landings in Gulf states. The interviews by captains or crew members are conducted on a subset of the fleet and include additional detailed catch and effort information. An excerpt from Nance (2004) summarizes the collection protocol of interview data:

> “Port agents only conduct interviews from a sample of the vessels that fish nearshore and offshore. The intent of this protocol is to select a few individuals that are representative of the total population and collect information from the sample rather than the entire population. The logistics of fishing, however, make it impossible for the port agents to perform interviews that are selected randomly from the vessel population. Most of the time port agents do not know where and when vessels are going to land, so specific vessels cannot be targeted in advance for selection. As a result, the port agents are instructed to regularly visit the docks in their areas and interview vessel captains as the opportunity arises. If there are more vessels in port than can be interviewed, the agents are instructed to select the vessels by "random" process, in an attempt to avoid systematic bias (i.e., always interviewing the same vessels, at the same port).”

Interviews were first conducted in 1958, where effort was reported at the trip-level as days fished. SEFSC took control of the Gulf Shrimp System (GSS) collection enterprise in 1984 which is also when port agents were asked to report trawling hours by time of day (day vs. night fishing with night defined as 6:30 pm - 6:30 am local time). The interview form also asked captains to report the number of trawls fished on a trip. Based on analyses conducted by Smith et al. (2023a), the time of day and trawl configuration have a significant impact on catch and effort. For this reason, shrimp effort estimation for SEDAR 98 will start in 1984 when port agents started collecting these two key variables.

Over time, port agent coverage began to decline as port agents retired or were reassigned and were not replaced and/or were asked to cover larger geographical areas. By 2014, port agents stopped conducting interviews.

Electronic Logbook

Summarized by Dettloff (2024):

> "Electronic Logbook (ELB) devices were originally developed by LGL in 2004 as a position logging system for commercial shrimping vessels in the Gulf of Mexico, with the goal of more accurately estimating spatial patterns of trawling effort than those collected by port agents. These devices record vessel location at 10 minute intervals using GPS, and the resulting speeds are used to identify potential vessel trawling activity. From 2004-2013, data from memory chips on these devices were collected and processed by LGL, and total fleet effort was estimated using LGL code. In mid-2013, these responsibilities were transferred to NMFS… In 2014, cellular Electronic Logbook devices (cELB) were implemented, in which positional data are automatically transmitted back to NMFS servers through the cellular network, as opposed to manual retrieval of memory chips. In early 2014, NMFS selected 500 Gulf of Mexico Shrimp Permit (SPGM) owners using a spatially stratified random sampling method weighted by landings in the prior season to participate in the cELB program. Consistent position data from devices were being received by the second quarter of 2014. An additional 100 vessels were selected to carry units in 2018."

From Lowther (2023):

> "In December of 2020 the 3G cellular network ceased to operate. While there had been some testing of replacement 4G units, these were not deemed to be a suitable replacement at the time. Thus, the data collection process reverted to the pre-3G period model, but instead of having staff remove and replace the SD cards, the vessel operators were sent replacement cards by mail and asked to do the switch themselves, and return the SD cards to NMFS. This is still the process in place as NMFS and the GMFMC continue to discuss new methods to collect effort data."

Vessel Operating Units (VOU)

In order to estimate effort by trawl configuration, two external data sources were used. The Vessel Operating Units (VOU) is an annual survey of active vessel participants in the Gulf of Mexico and South Atlantic fisheries. These data have previously been referred to as the vessel operation unit file (VOUF). VOU began in 1979 where port agents provide gear and vessel characteristics for active federal Coast Guard vessels larger than 5 tons.

Gear characteristics include number of full time crew, type of gear, number and quantity of gear, and the state and county in which the vessel operated during the year. The USCG physical characteristics include the type of hull construction, the gross tonnage, the overall length of the hull (in feet), the horsepower of the engine, and the year in which the vessel was built.

Starting in 2005, port agents started including state registered vessels in the VOU database. In more recent years with the help of trip ticket data and other data collection programs, vessels under 5 tons may also be reviewed and included by port agents. VOU data for a given year is typically QC'd and finalized around November the following year.

VOU data are used in the shrimp effort estimation procedure to obtain trawl configuration by shrimp vessels prior to ALG collecting this information directly from the fishers in 2011.

Annual Landings and Gear Survey (ALG)

The vessel and gear characterization survey began in 2005 where federally permitted Gulf of Mexico Shrimp vessels are required to report annual landings and gear characteristics. More background on this survey can be found in Smith et al. (2023b). Starting in 2011, vessels report the number of nets trawled for the majority of the year on an annual basis. Using the unique vessel identification number, the number of nets trawled can be added to the landings and effort datasets.

One limitation to this dataset is that vessel operators have until their permit expires the following year to complete the annual survey. As a result, ALG is typically not finalized and completed until more than a year after the calendar year the survey is collecting data for. To estimate shrimp fleet effort for 2023, the 2022 data on trawl configuration collected by the ALG survey had to be used in addition to the subset of data available for 2023.

Landings (Gulf Shrimp System & State Trip Ticket)

The Gulf of Mexico shrimp landings were extensively scrutinized during the SEDAR 87 data workshop (Atkinson et al. 2024). The landings presented and used for SEDAR 87 were also used for this assessment. Landings are used to scale the sampled effort to the fleet. For shrimp bycatch of Red Snapper, total effort is restricted to only the offshore penaeid (brown, pink, and white) shrimp effort. Therefore, the landings used to scale up to total effort includes only offshore federal and state vessels landing non-royal red catch. Other shrimp species (e.g. Atlantic seabob, rock shrimp, etc.) are fished at the same depths as the penaeids and are considered non-targeted landings that should be accounted for when calculating total penaeid shrimp effort (Dettloff 2024). Landings are provided in heads off weight in pounds.

Methods

A data set of total trawling effort in fishing days is required for estimating bycatch of Red Snapper in the shrimp fishery. Shrimp bycatch analysts are requesting effort stratified by year, quadrimester (Jan-Apr, May-Aug, Sep-Dec), area (statistical zones 1: 1-6, 2: 7-12, 3: 13-17, 4: 18-21), trawl configuration (2 net vs. 4 net), depth zone (0-10, 10-30, and 30+ fathoms), time of day (day vs. night trawling), and species. The effort data provided for SEDAR 87 did not consider trawl configuration for purposes of stratification and therefore methods developed by Dettloff (2024) had to be adjusted in order to accommodate this additional need. The areas defined for SEDAR 98 can be seen in Figure 1. The western zone 13-21 was further divided to capture the seasonal shrimp trawl closure off Texas waters that would have an impact on shrimp bycatch estimates of Red Snapper.

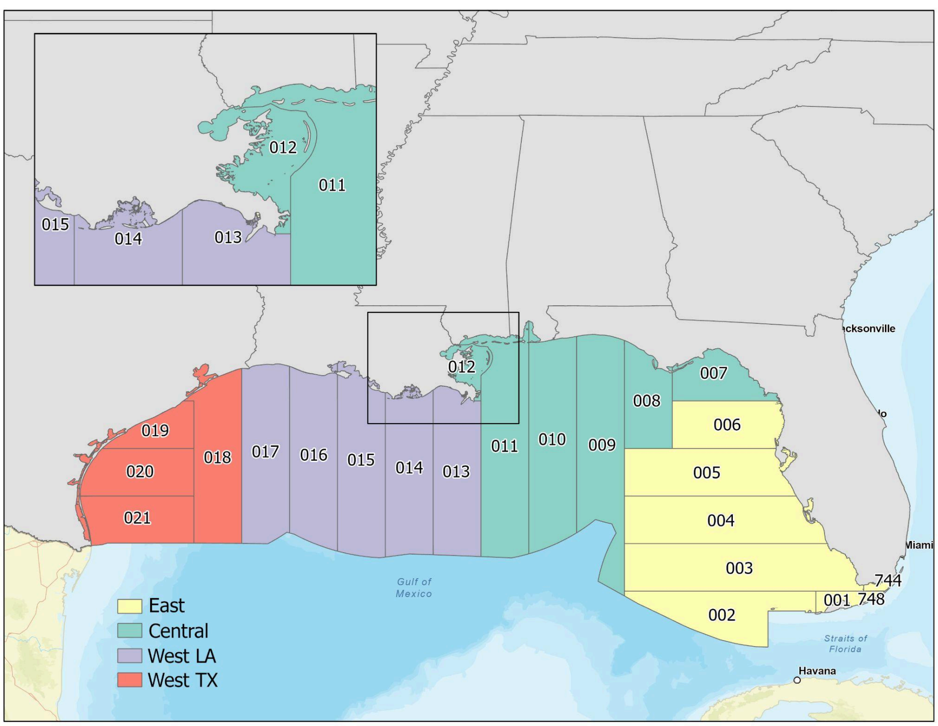

Figure 1. Map of aggregated areas used for Red Snapper shrimp bycatch estimation.

For SEDAR 87, the total effort estimates prior to 2014 were pulled from an historical effort file. The background and knowledge of how that file was created was not deeply explored nor well understood because analysts who created this file are no longer at the Science Center. Therefore, in order to get effort by all strata variables, effort was re-estimated for 1984-2014. These years were further divided into two data collection time periods where electronic logbook data was collected by LGL between 2007-2014 and the method developed by Detloff (2024) was applied. Prior to electronic logbooks, port agent interviews were used following the same general approach as Nance (2004).

Port agent interview-derived effort

A benefit of using port agent interview data is that trip-level catch and effort information were collected so that stratum catch-per-unit-effort (CPUE) can be calculated and applied to the total landings to estimate fleet effort. The relationship between interview (*int*) catch and effort and fleet (*ts*) catch and effort can be shown as Eq. 1

$$\frac{y_h^{(int)}}{x_h^{(int)}} = \frac{Y_h^{(ts)}}{X_h^{(ts)}} \quad (1)$$

Where $Y_h^{(ts)}$ is the time-series fleet catch (shrimp landings excluding royal red), $X_h^{(ts)}$ is the time-series fleet effort, and stratum h is area, quadrimester, and trawl configuration.

Interview Catch: $y_h^{(int)} = \sum_{hi} y_{hi}^{(int)}$, where i is a trip (i.e., interview), y is penaeid catch

Interview Effort: $x_h^{(int)} = \sum_{hi} x_{hi}^{(int)}$, where x is total trip effort (trawling at night, day, and night-day unspecified)

Time-series fleet effort is computed by Eq. 2

$$X_h^{(ts)} = \frac{Y_h^{(ts)} x_h^{(int)}}{y_h^{(int)}} \quad (2)$$

To ensure the measure of trawling effort is consistent between port agent interviews and electronic logbook data, interview trips from 2006-2014 were matched to electronic logbook or observer trips. In total 1,471 trips were matched and compared using a GLM ANOVA (Table 1). On average, trip effort was 8.1% higher for captain interviews compared to ELB/observer trips. This is likely because ELB and observer trawling effort is calculated as only the active trawling hours (not including run time between sites) which fishers may be accounting for. Therefore, a calibration factor of 0.925 was applied at the trip-level to adjust the interview effort to electronic logbook units.

Table 1. GLM analysis results used to adjust port agent interview effort to electronic logbook/observer effort units.

		GLM Estimates	
Matched Trips	**Source**	**Mean Tow-Hours**	**SE**
1,471	Interview	273.0	1.64
	ELB/Observer	252.5	1.63

For scaling interview effort to the fleet, the same area groupings used by Dettloff (2024) were applied (Figure 2). These statistical zones were considered fishing areas commonly trawled on the same trip based on a hierarchical cluster analysis using Ward's method. The area groupings were classified as statistical zones: 1: 1-3, 2: 4-8, 3: 9-14, 4: 15-18, 5: 19-21. Once effort is estimated for the fleet, effort is apportioned to the 1-21 statistical zones using interview data in order to aggregate into the area groupings for SEDAR 98 (Figure 1). This ensures shrimp trawling effort remains consistent across analytical products that may require different area aggregations.

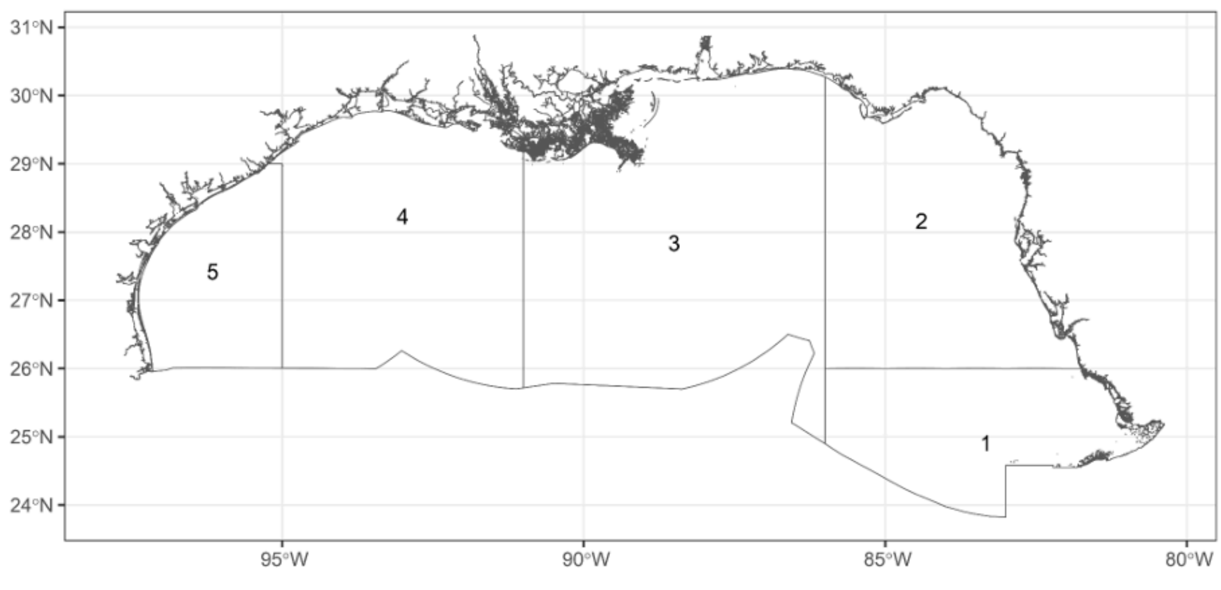

Figure 2. Map of aggregated areas used for scaling sampled effort to fleet effort.

To effectively scale the interview effort across the fleet based on trawl configuration, both the port agent interviews and total landings must be categorized by either two-net or four-net setups. Port agents began reporting the number of trawls fished for each trip interviewed in 1984. When this information was not reported for a given interview, the VOU data were used to impute trawl configuration so that each trip was associated with a two or four-net trawl. Total landings either from GSS or state trip ticket programs are not provided by trawl configuration. Therefore, VOU was joined to the landings by vessel ID to assign a net number. There was some additional cleaning of the VOU data in order to assign a single net number to all permitted shrimp vessels. One issue was that some vessels had multiple trawl configurations reported for the same year. This is because some vessels may land in multiple ports and are included in VOU by multiple port agents. For these cases, port agent interview vessel history was used to inform the trawl configuration for that vessel. When this was not possible, trawl configuration for a given year was imputed based on the vessel's history within the VOU dataset. When matching the cleaned VOU dataset to the landings, some landings could not be assigned a net number because landings were reported by state permitted vessels, landings were missing vessel ID or gear code, or landings were caught on a gear other than an otter trawl (the cleaned VOU dataset was focused on the dominant otter trawl gear). In these cases, landings were apportioned to two and four nets by year, state, and species. On average about 22 percent of the landings were apportioned to a trawl configuration.

A comparison of the interview landings and total landings by trawl configuration show that port agents disproportionally undersampled two-net vessels compared to the shrimp fleet (Figure 3). This is more apparent in the 1980s to mid-1990s where two-net trawling was a commonly used gear configuration for federal vessels. Therefore, calculating CPUEs by trawl configuration will improve the shrimp effort methodology by accounting for this discrepancy when scaling to the fleet and the differing CPUEs by trawl configuration.

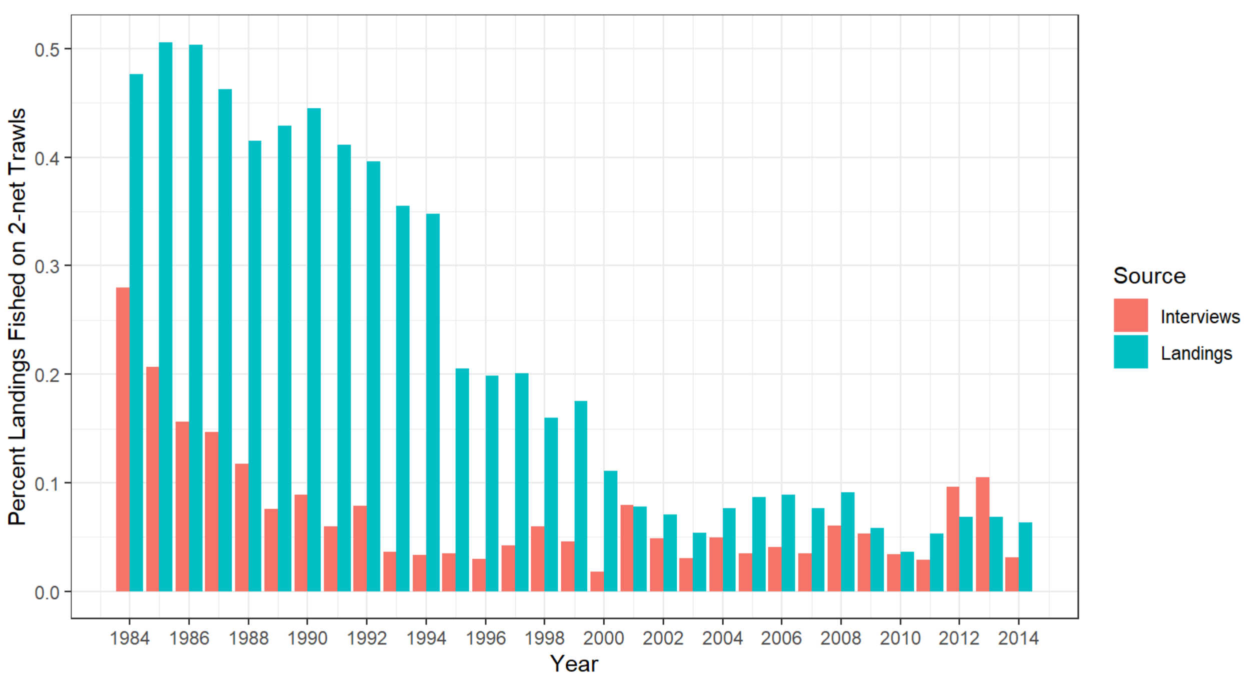

Figure 3. Annual percentage of reported shrimp landings trawled by 2 net vessels by data source (port agent interviews vs. canvas or trip ticket landings).

To stratify fleet effort by species (brown, pink, and white), time of day, statistical zone (1-21) and depth zone (0-10 ftm, 10-30 ftm, and 30+ ftm), port agent interview data were used to calculate proportions. Since interview data is the only source of information, we must assume the spatial distribution of interviews is representative of the fleet. Two modifications were made to the interview data to be consistent with Dettloff (2024). Any catch in statistical zones 1-7 are considered directed pink shrimp effort and fishing deeper than the 30 fathom zone in areas 8-21 is assumed to be directed toward brown shrimp. These adjustments were discussed and agreed during SEDAR 87 and were based on analyses of SEAMAP data to understand penaeid shrimp compositions across space.

An additional step was conducted to prepare the interview data before apportioning total stratum effort by species and time of day. For each trip *i*, effort can be recorded in 3 different categories: day, night, or day-night unspecified. Catch is only recorded for the whole trip, but by individual species (pink, brown, and white). Trips recording effort as day-night unspecified are dropped from the analysis. For trips with only day effort, catch is ascribed as catch-daytime. Likewise for trips with only night effort. For trips recording both daytime and nighttime effort, GLM-predicted catch by species, net number, and time of day were used to apportion catch to day and nighttime catch (Smith et al. 2023a) (Table 2). These catch proportions for time of day by species and net number can be estimated from Eq. (3)

$$\hat{p}\left(y_i^N\right) = \frac{x_i^N \hat{c}_N}{x_i^N \hat{c}_N + x_i^D \hat{c}_D} \text{ and } \hat{p}\left(y_i^D\right) = 1 - \hat{p}\left(y_i^N\right) \qquad (3)$$

where

$\hat{c}_N$ = model-predicted catch per standard tow for nighttime tows

$\hat{c}_D$ = model-predicted catch per standard tow for daytime tows

Table 2. Predicted catch (lbs) by gear category (time of day and number of trawls) from Smith et al. (2023a) updated using 2007-2023 observer data.

Gear category	Brown Shrimp	White Shrimp	Pink Shrimp
Day 2-net	11.44	32.22	0.70
Day 4-net	12.30	17.37	1.52
Night 2-net	17.95	25.89	0.37
Night 4-net	13.62	11.12	3.47

This additional proportioning of interview catches by species and time of day accounts for no more than 4 percent of the total interviews in a given year. The majority of the interviews report only daytime or nighttime effort for a given trip. Due to low sample sizes for some strata and the assumption that the spatial distributions of species, depth zone, and time of day have little change over time, proportions were calculated across all years (1984-2014). Interview trawling effort proportions were calculated for penaeid shrimp, depth zone, statistical zones (1-21), and time of day by area aggregations (Figure 2), quadrimester, and trawl configuration. Applying proportions by net number accounts for shifts in fishing behavior by depth where 2-net vessels tend to be more likely to fish in the shallower 0-10 fathom zone.

Once effort has been scaled to the fleet and apportioned, effort can be summed to the key strata used for shrimp bycatch estimation.

Electronic logbook-derived effort

Fleet effort was estimated from electronic logbook data from 2007-2023. The basic methodology is presented in more detail in Dettloff (2024). The additional work presented here for SEDAR 98 focuses on stratifying fleet effort into key strata necessary for shrimp bycatch estimation.

Assumptions

The following basic assumptions are required to obtain accurate estimates of total effort, given non-universal effort coverage of the fleet:

1. cELB devices are capturing all fishing activity, and are powered on for the full extent of vessel activity per federal regulations.
2. There is no systematic bias in effort classification. That is, there is an equal chance of false-positives and false-negatives.
3. The spatial distribution of cELB vessels is representative of the total fleet within strata.
4. CPUE of vessels with cELBs on board is representative of the total fleet.
5. Reporting of landings is similar between vessels with and without cELBs. That is, one group is no more or less likely than the other to completely and accurately report landings.

Stratification by gear configuration

Gear configuration (2 vs. 4 nets) was not included as a stratification variable in the original Dettloff (2024) effort estimation procedure, but is known to be an important variable for estimating Red Snapper bycatch in the Penaeid shrimp fleet (Smith et al. 2023a). This variable is not reported directly in trip ticket landings, but rather obtained from either VOU (pre-2011) or

ALG (2011-present) surveys for federally permitted SPGM vessels on an annual basis and joined to the trip ticket landings data by vessel ID. For this reason, net number is typically known for only 60-80% of vessels reporting offshore landings, so division of effort between the two net categories by strata (quadrimester x area) was done by proportioning fleet-scaled effort rather than directly as part of the scaling process. Based on these surveys, the average number of nets per vessel was seen to be consistently higher for ELB vessels than non-ELB vessels through time (Dettloff 2024), so an approach was needed to ensure that allocation of effort to net number by strata was reflective of the fleet as a whole rather than just vessels with ELB devices.

An analysis of shrimp observer data by Smith et al. (2023a) and modified here used a GLMM approach to determine that the total Penaeid CPUE of vessels fishing with 4 nets was approximately 1.23 times greater than vessels fishing with 2 nets for a given length of time on average. This information was paired to trip ticket landings from all vessels with known net number and used to scale offshore landings accordingly within strata to calculate the proportions of total effort that should be allocated to each net category (Eqs. 4 & 5).

$$p(2\,net)_{area/quad} = 1.23 * \Sigma landings_{2\,net/area/quad} / (1.23 * \Sigma landings_{2\,net/area/quad} + \Sigma landings_{4\,net/area/quad}) \quad (4)$$

$$p(4\,net)_{area/quad} = 1 - p(2\,net)_{area/quad} \quad (5)$$

The probability of a vessel fishing with 2 vs. 4 nets was seen to be correlated with fishing depth, with 2-net vessels more likely to be fishing at shallower depths (Figure 10). Bayes theorem (Eq. 6) was used to partition total fishing effort within each net category by depth bin (0-10 ftm, 10-30 ftm, 30+ ftm).

$$p(nets_i|depth)_{area/quad} = \frac{p(depth|nets_i)_{area/quad} * p(nets_i)_{area/quad}}{p(depth)_{area/quad}} \quad (6)$$

where $p(nets_i)_{area/quad}$ comes from Eqs. 4 and 5 based on landings, $p(depth|nets_i)_{area/quad}$ comes from the observed ELB effort proportions by depth within each net category, and

$$p(depth)_{area/quad} = \sum_{i=2,4} p(depth|nets_i)_{area/quad} * p(nets_i)_{area/quad} \quad (7)$$

If ELB data were not present for all depth bins within a given area/quad/nets combination, depth probabilities were first imputed at the area/nets-level, followed by the quadrimester/nets-level, and finally at the nets-level Gulf-wide for the entire year, ensuring all probabilities were scaled to sum to 1.

This allows the assumption of equal CPUE across depth bins to be relaxed since we are assuming that 4-net vessels are on average 1.23 times more efficient than 2-net vessels. Thus, the total amount of effort within area/quadrimester strata will remain constant, but the allocation of effort to the three depth zones within strata (and therefore state water corrections) may change. There was no evidence to suggest that fishing time of day was associated with net number, so this was not explicitly included as a stratification variable in calculating net proportions. The probabilities as calculated above were applied directly to the observed quantities of both day and night effort as reflected in the ELB data. Effort from the royal red shrimp fleet was considered too deep to interact with Red Snapper and therefore excluded from effort totals for bycatch estimation.

Results and Discussion

Port agent interview effort

As Nance (2004) noted, the number of port agent interviews have decreased over time. After addressing data errors and excluding trips where effort is reported at the trip-level and cannot be separated by stratum, Figure 4 presents the remaining trips used for analysis compared to the total number of trip interviews available in the SEFSC Oracle database.

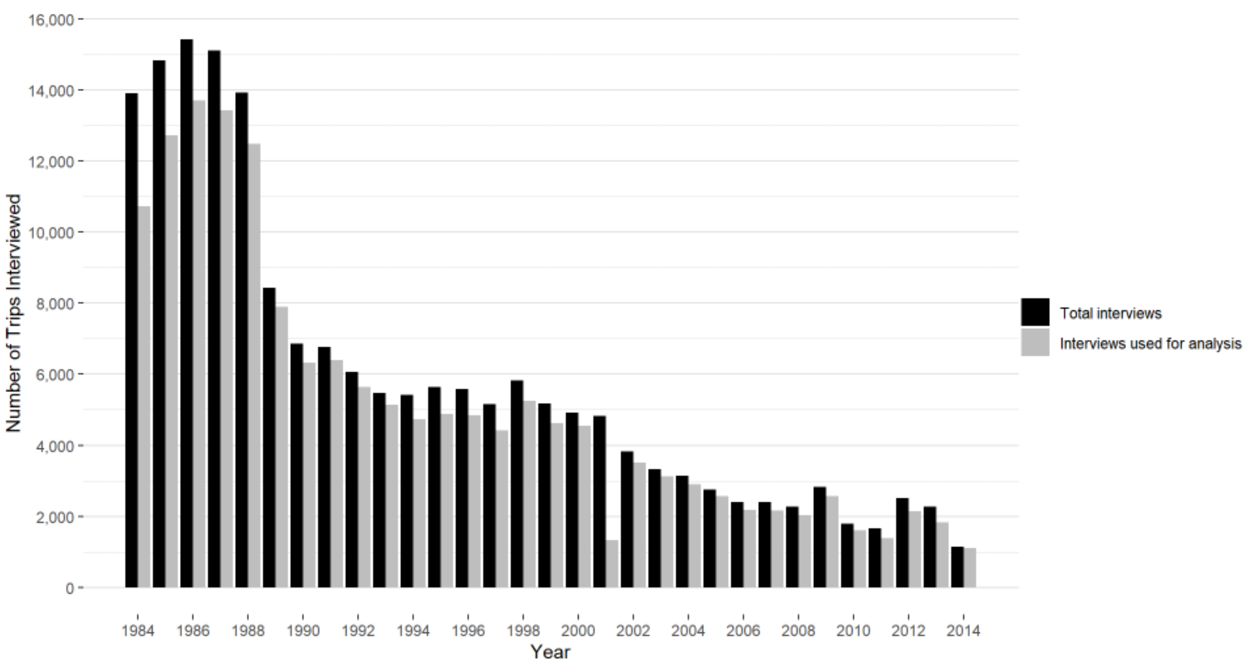

Figure 4. Total number of interviews conducted by port agents over time and the number of interviews used for calculating CPUEs to scale to the fleet.

Average annual CPUEs were calculated for all strata with sufficient sample sizes (Figure 5). For strata with less than 10 interviews, data were either pooled for a series of years or a linear interpolation was conducted if only a single year was missing. In 2001, there were two issues: 1) most interviews were of grouped vessels and were excluded for analysis and 2) there were a disproportionate number of trips with high effort and low catch leading to higher CPUEs compared to 2000 and 2002 distributions for the same strata. For this reason, most strata in 2001 were interpolated.

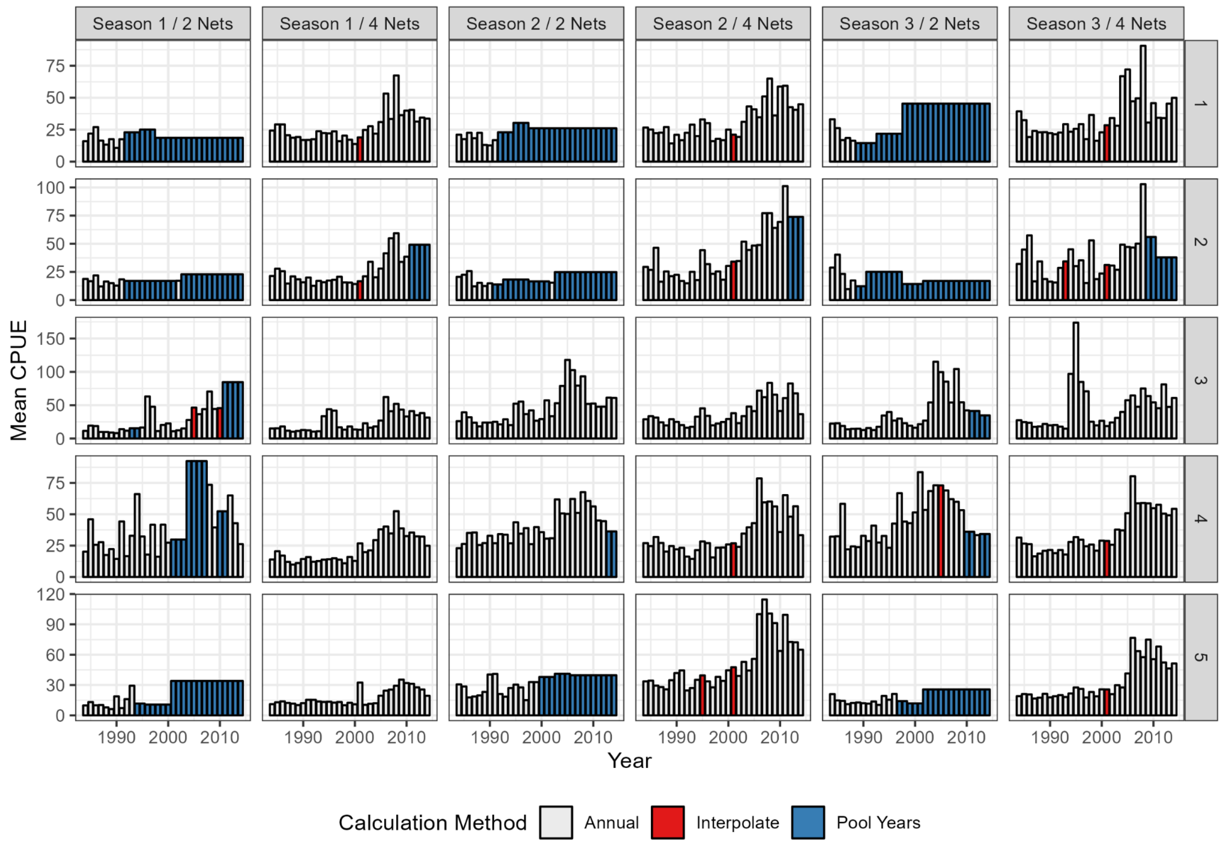

Figure 5. Average interview CPUE by season (1: Jan-Apr, 2: May-Aug, 3: Sep-Dec) and trawl configuration (2 net vs. 4 net) going across and area (1: 1-3, 2: 4-8, 3: 9-14, 4: 15-18, 5: 19-21) going down. When more than 10 interviews were conducted in a given strata, annual CPUEs were calculated. Otherwise for years with low sample sizes, data were either pooled across years or interpolated.

The total fleet effort re-estimated for SEDAR 98 was compared to historically computed shrimp effort estimates (Figure 6). In previously calculated trawling effort estimates using interview data, CPUEs were calculated by year, month, area (1-21 statistical zones), and depth (in 5-fathom increments) (Nance 2004). If no interviews were conducted for a given cell, years and areas were collapsed to estimate a mean CPUE for a given month and depth zone. If no interviews were conducted for a given month and depth zone, a general linear model was used to estimate CPUE for those missing cells. Annually, the re-estimated fleet trawling effort shows a similar trend to historic estimates even with a simplified approach of aggregating statistical zones into five areas and aggregating months into three quadrimesters. The use of a calibration factor (0.925) contributed to the largest difference in total effort values. Gallaway et al. (2003) also concluded that port agent interviews overestimate trip hours trawled when compared to electronic logbook positional data which calculates only the active fishing time. This study showed the total effort estimates using interview data could be adjusted to as much as 16 percent reduction. This was based on a pilot study with only 50 ELB units, whereas the calibration factor presented here is based on over 500 matched trips from nine years of ELB and observer data (2006-2014).

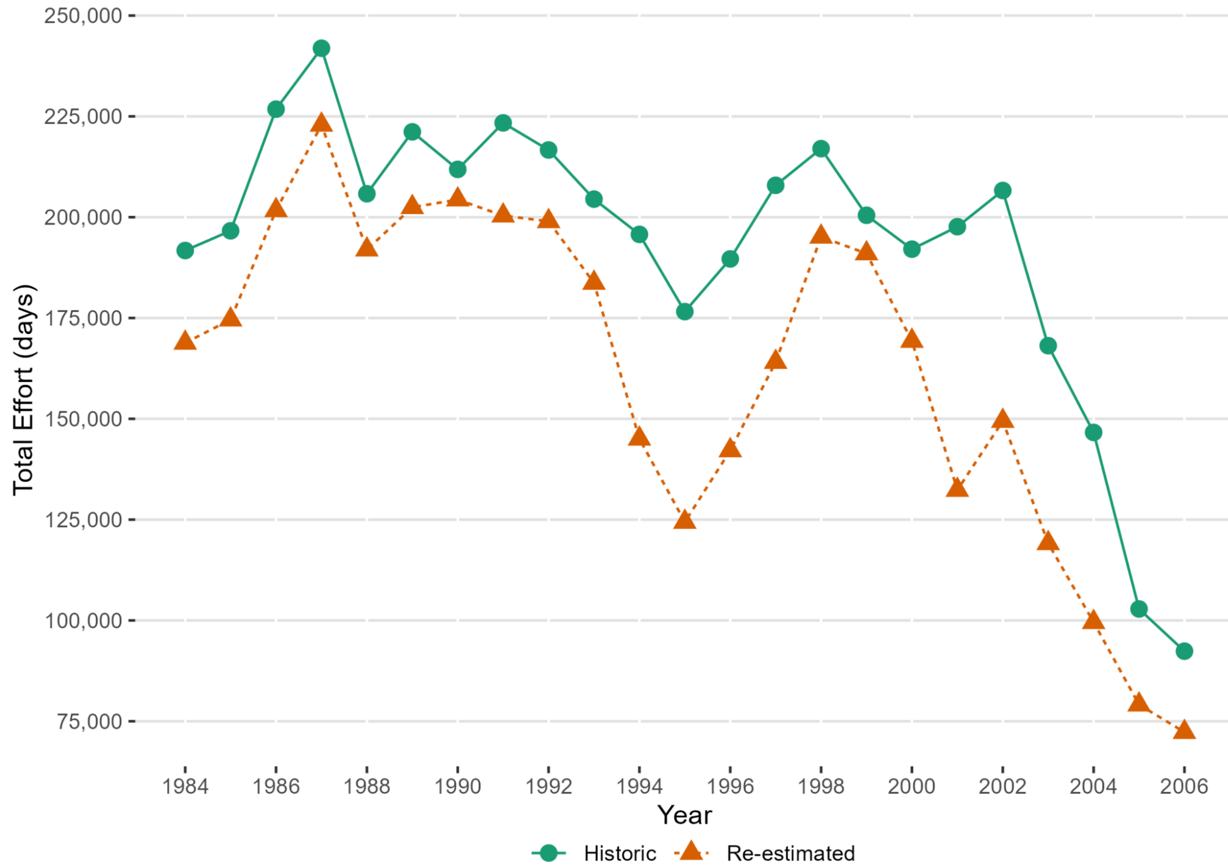

Figure 6. Comparison between the port agent interview re-estimated shrimp effort in trawling days to the annual trawling days calculated using historic methods.

Electronic Logbook effort

Known deficiencies in ELB data collection occurred in years or quadrimesters when either the collection of data transitioned from LGL to SEFSC or after the loss of 3G in December 2020 when chips were physically mailed to SEFSC by fishers. A validation of predicted Penaeid catch (by multiplying ELB effort to observer penaeid CPUE) to the trip ticket reported landings indicated we were potentially underestimating effort in these years. To correct for this, we fit a generalized linear mixed model (GLMM) with a Tweedie response structure to shrimp observer CPUEs at the tow level from 2007-2023. Terms in the model included a main effect for year (categorical), up to two-way interactions of season (3 quadrimesters), area (1-5 as used for effort scaling), depth zone (0-10, 10-30, 30+ ftm), day vs. night, and number of nets (2 vs. 4), and random effects for vessel, trip, and tow. Models were fit by maximum likelihood using the *glmmTMB* package in R (Brooks et al. 2017). The best fitting model was selected by AIC and included all combinations of two-way interactions of the five stratification variables except for season x net number and depth x net number. Year was not considered in interaction terms due to lack of data within certain stratum levels on an annual basis, but rather kept as a main effect to capture overall annual CPUE differences. Finally, model predicted CPUEs (Figure 7) were calculated at the year/area/season level and weighted using the *emmeans* package (Lenth 2025) according to the observed effort proportions (post net adjustment) among the remaining stratification variables in the ELB data within each year/area/season combination.

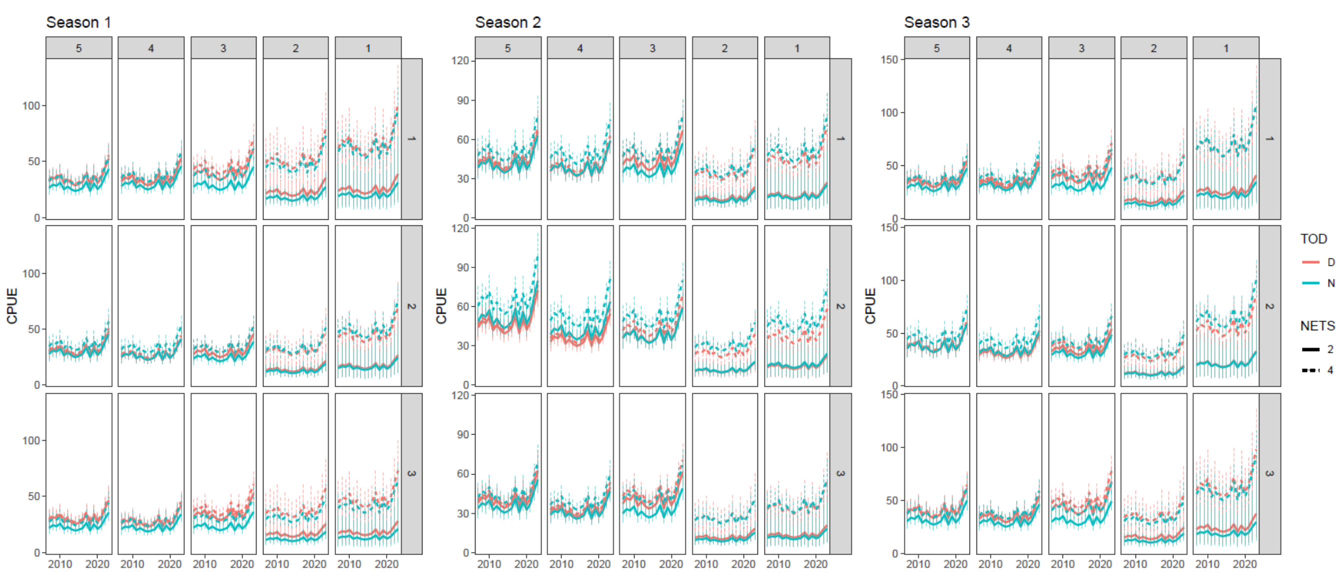

Figure 7. Model predicted observer CPUE with 95% confidence intervals, 2007-2023. Columns represent areas and rows represent depth zones.

Years or partial years that were determined to need adjustments based on known ELB data deficiencies included the following: 2013 (incomplete data due to transition of program from LGL to NMFS), 2014 Season 1 (incomplete data during implementation of new NMFS sample), 2020 Season 3 (loss of 3G in December 2020), and 2021-2023 (self-mailed chip retrieval era after loss of 3G). There was no reason to believe data deficiencies occurred in other years, and because of variability in the observer data associated with relatively low percent coverage, the observer adjustment was only applied to the above periods and not other years.

Sampling weights (w) at the year/season/area level were adjusted using the model predicted weighted CPUEs as follows, ensuring the adjustment did not allow sampling weights to fall below 1 (Eq. 8).

$$w\ adj._{year/area/quad} = w_{year/area/quad} * \frac{\Sigma fed.\ landings_{year/area/quad} \,/\, obs.\ CPUE_{year/area/quad}}{\Sigma ELB\ days_{year/area/quad} * w_{year/area/quad}} \quad (8)$$

A comparison between LGL and SEFSC ELB adjusted effort estimates produced similar Gulf-wide totals for the overlapping years of 2007-2022 (Figure 8). While Gulf-wide total estimates are similar in magnitude, comparison of estimates between the methods is not possible at the full stratum-level as effort by time of day, number of nets, and species breakdown was not estimated historically.

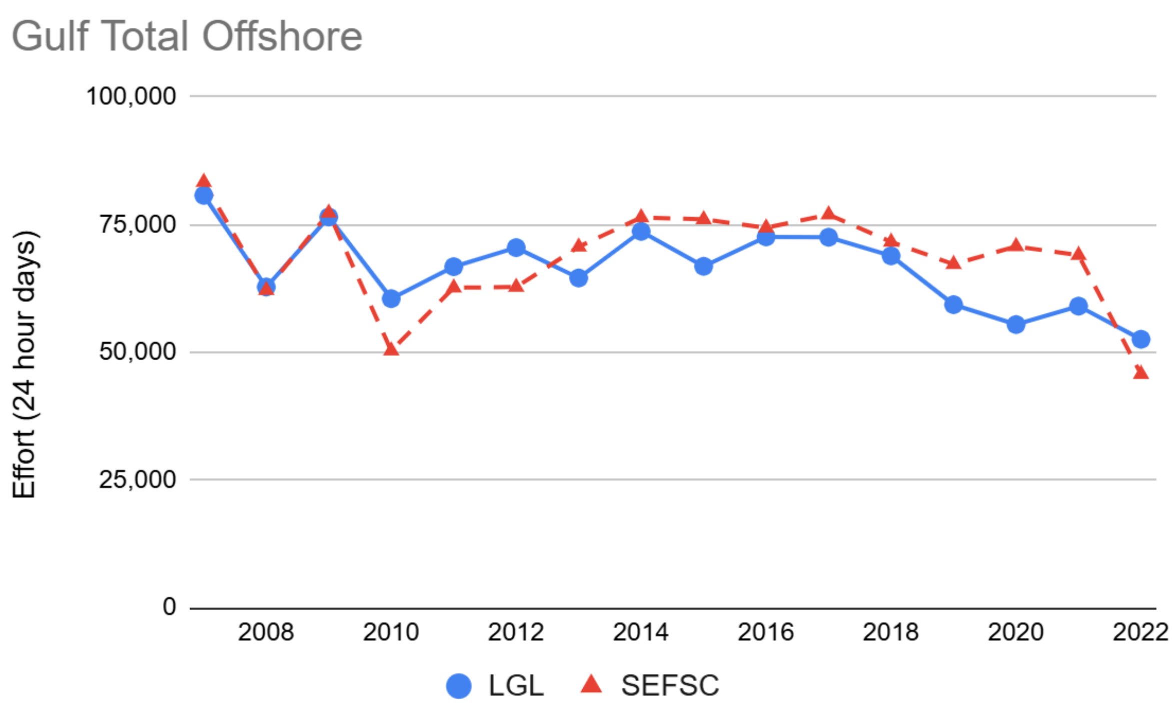

Figure 8. Comparison between LGL and SEFSC estimated Gulfwide annual trawling days, 2007-2022.

Comparison of Interview and ELB effort estimates

From 2007-2014, port agents were conducting interviews and LGL was collecting positional data. The annual estimates of shrimp trawling effort by data source compared favorably (Figure 9) for these overlapping years. Electronic logbook data are preferred over interview data during this time period because many strata lack sufficient sample sizes as the number of interviews decreased over time and many years were pooled to calculate interview CPUEs. The final effort dataset for estimating shrimp bycatch of Red Snapper uses interview data from 1984-2006 and ELB data from 2007-2023, adjusted using observer data for some years and quadrimesters (Figure 10).

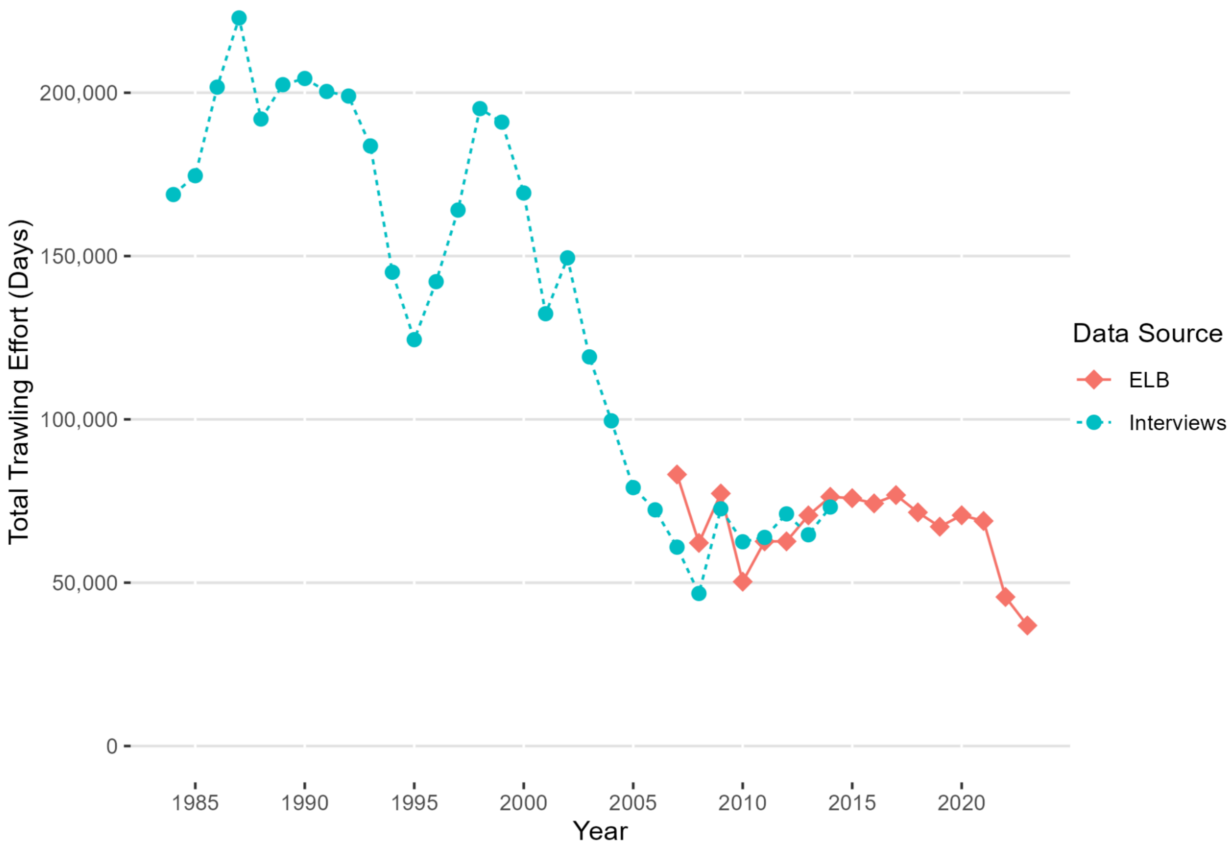

Figure 9. Port agent interview derived shrimp effort (in trawling days) from 1984-2014 and ELB derived effort from 2007-2023.

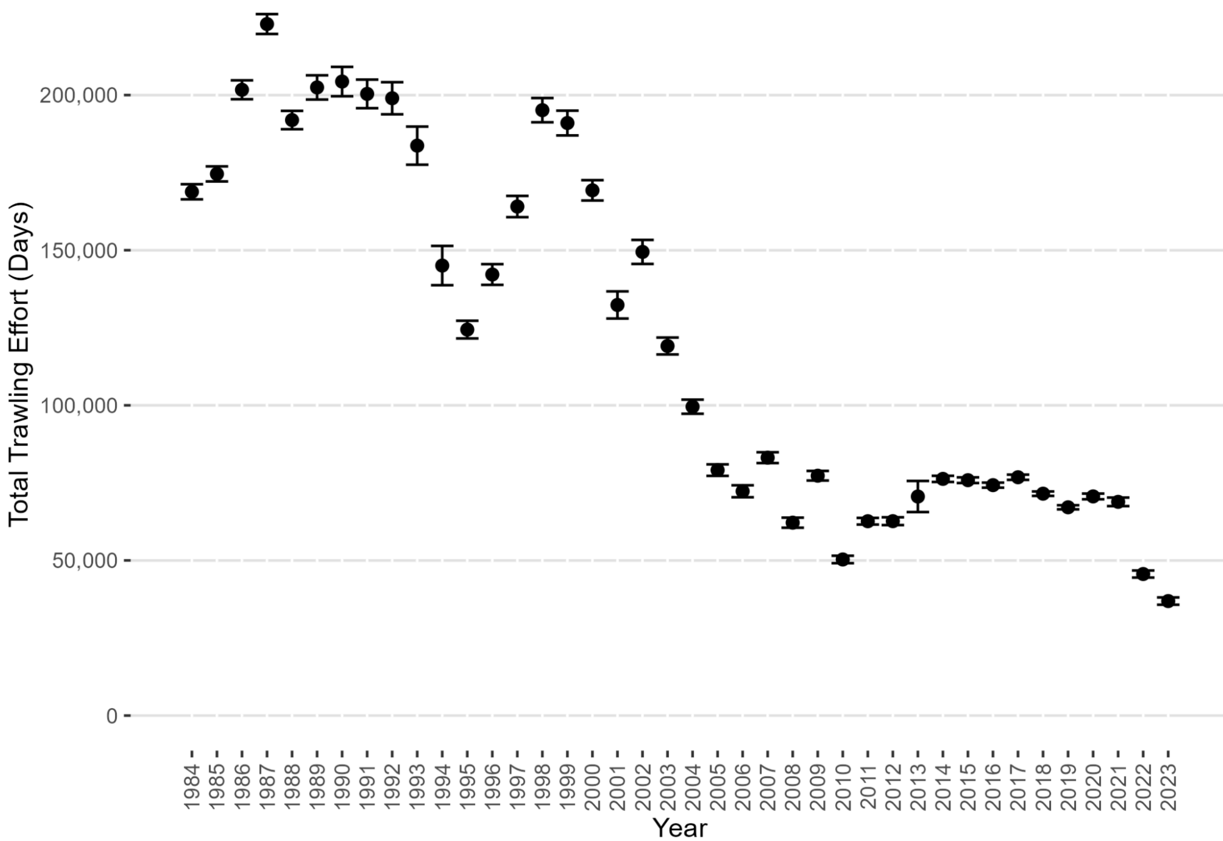

Figure 10. Combined port agent interview and ELB derived shrimp effort (in trawling days).

Fleet effort by strata

Shrimp offshore fleet effort has steadily decreased over time throughout the Gulf of Mexico (Table 3). Annual variations in shrimp effort tend to be driven by economic influences. Trawling effort by the bycatch area groupings (Figure 1), show the majority of brown shrimp effort is directed off Texas waters (area 4) and pink shrimp effort is centralized off the Florida Keys (area 1) (Figure 11). White shrimp effort tends to be concentrated off Louisiana waters (area 3). Figure 12 shows fleet effort by depth zone (1: 0-10 ftm, 2: 10-30 ftm, and 3: 30+ ftm) and net configuration. Most of the effort for penaeid shrimp is within the 10-30 fathoms using 4-net trawls. Most of the 2-net vessels are trawling in the shallower depths (0-10 fathoms) with the 2-net configuration being less common over time.

Table 3. Gulf of Mexico trawling effort (in days) by shrimp bycatch areas defined in Figure 1 as well as Gulf-wide trawling effort with associated CVs.

Year	West - TX	West - LA	Central	East	Total GoM Effort	Total GoM CV
1984	50,050	66,086	32,408	20,283	168,827	1.4
1985	55,004	70,962	29,196	19,432	174,594	1.4
1986	64,261	82,929	38,284	16,233	201,708	1.5
1987	73,347	91,619	38,341	19,588	222,895	1.4
1988	66,875	78,087	31,647	15,344	191,953	1.5
1989	63,859	83,590	39,078	15,938	202,466	1.9
1990	61,826	79,116	47,915	15,503	204,359	2.3
1991	62,146	86,068	38,480	13,690	200,384	2.3
1992	65,812	80,472	35,376	17,320	198,979	2.6
1993	64,883	78,266	25,626	14,926	183,700	3.3
1994	50,686	54,564	21,859	17,937	145,046	4.4
1995	44,983	43,162	14,438	21,824	124,407	2.3
1996	48,559	47,904	18,477	27,227	142,167	2.3
1997	53,674	63,900	22,051	24,448	164,074	2.1
1998	59,736	71,887	34,642	28,869	195,135	2.0
1999	58,645	79,642	34,900	17,807	190,994	2.1
2000	56,796	72,784	26,136	13,583	169,299	1.9
2001	41,483	53,866	20,864	16,134	132,347	3.3
2002	48,865	64,010	24,519	12,050	149,444	2.6
2003	36,404	52,002	19,652	11,069	119,127	2.3
2004	33,390	41,888	14,755	9,525	99,557	2.3
2005	26,860	33,179	11,726	7,343	79,109	2.3
2006	24,803	31,395	10,212	5,887	72,296	2.7
2007	24,004	46,350	5,540	7,239	83,132	2.1
2008	21,810	28,756	6,225	5,381	62,172	2.6
2009	24,499	39,582	7,737	5,489	77,307	2.0
2010	15,965	28,435	3,346	2,566	50,312	2.4
2011	21,871	31,650	5,712	3,409	62,641	1.7
2012	17,837	35,586	5,341	3,891	62,655	2.0

2013	13,591	45,684	9,743	1,587	70,604	7.1
2014	26,109	36,092	8,590	5,497	76,287	1.3
2015	23,462	38,363	9,469	4,577	75,871	1.2
2016	26,202	35,241	7,975	4,850	74,268	1.1
2017	25,297	37,344	8,020	6,159	76,821	1.1
2018	22,535	32,909	8,929	7,147	71,519	1.0
2019	20,323	32,741	7,473	6,593	67,130	1.0
2020	20,398	31,767	10,668	7,806	70,638	1.3
2021	20,966	33,107	8,366	6,448	68,888	2.0
2022	13,685	19,608	6,744	5,580	45,618	2.5
2023	11,778	15,961	5,627	3,534	36,900	3.2

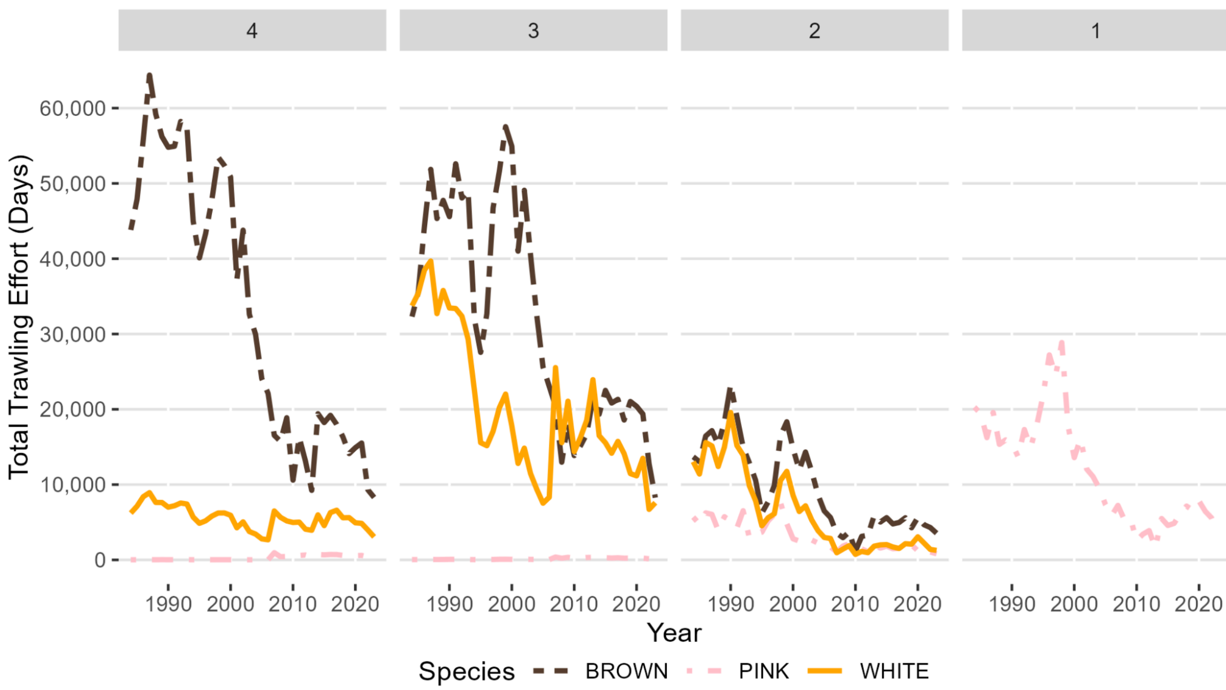

Figure 11. Scaled trawling effort (in days) by species (brown, pink, and white shrimp) and area grouping (see Figure 1, 4: West TX, 3: West LA, 2: Central, 1: East Gulf of Mexico).

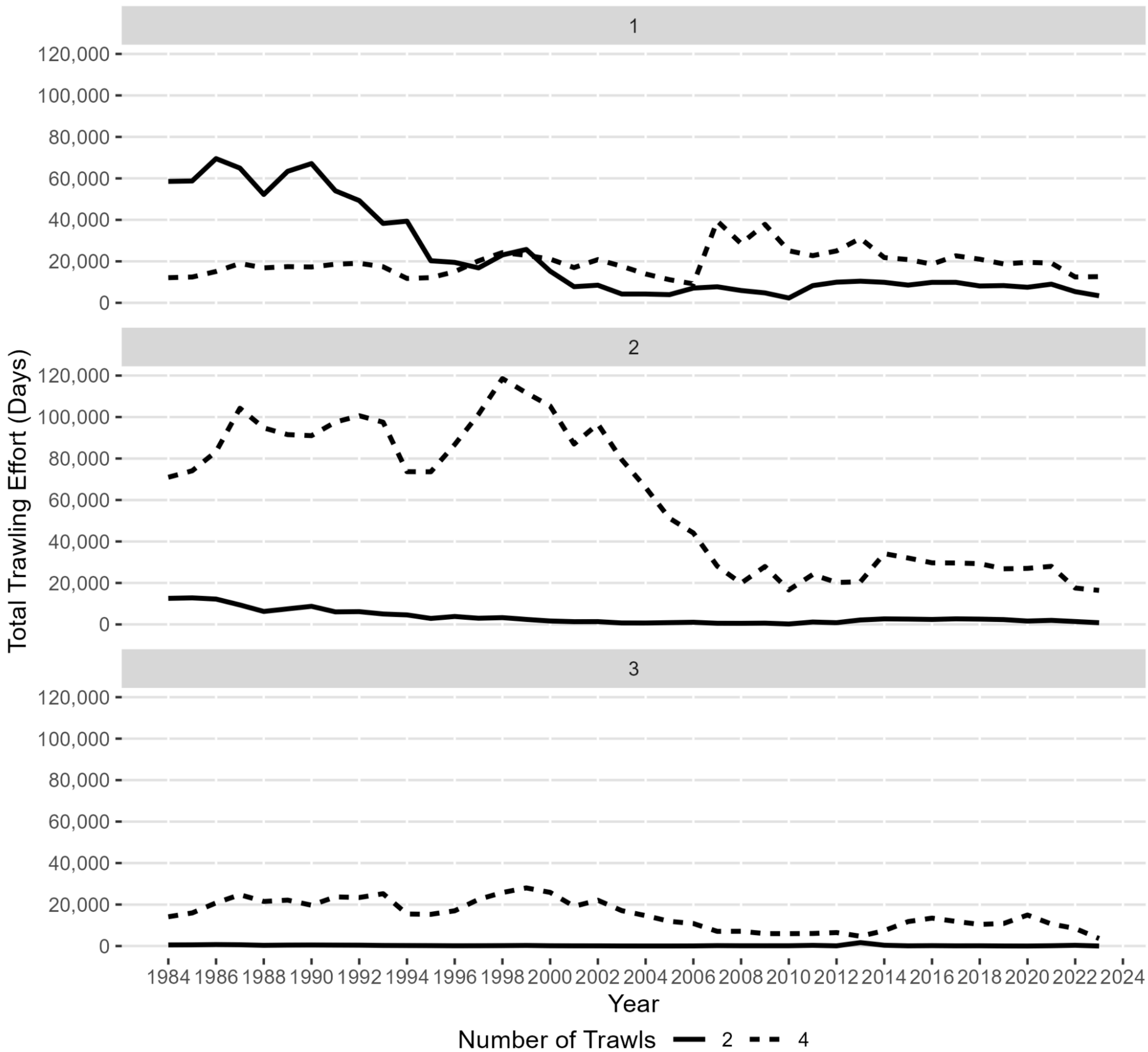

Figure 12. Scaled trawling effort (in days) by depth zone (1: 0-10 ftm, 2: 10-30 ftm, 3: 30+ ftm) and trawl configuration.

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