# Estimation of Fish Bycatch from Gulf Shrimp Trawls


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NOAA Fisheries
Southeast Fisheries Science Center
Fishery Statistics Division


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# Estimation of Fish Bycatch from Gulf Shrimp Trawls

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# General Approach to Estimating Bycatch: catch-per-unit effort expansion via total effort

Total Catch = CPUE x Total Fleet Effort

catch rate from observer sampling

Total Catch:

- Landings of target species
- Discards of target species (not kept, below min legal size, no quota, out of season)
- Bycatch of non-target species (fish, protected species, etc.)

# Gulf Shrimp Fleet Bycatch Annual Estimates: carried out separately for space-time strata *h*

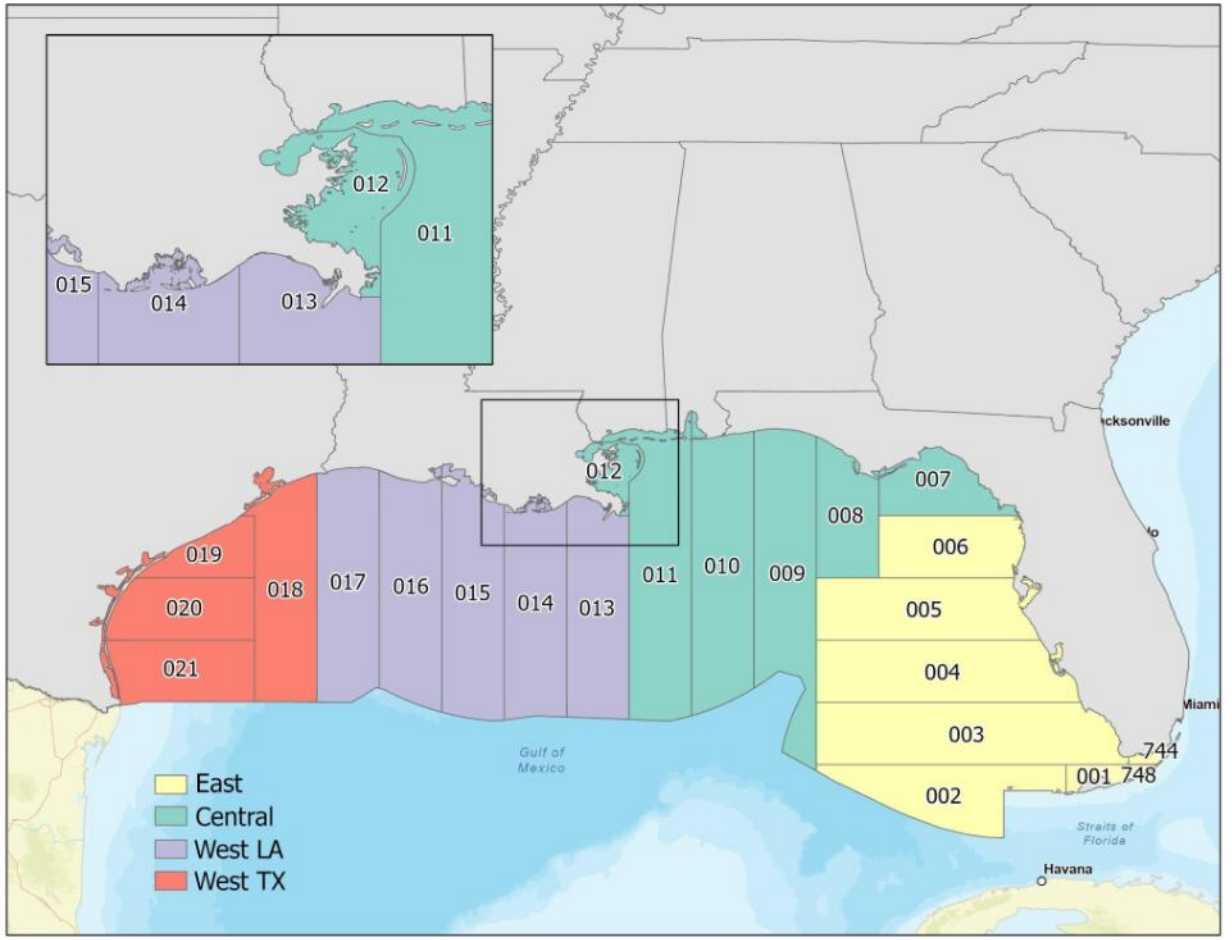
$$Bycatch_h = CPUE_h \times Effort_h$$

36 Space-Time Strata:
- Area: 4 combinations of statistical zones 1-21
- Depth: 3 intervals, 0-10 f, 10-30 f, >30 f
- Season: 3 4-month periods

Stratum estimates can be summed for different larger regions of the Gulf, e.g., East vs. West, or East-Central-West, etc., or Gulf-wide

Rationale: Animal populations are usually not distributed evenly through time and space: e.g., relative abundance is higher in some areas-depths-seasons and lower in others.

Stratification produces more accurate and precise estimates for patchily-distributed populations, provided that strata effectively delineate CPUE into low, moderate, and high CPUE space-time partitions.




NOAA FISHERIES

## Background

- Gulf shrimp trawl fishery: one of the premier US fisheries for many decades
- 1990s-early 2000s: fleet outfitted with TEDs and BRDs to reduce impact on non-target species
- 2007: IFQ for red snapper; prompted development of Shrimp Observer Program
- Onboard observers collect catch-effort data on target (shrimps) and non-target species.

## Initial Research, 2021

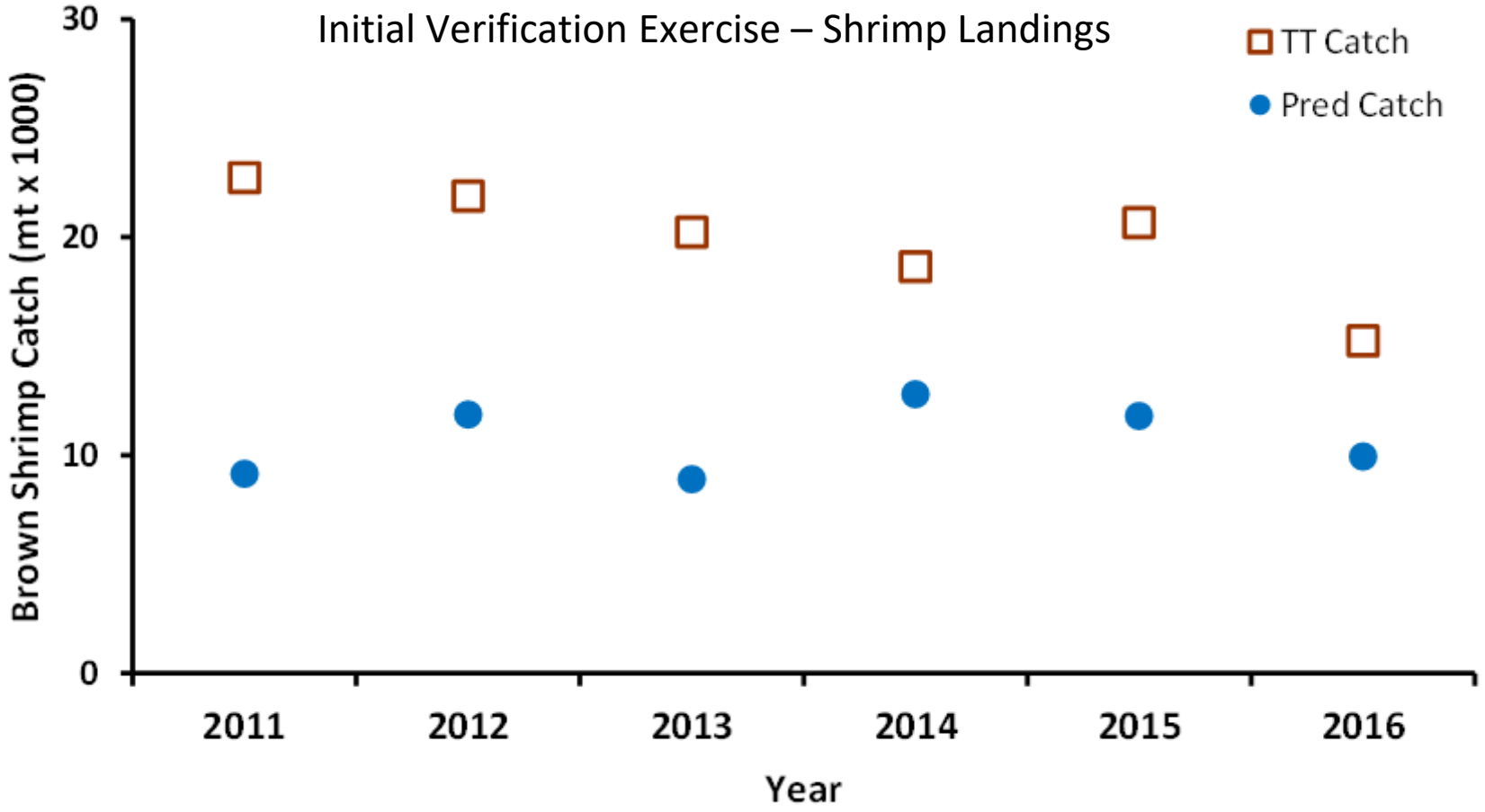
- Shannon Calay, then-director of the SEFSC Sustainable Fisheries Division (SFD), asked me to take a look at the procedures for estimating bycatch from Gulf shrimp trawls. She had concerns about the reliability of bycatch estimates for some fish species that were creating problems with stock assessments. I had worked previously with SFD and CIMAS scientists on addressing similar concerns with estimation of discards for the Gulf reef fish fleet.
- My first question: Do you have any way to cross-check the estimates to know whether they are in the ballpark of reality or whether they are from outer space?
- Her answer: No.
- We subsequently formed a small project team of federal and university scientists to develop a cross-check procedure: use the existing bycatch procedure to estimate total catch of brown shrimp, then compare with brown shrimp landings.

The team was provided ‘Legacy Code’ for processing observer data and estimating CPUE: developed in 2000’s, passed on to subsequent analysts; developers retired or no longer with NOAA. We adapted the most recent red snapper code for brown shrimp. The SEFSC Galveston Lab provided data for fleet total effort and landings.

Predicted catch from the bycatch procedure was about 50% of the landings.

Key concepts:
Accurate: predicted catch = trip-ticket catch
Biased: not equal

Conclusion: procedure produced biased estimates



Bias likely due to problems with input data and/or processing procedures:

- Observer CPUE
- Fleet Effort
- Fleet Landings

Our initial research provided some insight to these data sources.

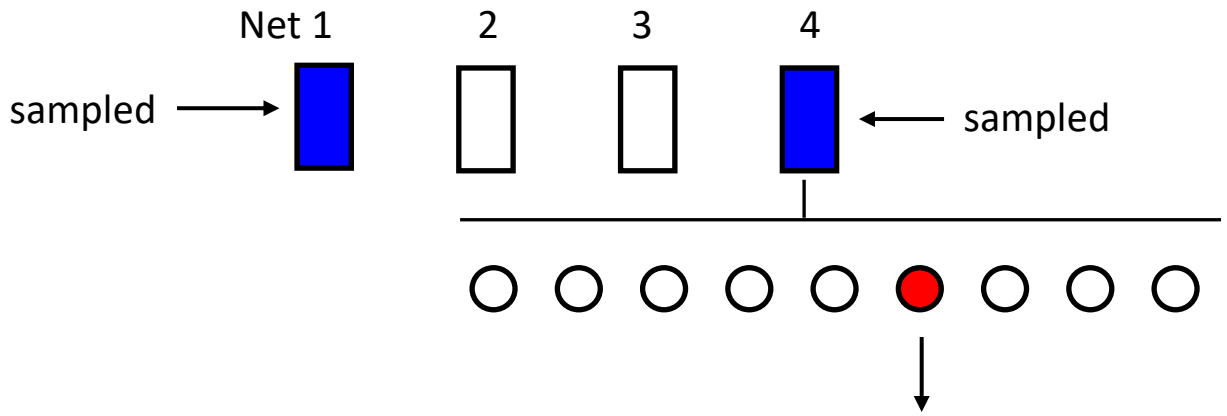
# Shrimp Observer Program History

- **2007** official start year for Gulf of America Shrimp Observer Program (side note: 2008 for South Atlantic Penaeid and Rock Shrimp)
- Overall goals:
    1. Provide general fishery bycatch characterization and catch rates for finfish species by area and target species
    2. Provide catch rates that can be used to estimate protected species bycatch levels
- At present, 2,550 seadays coverage goal for each quadrimester (4-month period). Seadays proportionally allocated spatially within time period based on industry effort.
- Attempt to obtain 1.5-2% coverage rate each year (effort metric: tow-hours)

# Observer Program on-deck sampling

Shrimp Tow: contents of trawl nets (2-net or 4-net configuration) emptied on deck in separate piles. Observer samples nets 1 and 4 for a 4-net trawl. Full net contents are shoveled into a series of baskets; each basket is weighed, then all baskets summed to get total catch weight of net.

Catch in numbers/weight recorded for all Red Snapper in each sampled net; other select species characterized via subsampling.




Species catch in numbers/weight recorded for 1 randomly selected basket. Ratio of weight of sampled basket to total net weight used to scale up catch from basket to net. Process is repeated for each sampled net.

# Characterized species via basket subsampling

| Shrimp | Sharks | Fish |
|---|---|---|
| Brown | Blacknose | Lane Snapper |
| Pink | Spinner | Vermilion Snapper |
| White | Finetooth | King Mackerel |
| | Blacktip | Spanish Mackerel |
| | Atlantic Sharpnose | Cobia |
| | Bonnethead | Longspine Porgy |
| | Smooth Dogfish | Atlantic Croaker |
| | Florida Smoothhound | Black Drum |
| | Lemon | Red Drum |
| | | Spotted Seatrout |
| | | Southern Flounder |

- Other species recorded as a group: other fish, etc.
- Length measurements recorded for Red Snapper only

Field protocols were designed to keep the observers from being overwhelmed by the sheer volume of trawl catches, and collect the key data for the principal target species (red snapper and penaeid shrimps, first and foremost).

Observers also collect detailed information on the trawl gear, and record biological information on captures of protected species.

Further reading:

Decossas, Gary and Sarina Atkinson. 2026. Southeast Shrimp Trawl Observer Program Metadata. SEDAR99-WP-02. SEDAR, North Charleston, SC. 20 pp.

# Fleet Effort

Reef fish discards, pelagic longline fleet discards:

- fleet effort obtained from commercial logbooks, where captains submit a trip report with fishing location, effort by gear, catch by species, etc. for every fishing trip during a given year.

Shrimp fleet bycatch:

- No traditional commercial logbook program; trip-ticket system for landings does not include detailed effort
- Selected subset of vessels is outfitted with an ELB, a GPS tracklog device that records lat-lon at 10 min intervals while at sea.
- GPS data used to estimate vessel tow-hours for space-time strata.
- Total fleet effort obtained with a CPUE expansion procedure using shrimp landings:

$$Total\ Effort = \frac{Total\ Landings}{\frac{catch\ (gps\ vessels)}{effort\ (gps\ vessels)}}$$

Trip-ticket database

- Thus, bycatch estimates depend on total fleet effort, and total fleet effort estimates depend on landings.
- Procedures involved another set of ‘Legacy Code’ that was even more convoluted than the code for processing observer data.

## Fleet Landings

- Shrimp landings also problematic: in later years (2014+) primarily from trip-ticket system in place for all Gulf States, but individual states implemented trip-tickets at different points in time prior to 2014.
- Earlier years involved mixing trip-ticket landings with dealer interview data.
- Procedures for combining the two sources were also convoluted and unclear.

The more we peeked under the covers concerning the three main elements—Observer CPUE, Fleet Effort, Fleet Landings—the more we suspected that factors involving all three were likely contributing to bias of bycatch estimates.

Concurrently during initial research phase:

- Responsibility for Gulf shrimp programs shifted in 2021-22 from Galveston Lab to SEFSC Fisheries Statistics Division (FSD) as part of realignment.
- Need by FSD to gain a better understanding of data sources, processing, and estimation for bycatch.

# Phase 1 Research, 2022-2023

- A reformulated and expanded project team was assembled by FSD/SFD in 2022
- Goal: improve the methodology for estimating bycatch
- Objectives:

1) Comprehensive understanding of the fundamental data sources, and refining/modernizing data processing procedures
2) Investigate potential additional stratification variables: gear characteristics, diurnal period, etc.
3) Cross-check the refined methodology for penaeid shrimps
4) Review of methodology by CIE (Council of Independent Experts), set up by NOAA nationwide for peer-review of stock assessments, statistical methods for abundance indices, etc.

- Research focused on 2014-2020, period with most reliable input data sources
- Team proceeded on parallel tracks: (A) observer and landings data and estimation (majority of team), and (B) effort data and estimation (Kyle Dettloff)

# Phase 1 **Key Findings/Improvements** for Bycatch Estimation

- **Refinement & modernization of observer data processing**
- **Developed original code for processing trip-ticket data from the source (GulfFIN)**
- **Complete redo of GPS processing and effort estimation procedures (legacy code scrapped)**

## Further Reading: Shrimp Fleet Effort Estimation

First version:

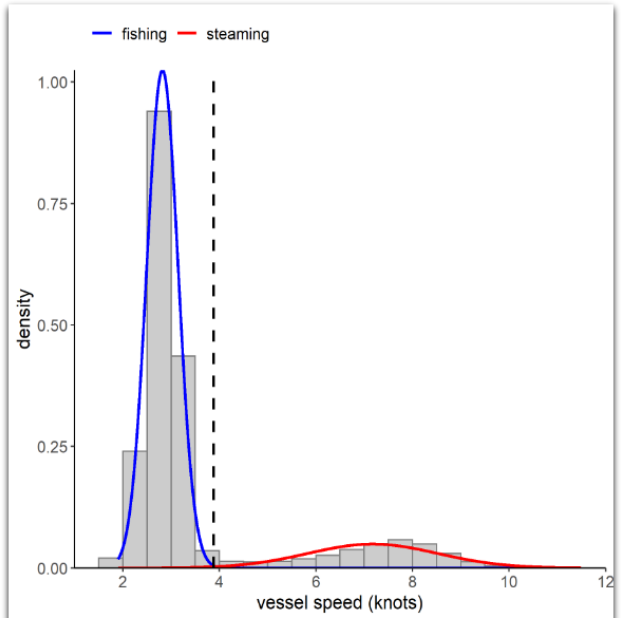
Dettloff, K. 2023. Estimation of commercial shrimp effort in the Gulf of Mexico. Report to Council of Independent Experts. NOAA SEFSC, 22 pp.

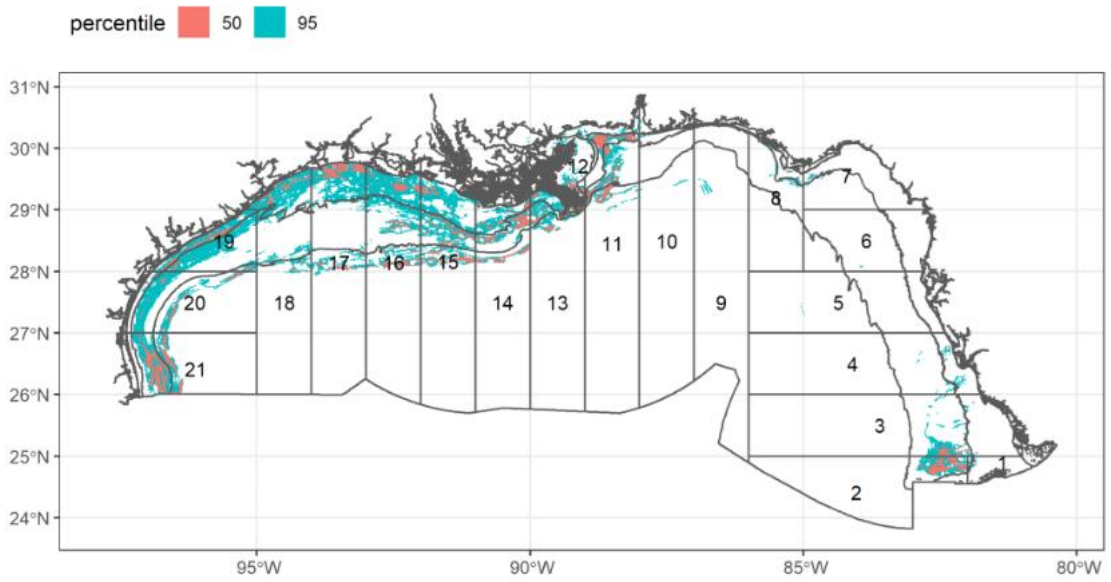
Updated version:

Dettloff, K. 2024. Estimation of commercial shrimp effort in the Gulf of Mexico. SEDAR Working Paper SEDAR87-DW-01. SEDAR, North Charleston, SC. 31 pp.

# Shrimp Effort Estimation

1. Calculate distribution from vessels with ELB units (i.e., GPS tracklogs)




Areas:

1. Zones 1-3
2. Zones 4-8
3. Zones 9-14
4. Zones 15-18
5. Zones 19-21

Quadrimesters:

1. Jan-Apr
2. May-Aug
3. Sep-Dec

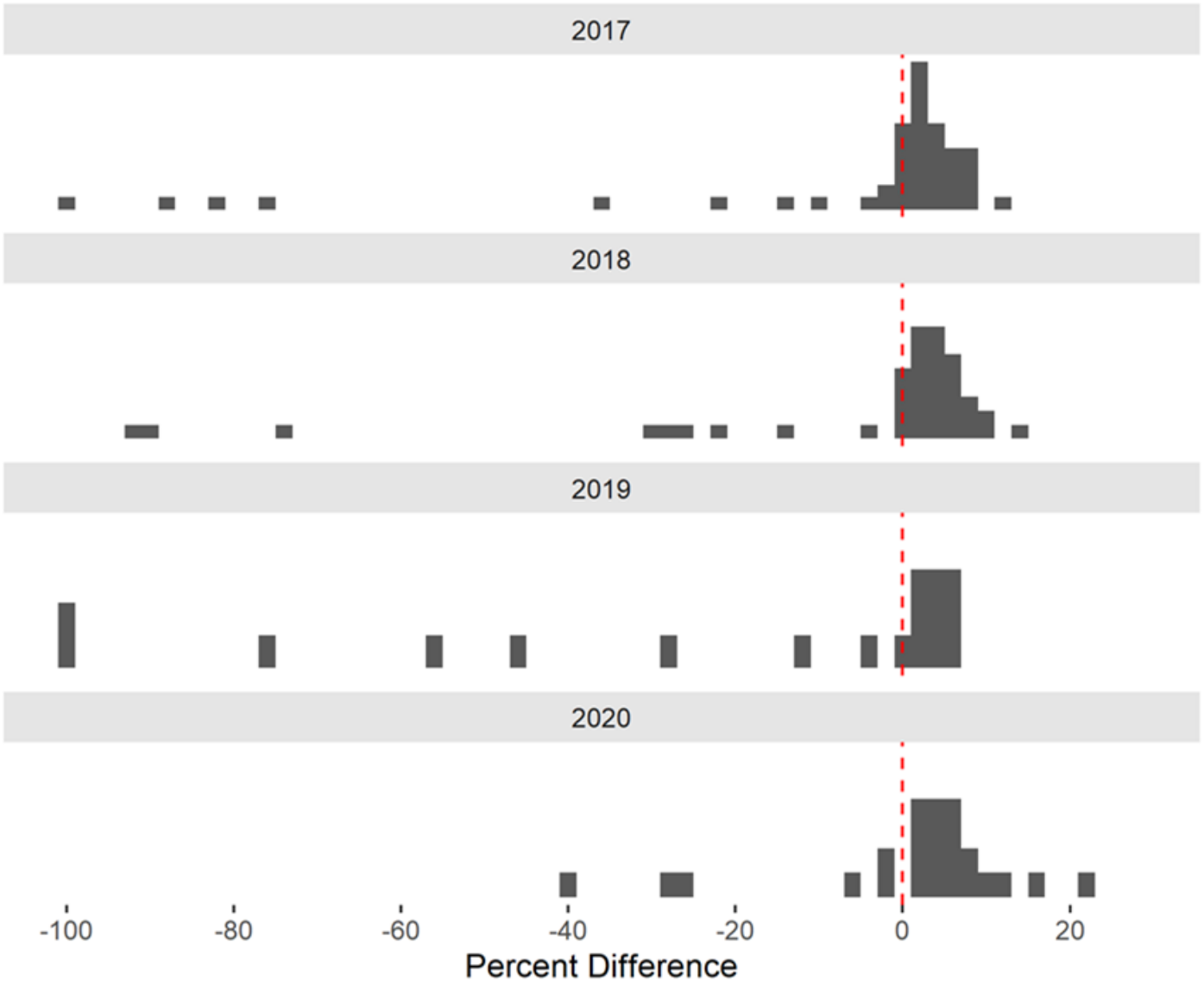
2. Scale to total fleet using landings

$$total\ effort = \sum ELB\ effort_{area/quad} \times (total\ landings_{area/quad} / ELB\ landings_{area/quad})$$

## Observer Data: Evaluation of potential bias in trip-level effort:

- Observer trips on vessels with tracklog devices
- No systematic bias in trip effort; negative skew, observers recorded trip effort but partial or missing tracklog effort
- Malfunctioning or switched-off tracklogs

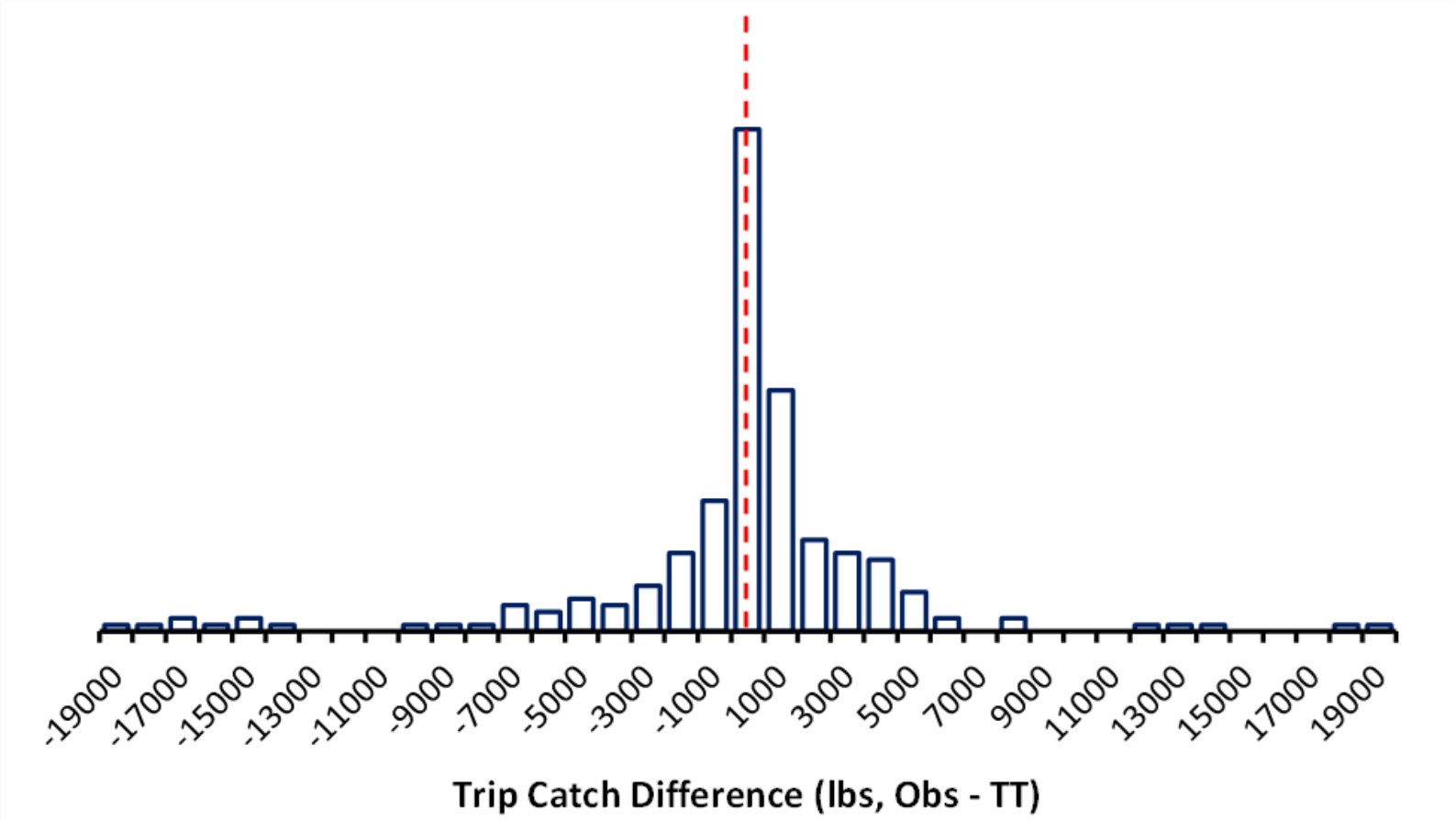
Effort Cross-Check: Observer vs. GPS tracklogs



## Observer Data: Evaluation of potential bias in trip-level catch:

- No bias between observer and trip-ticket catches of penaeid shrimps (3 species combined)
- Check on scale-up procedures for observer sub-sampling during trips
- Subsampling:
  -Tows within trip
  -Nets within tow
  -Catch within net
  -Species within catch
- However, biased for individual shrimp species; price depends on market size category not specific species; cases where dealers reported one species on trip-ticket whereas observers recorded 2 or more species.

Catch Cross-Check: Observer vs. Trip-Ticket



Conclusion: observer trip-level catch and effort were accurate (not biased)

**Next, evaluated potential bias of stratum-level estimates:**

- Area, Depth, Season—all three important for space-time partitioning of CPUE into low, moderate, and high levels for shrimps and red snapper
- Additional stratification variables: trawl characteristics, diurnal period (day, night)
- Results: designated 4 'Gear' categories, combo of net-configuration and diurnal period
  - D2, day 2-net
  - D4, day 4-net
  - N2, night 2-net
  - N4, night 4-net

- Gear catch rates analyzed using **Fishing Power** method: classical fishery science technique

Concept:

Beverton, R.J.H. and S.J. Holt. (1956) A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapports et Procès-Verbaux des Réunions, Cons. Intl. Explor. Mer 140:67-83.

Gulland, J.A. (1956) On the fishing effort in English demersal fisheries. Fish. Invest. Ser. II G.B. Minist. Agric. Fish. Food 20(5):1-41.

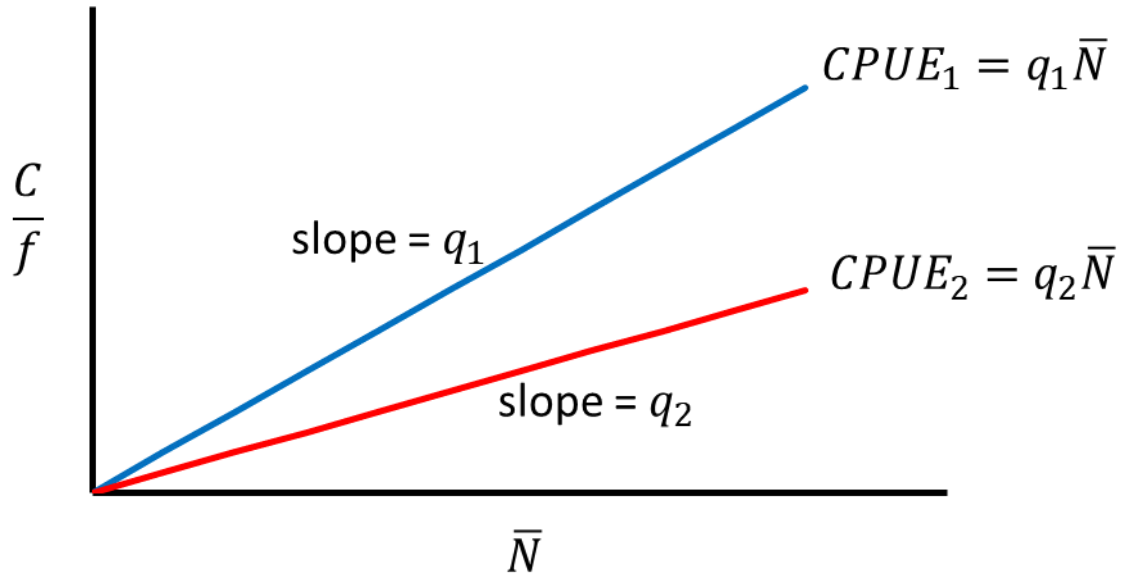
Statistical Estimation:

Robson, D.S. (1966) Estimation of the relative fishing power of individual ships. ICNAF Res. Bull. 3:5-15.

Fishing Power stems from fundamental catch equation:

$$C = F\bar{N} = fq\bar{N}$$

Fishing Power method: estimates relative catchability among different gears operating on the same unit stock.




$$\frac{CPUE_1}{CPUE_2} = \frac{q_1}{q_2} = \lambda_1$$

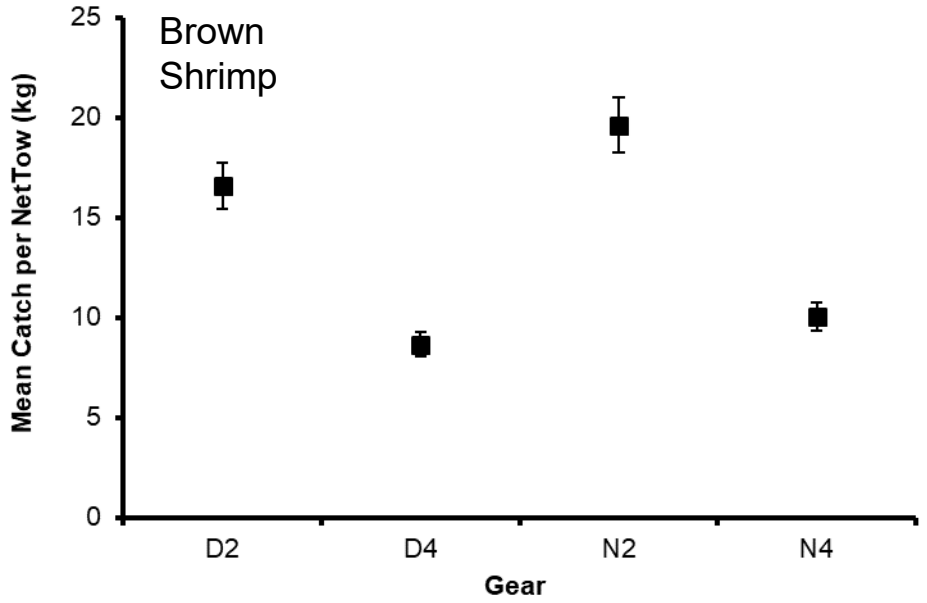
Fishing power λ is the relative catchability of one gear in terms of another

q, catchability: differs among gears, difficult to estimate empirically
f, nominal fishing effort: different units for different types of gears, e.g.,
trap soak-hours, longline hooks fished, recreational angler person-days,
etc.

Statistical Estimation

- Robson's approach, ascribe variation in CPUE to two factors:
  1) times and locations of sampling effort
  2) gear type
- 2-way ANOVA, isolates gear 'main effect' on CPUE from space-time variation in CPUE

GLM main effects predicted catch rate by gear categories

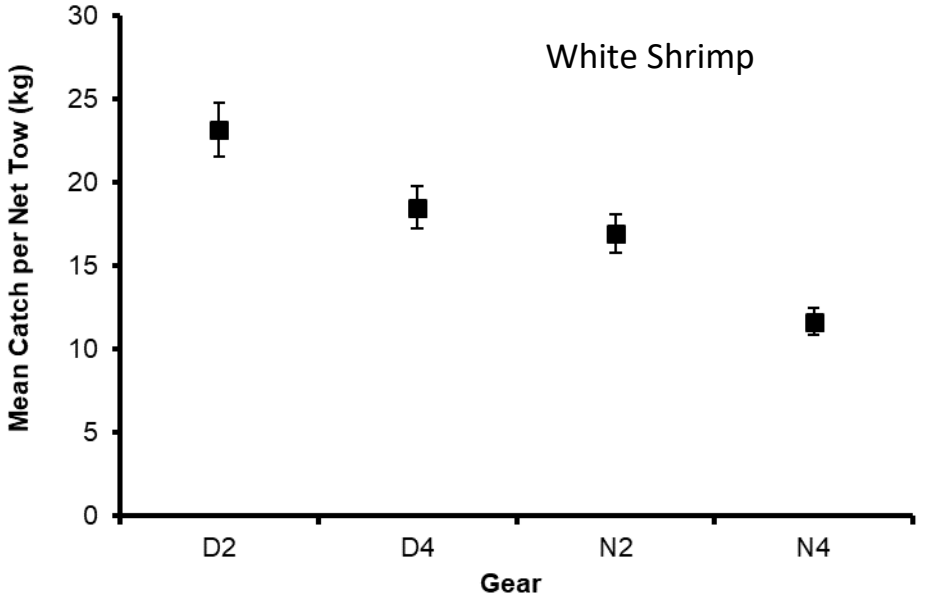



- Major: 2 > 4
- Minor: N > D
- Max Diff: N2 > D4 by 226%

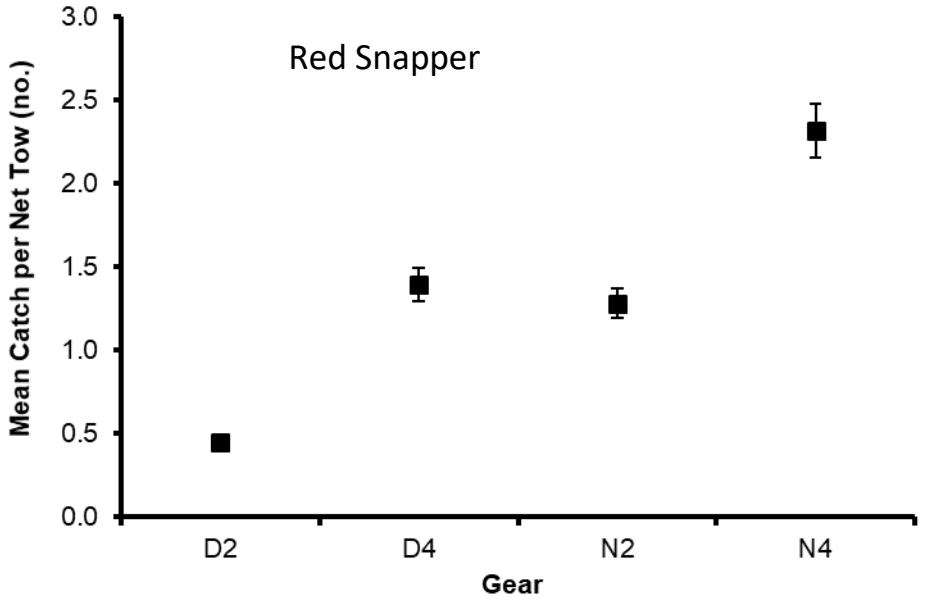
Day-night and 2-net/4-net differences reflect different animal behaviors.

Examples: Pink shrimp bury in sediment during daytime, emerge to forage etc at night. Red snapper shelter on reef habitat during the day, forage in soft substrates adjacent to reefs at night (eating shrimp!).

Red snapper likely better ability to avoid capture from a 2-net trawl vs. 4-nets that cover a wider swath collectively.




- Major: D > N
- Minor: 2 > 4
- Max Diff: D2 > N4 by 199%




- Major: N > D, 4 > 2
- Similar to Pink Shrimp
- Max Diff: N4 > D2 by 515%

Major differences in CPUE among gears → potential bias in stratum-level estimates

Example: Red Snapper, single stratum (area-depth-season), 2 gears

Hypothetical reality, gears as additional strata

| Gear | CPUE | Fleet Effort (tow-hrs) | Bycatch |
|---|---|---|---|
| **N4** | 5 | 750 | 3,750 |
| **D2** | 1 | 250 | 250 |
| | | 1,000 | 4,000 |

Can also compute bycatch from a weighted-average approach

- Simple random: weighted by proportion of sampled effort by gear (implicit)
- Stratified random: weighted by proportion of fleet effort by gear (explicit)

| | | | Simple Random | | Stratified Random | |
|---|---|---|---|---|---|---|
| **Gear** | Sampled tow-hrs | CPUE | $w_h$ | $w_h$*CPUE | $w_h$ | $w_h$*CPUE |
| **N4** | 15 | 5 | 15/20=0.75 | 3.75 | 750/1000=0.75 | 3.75 |
| **D2** | 5 | 1 | 5/20=0.25 | 0.25 | 250/1000=0.25 | 0.25 |
| | | | av CPUE = | 4.00 | | 4.00 |
| | | | Fleet Effort= | 1000 | | 1000 |
| | | | Bycatch= | 4,000 | | 4,000 |

Case 1: sampled effort by gear exactly proportional to fleet effort.

Simple random estimation is correct (i.e., unbiased).

| | | | Simple Random | | Stratified Random | |
|---|---|---|---|---|---|---|
| Gear | Sampled tow-hrs | CPUE | $w_h$ | $w_h$*CPUE | $w_h$ | $w_h$*CPUE |
| N4 | 5 | 5 | 5/20=0.25 | 1.25 | 0.75 | 3.75 |
| D2 | 15 | 1 | 15/20=0.75 | 0.75 | 0.25 | 0.25 |
| | | | av CPUE = | 2.00 | | 4.00 |
| | | | Fleet Effort= | 1000 | | 1000 |
| | | | Bycatch= | 2,000 | | 4,000 |

Case 2: observers sampled disproportionately more D2 effort compared to N4 effort.

Simple random estimation is less than the true number (i.e., negatively biased).

Case 3: observers sampled disproportionately more N4 effort compared to D2 effort.

Simple random estimation is higher than the true number (i.e., positively biased).

Stratified random estimates are not impacted by sampled effort proportion

| | | | Simple Random | | Stratified Random | |
|---|---|---|---|---|---|---|
| Gear | Sampled tow-hrs | CPUE | $w_h$ | $w_h$*CPUE | $w_h$ | $w_h$*CPUE |
| N4 | 18 | 5 | 18/20=0.9 | 4.5 | 0.75 | 3.75 |
| D2 | 2 | 1 | 2/20=0.1 | 0.1 | 0.25 | 0.25 |
| | | | av CPUE = | 4.6 | | 4.00 |
| | | | Fleet Effort= | 1000 | | 1000 |
| | | | Bycatch= | 4,600 | | 4,000 |

## Result: added gear as additional stratification variable, eliminating a major potential source of bias for Observer CPUE.

Ramifications: also needed to incorporate gear type into landings and effort stratification.

### Annual Landings & Gear Survey

- Previously unused data source, SEFSC Annual Landings and Gear Survey, enabled assignment of 2-net and 4-net gear types to fleet vessels for tracklog effort and trip-ticket landings

### Sparsely-sampled strata procedures for observer data

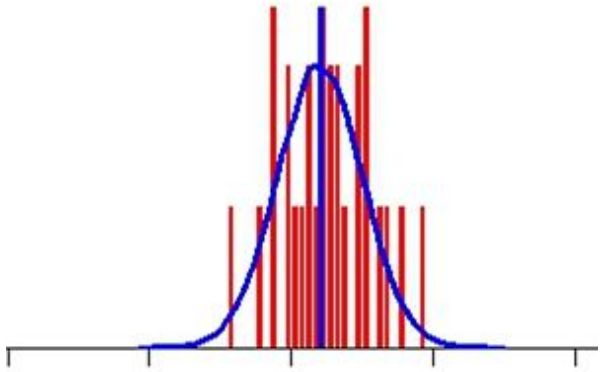
### A. Pooling of groups of years within season-region-depth-gear strata

- Within-strata interannual variability analyses: no systematic bias introduced in strata CPUE estimates by pooling years
- Variance of mean CPUE used annual average stratum sample size; avoided inflation of precision (i.e., treating pooled years as single survey)

### B. Fishing Power imputation procedure

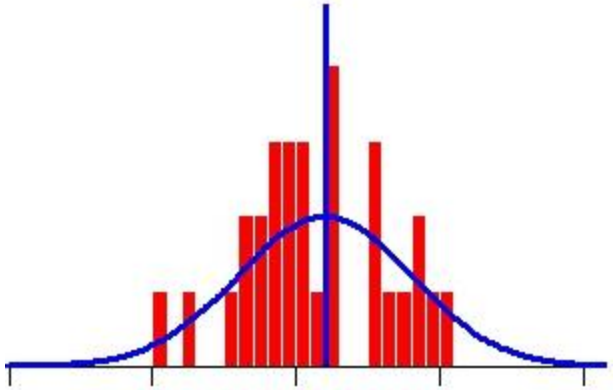
- Developed for remaining sparsely-sampled gear types (N2,D2,N4,D4) within specific season-area-depth strata
- Imputed strata accounted for 11% of fleet effort

CPUE, standard gear



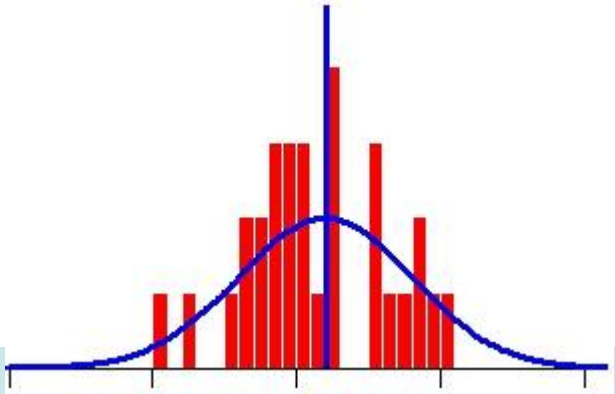
CPUE, gear=*s*

CPUE, gear 1



CPUE, gear=1

Standardized CPUE, gear 1



Standardized CPUE, gear=1

Each gear has its own measurement scale for CPUE, e.g., temperature in F or C

Estimates of fishing power,

$$\frac{CPUE_1}{CPUE_2} = \frac{q_1}{q_2} = \lambda_1$$

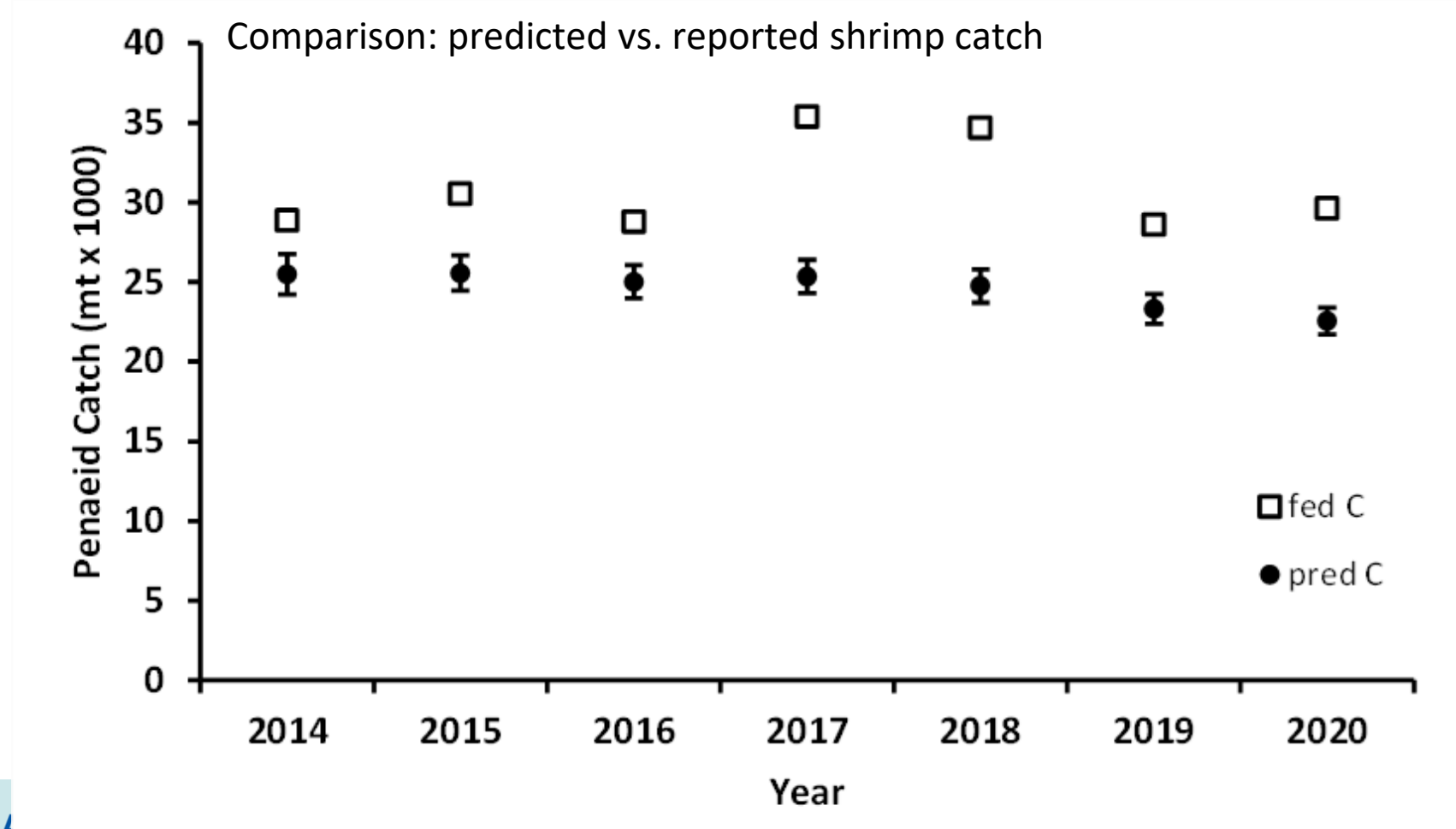
enable conversion of CPUE from one gear to another.

Fishing power multiplied by each effort observation, shifts CPUE distribution so that means line up for the standard gear and gear 1. Variance is not affected.

Imputation for sparsely-sampled strata entailed converting observer CPUE observations from a well-sampled gear type to a sparsely-sampled gear type, e.g., N4 to D2.

## Verification procedure, culmination of Phase 1 research

- Trip-ticket vs. observer-estimated landings differed by 10-20%
- Improvement from previous 45-50% difference, but bias issues remain



# Conclusion of Phase 1 observer and landings research: bycatch estimation report for CIE review

Smith, S.G., S. Atkinson, C. Peterson, J. Williams, K. Dettloff, A. Lowther. 2023. Improving estimation of bycatch from shrimp trawls in the Gulf of Mexico. Report to Council of Independent Experts. SEDAR Reference Document SEDAR98-RD-01. SEDAR, North Charleston, SC. 37 pp.

## Our Conclusions

- Analyses indicated unbiased observer trip catch and effort
- Incorporating gear type as an additional stratification variable improved accuracy of stratum-level estimates
- Remaining bias likely due to issues with total fleet effort, which is also impacted by issues with total llandings

## CIE Reviewers

- Bycatch methodology: sound approach, appropriate
- Agreed with our conclusions about remaining sources of bias
- Major recommendation #1: outfit entire fleet with tamper-proof GPS device
- #2: overhaul Shrimp Observer Program, especially statistical design and allocation of observer effort among strata
- Numerous additional suggestions: alleviating bias in fleet effort estimation, improving estimation of uncertainty, refining stratification scheme, etc.

# Follow-on Phase 2 Work, 2024
# SEDAR 98 (Gulf Red Snapper) and SEDAR 87 (Gulf Penaeid Shrimp)

- Bycatch methodology refined per technical CIE suggestions, mostly for improving effort estimation and reducing potential bias issues.
- Step 1: Applied to full observer time period 2007-2023
- Step 2: Applied to pre-observer, pre-GPS tracklog time period 1984-2006
- Much of the focus:
  (1) estimating more accurate commercial fleet shrimp landings and effort
  (2) extending landings and effort back in time with respect to space-time (area-depth-season) and gear (D2,D4,N2,N4) strata
  (3) further reading:

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

Atkinson, S., K. Dettloff, C. Peterson, S.G. Smith. 2025. Estimation of commercial shrimp effort in the Gulf of Mexico from 1984-2023. SEDAR98-DW-23. SEDAR, North Charleston, SC. 22 pp.

# Shrimp Landings, key element for estimating total fleet effort

Data Sources

- Gulf Shrimp System (GSS) - data collected by port agents from dealers who purchased shrimp where shrimp were unloaded; last year in 2014
- State trip ticket (STT) - programs to collect commercial seafood landings; implemented by the states in different years

Data compilation

- Commercial workgroup for SEDAR 87 extensively examined the data sources and data gaps and recommended years for each state to transition from GSS to trip ticket data. These years were confirmed by state representatives.
- Detailed data processing steps documented under SEDAR87-DW-06

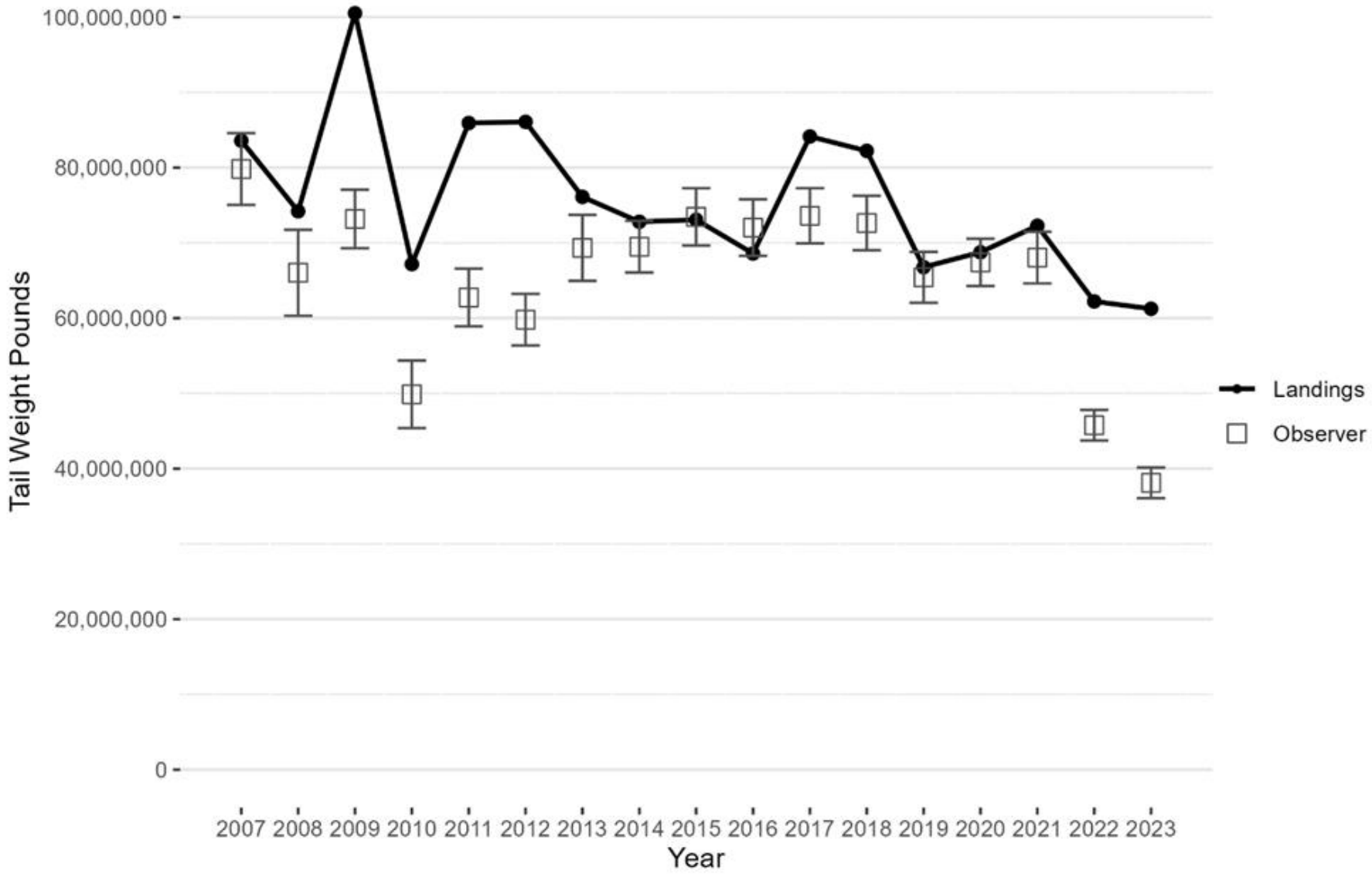
# State trip ticket start years

- AL, MS, LA: year recommended by the state
- TX did not have complete shrimp dealer coverage until 2014. TX recommend 2014 start
- FL had better reporting of key fields (area fished & market bin size) by 2003. FL concurs

| State | Start of Trip Ticket Program | GSS years used | STT years used |
|---|---|---|---|
| Florida (West Coast) | 1984 | 1960-2002 | 2003-2022 |
| Alabama | 2001 | 1960-2000 | 2001-2022 |
| Mississippi | 2012 | 1960-2015 | 2016-2022 |
| Louisiana | 1999 | 1960-1999 | 2000-2022 |
| Texas | 2008 | 1960-2013 | 2014-2022 |

# Phase 2 Verification procedure: predicted vs. reported shrimp catch

- Approx. match: 2014-2021
- General underestimation: 2007-2013, 2022-2023
- Correspondence appears related to changes in methods of effort data collection for ELBs
- Cellular transmission era showed best match
- Latest years with physical chips collection showed worst match.



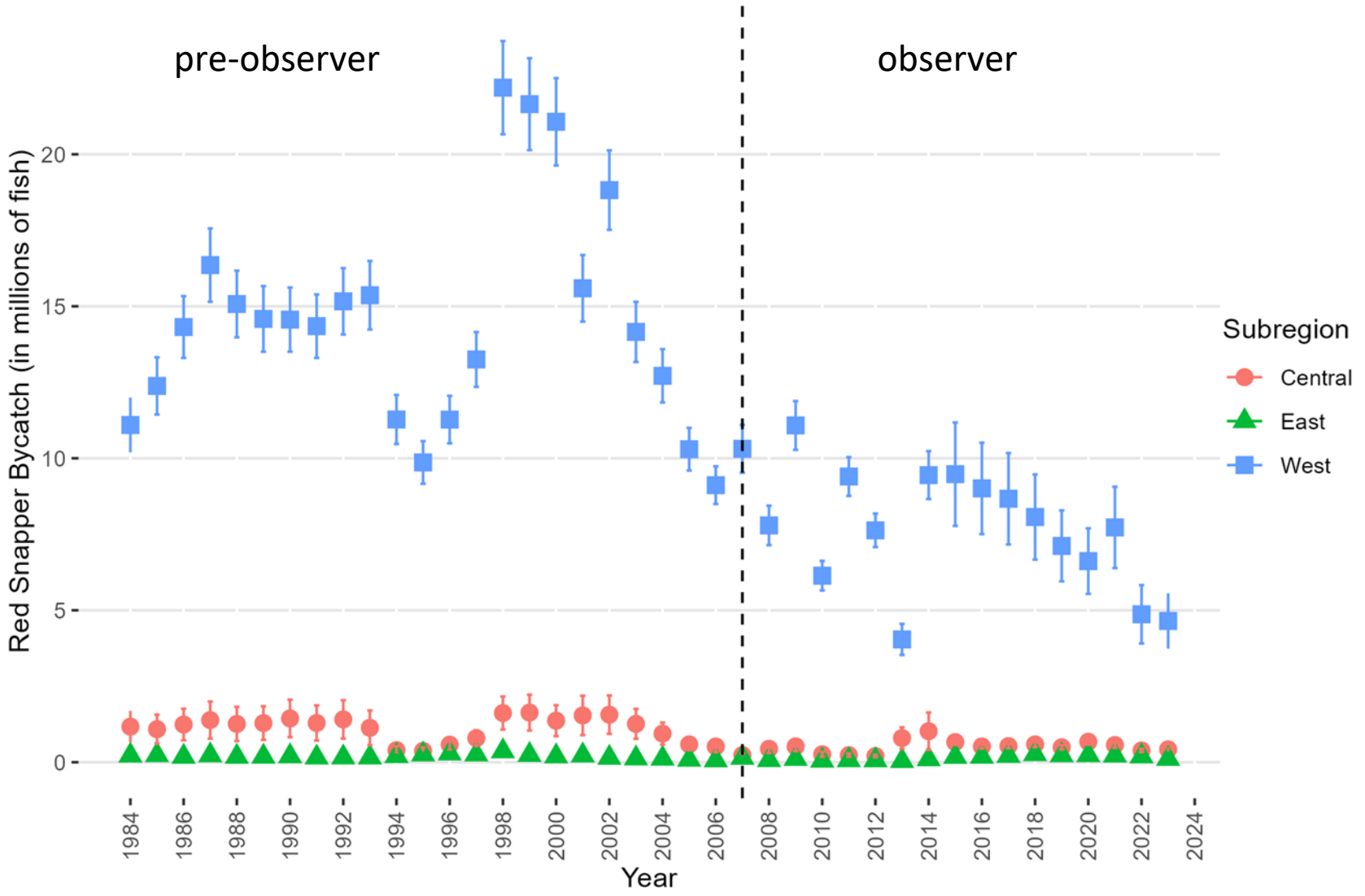
## Hindcasting: Bycatch estimates for pre-observer, pre-tracklog years (1984-2006)

- Majority of work: time-series of shrimp landings and effort for area-depth-season-gear strata
  A. Port agent dealer & captain interviews: trip landings-effort by net configuration and diurnal period
  B. Detailed in SEDAR working papers cited above

- Hindcasting procedure: related strata catch rates of red snapper and penaeid shrimp for 2007-2013
- Applied relationship to estimate strata catch rates for red snapper for 3 historical periods:
  1984-1990: moderate fleet effort, no BRD requirement
  1991-1997: high fleet effort, no BRD requirement
  1998-2006: decreasing fleet effort, BRD requirement
- Key assumption: stable relationship between shrimp and red snapper catch rates during period
- BRD analysis: red snapper mean catch per tow 7.1% higher for nets without BRD; used for historical adjustment of bycatch estimates pre-1998

- Majority: West (TX, LA)

## Red Snapper bycatch by Gulf zone, 1984-2023



# Comparison with previous bycatch estimates

- Previous estimates (SEDAR 52) showed similar patterns of increases and decreases, but were more volatile in terms of magnitude
- SEDAR 98 key differences: incorporated gear strata, improved shrimp landings and effort time-series
- SEDAR 52 used SEAMAP trawl data as a proxy for commercial trawls for pre-observer time period (pre-2007)
- Given that catch rates of commercial trawl gear types can differ by over 500%, equating SEAMAP trawls to commercial trawls might not be scientifically valid