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

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Introduction and Rationale:

Reef fishes along the U.S. South Atlantic (SA) coast have historically supported multi-million dollar commercial and recreational fisheries, with species such as Red Snapper, Vermilion Snapper, Gag, Red Porgy, Scamp, and Black Sea Bass among the most heavily targeted reef fishes over the past 50 years. In recent years, stock assessments for these and other species have documented varied degrees of overfishing, resulting in the implementation of restrictive management regulations (e.g., size limits, bag limits, trip limits, seasonal closures, annual quotas) to alleviate overfishing and rebuild overfished stocks as mandated by the Magnuson-Stevens Act. In particular, management of Red Snapper in the SA has involved some of the most restrictive management regulations implemented in this region, including a near-prohibition of harvest since 2010 (aside from very brief open seasons in recent years). These management practices have greatly eroded the utility of fishery-dependent data for assessing population trends through time; accordingly, assessment of stock recovery for Red Snapper is heavily reliant on fishery-independent data. In the region, the longest running source of fishery-independent data for reef fishes is the Marine Resources Monitoring, Assessment, and Prediction program (MARMAP; Bacheler and Ballenger 2015) chevron trap survey. Conducted since 1990, the MARMAP chevron trap survey was expanded in 2010 in collaboration with the NMFS Beaufort laboratory to dramatically increase overall sampling effort while also incorporating a video survey. Collectively referred to as the Southeast Reef Fish Survey (SERFS; Bacheler and Ballenger, 2015), this survey (since 2010) represents the only long-term fishery-independent index currently available for the assessment of Red Snapper and several other reef fishes in the SA.

To complement ongoing SERFS trap/camera surveys and provide another source of fishery-independent data for the assessment of managed reef fishes, the FWC Fish and Wildlife Research Institute (FWRI) developed a fishery-independent hooked-gear survey of SA hard bottom habitats beginning in 2012. This actively fished hooked-gear survey involves 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. From 2012 – 2018, FWRI conducted several hooked-gear surveys that have applied the RTD methodology (Guenther et al. 2013; Brodie and Switzer 2015; Paperno et al. 2018; Switzer et al. 2019). 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 where sampling effort was allocated among three latitudinal strata (NMFS zones 722, 728,732) and two depth strata (<30 m and >30 m; Figure 1), and annual sampling effort was distributed proportionally to the number of potential reef sampling sites within each spatial stratum. 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 reef locations 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, and to that end, an ongoing MARFIN study (Brodie et al. 2018) was funded with the explicit goal of extending the time series of this survey and developing an index.

Results from the 2016 study, which was specifically designed to address the relative selectivity of several sampling gears, highlighted the potential need for complementary fishery-independent data to augment data provided by the SERFS trap/camera survey, especially for Red Snapper. Results from this one-year study indicate that the SERFS chevron trap survey may exhibit a dome-shaped selectivity pattern where larger, older Red Snapper are underrepresented within chevron trap samples in comparison to samples from stereo-video (Figures 2A, 3A; Paperno et al. 2018, Williams 2020). Although important questions remain as to the exact nature of the selectivity function for chevron traps and to what degree spatial and temporal limitations may influence results of this study, additional sources of fishery-independent data for larger, older Red Snapper would clearly be of value. Results from the 2016 selectivity study indicate that the RTD survey conducted by FWRI is much less size selective at larger sizes than is the SERFS chevron trap survey, and in fact exhibits a selectivity pattern similar to unstandardized hooked gear (similar to how the industry would operate; Figures 2BC, 3BC, 4A; Paperno et al. 2018). Results from a 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 (Figures 5, 6; 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.

Survey Design and Sampling Methods:

We analyzed data collected in association with fishery-independent RTD surveys conducted in 2012, 2014, 2016, 2017, and 2018 by FWRI. For all surveys excluding 2014, sampling locations were selected using a stratified-random sampling design with sampling effort proportional to available habitat within each National Marine Fisheries Service (NMFS) statistical reporting zones (722, 728, and 732) and depth stratum (Nearshore <30 m and Offshore >30 m). For the 2014 survey, sites were selected to specifically target sites thought to contain spawning-capable Red Snapper; accordingly, shallow reef sites (< 20 m) were excluded from this study (Lowerre-Barbieri et al. 2015). An annual summary of sampling effort by year is illustrated in Table 1.

All sampling was conducted using chartered fishing vessels staffed with FWRI scientists. RTD sampling was conducted using powered (12V DC) Elec-tra-mate© rigs (model 940XP) outfitted with a Penn 115L 9/0 (Senator model) reel equipped with 45 kg test monofilament mounted onto a heavy-duty fiberglass fishing pole ~ 2.1 m. A barrel swivel was attached to the mainline from the reel. Two short leads ~ 0.20 m long were tied along the length of a ~ 1.8 m section of 36-45 kg test monofilament leader. Each fishing rig had two hooks baited with Atlantic Mackerel cut proportional to hook size. Three hook sizes were used in this survey: 8/0, 11/0, and 15/0 (Mustad circle hooks-Ref39960D). Fishers simultaneously dropped their rigs to the bottom and allowed it to soak for no more than two minutes. Although the site-specific number of total drops and the number of hooks fished per hook size did vary, particularly during the 2012 study, all three hook sizes were fished at all sampling stations. The number of each hook size used, and number of total drops were recorded at each station. Standard, fork, and total length were measured for all captured Red Snapper. A random sub-sample of Red Snapper were culled for biological data. 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), and Switzer et al. 2019 (2017, 2018).

Data Treatment and Standardization:

Data Summary:

In 2012 sampling extended into September and October, 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. As artificial reefs were not sampled in all years they were also excluded from the analyses. Final sample sizes for the index are provided in Table 1.

Standardization of Response Variable:

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

Explanatory Variables:

We considered 7 explanatory variables in the original model.

Year (*Y*) – Year was included since standardized catch rates by year are the objective of the analysis. We modeled data from 2012, 2014, and 2016-2018.

Month (*M*) – A temporal parameter based on month of sampling. Sampling occurred from April to August.

Depth (*DQ*) – Water depth may be an important component affecting the distribution of reef fish. All depths sampled (12-90 m) were included and treated as a quantile factor with four levels.

Latitude (*LatQ*) – The latitude of sampling location was included as a spatial parameter in the model and treated as a quantile factor with four levels.

8/0 hooks (Sm)- The total number of 8/0 hooks dropped on all rigs at each station was included as a continuous factor.

11/0 hooks (Md)- The total number of 11/0 hooks dropped on all rigs at each station was included as a continuous factor.

15/0 hooks (Lg)- The total number of 15/0 hooks dropped on all rigs at each station was included as a continuous factor.

Model Selection and Diagnostics:

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 negative binomial distribution to fit the data. 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= Y+M+DQ+LatQ+Sm+Md+Lg

Results:

The distribution of Red Snapper is presented in Figures A1-A5. In 2012, a total of 1,038 Red Snapper were captured, with 376 captured in 2014, 240 captured in 2016, 470 captured in 2017, and 2,527 captured in 2018. The number of Red Snapper captured at an individual sampling location ranged from 0 to 31 (Figure 7). The sizes of Red Snapper ranged from 207 mm to 965 mm total length (Figure 8) and the age ranged from 0 to 22 (Figure 9).

Annual standardized index values for Red Snapper in the U.S. South Atlantic 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 2012 to 2018 (Figure 10). 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 2012 there has been a general increase of abundance of Red Snapper in the U.S. South Atlantic. 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. RTD is an actively fished gear, however preliminary investigations have indicated that fisher variability is minimal due to the standardization of fishing protocols. Additionally, the slight differences in number of each hook size dropped at each sampling location appear to be accounted for by the model standardization.

The RTD survey method has also been used by FWRI in the Gulf of Mexico from 2014-2017. An index developed using data from this survey 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 five years of data over a seven-year time period. 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). Accordingly, we recommend the inclusion of the RTD index of abundance, as well as the associated age-composition data, as a complementary data input into the Red Snapper stock assessment.

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Table 1. List of total FWRI RTD stations sampled by year.

Year	# of RTD stations	Depth Range (m)	Latitude Range (deg N)	Longitude Range (deg W)
2012	283	12-90	28.004-30.584	-79.999 to -81.240
2014	74	23-72	28.650-30.293	-80.200 to -81.164
2016	93	16-73	28.007-30.516	-80.006 to -81.164
2017	107	13-76	28.171-30.520	-80.114 to -81.209
2018	337	16-87	28.006-30.584	-80.114 to -81.231

Table 2. Relative nominal CPUE, number of stations sampled (N), proportion of positive sets, standardized index, and coefficient of variation for FWRI Red Snapper RTD index of U.S. South Atlantic, 2012, 2014, 2016-2018.

Year	Nominal CPUE	N	Proportion positive	Standardized Index	CV
2012	3.67	283	0.48	0.6672	0.238073
2014	5.08	74	0.72	0.8428	0.905969
2016	2.58	93	0.48	4.7675	0.26118
2017	4.39	107	0.59	9.117	0.243873
2018	7.50	337	0.73	14.1826	0.193706

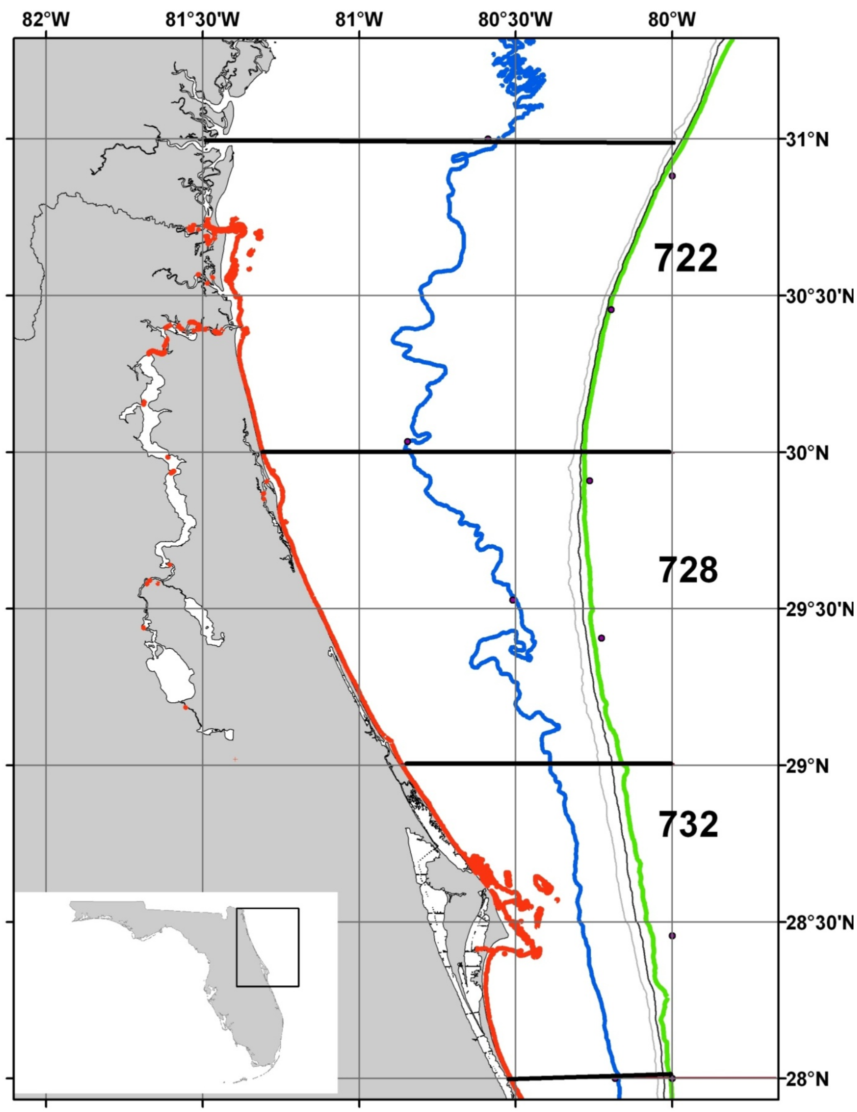


Figure 1. Study area for FWRI RTD surveys along the Atlantic coast of Florida (2012, 2014, 2016-2018), including NMFS statistical zones 722, 728 and 732. The colored lines represent the 10 m (red), 30 m (blue), and 70 m (green) isobaths.

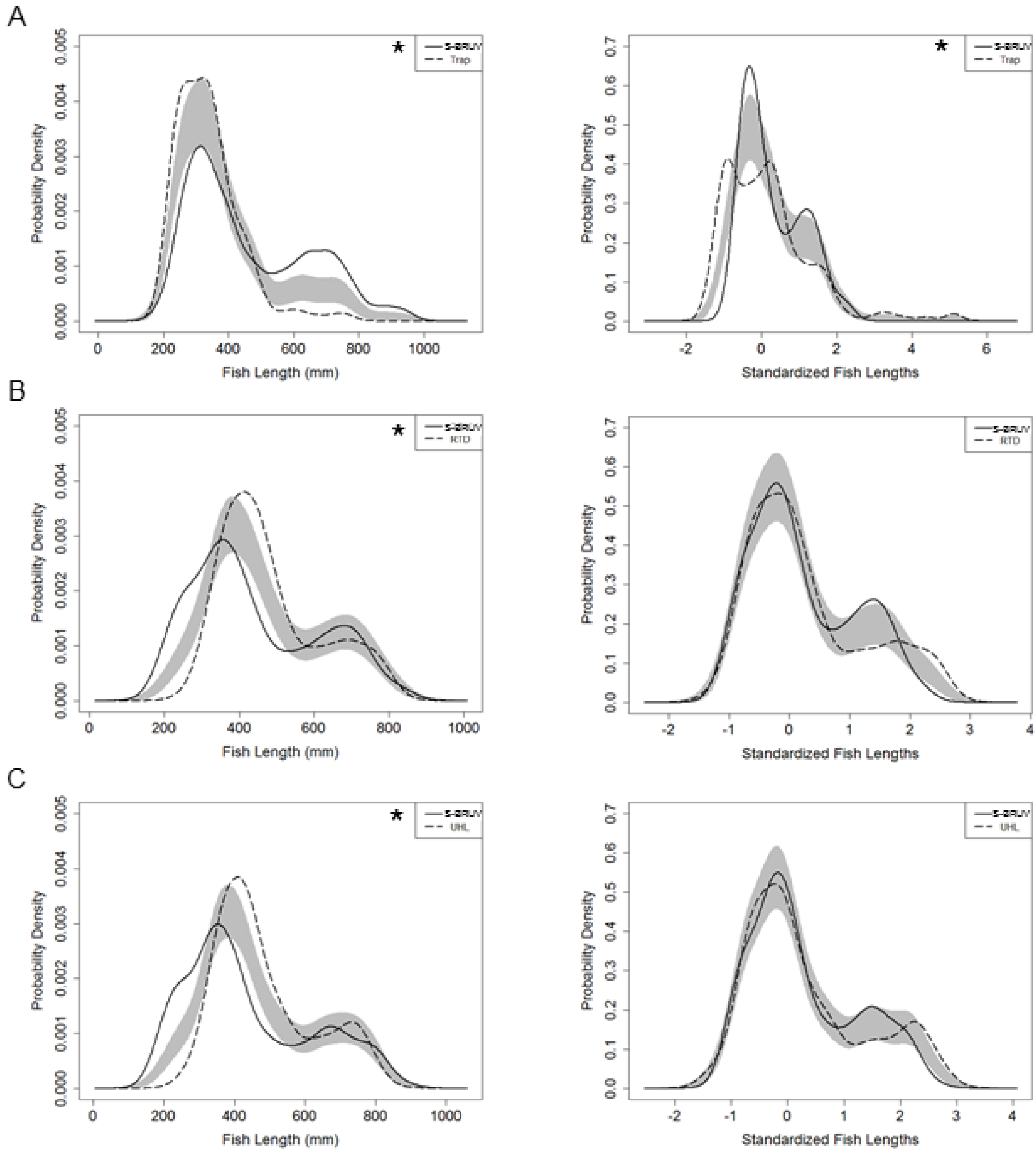


Figure 2. Comparison of kernel density estimate (KDE) probability density functions for Red Snapper (*Lutjanus campechanus*) sampled using A) trap, B) repetitive timed drop, or C) unstandardized hooked gear. Grey bands represent ±1 SE about the null model. Analyses of raw data (left column) provide a test of differences in both location and shape of the length-frequency distributions, whereas analyses of standardized data (right column) provide a test of shape only. An asterisk indicates significant differences between the two distributions ($p < 0.05$).

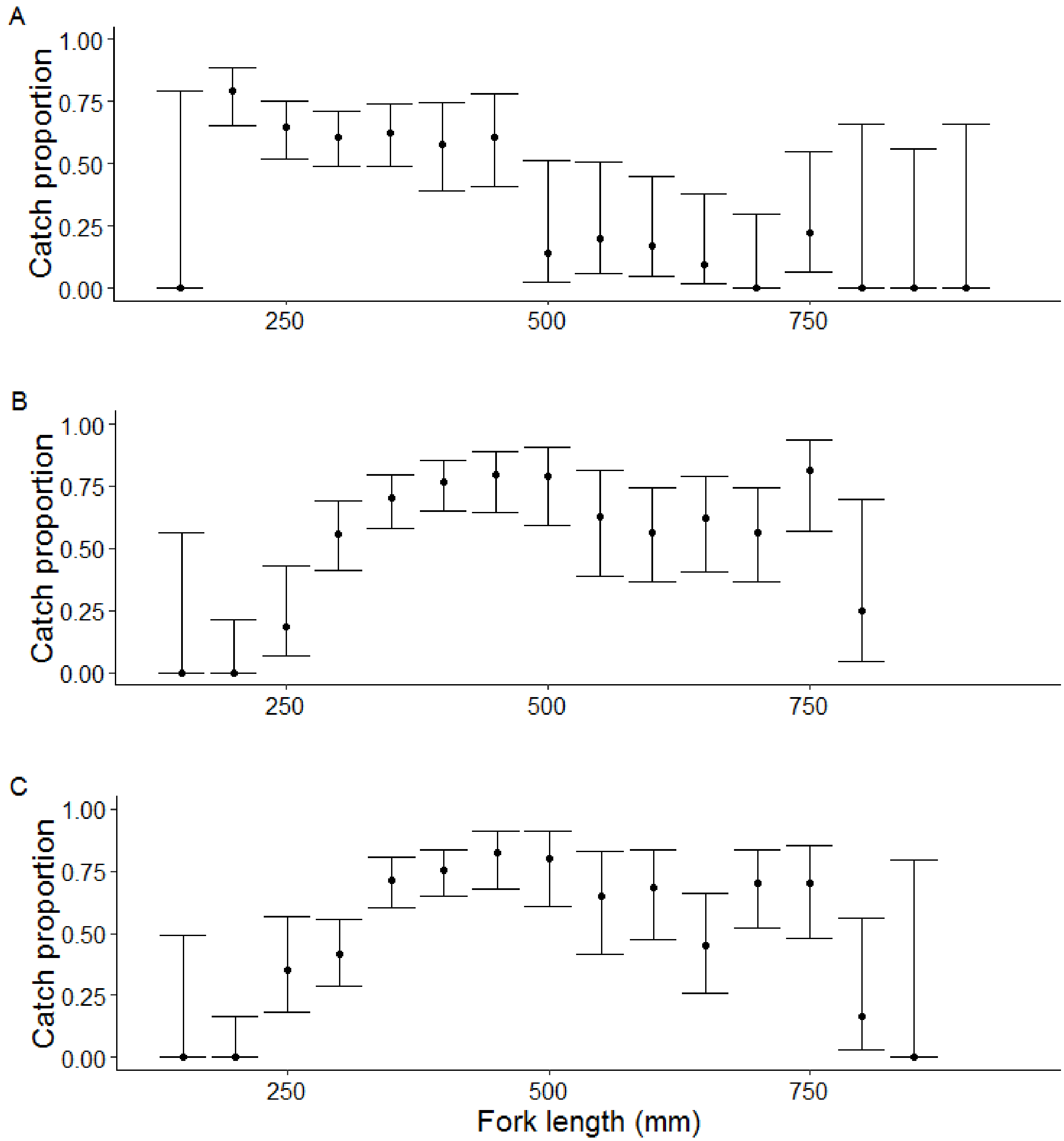


Figure 3. Relative selectivity for Red Snapper (*Lutjanus campechanus*) of A) traps, B) repetitive timed-drop, and C) unstandardized hooked gear, each relative to their corresponding stereo-camera. Error bars represent 90% confidence intervals.

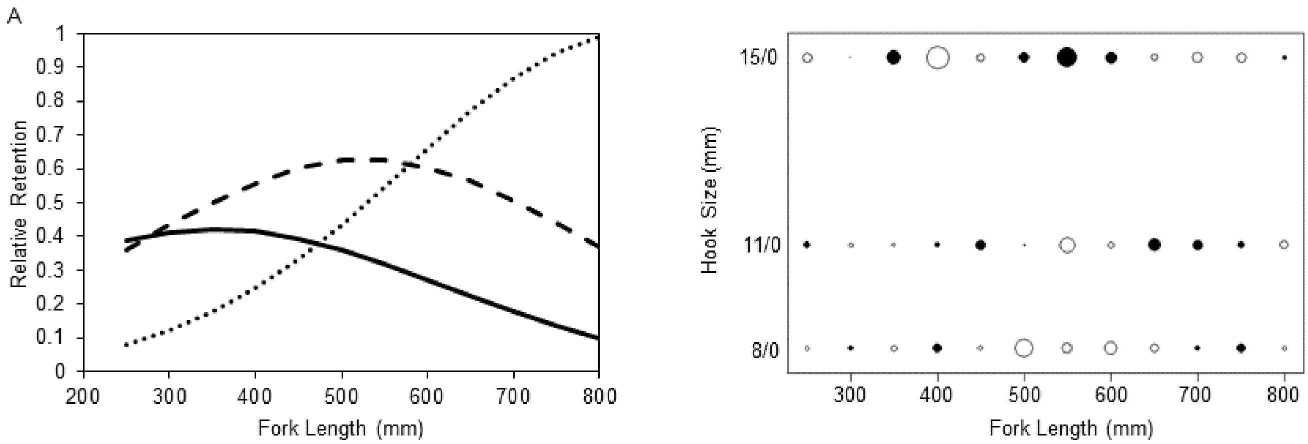


Figure 4. Hook selectivity curves for Red Snapper (*Lutjanus campechanus*) calculated from the normal distribution assuming proportional fishing intensity with increasing hook size calculated from the lognormal distribution assuming fishing intensity proportional to hook size. Solid lines represent 8/0 hooks, dashed lines represent 11/0 hooks, and dotted lines represent 15/0 hooks. Graphs on right side are the deviance residuals, closed circles represent positive residuals and open circles represent negative residuals. The area of the circle is proportional to the absolute value of the residual (Figure 41 from Paperno et al. 2018).

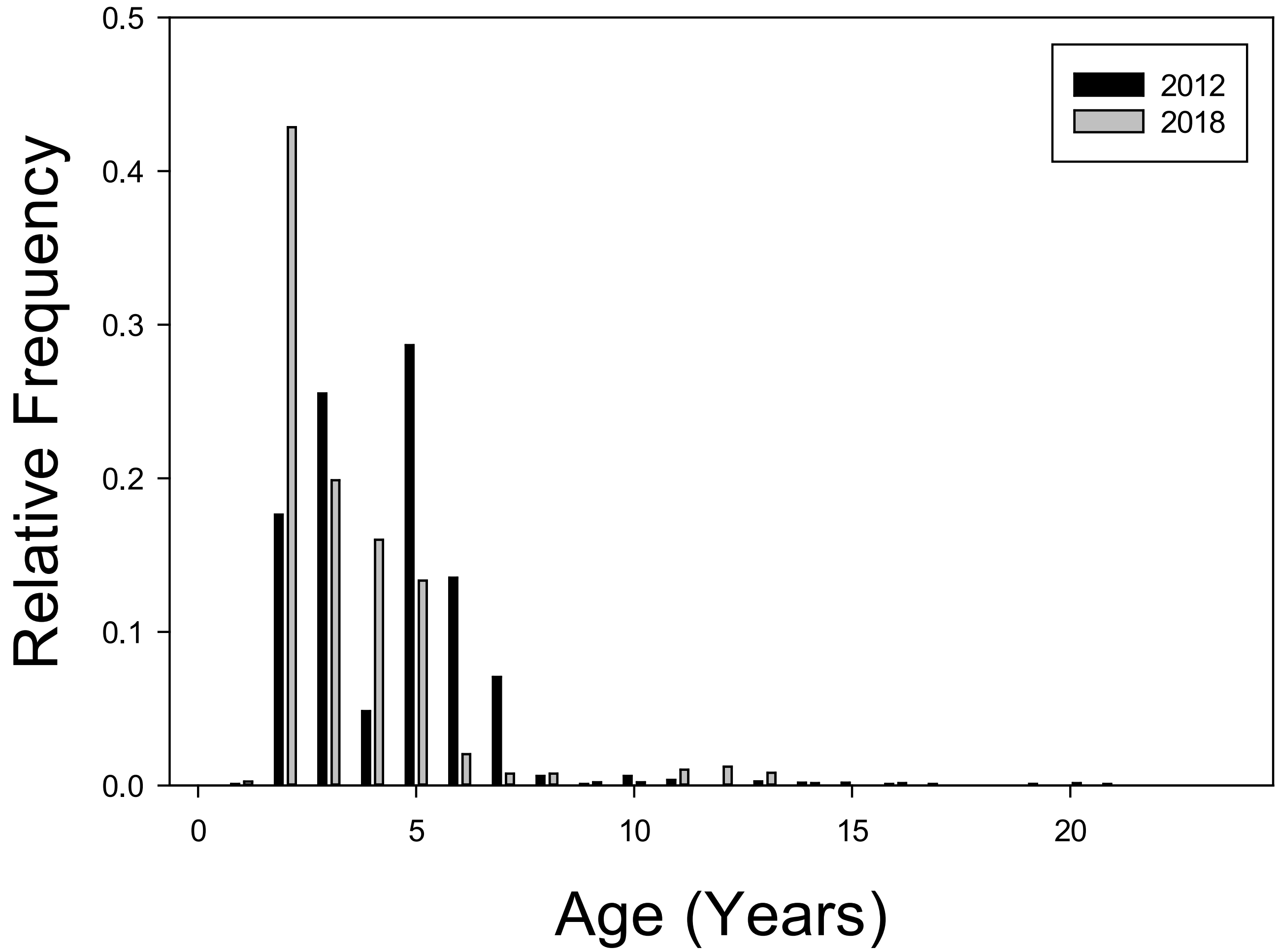


Figure 5. Age frequency (Years) of Red Snapper collected during FWC RTD hooked-gear surveys along the Atlantic coast of Florida in 2012 (black bars) and 2018 (gray bars; Figure 16 from Switzer et al. 2019).

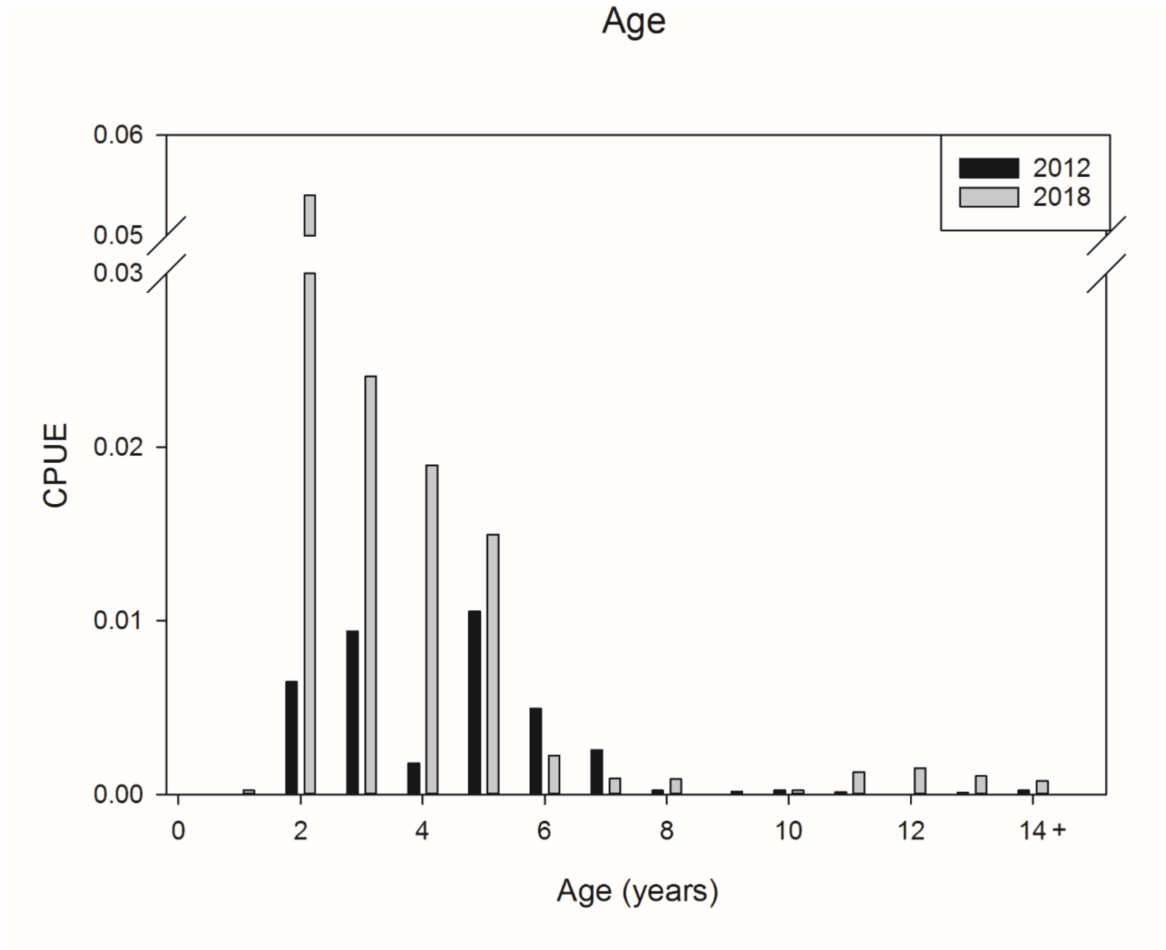


Figure 6. Catch-per-unit-effort (CPUE) for Red Snapper collected during FWC RTD hooked-gear surveys along the Atlantic coast of Florida in 2012 (black bars) and 2018 (gray bars). CPUE was calculated as the number of Red Snapper collected for each age class per total number of hooks dropped per survey year (all hook sizes, NMFS statistical zones, and depth strata combined). Unaged Red Snapper from each survey year (2012, n=32; 2018, n=688) were assigned ages for this comparison based on an age-length key developed from all individuals aged during the given survey year (Figure 22 from Switzer et al. 2019).

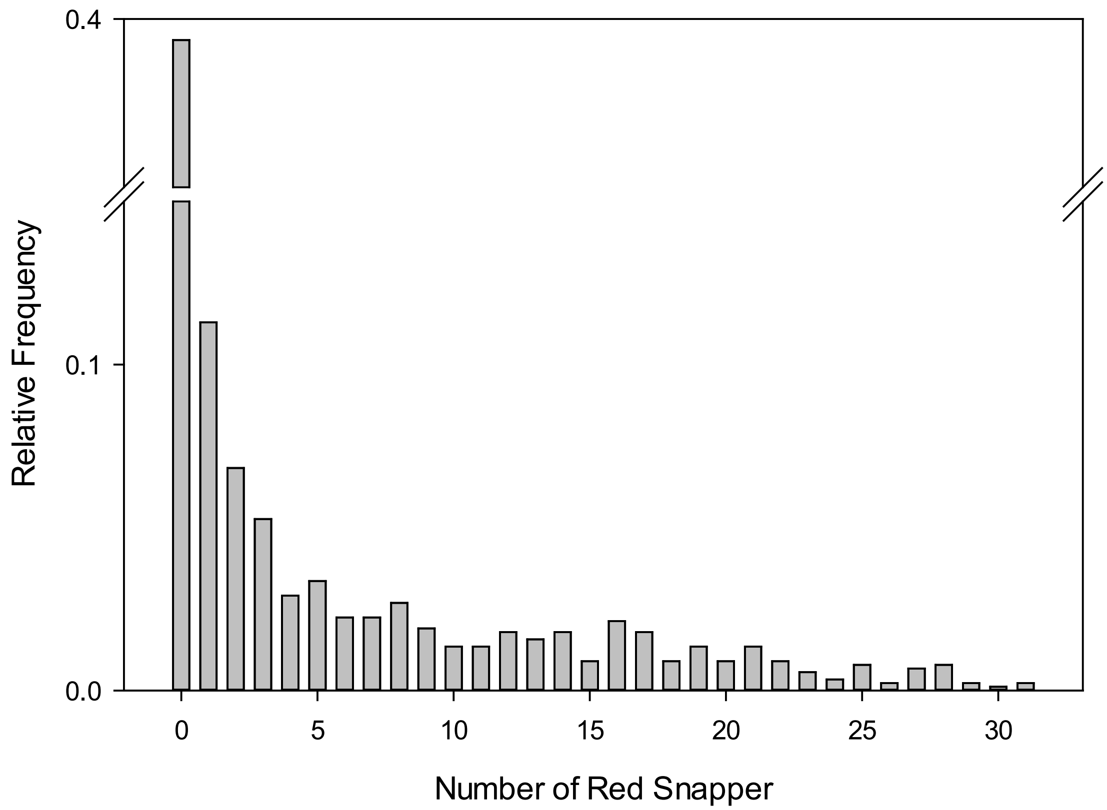


Figure 7. Number of Red Snapper captured per site in the FWRI repetitive timed drop surveys from 2012, 2014, and 2016-2018.

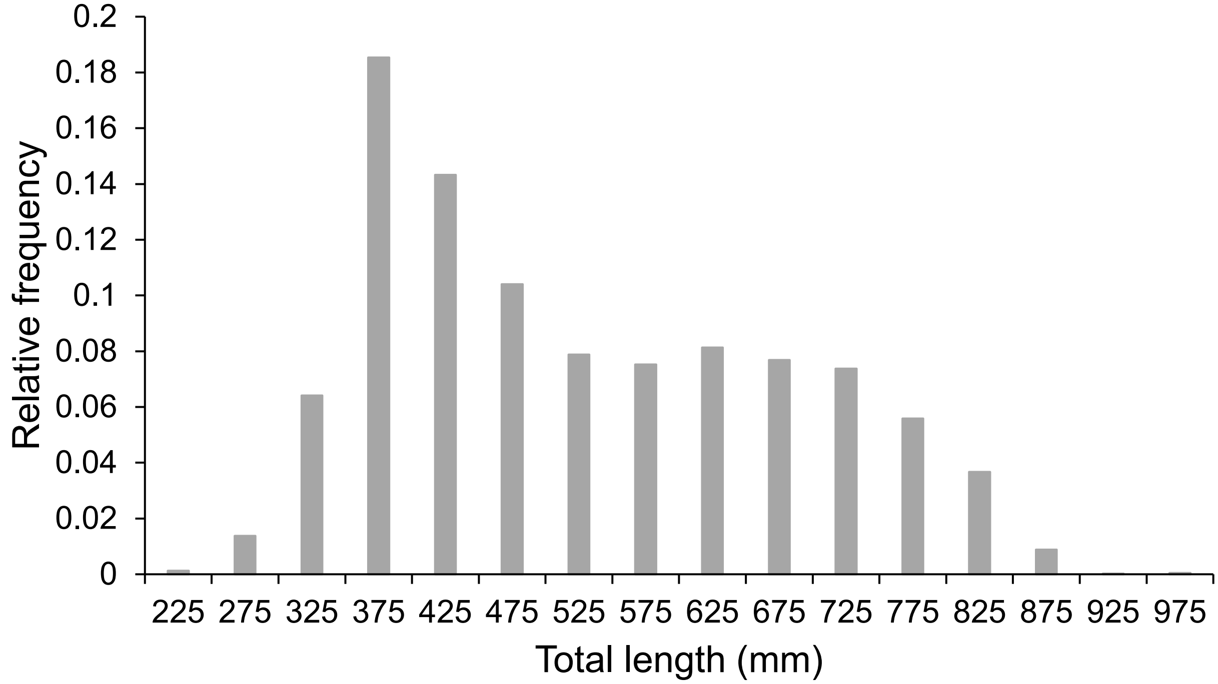


Figure 8. Size frequency distribution for Red Snapper captured in the FWRI repetitive timed drop surveys from 2012, 2014, and 2016-2018.

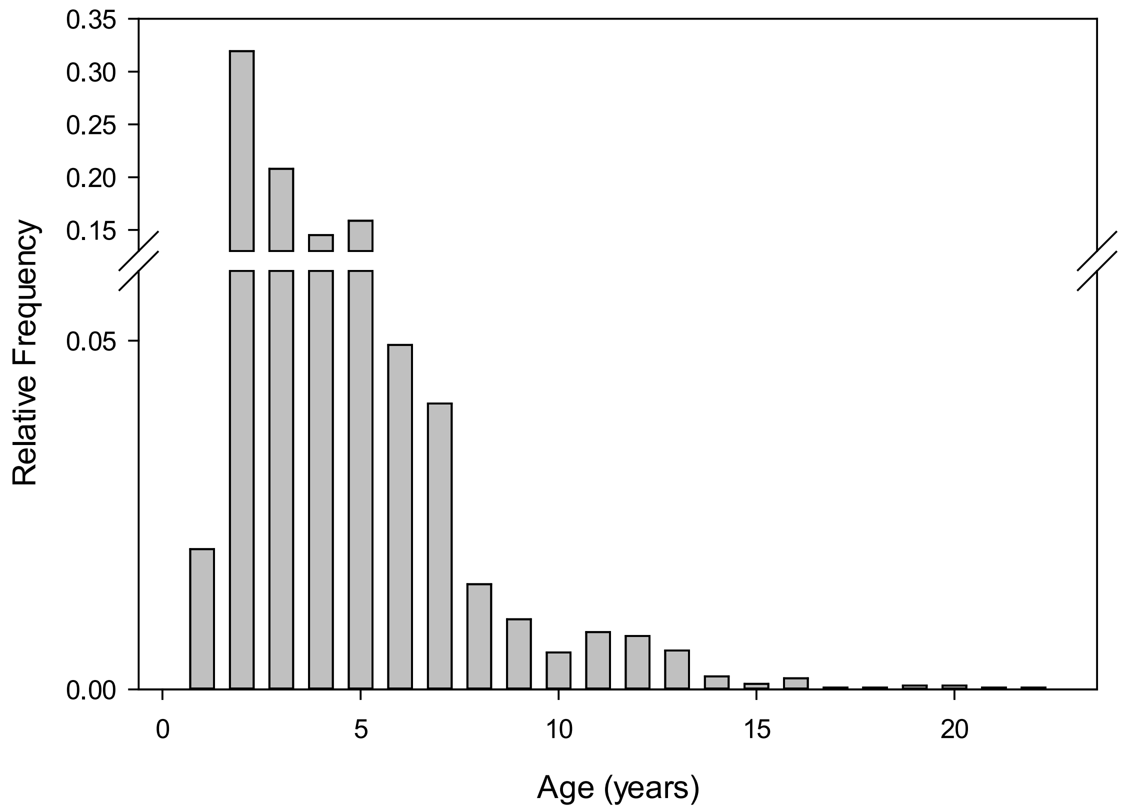


Figure 9. Age frequency distribution for Red Snapper captured in the FWRI repetitive timed drop surveys from 2012, 2014, and 2016-2018.

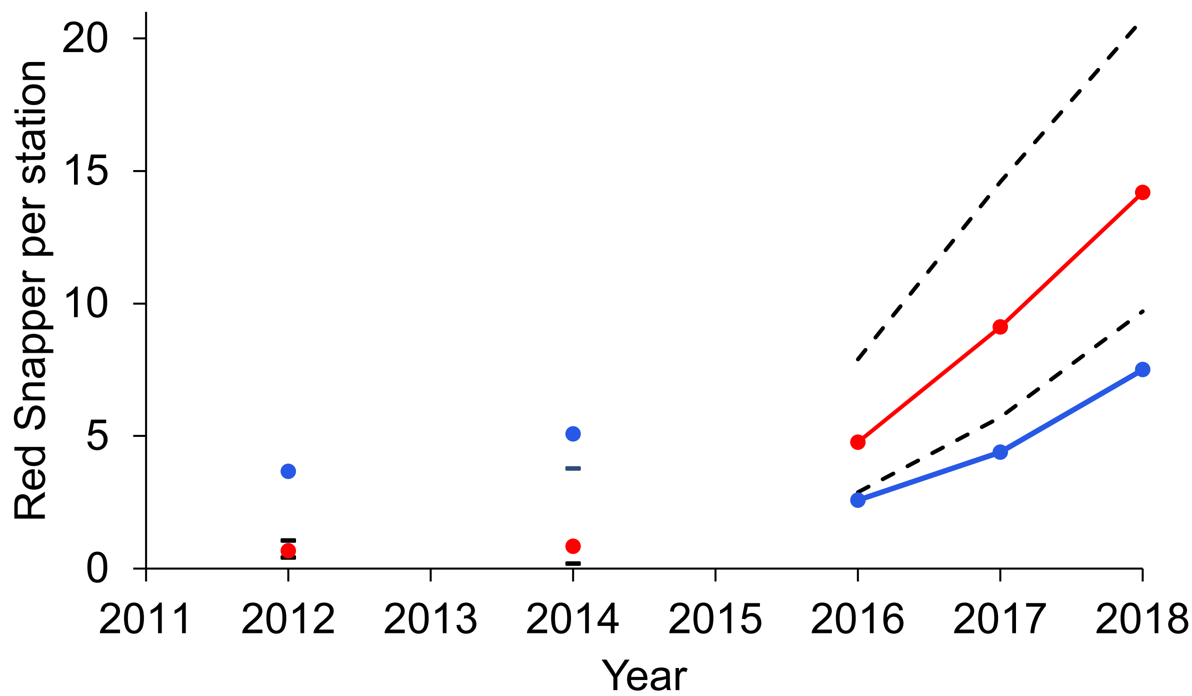
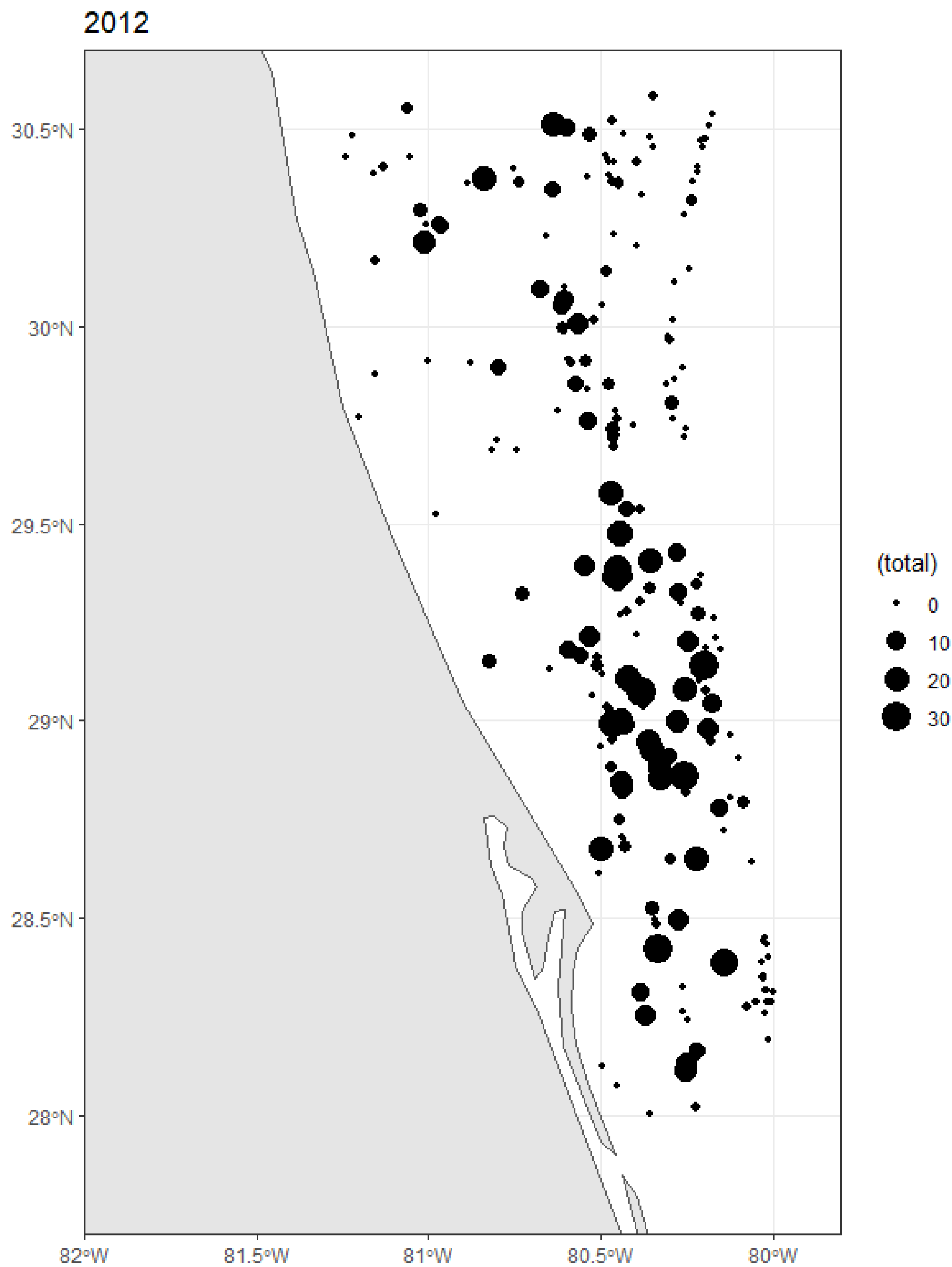


Figure 10. Relative standardized index (red line) with 95% confidence intervals and the nominal CPUE (blue line) for Red Snapper CPUE in the FWRI repetitive timed drop survey.

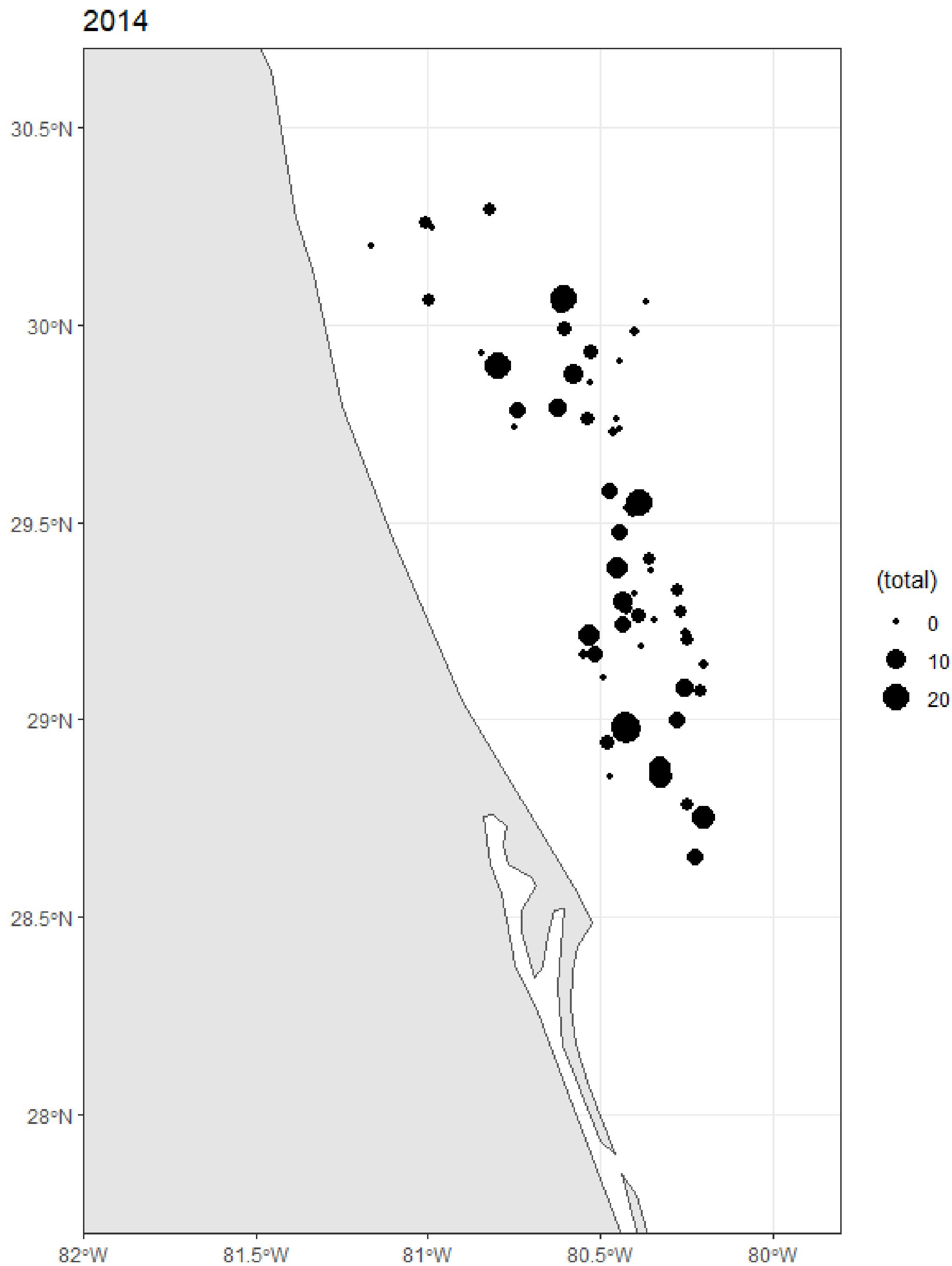
Appendix A

Figures A1-A5. Annual distribution of stations sampled (2012, 2014, 2016 – 2018) during the FWRI repetitive timed drop survey. Symbols represent total number of Red Snapper captured on all hooks at a station.

A1.

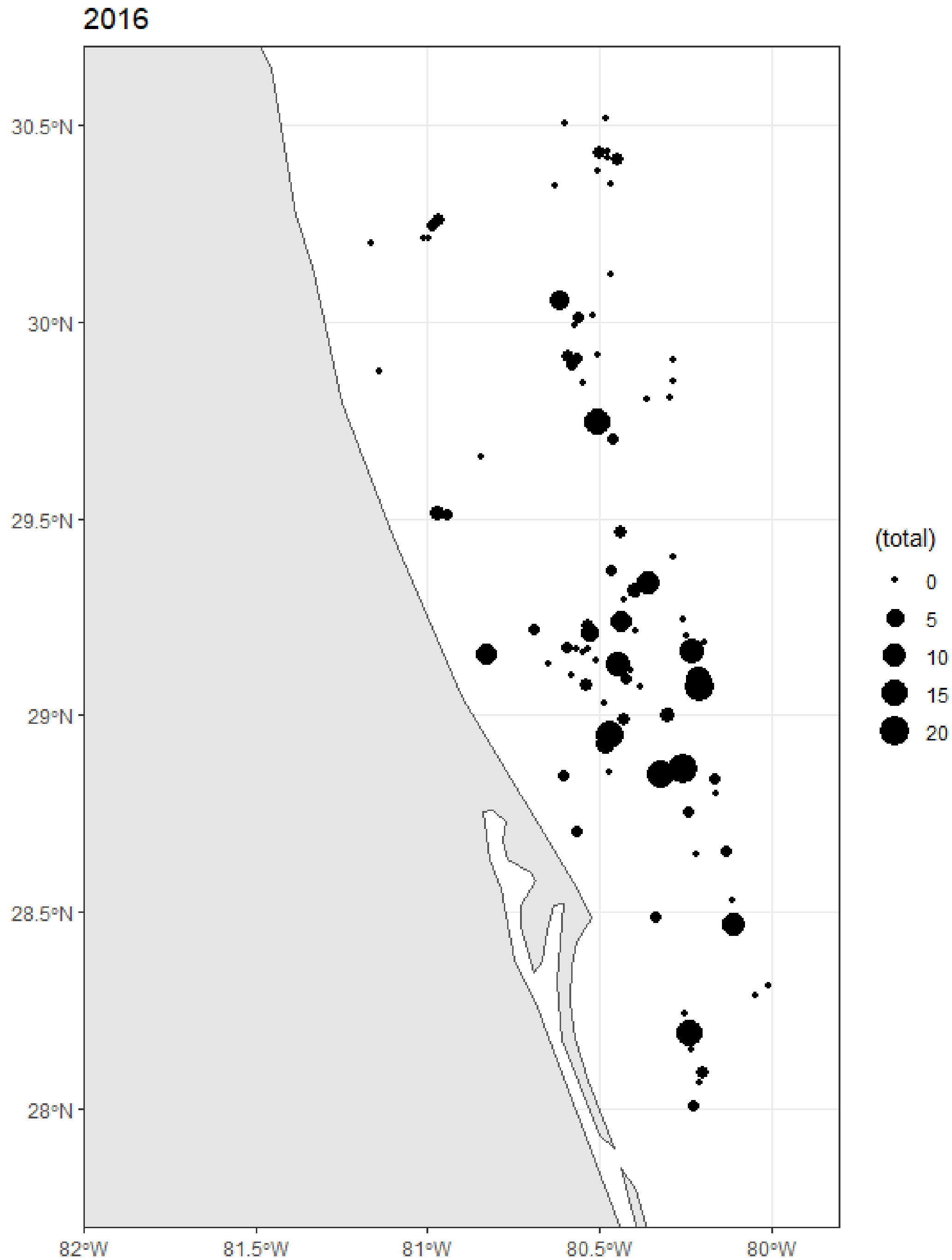


A2.

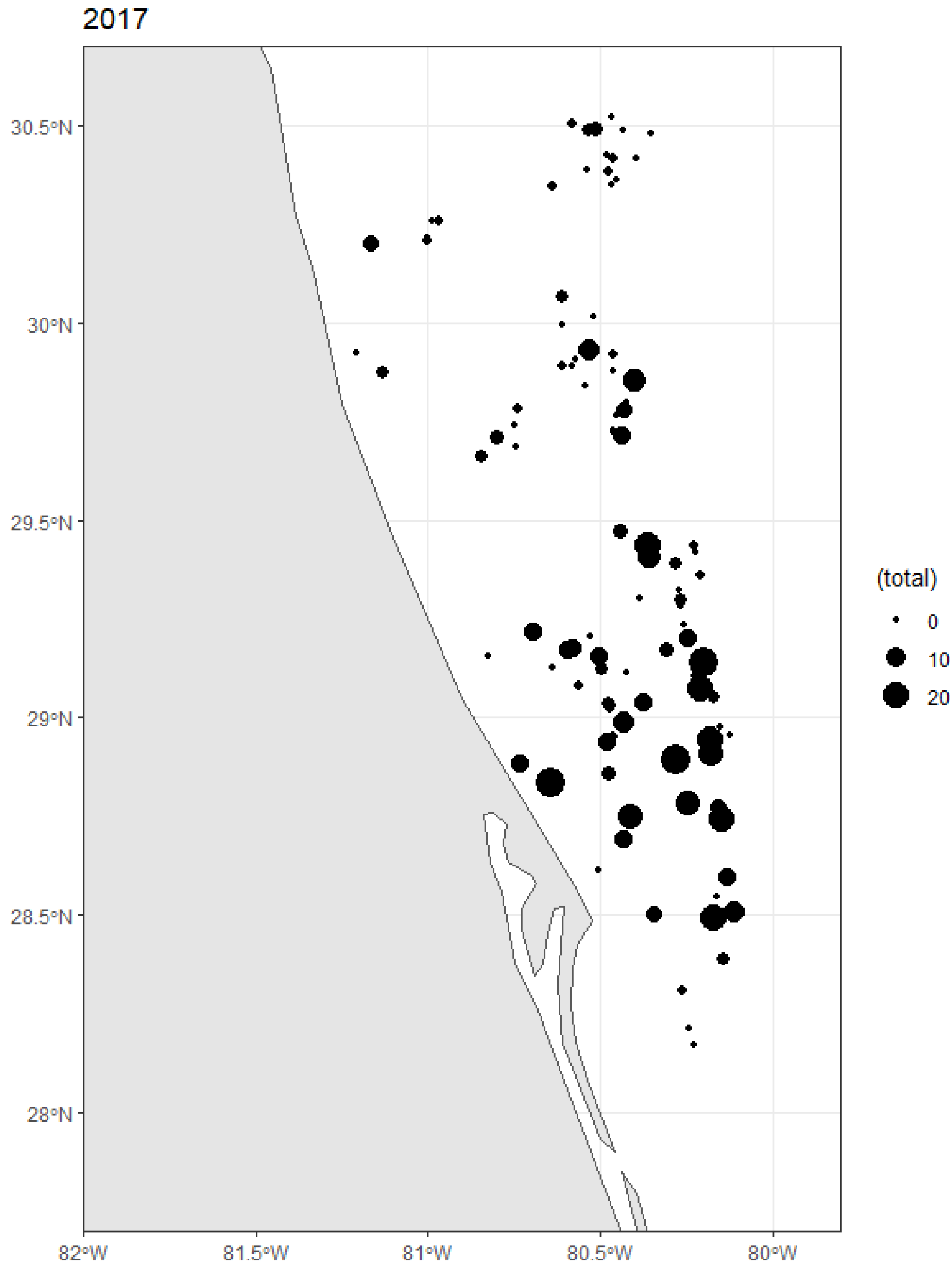


2014
30.5°N
30°N
29.5°N
29°N
28.5°N
28°N
82°W
81.5°W
81°W
80.5°W
80°W
(total)
0
10
20

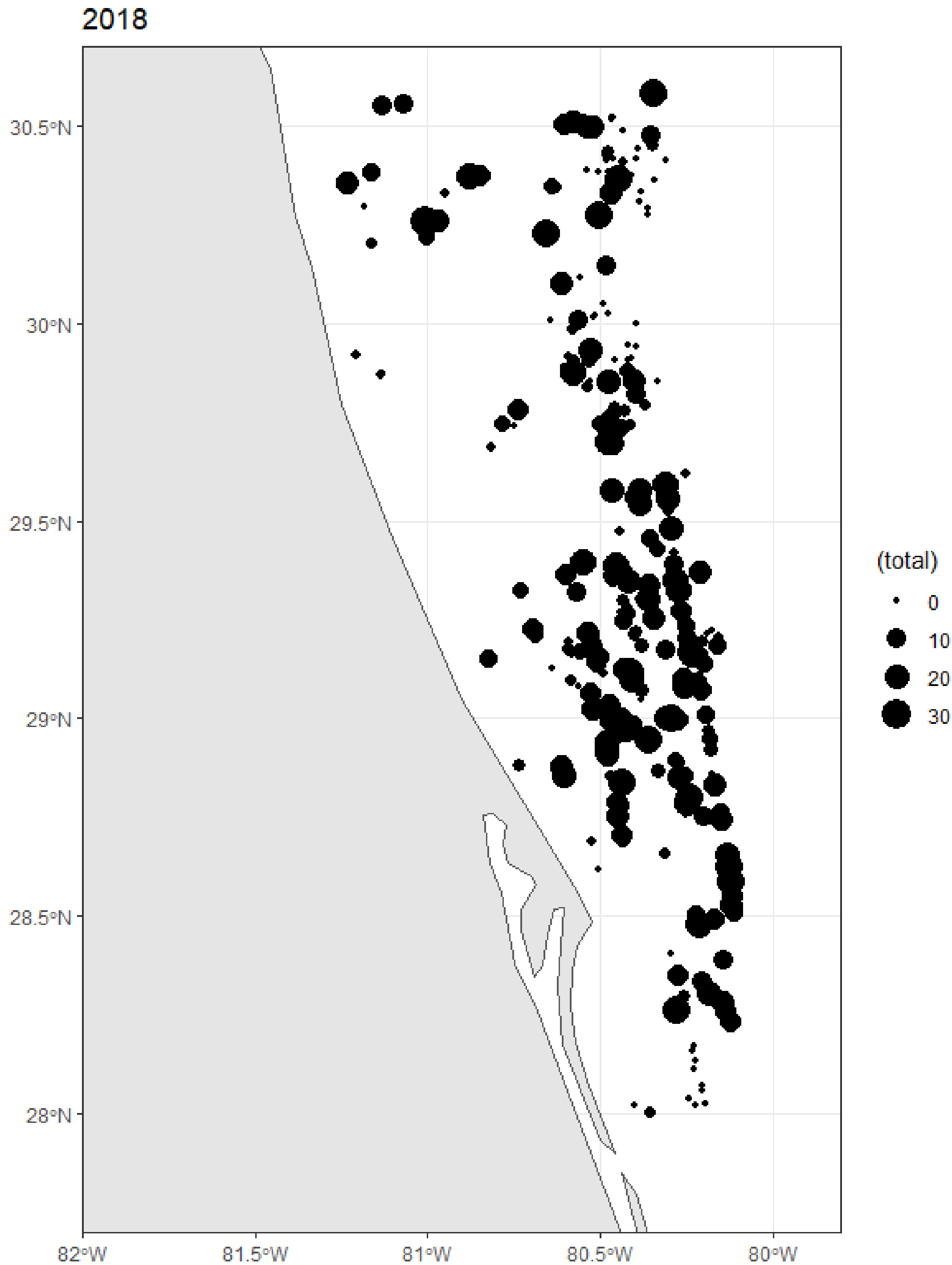
A3.


2016
30.5°N
30°N
29.5°N
29°N
28.5°N
28°N
82°W
81.5°W
81°W
80.5°W
80°W
(total)
0
5
10
15
20

A4


2017
30.5°N
30°N
29.5°N
29°N
28.5°N
28°N
82°W
81.5°W
81°W
80.5°W
80°W
(total)
0
10
20

A5.


2018
30.5°N
30°N
29.5°N
29°N
28.5°N
28°N
82°W
81.5°W
81°W
80.5°W
80°W
(total)
0
10
20
30