# Update of Red Snapper, *Lutjanus campechanus*, Reproductive Life History from the MARMAP/SERFS and FWRI

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# Update of Red Snapper, *Lutjanus campechanus*, Reproductive Life History from the MARMAP/SERFS and FWRI

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**Introduction**

Red Snapper, *Lutjanus campechanus*, is a large, long-lived, member of the family Lutjanidae, with a maximum reported age of 51 yr (SEDAR41, 2017). Red Snappers are distributed in marine waters throughout the Gulf of Mexico south to the Yucatan Peninsula and in United States (U.S.) Atlantic waters north to North Carolina (Nelson and Manooch, 1982; Manooch and Potts, 1997). Along the southeastern U.S., adult Red Snapper are associated with structured habitats such as coral reefs, wrecks, rocky outcroppings, and live-bottom (Moseley, 1966; Nelson and Manooch, 1982; Barans and Henry, 1984; Sedberry and Van Dolah, 1984). Red Snapper are gonochorists with indeterminate fecundity (Woods, 2003; Brulé et al., 2010) that spawn during April through November in the Atlantic waters of the southeastern U.S. with peak spawn occurring June through August (White and Palmer, 2004; Lowerre-Barbieri et al. 2015; Wyanski et al. 2015).

In preparation for SEDAR 90, fishery-independent and fishery-dependent samples collected by MARMAP, the SouthEast Area Monitoring and Assessment Program, South Atlantic (SEAMAP-SA), and the Southeast Fishery-Independent Survey (SEFIS), collectively referred to as the SouthEast Reef Fish Survey (SERFS) were combined with samples from Florida Fish And Wildlife Research Institute (FWRI) and were added to the dataset from SEDAR 73.

**Objective**

1. Provide current estimates of reproductive parameters (i.e., age and size at maturity, sex ratios, spawning fraction and spawning frequency) for female Red Snapper in the Atlantic waters of the southeastern U.S. for an on-going assessment.
2. Estimate batch fecundity of female Red Snapper in the Atlantic waters of the southeastern U.S., accounting for size/age differences.

Data presented in this report are based on a query of the combined MARMAP/SERFS database on April 1, 2025.

**Methods**

*MARMAP/SERFS data*

Sampling area

- Cape Hatteras, NC, to St. Lucie Inlet, FL with limited sampling in the Florida Keys
  - General increase in sampling intensity (# of annual chevron trap deployments) through time
    - The largest increase occurred beginning in 2010, during the formation of SERFS
  - Gradual shift regarding the spatial coverage and density of samples through time
    - More geographic coverage and density in southern and northern latitudes in later years
    - The largest shift occurred beginning in 2010, during the formation of SERFS
- Sampling depths range from 13 to 212 m
  - Generally, less than 100 m

Sampling season

- May through September
  - Limited earlier and later sampling in some years

Survey Design

- Simple random sample survey design
  - Annually, randomly selected stations from a chevron video trap universe of confirmed hard-bottom habitat stations

- o No two stations are randomly selected that are closer than 200 m from each other
  - ▪ Minimum distance is typically closer to 400 m

• Video traps deployed on suspected hard-bottom in a given year (reconnaissance) are evaluated based on catch and/or video or photographic evidence of bottom type for inclusion in the universe in subsequent years

<u>Primary Sampling Gear – Chevron Video Traps</u> (video camera(s) added in 2010)

(see Collins 1990 and Smart et al. 2015 for more detailed descriptions)

• Arrowhead shaped, with a total interior volume of 0.91 m3

• Constructed of 35 x 35 mm square mesh plastic-coated wire with a single entrance funnel ("horse neck")

• Baited with a combination of whole or cut clupeids (Brevoortia or Alosa spp., family Clupeidae), most often Brevoortia spp.

- o Four whole clupeids on each of four stringers suspended within the video trap
- o Approximately 8 clupeids placed loose in the video trap

• Soak time of approximately 90 minutes

• Daylight hours

<u>Other Sampling Gears</u>

- Prior to 1988 (pre chevron trap) primary gear was hook and line and snapper/bandit reel
- Other gear types below have limited temporal use with variable intensities

<u>Data Filtering/Inclusion</u>

- Projects coordinated by MARMAP/SERFS (Project Codes)
  - P05/Q26/Q56/T59/T60/T61/T62/T70 – MARMAP/SEAMAP-SA/SEFIS (Fishery-Independent)
  - P50/T12 – Port Sampling (Fishery-Dependent)
- Gear (Codes and Descriptions)
  - 014 - Hook and Line
  - 041 - Mini-Antillean "S" Trap
  - 043 - Snapper Reel
  - 053 - Blackfish trap
  - 061 - Short-bottom Longline
  - 065 - Speargun
  - 074 - Florida Antillean trap
  - 073 - Experimental Trap
  - 226 - Commercial High-Rise Roller Trawl
  - 324 - Chevron trap
  - 335 - Longline
  - 603 - Repetitive Timed-Drop Hook and Line
  - 604 - Standardized Sabiki Rig

See Smart et al. 2015 for full description of MARMAP/SERFS survey design and gear.

*FWRI data*

See Lowerre-Barbieri et al. (2015) for full description of survey design and gear

<u>Sampling area</u>

- East coast of Florida (~28°00′ N to 30°45′ N) on presumed hard-bottom reef habitats

- Depth was broken into two strata: nearshore-30 m and 30 m-100 m

<u>Sampling season</u>

- April through October (majority April – Aug.)

<u>Survey Design</u>

- Randomized within each stratum. Grid-based design around suitable habitat locations with sampling units 0.3 nautical miles latitude × 0.1 nautical miles longitude grid cells.
    - Monthly allocated to depth (Inshore: 12/zone Offshore: 20/zone)

<u>Primary Sampling Gear</u>

- Main method: Active hook-and-line fishing using repetitive timed drop method (88% of total samples).
    - rig consisted of a 2-hook combination (top hook listed first): 8/0 and 11/0, 8/0 and 15/0, or 11/0 and 15/0 size hooks
    - 12 drops/site inshore, 10 drops/site offshore
- Other gears used: Vertical bottom long line and Horizontal bottom long line

<u>Data Filtering/Inclusion</u>

- Only females with maturity data were provided (n=1057)

*Life History Processing*

All fish caught were weighed to the nearest gram (g) and measured in millimeters (mm) for a pinched tail maximum total length (MaxTL). Prior to 2017, in the field, otoliths and gonad samples were removed and stored for processing following MARMAP/SERFS and FWRI protocols (Smart et al. 2015; Lowerre-Barbieri et al. 2015). In 2017, MARMAP/SERFS gonads were visually assessed as male, female or unknown, but only female and unknown were preserved and processed for histology. In 2024 SERFS sampling began a 3-year pattern of cycling macro sexing all Red Snapper vs histologically assessing.

Fecundity samples were taken from individuals with ovaries that had oocytes undergoing maturation (stage-2 and stage-3 yolked oocytes) but prior to ovulation (Hunter et al. 1992). A regression equation was developed to convert fresh weight to preserved weight of gonads. When the gonad was not appropriate for fecundity, it was only prepared for histological processing and sex/phase assignment; either the whole gonad or a representative portion, depending on the gonad size, was fixed in an 11% seawater-buffered formalin solution.

In the laboratory, otolith processing followed MARMAP/SERFS protocols (Smart et al. 2015) and FWRI protocols (Lowerre-Barbieri et al. 2015). In summary, otoliths, were embedded in epoxy resin, sectioned dorsoventrally through the core with a low speed Isomet saw and mounted on glass microscope slides. One to three otolith sections were examined with transmitted light under a dissecting microscope. Counts were made from the core of each otolith to the outer edge of each opaque zone and to the edge of the otolith. Sections were examined independently by two readers and re-examined jointly when differences in age estimation occurred.

All age data provided to SEDAR90 included increment count and calendar age. The adjusted calendar age is based on timing of annulus formation (July) and width of translucent edge present. If the otolith section had an opaque or narrow translucent edge, regardless of date captured, the calendar age equals the number of increments (annuli) counted on the section. If the otolith section came from a fish that was captured during or after July, regardless of edge type, the calendar age equals the number of increments counted on the section. If the otolith section had a wide translucent edge and was captured before July, then calendar age equals the number of increments counted on the section plus one.

In the laboratory, histological processing followed MARMAP/SERFS protocols (Smart et al. 2015) and FWRI protocols (Lowerre-Barbieri et al. 2015). Briefly, tissue was dehydrated, infiltrated with paraffin, embedded in paraffin, and transverse sectioned (3-8 µm thick) prior to mounting on slides and staining with hematoxylin and a counterstain (eosin-y for MARMAP/SERFS and metanil yellow for FWRI). Sex and reproductive phase were assigned independently by two readers using histological criteria from Brown-Peterson et al. (2011) and re-examined jointly when differences in assignment occurred. If consensus could not be reached, then unknown sex and/or phase was assigned.

Fecundity samples were combined between MARMAP/SERFS samples and FWRI samples, similar to Wyanski et al. (2020). Histological samples were processed and examined to assess reproductive phase and search for evidence that ovulation had begun (i.e., postovulatory complexes (POC)). All specimens with new POCs (approximately <24 hrs old based on size, organization and appearance of the granulosa cells' nuclei) were not used for the estimation of batch fecundity. Batch fecundity was estimated gravimetrically by MARMAP/SERFS and Lowerre-Barbieri et al. (2015) using the hydrated oocyte method (see Hunter and Macewics, 1985; Murua et al., 2003). The protocols for processing Red Snapper ovarian tissue were similar, except for the methods of fixing tissue and separating oocytes. Lowerre-Barbieri et al. (2015) hydraulically separated the oocytes prior to fixation in 2% neutrally buffered formalin and then weighed subsamples, whereas MARMAP/SERFS fixed the tissue in 10% seawater-buffered formalin, weighed subsamples, transferred subsamples to 5% seawater-buffered formalin, and then separated oocytes manually or hydraulically (beginning in 2021). MARMAP/SERFS investigators obtained 2 or 3 subsamples per specimen that weighed 75-175 mg, versus 2 subsamples weighing 100 mg in Lowerre-Barbieri et al. (2015).

*Life History Analysis*

To ensure that females were correctly assigned to the immature and regenerating categories, the length frequency histogram of females that were definitely mature (i.e., developing, spawning capable, or regressing) were compared with the histograms for females assessed as immature and regenerating/early developing.

Maturity analysis was performed for only female Red Snapper. Males were not analyzed for sexual maturity due to extremely low numbers of immature specimens and lack of recent samples staged histologically due to funding restraints. Females of uncertain maturity were excluded from all reproductive analyses. All specimens with known stages for maturity were included in the maturity analyses, regardless of project, gear, or source (n=8,043). The definition of maturity with the least associated uncertainty was the "Spawning" definition, which classified individual fish with spawning indicators (oocyte maturation or postovulatory complexes) as mature while individual fish with primary growth oocytes and no cortical alveoli oocytes were classified as immature (Lowerre-Barbieri et al., 2023; n=4401). Age and length-based maturity analyses were done using calendar age and MaxTL. To estimate age/length maturity ogives, age at 50% maturity ($A_{50}$) and length at 50% maturity ($L_{50}$), five functions were tested and compared: logit link, probit link, cloglog link, Cauchy link and Gompertz. The best fit model was selected by Akaike information criterion (AIC; Akaike, 1973) and used to predict the maturity at age and length for Red Snapper. Age at maturity was estimated for 4 periods, dictated by adequate sample availability, range in sizes to appropriately address maturity estimates, and changes in spawning stock biomass. To quantify uncertainty around age and lengths at 50% maturity for each time period, nonparametric bootstrapping was conducted, resampling 1000 times with replacement and calculating standard error and 95% confidence intervals for each time period. We tested for significant differences in $A_{50}$ and $L_{50}$ among time periods using one-way ANOVA and Tukey's HSD post-hoc test to test significant differences between time periods.

- 1978-2023 (entire time series)
- 2010-2023 (formation of SERFS and increase in sample size/range/density)
- 2010-2016 (lower spawning stock biomass)
- 2017-2023 (increasing spawning stock biomass)

To test whether the sex ratio differed significantly from parity (i.e., 1:1), we conducted three separate regression analyses to evaluate the relationship between sex ratio and year, MaxTL (mm), and calendar age (with age group 20+). Sex ratio was compared by year using samples from all gears, as well as limited to samples from only chevron traps. When comparing with calendar age and length, all specimens with a known sex assignment, regardless gear type were assessed to maximize the age and size range. Linear and nonlinear (logarithmic and power) relationships between sex ratio and the three parameters were explored and the model with the lowest AIC was selected as model of best fit. A one-sample t-test was used to assess whether the slope significantly differed from 0, indicating deviation from a 1:1 sex ratio. Chi squared analysis was preformed to test if each year, length bin or age bin was significantly different from the 1:1 sex ratio.

Estimates of spawning fraction were based on histological criteria; the presence of migratory nucleus oocytes (MNOs) or hydrated oocytes (HOs) , which persist for ~10 hours (Jackson et al. 2006) or POCs (not restricted to POCs less than 24 hrs old due to limitations in the resolution in the data available) which all indicate imminent or recent spawning (Hunter and Goldberg 1980; Hunter et al. 1986). Estimates of spawning fraction represented the proportion of specimens with one or more of the above criteria among all adult females (active + inactive) by month and by calendar age, adjusted to daily using a daily calibration ((Spawning proportion*34 hrs)/24 hrs); Jackson et al. 2006; Porch et al. 2015). Females with uncertain and immature maturity phases were excluded. All other specimens with known stages for maturity were included in this analysis, regardless of project, gear, source (fishery-independent and dependent). Due to limited sample sizes, samples over the age of 9 years old were grouped into age groups (9-11, 12-14 and 15+), a 2+ age group was also reported to represent samples above the $A_{50}$. Samples were limited within the core spawning season. The core method calculates the spawning season duration by determining the number of days between the first and last day of capture of an individual with spawning indicators, however restricting the timeframe by calculating the binomial regression of 50% developing vs spawning at the beginning of the season and 50% spawning vs regressing/regenerating at the end of the season (Lowerre-Barbieri et al. 2023). Spawning frequency is calculated by dividing the spawning season duration by the inverse of the spawning fraction (aka spawning interval; Hunter and Macewicz 1985; Lowerre-Barbieri et al. 2011).

For batch fecundity analysis, counts were converted from the preserved subsample weight to preserved whole gonad weight for estimates of batch fecundity. We applied a conversion developed for this study for any individual that did not have a preserved whole gonad weight:

$$\text{preserved wt (g)} = \text{fresh wt (g)} * 0.8833 - 1.6071$$

There was a range of fresh gonad wt = 7 to 51 g, an adj. $r^2$ value = 0.91 and a sample size =29. Batch fecundity to MaxTL (mm) was explored with regression analysis using a linear and nonlinear (logarithmic and power functions) approach. Two power function models (with and without intercept; $BF = bX^z$ and $BF = a + (b*X^z)$) were tested, the latter to relax forcing the intercept through the origin. The approach with the lowest AIC value was selected.

Data analyses were performed using R software (R Core Team 2023) in the RStudio environment (RStudio Team, 2023).

## Results

Red Snapper included in the reproductive analyses for SEDAR 90 were captured between latitude 24.34° and 35.36° N and at a depth range of 14 to 212 meters, from fishery-independent and fishery-dependent sources, between 1978 – 2024. Specimens utilized ranged in size from 159 to 997 mm MaxTL. All specimens smaller than 159 mm had unknown sex assignments (n=18). Increment counts in sagittal otoliths ranged from 0-45. Raw data were provided to the SEDAR 90 Data Workshop in 2025. There was minimal overlap in the peak length distributions of immature or regenerating/early developing Red Snapper and substantial overlap of regenerating/early developing and definitely mature individuals indicating that maturity stages were assigned correctly (Figure 1).

There were 8,043 females with known sex, maturity and calendar age information and 8,077 females with known sex, maturity and MaxTL information. Overall, calendar age for females at 50% maturity ($A_{50}$) was 1.67 yr (Gompertz, proportion mature = $\exp((-\beta / \beta1)*\exp(-\beta1 *age))$; 95% confidence intervals (CI) = 1.40-1.95 yr; Table 1) and length at 50% maturity ($L_{50}$) was 326 mm MaxTL (Logit, proportion mature = $1/1+ \exp(-((a+(b*MaxTL))$; 95% CI = 279-380 mm; Table 2). For all time periods, less than 16% of age 1 fish were mature, over 65% of age 2 fish were mature, and over 90% of age 3 fish were mature (Table 3). For all time periods, less than 20% of individuals less than 300 mm are mature and by 380 mm over 90% of individuals were mature (Table 4). The analysis of calendar age at maturity for the various time periods revealed the Gompertz model produced the lowest AIC value for all time periods. Age at maturity for female Red Snapper in 2010-2023, 2010-2016, & 2017-2023 was 1.61 yr (95% CI = 1.39-1.82 yr; n=4401), 1.58 yr (95% CI = 1.25-1.90 yr; n=1549) and 1.63 yr (95% CI = 1.34-1.91 yr; n=2852), respectively (Table 1). The bootstrapped values for $A_{50}$ were found to be statistically significantly different between all time periods, however the overlapping 95% confidence intervals bring into question the biological significance of these differences (all p values < 0.001; Figure 2A). The analysis of length at maturity for the various time periods revealed the Logit link model most often produced the lowest AIC values. Length at maturity for female Red Snapper from 2010-2023, 2010-2016, & 2017-2023 was 322 mm MaxTL (95% CI = 373-380), 349 mm MaxTL (95% CI = 253-481) and 315 mm MaxTL (95% CI = 255-389), respectively (Table 2). The bootstrapped values for $L_{50}$ were found to be statistically significantly different between all time periods (all p values < 0.001; Figure 2B). While there is overlap in confidence intervals for 1978-2023, 2010-2023 and 2017-2023, an increase in $L_{50}$ in the 2010-2016 period is observed, however this difference may not be biologically relevant.

The ratio of females to males for all MARMAP/SERFS samples is less than would be expected if the population sex ratio was 1:1 (0.96; n=16937; Female = 8295; Males = 8642; chi squared p =0.013; Table 5), but the significant result is likely the result of a large dataset and has no biological significance. When comparing across years using a regression test, there was no significant change from 1:1 sex ratio regardless of whether the data was limited to chevron trap only or not (Figure 3; logarithmic: t (31) = 0.89, p = 0.378; t (42) = 1.94, p = 0.059, respectively). When examining age-specific sex-ratios, regression analysis did not find a significant difference from a 1:1 overall (Logarithmic: t(18) = 1.06, p =0.31; Adj $R^2$ =0.17), but a distinct trend was observed in the data, with younger fish (ages 1-3) having more male oriented sex ratios and older fish (6-20) having more female oriented sex ratios, however when ages 20-48 (n =27) are grouped they exhibit a 1:1 sex ratio (Figure 4A; Table 6). There was a similar trend with total length and sex ratio, with a statistically significant difference from 1:1 ratio (Logarithmic: t (31) = -2.64, p =0.01; Adj $R^2$ =0.33) with sizes over 650 mm were more female dominant (Figure 4B; Table 7).

Female Red Snapper have a protracted spawning season. Females with spawning indicators were captured throughout much of the year, with the monthly proportion of spawning individuals to adult females >10% from April-November, and >50% from June through September (Figure 5; Table 8). The core spawning season was found to be between Julian Day 144 and 303 (~May 24th – Nov 3rd). Spawning fraction limited to core spawning season by calendar age was 0.16 in age 1 fish, 0.45 for fish ages 2+ and ranged from 0.41-0.50 in the other age groups (Table 9). Spawning frequency was 25 spawns per year in age 1 fish, 71 spawns per year for fish ages 2+ and ranged from 55-78 in the other age groups (Table 9).

A total of 129 Red Snapper was collected from 1999-2023 to assess batch fecundity, including 32 specimens collected and processed by MARMAP/SERFS since 2019 that were added to the dataset (n=97) analyzed for SEDAR73. The 129 specimens ranged in length from 314 to 958 mm MaxTL, in whole weight from 470 g to 11,830 g and in calendar age from 2 to 18 yr. Although the fits of the linear regression equations were good, the logarithmic function model was applied to the data because batch fecundity exhibited a non-linear relationship with total length (MaxTL) and whole weight (W), and to a lesser degree with calendar age (Figure 6 & Table 10; Adj. $R^2$ = 0.57-0.76). Having few samples over the length of 900 mm, weight of 9000 g and the age of 10 led to higher uncertainty in batch fecundity at larger sizes and ages. Future sampling efforts should target filling this data gap.

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## Tables

**Table 1**. Results of various regression model analyses for age 50% at maturity for female Red Snapper, by period. Data for all projects and gears were combined. Age is expressed in calendar age. n=number of fish used in analyses, $A_{50}$= age at which 50% of population has reached sexual maturity. Analysis was conducted using “Spawning” definition for maturity (Any individuals with immanent spawning markers per Lowerre-Barbieri et al. 2023). Gompertz: Proportion mature = exp ((-β/ $\beta_1$) *exp(-$\beta_1$*age).

| | | | | | Parameter Estimates | |
|---|---|---|---|---|---|---|
| Period | Model | n | $A_{50}$ | 95% CI | β (Std Err) | $\beta_1$ (Std Err) |
| 1980-2023 | Gompertz | 4601 | 1.67 | 1.40-1.95 | 14.303 (1.924) | 1.550 (0.053) |
| 2010-2023 | Gompertz | 4401 | 1.61 | 1.39-1.82 | 10.000 (1.207) | 1.435 (0.047) |
| 2010-2016 | Gompertz | 1549 | 1.58 | 1.25-1.90 | 10.000 (1.807) | 1.454 (0.074) |
| 2017-2023 | Gompertz | 2852 | 1.63 | 1.34-1.91 | 10.000 (1.611) | 1.424 (0.061) |

**Table 2.** Results of various regression model analyses for length 50% at maturity for female Red Snapper, by period. Data for all projects and gears were combined. Length is maximum (pinched tail) total length (MaxTL) in mm. n=number of fish used in analyses, $L_{50}$=length at which 50% of the population has reached sexual maturity. Analysis was conducted using "Spawning" definition for maturity (Any individuals with immanent spawning markers per Lowerre-Barbieri et al. 2023). Logit: Proportion mature = 1/1+ exp -((β +(b*MaxTL)).

| | | | | | Parameter Estimate | |
|---|---|---|---|---|---|---|
| Period | Model | n | $L_{50}$ | 95% CI | β (Std Err) | $\beta_1$ (Std Err) |
| 1980-2023 | Logit Logistic | 4635 | 325.6 | 279-380 | -15.847 (0.633) | 0.049 (0.002) |
| 2010-2023 | Logit Logistic | 4421 | 322.24 | 273-380 | -18.088 (0.774) | 0.056 (0.002) |
| 2010-2016 | Logit Logistic | 1564 | 348.77 | 253-481 | -21.233 (1.770) | 0.061 (0.005) |
| 2017-2023 | Logit Logistic | 2857 | 314.86 | 255-389 | -20.442 (1.115) | 0.065 (0.003) |

**Table 3**. Observed percentage of mature specimens by calendar age for female Red Snapper, by period. Analysis was conducted using "Spawning" definition for maturity (Any individuals with imminent spawning markers per Lowerre-Barbieri et al. 2023). *n*=number of specimens available from all projects and gears.

| | 1980-2023 | | 2010-2023 | | 2010-2016 | | 2017-2023 | |
|---|---|---|---|---|---|---|---|---|
| | n=4601 | | n=4401 | | n=1549 | | n=2852 | |
| Calendar Age | Observed % | n | Observed % | n | Observed % | n | Observed % | n |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | | 0 |
| 1 | 14 | 350 | 15 | 341 | 13 | 157 | 16 | 184 |
| 2 | 66 | 1190 | 67 | 1141 | 69 | 410 | 66 | 731 |
| 3 | 92 | 1406 | 93 | 1343 | 96 | 390 | 92 | 953 |
| 4 | 96 | 547 | 98 | 510 | 98 | 131 | 98 | 379 |
| 5 | 99 | 370 | 99 | 349 | 99 | 151 | 99 | 198 |
| 6 | 100 | 235 | 100 | 227 | 100 | 101 | 100 | 126 |
| 7+ | 100 | 502 | 100 | 489 | 100 | 208 | 100 | 281 |

**Table 4**. Percentage of mature specimens by maximum (pinched tail) total length interval (MaxTL, mm) for female Red Snapper, by period. Analysis was conducted using "Spawning" definition for maturity (Any individuals with immanent spawning markers per Lowerre-Barbieri et al. 2023). *n*=number of specimens available from all projects and gears.

| | 1980-2023 | | 2010-2023 | | 2010-2016 | | 2017-2023 | |
|---|---|---|---|---|---|---|---|---|
| | n=4653 | | n=4421 | | n=1564 | | n=2857 | |
| MaxTL (mm) | Observed % | n | Observed % | n | Observed % | n | Observed % | n |
| 150-250 | 0 | 213 | 1 | 194 | 0 | 72 | 1 | 122 |
| 251-260 | 0 | 89 | 0 | 83 | 0 | 29 | 0 | 54 |
| 261-270 | 3 | 87 | 4 | 83 | 0 | 26 | 5 | 57 |
| 271-280 | 6 | 104 | 6 | 102 | 0 | 35 | 9 | 67 |
| 281-290 | 7 | 67 | 8 | 65 | 0 | 16 | 10 | 49 |
| 291-300 | 14 | 93 | 14 | 91 | 3 | 30 | 20 | 61 |
| 301-310 | 36 | 80 | 37 | 78 | 0 | 14 | 45 | 64 |
| 311-320 | 61 | 80 | 62 | 79 | 14 | 14 | 72 | 65 |
| 321-330 | 69 | 70 | 71 | 66 | 43 | 7 | 75 | 59 |
| 331-340 | 74 | 117 | 78 | 111 | 38 | 16 | 85 | 95 |
| 341-350 | 79 | 113 | 81 | 110 | 46 | 24 | 91 | 86 |
| 251-360 | 87 | 172 | 90 | 164 | 71 | 34 | 95 | 130 |
| 361-370 | 85 | 137 | 90 | 129 | 76 | 37 | 96 | 92 |
| 371-380 | 93 | 180 | 96 | 171 | 91 | 44 | 98 | 127 |
| 381-390 | 93 | 149 | 98 | 138 | 96 | 53 | 99 | 85 |
| 391-400 | 95 | 175 | 97 | 167 | 94 | 48 | 98 | 119 |
| 401-410 | 97 | 129 | 98 | 125 | 100 | 39 | 98 | 86 |
| 411-420 | 100 | 141 | 100 | 134 | 100 | 51 | 100 | 83 |
| 421-430 | 98 | 114 | 99 | 107 | 97 | 39 | 100 | 68 |
| 431-440 | 99 | 149 | 100 | 143 | 100 | 57 | 100 | 86 |
| 450+ | 100 | 2176 | 100 | 2081 | 100 | 879 | 100 | 1202 |

**Table 5.** Red Snapper sex ratio and proportion female by year for all gears and all projects.

| Year | Male n | Female n | Total n | Female:Male | Proportion Female | $Chi^2$ p value |
|---|---|---|---|---|---|---|
| 1978-2024 | 8642 | 8322 | 16964 | 0.96 | 0.49 | 0.013 |
| 2010-2024 | 8067 | 7667 | 15734 | 0.95 | 0.49 | 0.001 |
| 2010-2024 Chevron only | 7470 | 7068 | 14538 | 0.95 | 0.49 | <0.001 |
| 2010-2016 | 2038 | 2171 | 4209 | 1.07 | 0.52 | 0.04 |
| 2017-2024 | 6029 | 5496 | 11525 | 0.91 | 0.48 | <0.001 |
| 1978 | 1 | 2 | 3 | 0.67 | 2 | 0.56 |
| 1979 | 3 | 9 | 12 | 0.75 | 3 | 0.08 |
| 1980 | 6 | 10 | 16 | 0.63 | 1.67 | 0.32 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1981 | 5 | 3 | 8 | 0.38 | 0.60 | 0.48 |
| 1982 | 1 | 2 | 3 | 0.67 | 2 | 0.56 |
| 1984 | 9 | 12 | 21 | 0.57 | 1.33 | 0.51 |
| 1986 | 0 | 2 | 2 | 1 | | 0.16 |
| 1987 | 3 | 1 | 4 | 0.25 | 0.33 | 0.32 |
| 1988 | 21 | 29 | 50 | 0.58 | 1.38 | 0.26 |
| 1989 | 3 | 6 | 9 | 0.67 | 2.00 | 0.32 |
| 1990 | 16 | 12 | 28 | 0.43 | 0.75 | 0.45 |
| 1991 | 14 | 15 | 29 | 0.52 | 1.07 | 0.85 |
| 1992 | 13 | 17 | 30 | 0.57 | 1.31 | 0.47 |
| 1993 | 13 | 18 | 31 | 0.58 | 1.38 | 0.37 |
| 1994 | 28 | 28 | 56 | 0.50 | 1.00 | 1.00 |
| 1995 | 11 | 16 | 27 | 0.59 | 1.45 | 0.34 |
| 1996 | 17 | 26 | 43 | 0.60 | 1.53 | 0.17 |
| 1997 | 29 | 48 | 77 | 0.62 | 1.66 | 0.03 |
| 1998 | 23 | 23 | 46 | 0.50 | 1 | 1 |
| 1999 | 77 | 71 | 148 | 0.48 | 0.92 | 0.62 |
| 2000 | 185 | 204 | 389 | 0.52 | 1.10 | 0.34 |
| 2001 | 24 | 26 | 50 | 0.52 | 1.08 | 0.78 |
| 2002 | 21 | 15 | 36 | 0.42 | 0.71 | 0.32 |
| 2003 | 1 | 3 | 4 | 0.75 | 3 | 0.32 |
| 2004 | 4 | 1 | 5 | 0.20 | 0.25 | 0.18 |
| 2005 | 6 | 7 | 13 | 0.54 | 1.17 | 0.78 |
| 2006 | 4 | 2 | 6 | 0.33 | 0.50 | 0.41 |
| 2007 | 17 | 18 | 35 | 0.51 | 1.06 | 0.87 |
| 2008 | 15 | 17 | 32 | 0.53 | 1.13 | 0.72 |
| 2009 | 9 | 12 | 21 | 0.57 | 1.33 | 0.51 |
| 2010 | 86 | 82 | 168 | 0.49 | 0.95 | 0.76 |
| 2011 | 52 | 76 | 128 | 0.59 | 1.46 | 0.03 |
| 2012 | 251 | 251 | 502 | 0.50 | 1 | 1 |
| 2013 | 209 | 292 | 501 | 0.58 | 1.40 | <0.001 |
| 2014 | 374 | 430 | 804 | 0.53 | 1.15 | 0.05 |
| 2015 | 488 | 503 | 991 | 0.51 | 1.03 | 0.63 |
| 2016 | 578 | 537 | 1115 | 0.48 | 0.93 | 0.22 |
| 2017 | 795 | 742 | 1537 | 0.48 | 0.93 | 0.18 |
| 2018 | 1106 | 960 | 2066 | 0.46 | 0.87 | 0.001 |
| 2019 | 1021 | 952 | 1973 | 0.48 | 0.93 | 0.12 |
| 2020 | 57 | 46 | 103 | 0.45 | 0.81 | 0.28 |
| 2021 | 270 | 265 | 535 | 0.50 | 0.98 | 0.83 |
| 2022 | 949 | 918 | 1867 | 0.49 | 0.97 | 0.47 |
| 2023 | 1034 | 861 | 1895 | 0.45 | 0.83 | <0.001 |
| 2024 | 797 | 752 | 1549 | 0.49 | 0.94 | 0.25 |

**Table 6**. Red Snapper sex ratio by maximum (pinched tail) total length (MaxTL, mm) 1978-2024, including all projects and gears.

| MaxTL (mm) | Male n | Female n | Total n | Female:Male | Proportion Female | $Chi^2$ p value |
|---|---|---|---|---|---|---|
| 151-175 | 1 | 4 | 5 | 4 | 0.8 | 0.18 |
| 176-200 | 19 | 10 | 29 | 0.53 | 0.34 | 0.09 |
| 201-225 | 80 | 62 | 142 | 0.78 | 0.44 | 0.13 |
| 226-250 | 172 | 135 | 307 | 0.78 | 0.44 | 0.03 |
| 251-275 | 307 | 269 | 576 | 0.88 | 0.47 | 0.11 |
| 276-300 | 440 | 331 | 771 | 0.75 | 0.43 | <0.001 |
| 301-325 | 535 | 418 | 953 | 0.78 | 0.44 | <0.001 |
| 326-350 | 672 | 532 | 1204 | 0.79 | 0.44 | <0.001 |
| 351-375 | 830 | 633 | 1463 | 0.76 | 0.43 | <0.001 |
| 376-400 | 873 | 716 | 1589 | 0.82 | 0.45 | <0.001 |
| 401-425 | 721 | 618 | 1339 | 0.86 | 0.46 | 0.005 |
| 426-450 | 601 | 532 | 1133 | 0.89 | 0.47 | 0.04 |
| 451-475 | 483 | 459 | 942 | 0.95 | 0.49 | 0.43 |
| 476-500 | 426 | 434 | 860 | 1.02 | 0.50 | 0.79 |
| 501-525 | 386 | 380 | 766 | 0.98 | 0.50 | 0.83 |
| 526-550 | 314 | 349 | 663 | 1.11 | 0.53 | 0.17 |
| 551-575 | 273 | 281 | 554 | 1.03 | 0.51 | 0.73 |
| 576-600 | 193 | 235 | 428 | 1.22 | 0.55 | 0.04 |
| 601-625 | 172 | 202 | 374 | 1.17 | 0.54 | 0.12 |
| 626-650 | 164 | 182 | 346 | 1.11 | 0.53 | 0.33 |
| 651-675 | 120 | 165 | 285 | 1.38 | 0.58 | 0.008 |
| 676-700 | 154 | 183 | 337 | 1.19 | 0.54 | 0.11 |
| 701-725 | 103 | 193 | 296 | 1.87 | 0.65 | <0.001 |
| 726-750 | 125 | 153 | 278 | 1.22 | 0.55 | 0.09 |
| 751-775 | 128 | 194 | 322 | 1.52 | 0.60 | <0.001 |
| 776-800 | 115 | 223 | 338 | 1.94 | 0.66 | <0.001 |
| 801-825 | 82 | 126 | 208 | 1.54 | 0.61 | 0.002 |
| 826-850 | 51 | 95 | 146 | 1.86 | 0.65 | <0.001 |
| 851-875 | 21 | 50 | 71 | 2.38 | 0.70 | <0.001 |
| 876-900 | 9 | 39 | 48 | 4.33 | 0.81 | <0.001 |
| 901-925 | 2 | 19 | 21 | 9.5 | 0.90 | <0.001 |
| 926-950 | 3 | 6 | 9 | 2 | 0.67 | 0.32 |
| 951-975 | 1 | 1 | 2 | 1 | 0.5 | 1 |
| 976-1000 | 0 | 3 | 3 | | 1 | 0.08 |

**Table 7**. Red Snapper sex ratio by Calendar Age from 1978-2024, including all projects and gears.

| Calendar Age | Male n | Female n | Total n | Female:Male | Proportion Female | $Chi^2$ p value |
|---|---|---|---|---|---|---|
| 1 | 851 | 657 | 1508 | 0.77 | 0.44 | <0.001 |
| 2 | 2480 | 1937 | 4417 | 0.78 | 0.44 | <0.001 |
| 3 | 2744 | 2516 | 5260 | 0.92 | 0.48 | 0.002 |
| 4 | 1268 | 1217 | 2485 | 0.96 | 0.49 | 0.31 |
| 5 | 472 | 594 | 1066 | 1.26 | 0.56 | <0.001 |
| 6 | 272 | 415 | 687 | 1.53 | 0.60 | <0.001 |
| 7 | 124 | 223 | 347 | 1.80 | 0.64 | <0.001 |
| 8 | 73 | 154 | 227 | 2.11 | 0.68 | <0.001 |
| 9 | 63 | 103 | 166 | 1.63 | 0.62 | 0.002 |
| 10 | 49 | 99 | 148 | 2.02 | 0.67 | <0.001 |
| 11 | 32 | 45 | 77 | 1.41 | 0.58 | 0.14 |
| 12 | 23 | 49 | 72 | 2.13 | 0.68 | 0.002 |
| 13 | 14 | 41 | 55 | 2.93 | 0.75 | <0.001 |
| 14 | 15 | 29 | 44 | 1.93 | 0.66 | 0.04 |
| 15 | 9 | 20 | 29 | 2.22 | 0.69 | 0.04 |
| 16 | 9 | 21 | 30 | 2.33 | 0.7 | 0.03 |
| 17 | 7 | 20 | 27 | 2.86 | 0.74 | 0.01 |
| 18 | 6 | 16 | 22 | 2.67 | 0.73 | 0.03 |
| 19 | 4 | 10 | 14 | 2.5 | 0.71 | 0.11 |
| 20+ | 14 | 13 | 27 | 0.93 | 0.48 | 0.85 |

**Table 8**. The spawning fraction of Red Snapper (# female spawners/# adult females) by month group from 1978-2023, including all projects, and gears. A spawner had one or more indicators of spawning. MNO = Migratory Nucleus Oocytes, HO = hydrated oocytes, POC = postovulatory complex. Adult females included active and inactive adults.

| Month | Adult n | Spawners n | Spawning Prop. (MNO, HO, POC) |
|---|---|---|---|
| Jan | 21 | 2 | 0.10 |
| Feb | 48 | 2 | 0.04 |
| March | 135 | 2 | 0.01 |
| April | 597 | 72 | 0.12 |
| May | 1410 | 553 | 0.39 |
| June | 1836 | 1289 | 0.70 |
| July | 1182 | 826 | 0.70 |
| Aug | 970 | 505 | 0.52 |
| Sept | 907 | 488 | 0.54 |
| Oct | 127 | 42 | 0.33 |
| Nov | 29 | 5 | 0.17 |
| Dec | 40 | 1 | 0.03 |

**Table 9.** The spawning fraction ((# female spawners/# adult females)*daily correction factor) and the spawning frequency of Red Snapper (spawning season duration/ spawning interval) by calendar age group in MARMAP/SERFS histological data from 1978-2023 from all projects and gears, limited to the core spawning season (Julian day 144-303). A spawner had one or more indicators of spawning. MNO = Migratory Nucleus Oocytes, HO = hydrated oocytes, POC = postovulatory complex. Adult females included active and inactive adults. Daily correction factor used was (34/24).

| Calendar Age (yr) | Adult n | Spawners n | Spawning Proportion | Spawning Fraction | Spawning Season Duration | Spawning Interval | Spawning Frequency |
|---|---|---|---|---|---|---|---|
| 1 | 221 | 50 | 0.23 | 0.16 | 154 | 6 | 25 |
| 2 | 1265 | 743 | 0.59 | 0.41 | 156 | 2 | 65 |
| 3 | 1676 | 1119 | 0.67 | 0.47 | 156 | 2 | 74 |
| 4 | 701 | 451 | 0.64 | 0.45 | 155 | 2 | 70 |
| 5 | 481 | 312 | 0.65 | 0.46 | 149 | 2 | 68 |
| 6 | 296 | 199 | 0.67 | 0.47 | 139 | 2 | 66 |
| 7 | 207 | 129 | 0.62 | 0.44 | 124 | 2 | 55 |
| 8 | 143 | 83 | 0.58 | 0.41 | 142 | 2 | 58 |
| 9-11 | 202 | 129 | 0.64 | 0.45 | 154 | 2 | 69 |
| 12-14 | 94 | 58 | 0.62 | 0.44 | 130 | 2 | 57 |
| 15+ | 67 | 47 | 0.70 | 0.50 | 158 | 2 | 78 |
| 2+ | 5132 | 3270 | 0.64 | 0.45 | 158 | 2 | 71 |
| All | 5407 | 3345 | 0.62 | 0.44 | 158 | 2 | 69 |

**Table 10.** Recommended logarithmic regression equations BF= EXP a+b*Log(X) for Red Snapper batch fecundity (BF) versus maximum (pinched tail) total length (MaxTL, mm), Total weight (g), and calendar age.

| X | Range of X | a | $SE_a$ | b | $SE_b$ | n | Adj. $R^2$ |
|---|---|---|---|---|---|---|---|
| MaxTL (mm) | 314 to 958 | -15.997 | 1.404 | 4.542 | 0.223 | 129 | 0.76 |
| Whole Weight (g) | 470 to 11830 | 1.398 | 0.566 | 1.442 | 0.073 | 129 | 0.75 |
| Calendar Age | 2 to 18 | 9.644 | 0.245 | 2.098 | 0.163 | 126 | 0.57 |

## Figures

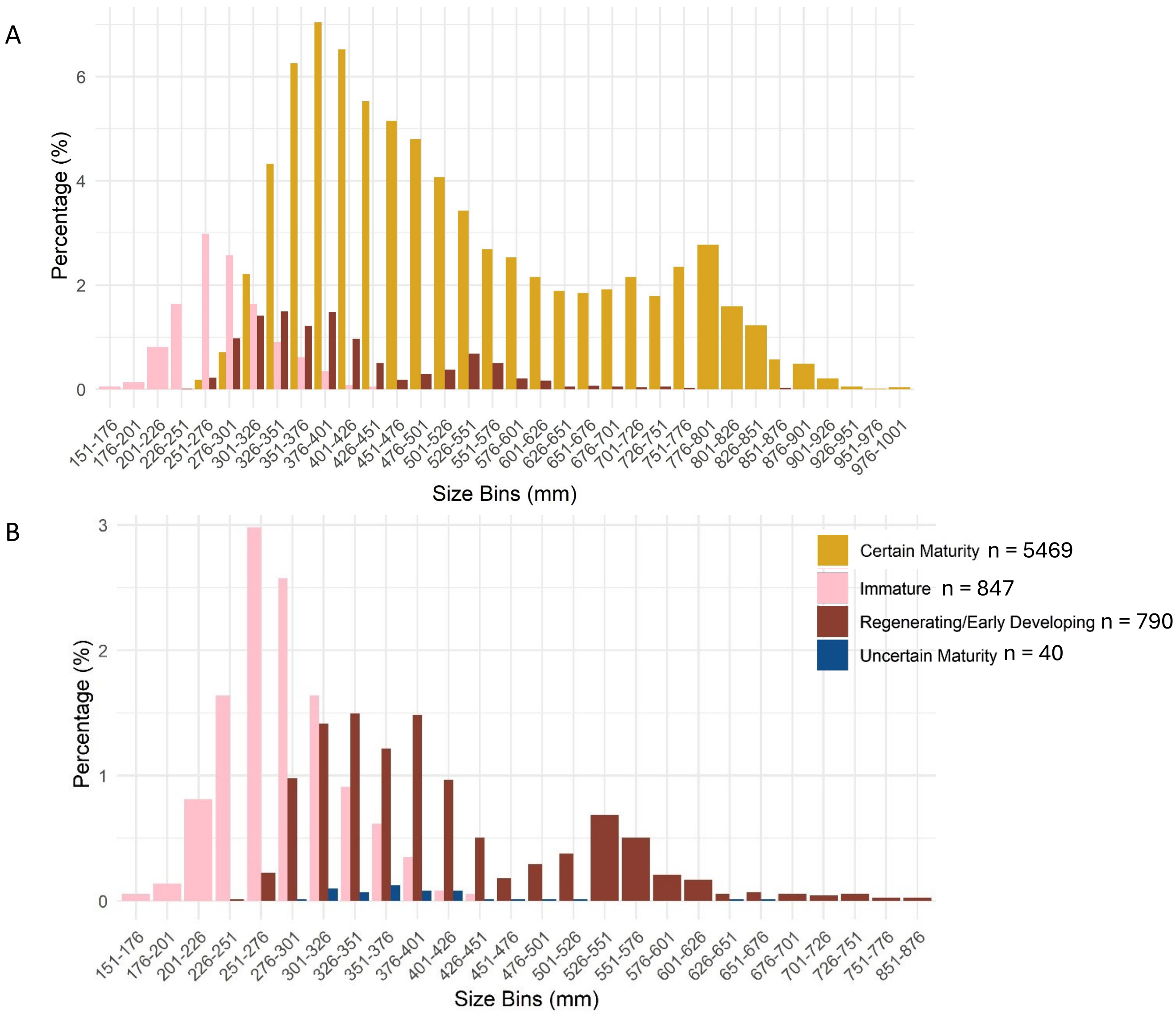


**Figure 1.** A) A comparison of female Red Snapper length-frequency histograms specimens that were categorized as 1) immature, 2) definitely mature, or 3) regenerating or early developing. Definitely mature specimens were developing, spawning capable, or regressing. B) Female Red Snapper histological staging of immature, regenerating/CAO and uncertain maturity. Both graphs provide data from all years and all gears. n= numbers of fish.

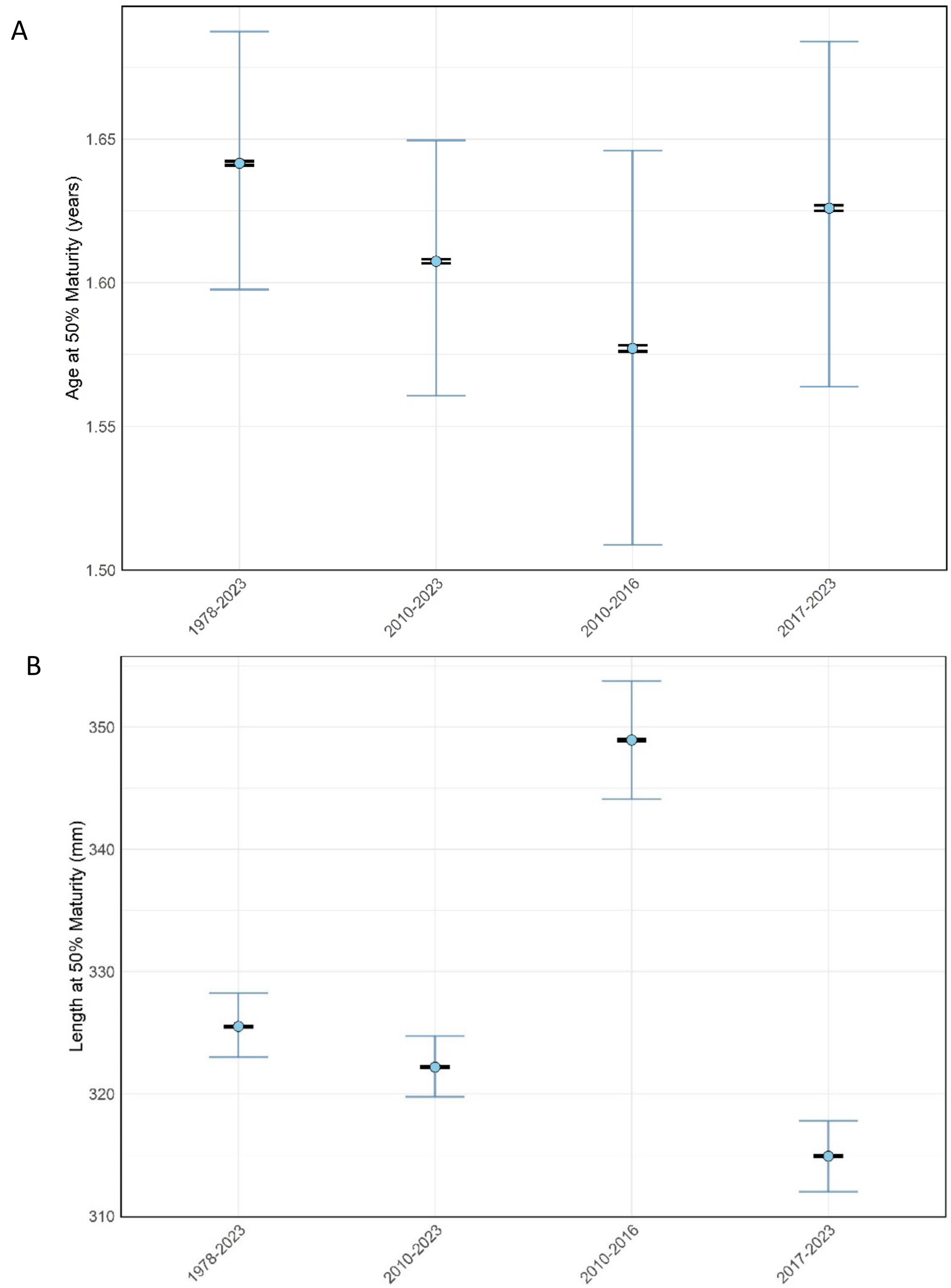


**Figure 2.** Bootstrapped mean A) age and B) length at 50% maturity for Red Snapper by time period. Black bars represent standard error and blue bars represent 95% confidence intervals.

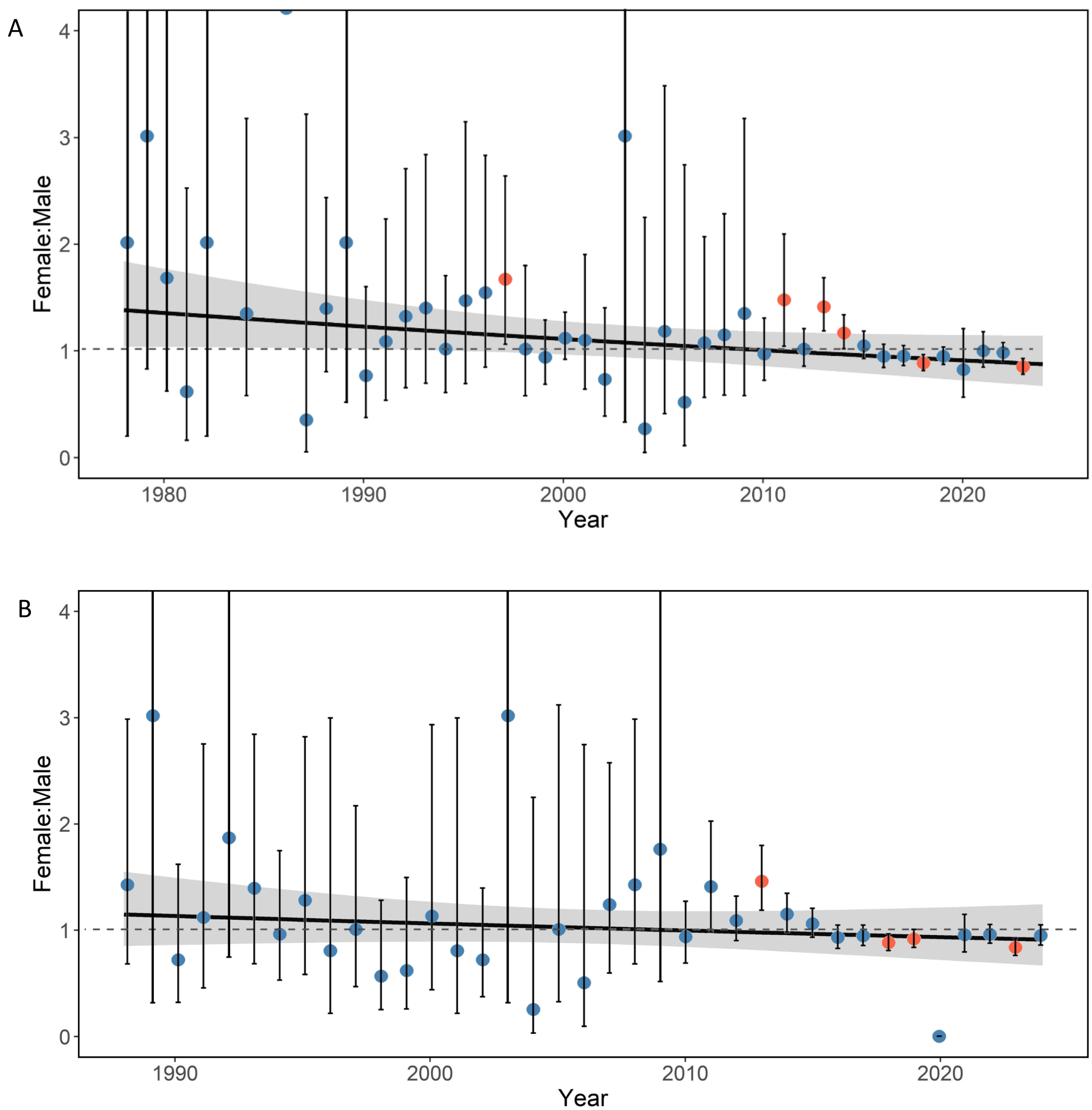


**Figure 3.** Female to male sex ratio for Red Snapper by year A) not restricted by gear and B) restricted to chevron trap only. Red dots represent sex ratios for a specific year with statistically significant difference from 1:1 based on chi squared test and blue dots represent sex ratios not significantly different from 1:1 ratio. Black bars represent standard error, black line represents the linear regression of sex ratio by the respective variable, the gray shaded region represents standard error and the black dotted line represents the 1:1 sex ratio.

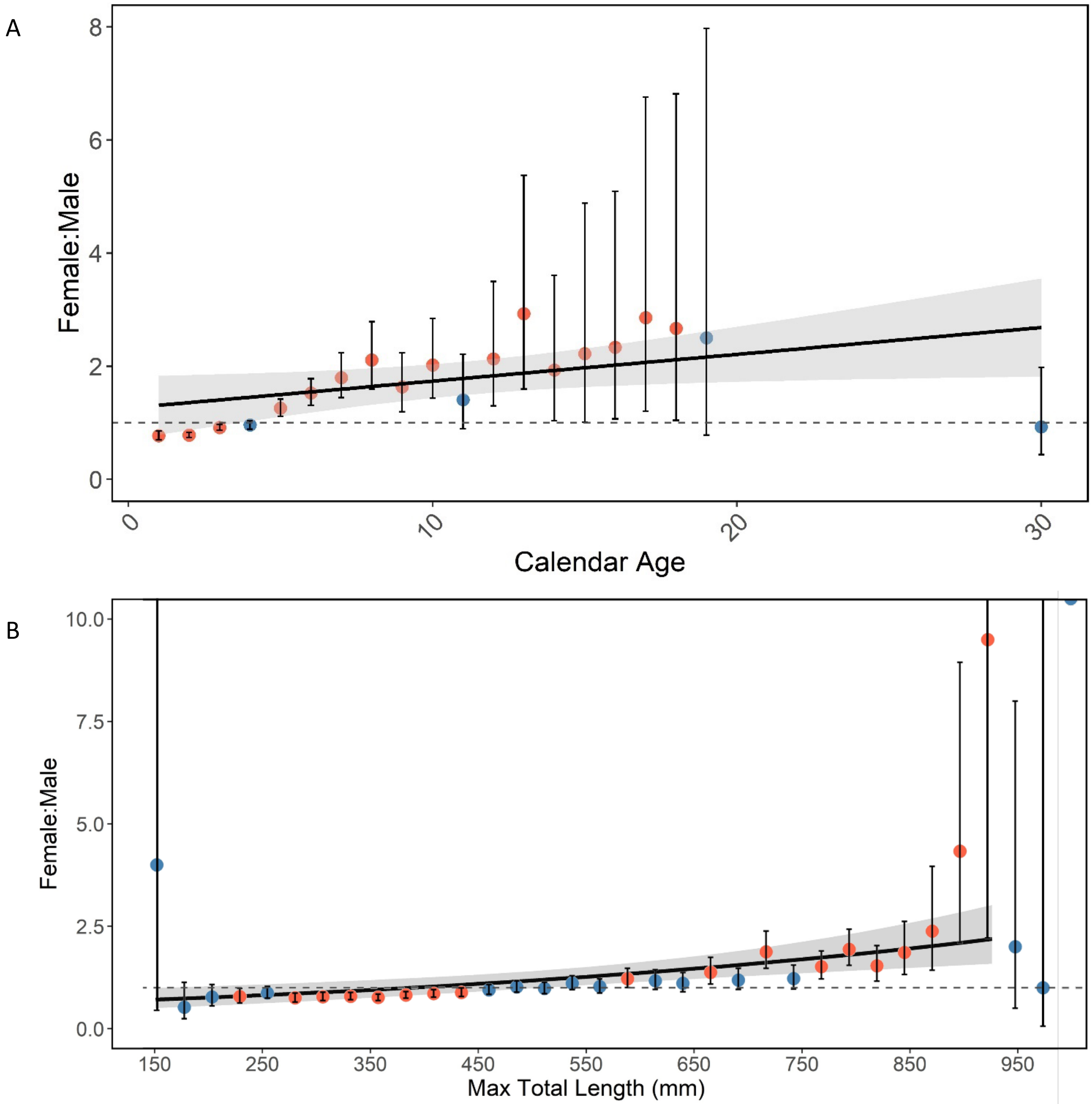


**Figure 4.** Female to male sex ratio for Red Snapper by A) calendar age and B) max TL in mm. Calendar ages 20 and above were grouped in 20+ age bin. Red dots represent sex ratios for a specific calendar age or length bin with statistically significant difference from 1:1 based on chi squared test and blue dots represent sex ratios not significantly different from 1:1 ratio. Black bars represent standard error, black line represents the linear regression of sex ratio by the respective variable, the gray shaded region represents standard error and the black dotted line represents the 1:1 sex ratio.

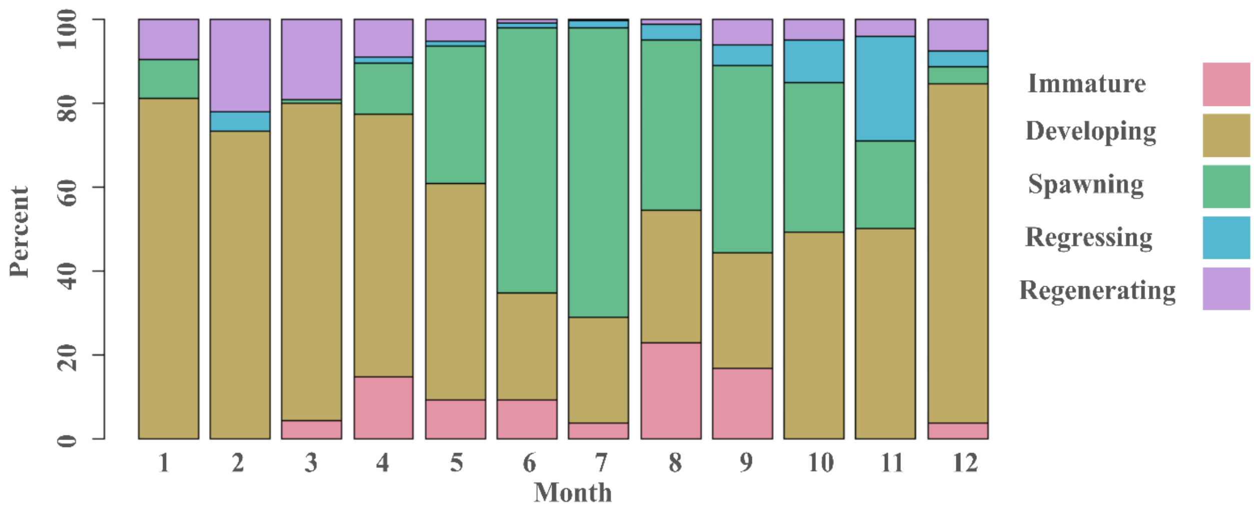


**Figure 5.** Female Red snapper spawning seasonality, 1978-2023. Developing includes specimen with cortical alveolar oocytes (CAO) and vitellogenesis and Spawning includes specimen with Migratory Nucleus Oocytes (MNO) and Hydrated Oocytes (HO) and Postovulatory Complexes (POC).

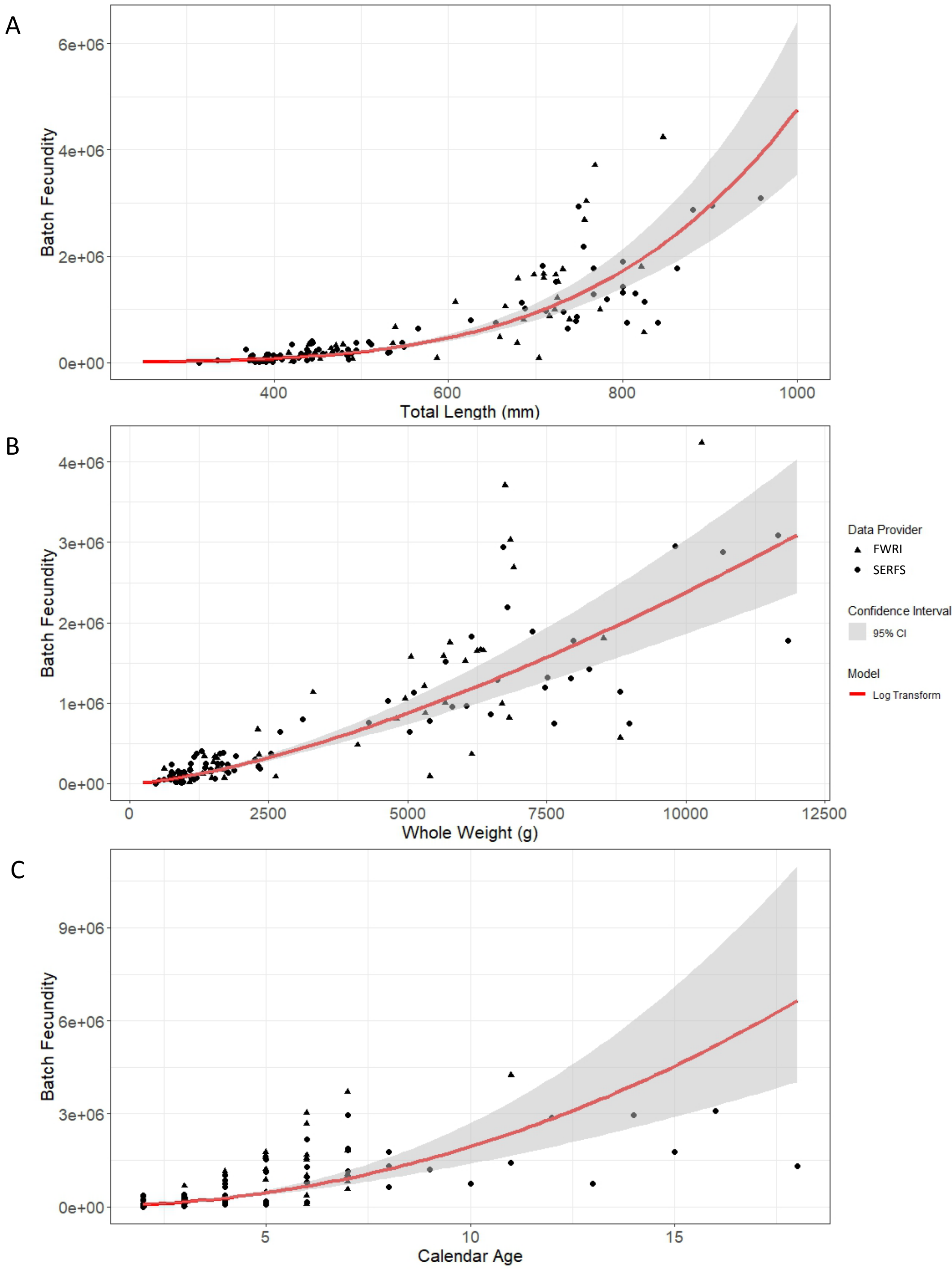


**Figure 6.** Non-linear regression analysis of batch fecundity (BF) versus A) total length and B) total weight C) Calendar Age in Red Snapper using the logarithmic function (Red Line, BF= EXP a+b*Log(X)) with 95% confidence intervals (gray shaded region). The Red Snapper were collected in 1999-2023 primarily during fishery-independent sampling off the Atlantic coast of the southeastern United States by Florida's Fish & Wildlife Research Institute (FWRI, closed triangles) and the SouthEast Reef Fish Survey (SERFS, closed circles).