Indices of abundance for Red Snapper (*Lutjanus campechanus*) from the Florida Fish and Wildlife Research Institute (FWRI) repetitive timed drop hooked-gear survey in the U.S. South Atlantic

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Indices of abundance for Red Snapper (*Lutjanus campechanus*) from the Florida Fish and Wildlife Research Institute (FWRI) repetitive timed drop hooked-gear survey in the U.S. South Atlantic

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Introduction

To complement ongoing Southeast Reef Fish Survey (SERFS) trap/camera surveys and provide another source of fishery-independent data for assessing the status of managed reef fish stocks, the Florida Fish and Wildlife Research Institute (FWRI) developed a standardized hooked-gear survey of hard-bottom habitats in the U.S. South Atlantic (SA) beginning in 2012. The FWRI completed annual hooked-gear surveys in 2012, 2014, 2016-2018, and 2021-2024 resulting in a thirteen-year time series on which an index of abundance for Red Snapper can be based.

The actively-fished hooked-gear survey developed by FWRI is a highly-standardized sampling approach in which a series of repetitive timed drops (RTD) are conducted at each sampling station to standardize overall bottom soak time and effort for each individual fisher. FWRI has completed several hooked-gear surveys that have applied the RTD methodology. The first was a study completed in 2012 that employed a combination of bottom longlines, vertical longlines, and the RTD hooked-gear (Guenther et al. 2013). All three gears were able to capture a wide size range of Red Snapper, though the RTD hooked-gear collected significantly more fish during the study and proved to be the most effective hooked-gear to collect Red Snapper. Subsequent FWRI RTD hooked-gear surveys have been completed in 2014 (Brodie and Switzer 2015), 2016 (Christiansen et al. 2022; Paperno et al. 2018), 2017, 2018 (Switzer et al. 2019), 2021-2023 (Brodie et al. 2024), and 2024. Although each study addressed subtly-different objectives, the same standardized gear and sampling protocols (aside from some variability in the total number of hook-specific drops conducted per sampling site) were used for all studies, and each study was conducted using a nearly-identical stratified-random survey design. The sampling frame of hard-bottom sampling sites largely consists of the same sites that comprise the SERFS sampling frame, with the addition of a limited number of natural and artificial reef sites provided by local fishermen. Because of these consistencies, these data lend themselves to the development of a standardized index to account for subtle differences between sampling years.

The FWRI RTD hooked-gear surveys have shown great utility in capturing a wide size and age range of Red Snapper and have augmented data provided by the SERFS trap/camera survey. Although not used as a formal index during SEDAR 73 due to the short time series available, the FWRI RTD hooked-gear data was incorporated into a sensitivity run to independently verify the increased abundance trends seen by the SERFS trap and video data. At the September 2017 SAFMC Meeting, SERFS data was presented that showed that Red Snapper relative abundance had been increasing and reached the highest level seen over the entire time series (1990-2017) in 2017 (NMFS 2018). The presented FWRI RTD survey data (2012-2017) also documented an increased abundance of Red Snapper and corroborated a similar peak abundance in 2017 (Christiansen et al. 2020; NMFS 2018).

Additionally, the FWRI study completed in 2016 (Paperno et al. 2018; Christiansen et al. 2022) was designed to address questions regarding the selectivity of Red Snapper and other reef fishes to gear types used during fisheries independent surveys in the SA off the east coast of Florida and highlighted the potential need for complementary fishery-independent data to augment data provided by the SERFS trap/camera survey, especially for Red Snapper. The study examined the selectivity of capture gears (SERFS chevron traps, and FWC Repetitive Timed Drop [RTD hooked-gear]) to that of stereo-camera (S-BRUV) observations. Results of that study indicated that the RTD hooked-gear survey was much less size selective at larger sizes than the SERFS chevron trap survey (Christiansen et al. 2022) which led to a dome-shaped selectivity function being deemed most appropriate for the chevron traps since larger Red Snapper appeared to be under-sampled (SEDAR 73). Results from the 2018 RTD survey were able to document an increase in effort-adjusted abundance of both young and old Red Snapper since the first RTD survey was conducted in 2012 (Switzer et al. 2019). Combined, these results indicate that data from the RTD survey may be a useful complementary sampling approach to the SERFS chevron trap survey to provide relative abundance data and associated life history data for a broader size- and age-range of fish (including potentially older fish). Accordingly, we developed a standardized index of relative abundance for data from the FWRI RTD survey, results of which are summarized below.

Methods

Sampling Location

All sampling effort was focused on identified hard-bottom habitats and stratified based on latitude and depth. Surveys were conducted within three regions of the South Atlantic: NMFS statistical zones 722, 728, and 732. These regions occupy the portion of the South Atlantic Bight from roughly 28° 00’ N (Melbourne, FL) to 30° 45’ N latitude (Florida-Georgia border; **Figure 1**). Each statistical zone (zone) was subdivided into two depth strata – nearshore (< 30 m) and offshore (30 - 90 m). The survey area also contains home ports for many industry vessels, which facilitated the cooperation of commercial and recreational fishers to complete sampling.

Survey Design

Red Snapper were quantified on a yearly basis during a fisheries-independent survey using a stratified-random sampling design. Sampling sites containing reef habitat were randomly selected from an established FWC universe that includes sites from the federal Southeast Reef Fish Survey (SERFS) sampling universe, prior FWC work conducted in the region, data from USGS, and sites provided from participating commercial and recreational fishers. All sampling for this project was conducted during daylight hours (approximately 0600 - 2000 hours) from April – August of each survey year. Sampling effort was stratified by National Marine Fisheries Service (NMFS) statistical reporting zones (722, 728, and 732) and depth (inshore: <30 m and offshore: 30–150 m; **Figure 1**). For most survey years (2012, 2016 – 2018, and 2021 – 2024), annual sampling effort was proportionally allocated based on the percentage of the total number of possible reef sites in the sampling frame that fell within each spatial stratum. For the 2014 survey, sites were randomly selected from a truncated universe of available sites selected to specifically target spawning Red Snapper.

RTD Description and Deployment Procedures

All sampling was conducted using chartered fishing vessels staffed with FWRI scientists. RTD sampling was conducted using a powered (12V DC) Electramate© rigs (model 940XP) outfitted with a Penn 115L 9/0 (Senator model) reel equipped with 45 kg (100 lb.) test monofilament. The entire rig was mounted onto a heavy-duty fiberglass fishing pole (~ 2.4 m). Terminal tackle for all Electramate© rigs was standardized. A barrel swivel was attached to the mainline from the reel. Starting from the swivel a 1.8 m section of 45 kg (100 lb.) test monofilament leader was attached. Two short leads (~ 0.2 m long) were tied along the length of this leader (i.e., “dropper loops”); one located near the top of the rig and the other near the bottom. A specific hook size (either 8/0, 11/0, and 15/0 Mustad circle hooks (Ref 39960D) was assigned to both the top and bottom leads for each rig. A lead egg sinker or bank sinker (size depending on prevailing current conditions, ranging from 0.17 kg to 0.40 kg), was inserted at the bottom of the leader followed by a barrel swivel. All hooks were baited with Atlantic mackerel (*Scomber scombrus*) cut proportional to hook size.

Active hooked-gear fishing methods and effort were standardized at all sampling sites. At each sampling site, anglers were randomly assigned to a particular fishing rig to remove any biases of angler experience with respect to hook size or fishing position on the boat. A series of 10 “team drops” where then performed with all fishers simultaneously dropping their rigs to the bottom and allowing their rigs to soak for no more than two minutes starting when the first rig reached the bottom. All fishers soaked their rigs in contact with the bottom and retrieved their rig as soon as a fish was hooked or once the two-minute time period elapsed. All fishers then retrieved their rig and re-baited their hooks. Fishers who retrieved their rig during the two-minute time period (caught fish, checked bait, lost fish, etc.) were not permitted to re-drop their rig during that “team drop”.

Subsequent drops began only when all fishers retrieved their rig, processed any captured fish, and re-baited hooks.

The number and combination of hooks fished at each RTD hooked gear site varied for two reasons. First, during the early years of the study, the number of anglers and the distribution of hook sizes varied from year to year to meet specific study objectives (sampling methods were standardized to three anglers fishing a pair of identical hook sizes beginning in 2015). And second, there are instances where individual fishers may skip one or multiple drops due to damage to or loss of terminal tackle. However, all three hook sizes were used during each sampling year, and the number of each hook size used, and the number of total drops were recorded at each station from which total number of hooks fished can be calculated. All Red Snapper captured were measured to the nearest mm [standard length (SL), fork length (FL), and total length (TL)]. Where measurements were not recorded due to uncontrollable situations (i.e., fish partially preyed upon prior to landing), plus counts towards overall catches were recorded. Although most Red Snapper were culled for life history studies, a random sub-sample of Red Snapper were retained near the end of some seasons when our annual culling quotas as established on our LOA were approached.

Data Reduction

In 2012, sampling extended into September and October which does not correspond to any other survey year, therefore data from these months were excluded from the analyses. A portion of sampling conducted in 2014 and 2015 was designed to target spawning capable Gag; as these sites used a different site selection protocol, they were excluded from the analyses. In addition, artificial reef sampling sites were removed for analysis from all sampling surveys as they were not sampled in all years. Sites where no temperature data were available were excluded from analyses. Initial model results presented at the data workshop included data from 2012 – 2014. During initial index workgroup discussions, concerns were raised as to whether the model was adequately accounting for variability in the number of hooks dropped by size during the early years of the survey before hook deployments were standardized in 2016. Accordingly, the model was truncated to exclude data from 2012 and 2014. Final yearly sample sizes for the revised index are provided in **Table 1**.

Index Development

To calculate the RTD index of Red Snapper the total catch at each station was modeled as the total number of all Red Snapper captured from all hook sizes combined.

We considered 5 explanatory variables in the original model.

1. **Year (*Y*)** – Year was included since standardized catch rates by year are the objective of the analysis. We modeled data collected from 2016, 2017, 2018, 2021, 2022, 2023, and 2024.
2. **Month (*MQ*)** – A temporal parameter based on month of sampling. Sampling occurred from April to August and was treated as a quantile factor.

3. **Depth (*DQ*)** – Water depth may be an important component affecting the distribution of reef fish. All depths sampled (11-90 m) were included and treated as a quantile factor.
4. **Temperature (TQ)** – Temperature may affect the distribution of reef fish. Temperature ranged from 10.5 to 36.7°C and was treated as a quantile factor.
5. **Statistical Zone (*Zone*)** – National Marine Fisheries Service (NMFS) statistical reporting zones (722, 728, and 732) were included.

The total number of Red Snapper captured represents count data and therefore does not conform to assumptions of normality. Therefore, the data were modeled using the Poisson and negative binomial distributions to fit the data. Additionally, catch data often has a disproportionate number of zero counts that may differ from the standard error distributions used for count data. To address the excess zeros the zero-inflated Poisson and zero-inflated negative binomial models were also fit to the data. These approaches model the zero counts using two different processes, a binomial and a count process (Zuur et al. 2009). To account for the different number of hooks used at each station in the beginning years of the survey, the number of hooks dropped at each station was used as an offset (hooks). Backwards step-wise model selection and comparisons of AIC values were used to determine the optimal model. The final index model is given by the following equation:

$$total \sim Y + Zone + DQ + MQ + TQ + offset(log(hooks)) | Y + Zone + DQ + MQ + TQ + offset(log(hooks))$$

In this formulation, variables to the left of the "|" apply to the count sub-model, and variables to the right apply to the binomial sub-model. Model diagnostics showed no discernible patterns of association between Pearson residuals and fitted values or the fitted values and the original data (**Figure 2**). An examination of residuals for the spatial and environmental model parameters showed no clear patterns of association, indicating general correspondence to underlying model assumptions (Zuur et al. 2009; **Figure 3**). Lastly, a comparison of predicted values from the best model against original data distribution indicates a good fit of the zero-inflated data structure (**Figure 4**). Confidence intervals were determined by bootstrapping the model fitting over 1,000 iterations. The relative nominal total was calculated as the mean catch per year and then standardized to one by dividing by the overall mean for the entire time series. The proportion of positive sets was calculated as the proportion of stations that caught at least one Red Snapper. The estimated index values were then standardized to one by dividing by the overall predicted mean for the entire time series. All data manipulation and analysis were conducted using R version 4.4.2 (R Core Team 2024). Modeling was conducted using the zeroinfl function of the pscl package (Jackman 2008), available from the Comprehensive R Archive Network (CRAN).

Results

A total of 1,312 sites were sampled between April 2016 – July 2024 (**Table 1**). A total of 87 sites were completed in 2016, 88 in 2017, 311 in 2018, 215 in 2021, 193 in 2022, 214 sites in 2023, and 204 in 2024. A total of 78,600 hooks were deployed during the examined sampling period and ranged from a high of 18,656 hooks deployed in 2018 to a low of 5,180 total hooks

deployed in 2014 (**Table 1**). For specific sampling details of the individual RTD studies refer to Guenther et al. 2013 (2012), Brodie and Switzer 2015 (2014), Paperno et al. 2018 (2016), Switzer et al. 2019 (2017, 2018), Brodie et al. 2024 (2021-2023).

The distribution of collected Red Snapper for each survey year is presented in **Figure 5**. In 2012, a total of 990 Red Snapper were captured, with 360 captured in 2014, 214 captured in 2016, 394 captured in 2017, 2,344 captured in 2018, 1,844 captured in 2021, 1,915 captured in 2022, 2,417 captured in 2023, and 1,858 captured in 2024. The proportion positive captured varied from 0.46 in 2016 to 0.83 in 2023 (**Table 2**). The number of Red Snapper captured at an individual sampling location ranged from 0 to 35 (**Figure 6**). The sizes of Red Snapper ranged from 205 mm to 965 mm total length (**Figure 7**) and the age ranged from 1 to 33 (**Figure 8**).

Annual standardized index values for Red Snapper in the U.S. SA including coefficients of variation, are presented in Table 2. The standardized index values indicate an overall increasing trend in estimated mean abundance of Red Snapper for the years 2016 to 2023 followed by a decrease in 2024 (**Figure 9**). In general, the CV's across years were low and the proportion of sites with Red Snapper captured increased with year (**Table 2**).

Discussion and Recommendations on Use

The FWRI RTD index of abundance indicates that since 2016 there has been a general increase of abundance of Red Snapper in the U.S. SA. The FWRI RTD survey is a highly-standardized hooked-gear survey following a statistically robust survey design. While the survey area is restricted to Florida waters, it covers a significant portion of the SA shelf, including the historic core of the population's distribution in this region. This study was conducted over a large geographic region and at a wide range of depths, therefore observed patterns are likely reflective of the population as a whole. Additionally, the slight differences in number of each hook size dropped at each sampling location appear to be accounted for by the model standardization. While the RTD is an actively fished gear, preliminary investigations have indicated that fisher variability is minimal due to the standardization of fishing protocols (Winner et al. 2022). An index developed using FWRI RTD data collected in the Gulf from 2014-2017 was critically evaluated and accepted for use in the Gulf Red Grouper stock assessment (Christiansen et al. 2018; SEDAR 61 2019), showing the utility of the RTD method to provide valuable fishery-independent information.

While the RTD survey in the SA has an incomplete time series, it does provide seven years of data over a nine-year time period, and no major issues were identified during model standardization analyses. The use of multiple hook sizes in this survey allows for a wide size range of Red Snapper to be captured, including larger (older) fish that may be underrepresented in the chevron trap survey (Paperno et al. 2018). Additional data for larger (older) fish provided by the RTD survey is critical as Red Snapper were considered overfished largely due to the paucity of older fish in the population (SEDAR 41 2016; SEDAR 73 2021). Accordingly, the RTD index of abundance, as well as the associated age-composition data, would seem to provide valuable additional data inputs into the Red Snapper stock assessment.

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Table 1. List of total FWRI RTD hooked-gear sites sampled by study year.

Year	# of RTD stations	Total # Hooks Dropped	Depth Range (m)	Latitude Range (deg N)	Longitude Range (deg W)
2016	87	5,180	11-73	28.150 to 30.516	-80.006 to -81.164
2017	88	5,280	13-76	28.171 to 30.258	-80.114 to -81.209
2018	311	18,656	16-80	28.006 to 30.584	-80.114 to -81.231
2021	215	12,858	13-70	28.008 to 30.519	-80.071 to -81.164
2022	193	11,564	14-74	28.010 to 30.520	-80.030 to -81.164
2023	214	12,828	11-74	28.010 to 30.533	-80.114 to -81.210
2024	204	12,234	16-74	28.008 to 30.566	-80.675 to -81.066

Table 2. Standardized nominal CPUE (Total number of Red Snapper per total sites sampled), number of sites sampled (N), proportion of positive sets, standardized index, and coefficient of variation for FWRI Red Snapper RTD index of U.S. South Atlantic, 2016-2024.

Year	Standardized Nominal CPUE	N	Proportion positive	Standardized Index	CV
2016	0.32	87	0.46	0.3444	0.1896
2017	0.59	88	0.60	0.5340	0.1586
2018	0.99	311	0.72	0.9661	0.0624
2021	1.12	215	0.76	1.2403	0.0644
2022	1.30	193	0.76	1.3121	0.0662
2023	1.48	214	0.83	1.4212	0.0613
2024	1.19	204	0.80	1.1818	0.0689

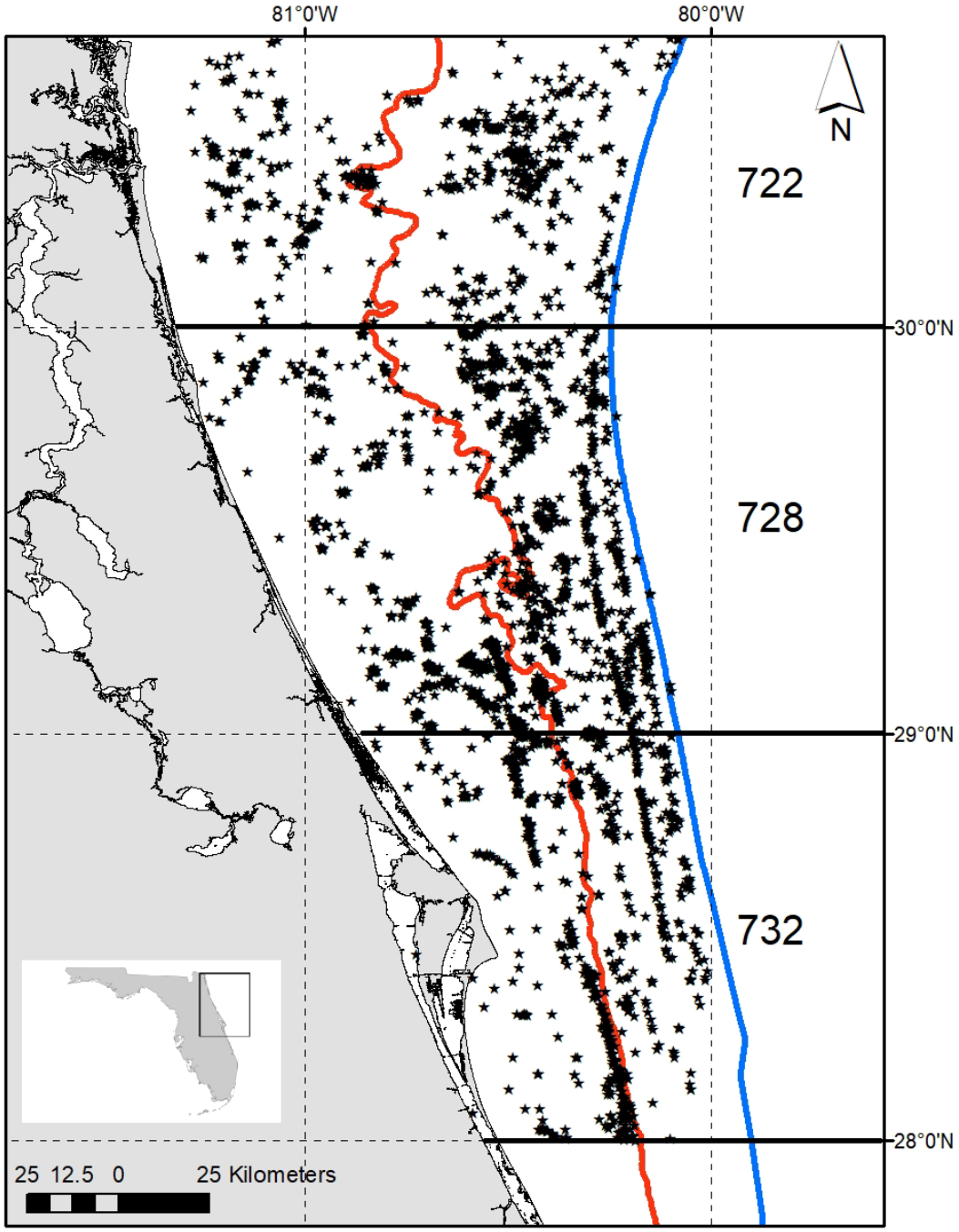

Figure 1. Study area (sampling bounded by 28º 00'N and 30º 45'N) for FWRI RTD hooked-gear surveys along the Atlantic coast of Florida (2012-2024), including NMFS statistical zones 722, 728 and 732. The red and blue lines represent the 30-m and 150-m isobaths, respectively. Stars represent all potential hardbottom sites in the FWRI sampling universe.

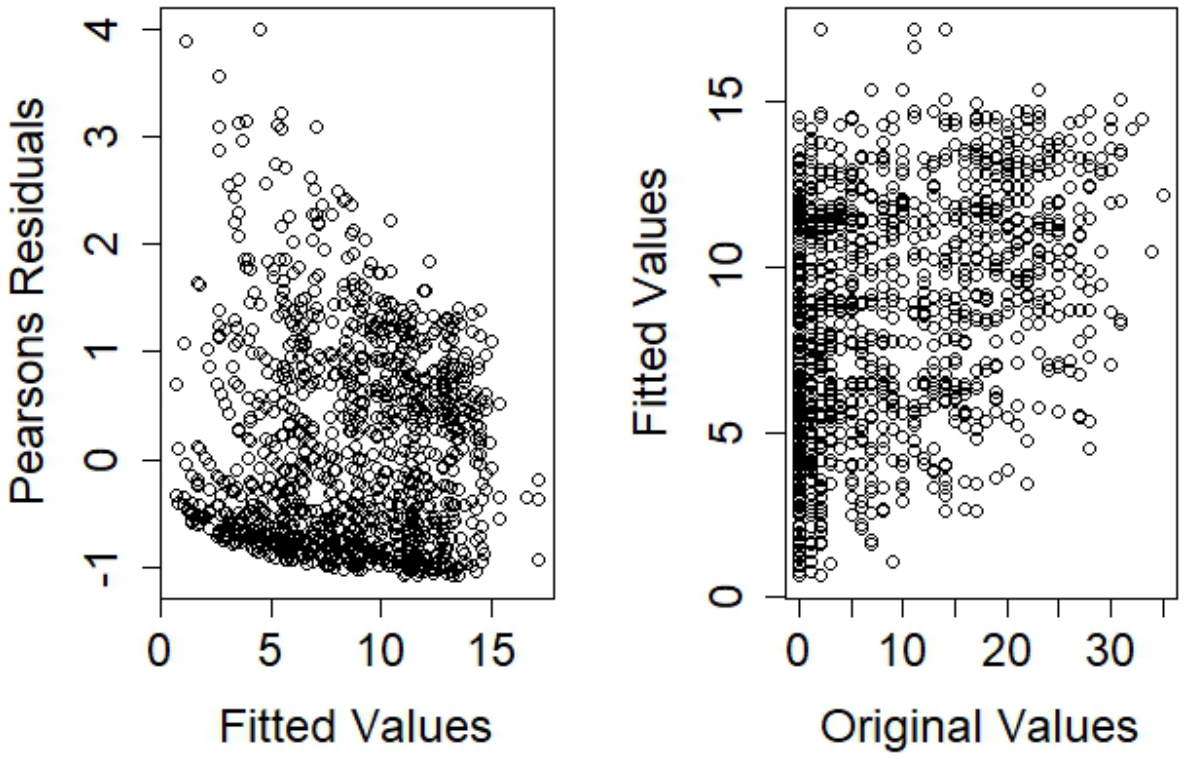

Figure 2. Model diagnostic plots showing fitted best model values against Pearson residuals (left panel) and fitted values plotted against original data values (right panel).

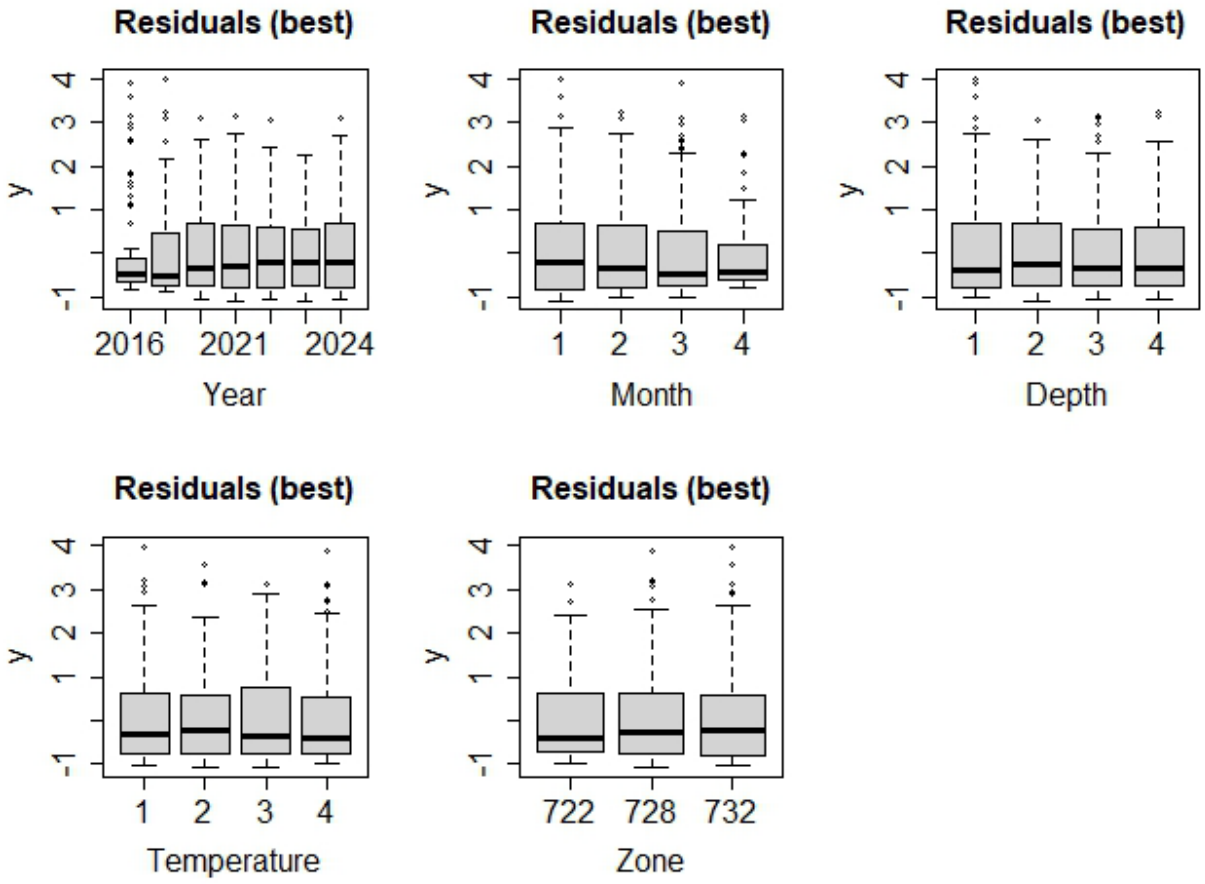

Figure 3. Model diagnostic plots showing Pearson residuals for the final (best) model plotted against spatiotemporal and environmental model parameters.

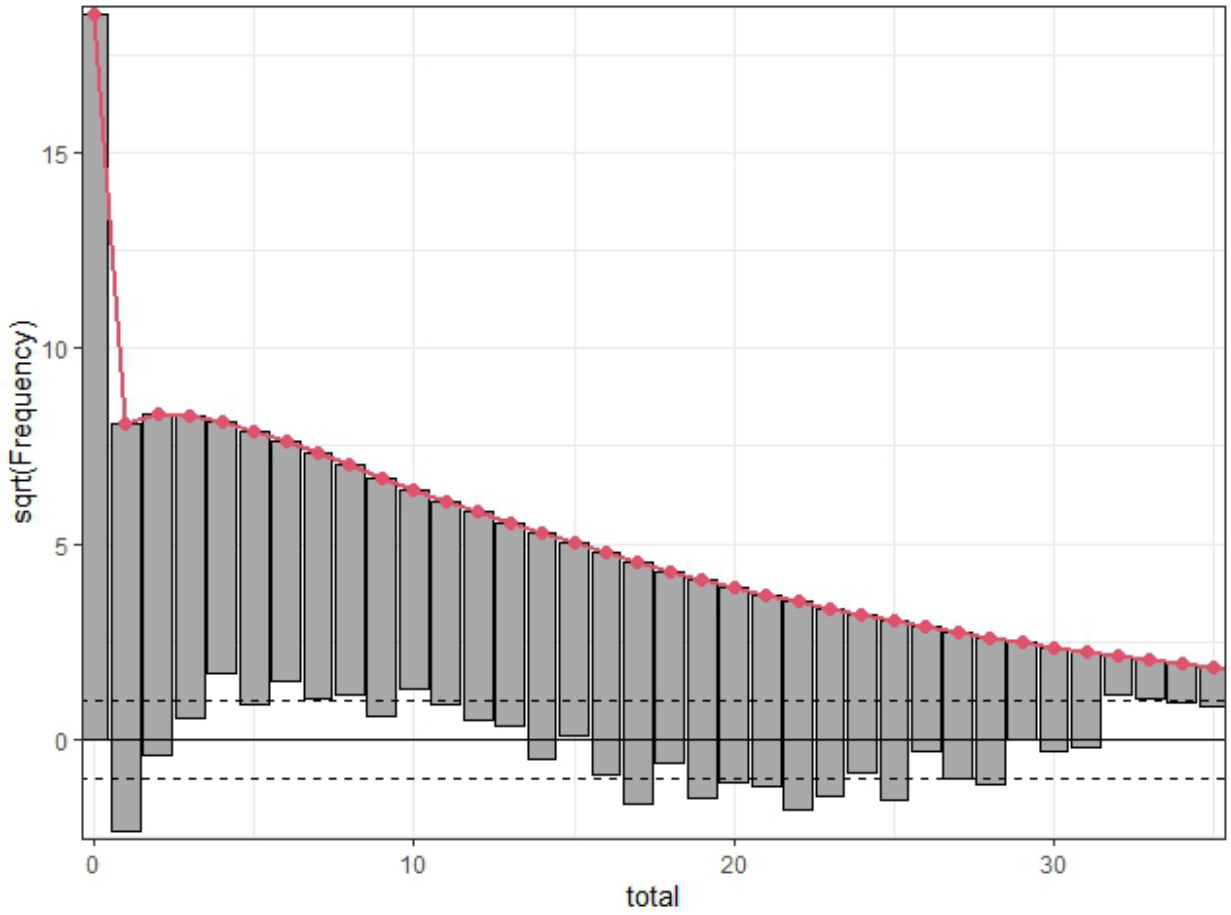

Figure 4. Model diagnostic plots of fitted model values (red line) against the original data distribution for the preferred model.

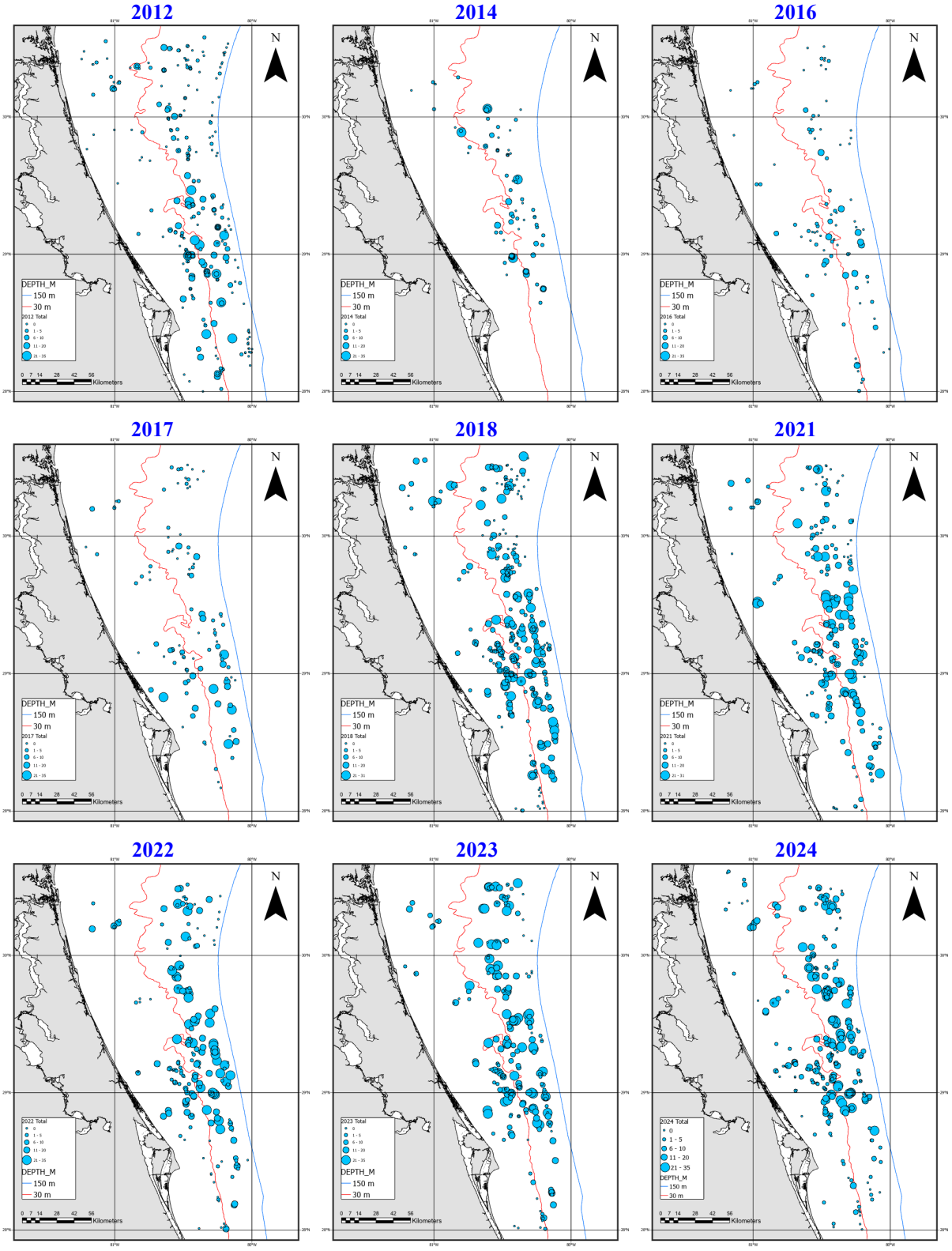

Figure 5. Sampling distribution of all collections by year for the FWRI RTD hooked-gear survey (2012-2024). Blue circles represent the total number of Red Snapper captured at each station. Note that data from 2012 and 2014 were not included in the final index model, but associated size and age composition data were provided for these years.

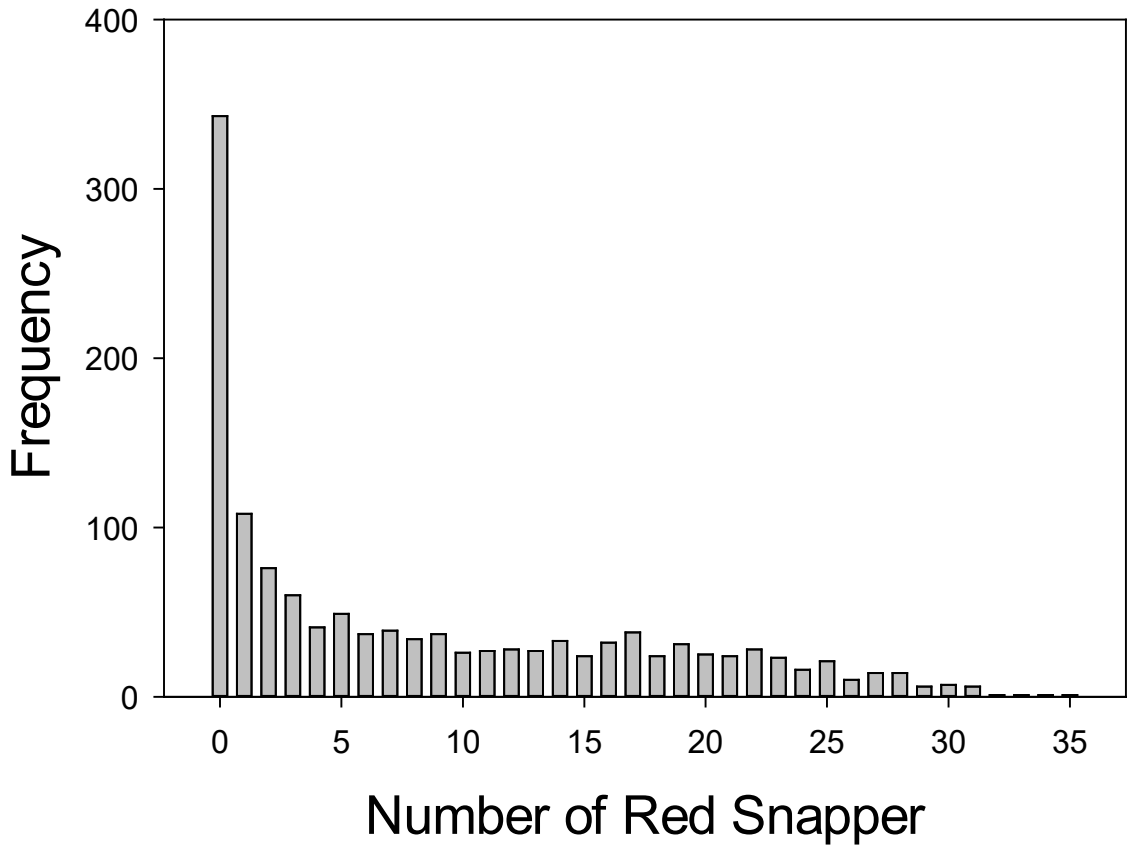

Figure 6. Number of Red Snapper captured per site in the FWRI repetitive timed drop surveys from 2016-2024.

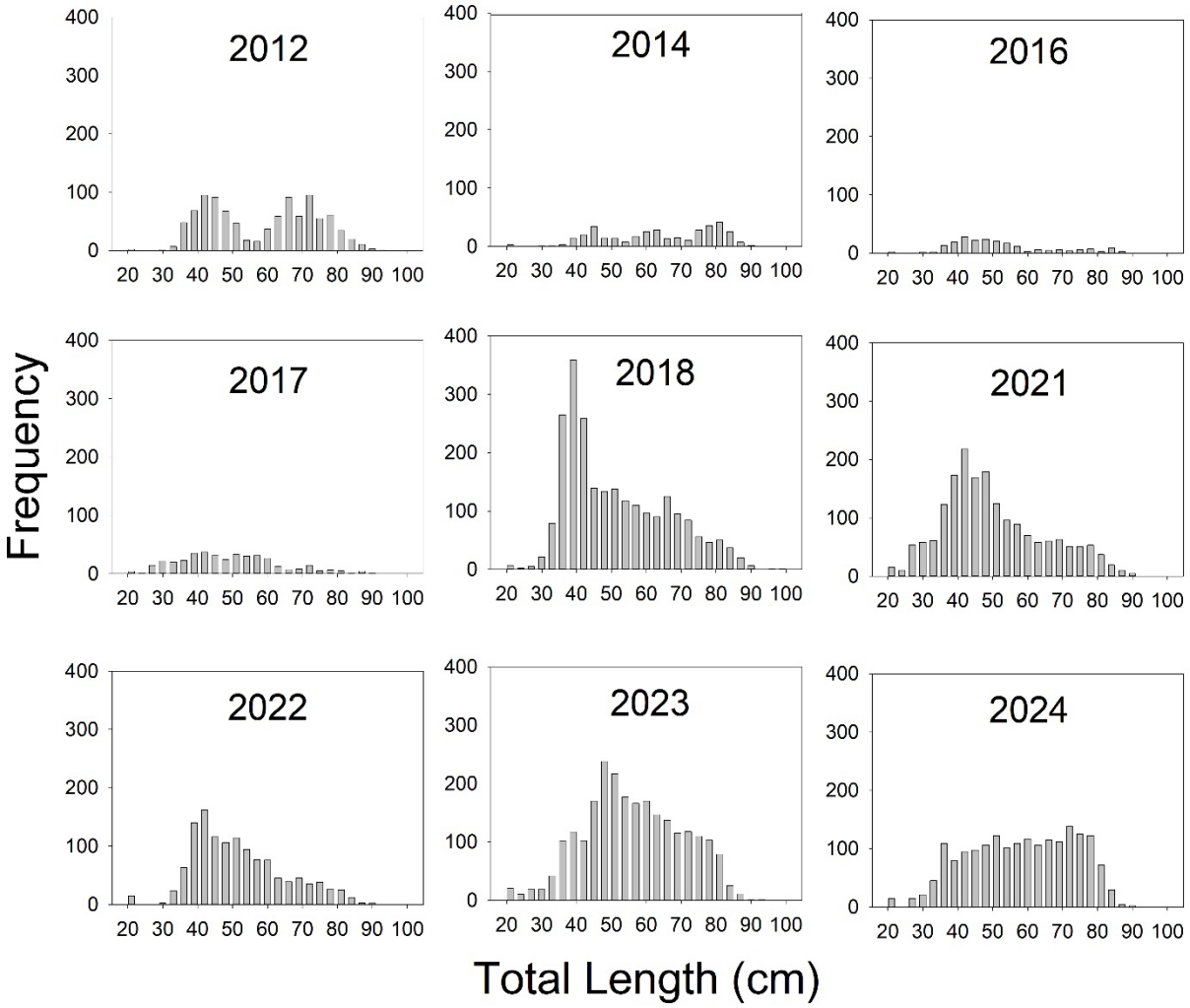

Figure 7. Length frequency of Red Snapper collected during FWRI RTD hooked-gear surveys along the Atlantic coast of Florida (2012-2024) by survey year. Note that data from 2012 and 2014 were not included in the final index model, but associated size and age composition data were provided for these years.

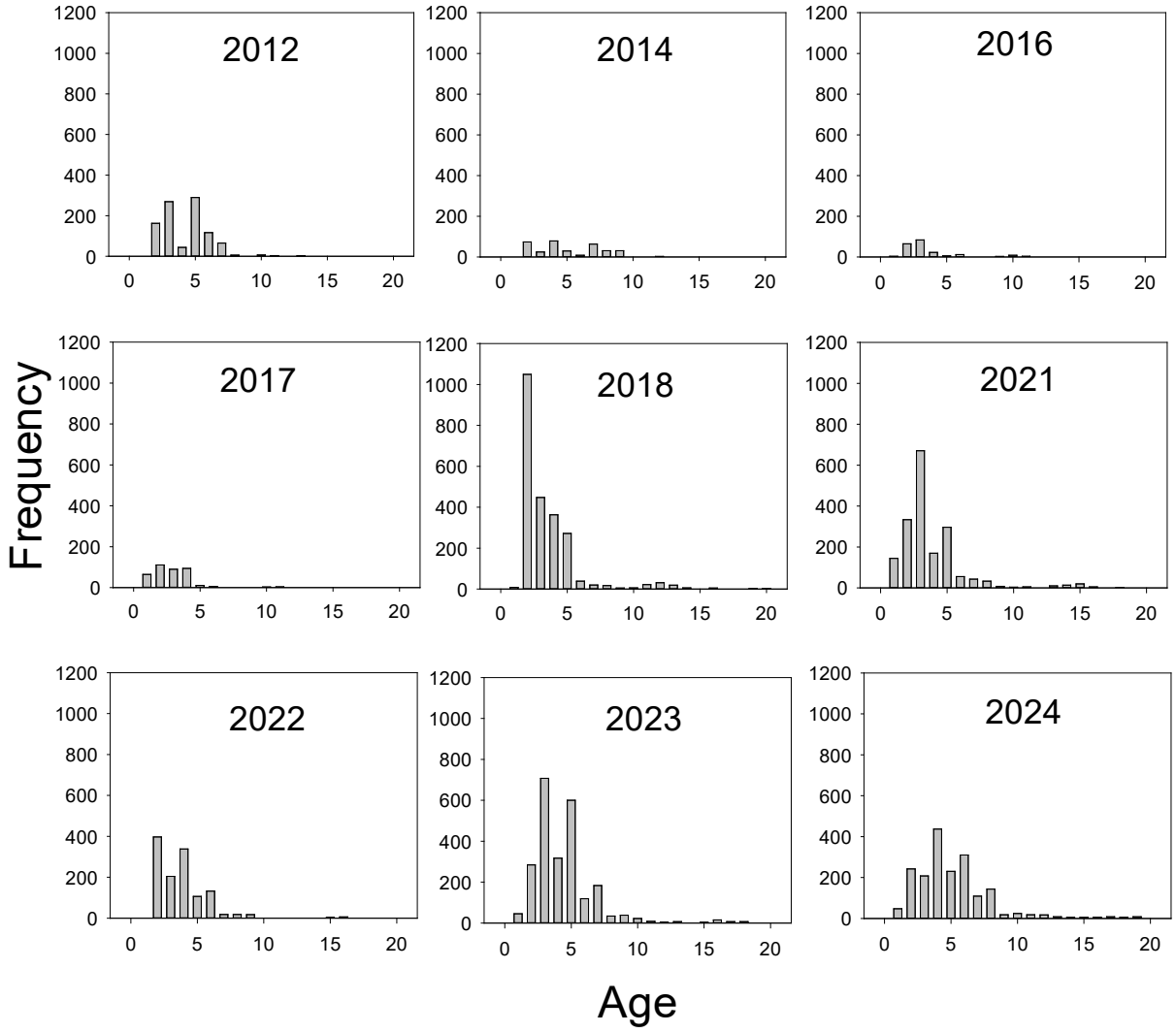

Figure 8. Age frequency of Red Snapper collected during FWRI RTD hooked-gear surveys along the Atlantic coast of Florida (2012-2024) by survey year. All fish greater than 20 years are combined into the final set of relative frequency bars. Note that data from 2012 and 2014 were not included in the final index model, but associated size and age composition data were provided for these years.

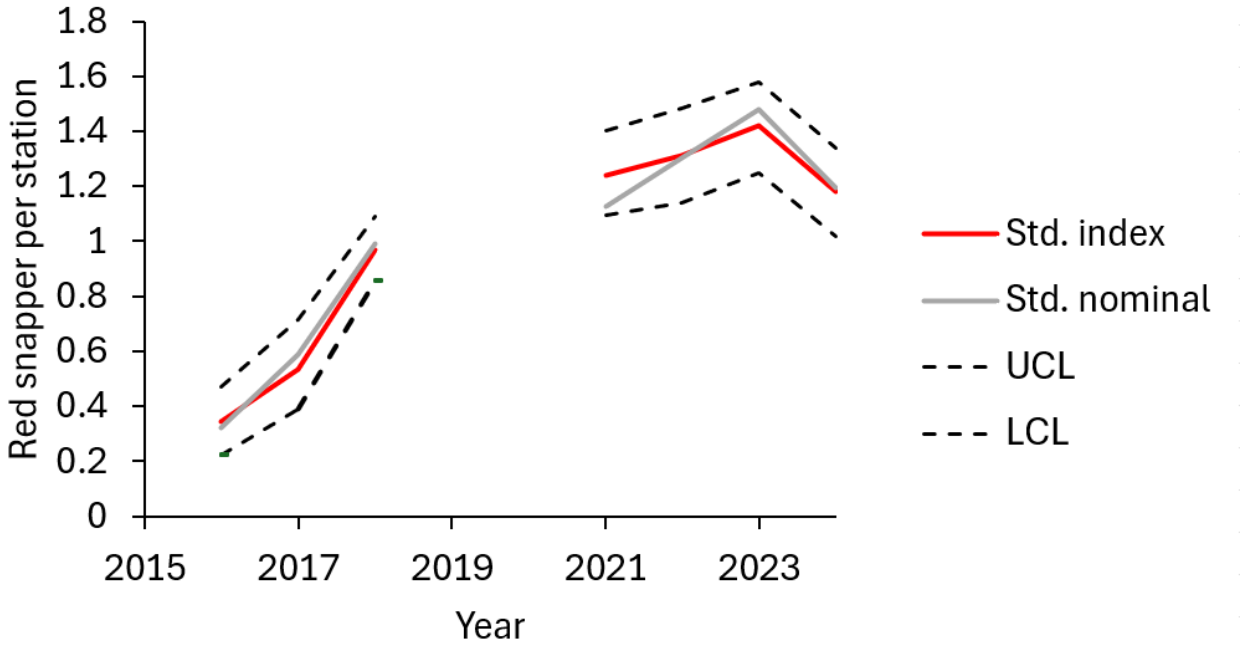

Figure 9. Relative standardized index (red line) with 95% confidence intervals (dashed lines) and the standardized nominal per site CPUE (gray line) for Red Snapper in FWRI RTD hooked-gear surveys.