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ARTICLE

Survey Methods for Estimating Red Snapper Landings in a High-Effort Recreational Fishery Managed with a Small Annual Catch Limit

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Abstract
Before the Red Snapper *Lutjanus campechanus* stock in the southeastern U.S. Atlantic was formally assessed, recreational harvest was permitted year-round. However, in 2010, all sectors of the fishery were closed to immediately end overfishing. In recent years, the recreational fishery for Red Snapper in the region has been managed with a substantially reduced catch limit and an annual harvest season ranging from 0 to 8 d. To obtain a precise estimate of recreational harvest over this reduced time scale, a new creel survey method was developed in Florida, where the majority of Red Snapper landings in the region occur. The fishery was intensely monitored during the short sample window when the harvest season was open, and the survey design took advantage of choke points at ocean inlets that restrict recreational boat access to offshore fishing grounds. Landings estimates from this specialized survey were more precise than the general survey that has historically been used in the region to monitor saltwater recreational fisheries over larger spatial and temporal scales. Fishing effort was highly concentrated, and the fishery was capable of reaching the small annual catch limit over the short time periods allowed. Fishing effort and landings were highest between Ponce Inlet and Cape Canaveral, and the majority of Red Snapper were harvested from shallow depths (<29 m). Fish from shallow depths were approximately equally distributed among younger (1–5 years) and older age-classes. However, as fishing moved into deeper waters (≥29 m), a greater proportion of fish were older than 5 years. Precise landings estimates from the survey enabled managers to monitor the recreational fishery against a small annual catch limit, and the survey also revealed spatial patterns of effort and CPUE in the region's private boat segment of the recreational fishery, which had been poorly understood.

The southeastern United States supports the greatest concentration of recreational fishing effort in the nation (Coleman et al. 2004; USFWS and U.S. Census Bureau 2011). Revisions to the Magnuson–Stevens Fishery Conservation and Management Act in 2006 required that landings be constrained within prescribed catch limits (Methot et al. 2014); thus, over the past decade, harvest seasons for year-round, high-effort, open-access recreational fisheries in the southeastern United States have been substantially reduced. With this evolution, a need has emerged for precise estimates of landings over reduced temporal scales. This point was highlighted by a nationwide review of recreational fishery survey methods, which found that catch estimates were not robust or timely enough for the scales at which fishery managers have been applying them (NRC 2006). Implementation of directed surveys to improve statistics for pulsed and rare-event recreational fisheries was recently identified as a priority action for supporting stock assessments and informing fisheries management in the United States (NMFS 2015).

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Boat-based recreational fisheries off the Atlantic coast of Florida emerged as early as the late 1800s and experienced rapid development after World War II (Gregg 1902; Moe 1963; Rivkin 2009). Throughout recent decades, effort and participation in saltwater recreational fisheries have continued to trend upward (Hanson and Sauls 2011). The first benchmark survey of offshore fisheries operating in the region was conducted in the early 1960s, and long-lived reef fishes were identified as primary target species in the established commercial fishery and the growing recreational fishery (Moe 1963). In his report, Moe (1963) identified the biology and ecology of targeted offshore stocks as fundamental research needs. Historically, the Red Snapper *Lutjanus campechanus* was one of the most economically valuable reef fish species within the jurisdictional region of the South Atlantic Fishery Management Council (exclusive economic zone adjacent to North Carolina through the Atlantic coast of Florida; hereafter, "South Atlantic"). The center of Red Snapper abundance in the South Atlantic lies between Georgia and northeastern Florida (between 38°N and 28°N; Moe 1963; Mitchell et al. 2014), and the stock is managed as a single unit separate from the Gulf of Mexico stock. The first regional study on the stock's status was conducted in the late 1990s and documented a truncated age distribution indicative of high exploitation (Manooch et al. 1998). By the time the first full assessment of South Atlantic Red Snapper was conducted in 2008, the stock had been severely overfished (SEDAR 2009), and the basic surveys and research that were needed to monitor population dynamics were still sorely lacking (Rindoneet al. 2015). Data on size and age selectivity for fisheries are of vital importance to stock assessment, yet only one study of the commercial hook-and-line fishery for Red Snapper in the region has been published (Mitchell et al. 2014), and no studies have focused on the recreational sector.

Prior to assessment of the South Atlantic Red Snapper stock, the recreational fishery for Red Snapper was managed with a minimum size limit (30.48 cm [12 in] TL in 1983, which was increased to 50.8 cm [20 in] TL in 1992), a daily bag limit, and no closed season. After the stock was found to be overfished, a complete moratorium on commercial and recreational fisheries was imposed in 2010 and 2011. In 2012, a small annual catch limit was allowed, but given the potentially high level of effort, recreational harvest was only reopened for 6 d to ensure that the limit was not exceeded. However, regional fishery managers were concerned that the existing survey used to monitor recreational landings over large scales would yield highly imprecise estimates for the short harvest season. Since 1981, saltwater recreational fisheries in the South Atlantic have been monitored by the Marine Recreational Fisheries Statistics Survey, which is administered by the National Marine Fisheries Service (NMFS). The survey was renamed the Marine Recreational Information Program (MRIP) after an independent review (NRC 2006) and subsequent improvements to data collection and estimation procedures (NMFS 2008). The MRIP is a general survey that is designed to monitor effort and catch for saltwater recreational fishing activity from shore, private boats, and charter boats in inshore, nearshore, and offshore waters over large temporal and spatial scales. The MRIP estimates fishing effort through an off-site, bimonthly, random telephone survey of coastal households that is complemented with an on-site access point intercept survey to measure CPUE (Essig and Holliday 1991). Catch estimates are generally precise on an annual scale; however, precision can be quite low (coefficient of variation > 40%) for fisheries that are localized or highly seasonal and thus are encountered infrequently during the intercept survey.

To lend support for allowing a recreational season for Red Snapper, the Florida Fish and Wildlife Conservation Commission (FWC) worked with NMFS to develop specialized survey methods that could provide more precise harvest estimates over a short temporal scale for major segments of the recreational fishery. The largest segment of the recreational fishery for Red Snapper is composed of anglers fishing from privately owned boats (SEDAR 2016). During the 3 years (2007–2009) leading up to the moratorium, private boat anglers in Florida accounted for more than 60% of all Red Snapper recreational landings estimated by the MRIP survey in the region (NMFS, Fisheries Statistics Division, personal communication). This segment of the fishery is the most difficult to monitor. Here, we describe Florida FWC's efforts to monitor Red Snapper harvest in the private boat recreational fishery over the three short harvest seasons that occurred in 2012–2014. The goals of the present study were to (1) develop a cost-effective method for monitoring private boat recreational effort and CPUE along Florida's Atlantic coast during the Red Snapper season, (2) develop methods for precisely estimating landings over a short temporal scale, and (3) facilitate management of the open-access, private boat recreational fishery whenever a limited season is warranted.

METHODS

During 2012–2014, recreational harvest of Red Snapper was open for a total of six weekends (Friday–Sunday). The season varied each year and included two weekends (6 d) during September 2012, one weekend (3 d) in August 2013, and three weekends (8 d, with the third weekend only open on Friday and Saturday) during July 2014. The survey design took advantage of choke points at ocean inlets that concentrate recreational fishing effort for Red Snapper over small spatial scales relative to Florida's coastline; sample periods were focused on the short temporal scale (days) of the recreational season. The area included in this study was the Atlantic coast of Florida from the state boundary with Georgia (~31°N) south to 27°N, which is the southern limit for recreational boat access to fishing grounds where Red Snapper may be abundant enough to be targeted (Moe 1963). Any trip into the

Atlantic Ocean that originates in this study area must pass through one of the nine navigable inlets (depicted in Figure 1) that serve as egress points.

We chose two complementary on-site methods to directly measure the effort and catch components of the fishery. On-site methods are not cost prohibitive over small spatial and temporal scales, and they have the benefit of increased precision since effort is directly observed and details can be collected from respondents on the same day the trip concludes (Pollock et al. 1994; Hartill et al. 2012). On-site methods are also recommended for fisheries

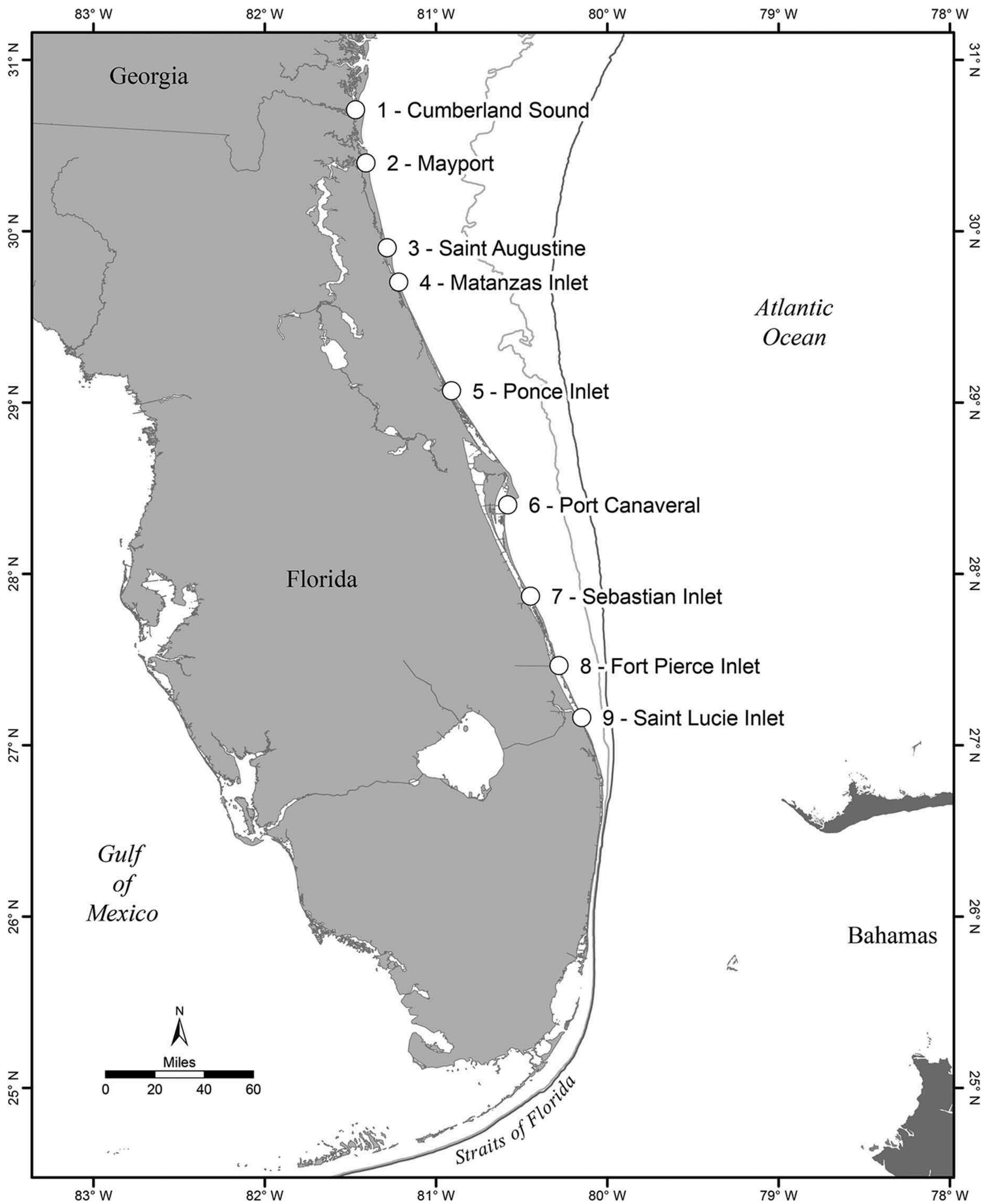

FIGURE 1. Inlets included in the study area off the Atlantic coast of Florida, where private boat recreational harvest of Red Snapper was monitored. Bathymetry lines for 29 m (light gray) and 49 m (dark gray) are shown.

with well-defined access points and a spatiotemporal sample frame for which a list of known participants is not available (Pollock et al. 1994). Since a general license that covers all saltwater recreational fishing privileges throughout Florida is the only current requirement for participation in the Red Snapper fishery, a list of known participants for this small segment of the overall population of licensed anglers was not available. In this study, effort was estimated by directly observing recreational boats as they passed through ocean inlets during the open harvest season, and these observations were combined with auxiliary data from a separate on-site intercept survey of recreational boating parties. Auxiliary data have been demonstrated as effective for use in estimating the proportion of recreational boat trips that participate in a fishery (Steffe et al. 2008). The on-site intercept survey also served the purpose of directly measuring CPUE for targeted trips. Landings were estimated by multiplying mean CPUE and effort. Methods for the two complementary on-site survey methods are further described below.

Inlet Boat Activity Survey

During each fishing season, a total of nine inlets were monitored for boat traffic (Figure 1). Two centrally located inlets (one north and one south of Cape Canaveral) were designated as reference points, where boat traffic was monitored continuously every day between sunrise and sunset (0700–1900 hours). Saint Augustine (inlet 3) served as the northern reference during each of the 3 years. Sebastian Inlet (inlet 7) served as the southern reference during the first year of the study; however, this inlet was difficult to access for continuous monitoring, so Fort Pierce Inlet (inlet 8) was designated as the southern reference during the latter 2 years. For the remaining seven inlets, boat traffic was monitored during one time period over three randomly selected days during the first season in 2012 and every day during the subsequent seasons in 2013 and 2014. During the two shortest seasons (2012 and 2013), time periods were randomly selected and defined as morning (0700–1359 hours) or afternoon/evening (1400–1900 hours). During the 2014 season, days were divided into shorter periods, defined as morning (0700–1100 hours), mid-day (1100–1500 hours), and evening (1500–1900 hours), which were randomly sampled without replacement each weekend.

Observers were stationed at the mouth of an inlet, where vessels could be clearly seen exiting into the Atlantic Ocean. Monitoring took place from land except at the largest inlet (Mayport; inlet 2), where monitoring also took place from a small boat. For this inlet, an exception to the random selection of time period was permitted in 2013 to accommodate limited availability of the observation boat. If the viewer could not ascertain with the aid of binoculars whether a vessel was a private recreational powerboat, then the vessel was classified as undetermined (<2% of vessels). If a vessel was observed making multiple passes through an inlet, field observers noted this on the data sheet so that only one trip was counted for that vessel on that day.

Access Point Trip Intercept Survey

A list of boating access sites in the vicinity of each inlet from which private recreational boats embark on offshore trips was compiled for the study area. The list included 54 public and privately operated boat ramps, marinas, and dry-dock facilities. Since estimates of fishing pressure specifically for offshore fishing was not known prior to initiating this study, each site was assigned a fishing pressure rating of either high (50+ anglers) or low (<50 anglers) based on the number of private boat anglers (inland and offshore) that are typically encountered during MRIP intercept assignments. A list of all possible site × day combinations was generated, and for each inlet, a fixed number of combinations for high- and low-pressure sites (50% for each type) was randomly selected without replacement. A subset of selected combinations was assigned to field staff located throughout the region, and the remaining combinations were held in reserve and issued when staff were available to work an additional assignment. This method was chosen to ensure that a minimum number of randomized combinations was assigned while also optimizing the use of available staff throughout the region, thus maximizing opportunities to collect data during the short sampling windows. Potential bias due to a disproportionate distribution of intercept samples relative to fishing effort across the region was handled in the estimation methods described below. Once issued, assignments were moved only for circumstances that would otherwise result in cancellation. For example, one assignment was moved to an adjacent site due to construction at the assigned boat ramp, and a few assignments were moved to different days when staff were unavailable.

During a scheduled intercept assignment, field staff arrived at their assigned site at 1000 hours and remained on site until sunset or until the site closed (whichever occurred first); this was done in order to avoid the potential for bias due to varying catch rates for trips returning at different times of day (Su and Clapp 2013). As recreational vessels returned to the site, boat parties were approached to confirm the nature of their trip and the operators were interviewed to determine whether the vessel had exited through the inlet into the Atlantic Ocean. If not, the interview was complete; if so, the operator was also asked whether the party had fished for or caught Red Snapper (regardless of the intended target species). The exit time through the inlet was recorded for all ocean trips, and the following additional information was collected only if the party had fished for Red Snapper: (1) the number of people in the party, (2) the number of people who fished, (3) the number of Red Snapper harvested and the number released by the party, (4) the number of hours spent fishing, (5) the average depth fished (ft), and (6) the minimum and maximum distances from shore (mi) at which fishing took place. If Red Snapper were harvested, the interviewer asked for permission to inspect the fish, recorded the length (mm at the midline) and weight (kg) of each fish, and extracted otoliths. Otoliths were sectioned, aged, and blind-validated by two separate readings in accordance with established procedures (Vanderkooy 2009). If there was disagreement, a third blind reading was also conducted.

Effort Estimation

Three main steps were used to estimate fishing effort for each annual Red Snapper season: (1) the number of recreational boats observed exiting through each inlet during daylight hours was expanded to generate an unadjusted seasonal estimate of trips in the Atlantic Ocean across all inlets, (2) the seasonal estimate of boat trips was multiplied by the proportion of trips that were targeting Red Snapper to estimate the numbers of trips that were fishing, and (3) estimated fishing trips were adjusted to account for additional boats that exited through the inlets before sunrise. The seasonal estimate for the number of boat trips (step 1) was calculated using two methods. The first method used a ratio estimator (Cochran 1977) to expand observations from inlets that were observed only during randomly sampled time periods relative to observations in a corresponding reference inlet (i.e., that was observed across all time periods). The ratio estimator was calculated for the northern and southern reference inlets to yield two separate estimates. The second method has traditionally been used to expand instantaneous counts of fishing effort, such as those from aerial surveys, to an entire fishing period of interest (Pollock et al. 1994). For this application, we used the count of boats exiting a given inlet during each sampled period to generate an expanded estimate for the number of boats exiting through that inlet. The advantage of this method is that it does not require complete daytime coverage at a separate reference inlet over the fishing season. To evaluate how accurately this method estimated the number of boat trips, day × time period combinations were randomly sampled 30 times from each of the two reference inlets and were used to generate repeated estimates, which were then compared to the observed values.

Step 1.—For the ratio estimator ($\hat{R}$), the number of boats observed (y) during each sample i for inlet h was summed and then divided by the number of boats observed in a corresponding reference inlet (x) during the same period,

$$\hat{R}_h = \sum_{i=1}^{n} y_{h,i} \Big/ \sum_{i=1}^{n} x_{h,i}. \quad (1)$$

The total unadjusted number of boats that entered the Atlantic Ocean during the Red Snapper harvest season ($\hat{Y}$) was estimated for each sampled inlet as

$$\hat{Y}_h = \hat{R}_h X, \quad (2)$$

where X is the total number of boats that were observed exiting through a corresponding reference inlet (between 0700 hours and sunset) across all days of the season. Estimated variance for each sampled inlet was calculated via the equation of Cochran (1977),

$$\mathrm{var}(\hat{Y}_h) = \left[N^2(1 - n_h/N)/n_h(n_h - 1)\right] \times \sum_{i=1}^{n} (y_{h,i} - \hat{R}x_{h,i})^2, \quad (3)$$

where N is the total number of daytime periods in the season (e.g., in 2014, N = [8 d] × [3 periods/d]) and n is the number of periods sampled for inlet h. The overall seasonal estimate across all k sample inlets was simply

$$\hat{Y} = \sum_{h=1}^{k} \hat{Y}_h. \quad (4)$$

Based on the assumption that that the error around estimates for each sample inlet was independent and random, variance was propagated by

$$\mathrm{var}(\hat{Y}) = \sqrt{\sum_{h=1}^{k} \mathrm{var}\left(\hat{Y}_h\right)}. \quad (5)$$

For the expansion method, a weighted mean of y_i values for an inlet was used to calculate an expanded estimate for $\hat{Y}_h$. The primary sample weight (P) for period p was calculated as the total number of days in the season divided by the number of days the period was sampled. If an inlet could not be observed for the entire time period sampled (e.g., when boat counts had to be suspended due to lightning), a secondary sample weight (S_i) was calculated as the total minutes in period p divided by the total minutes of observation during that period. The mean weighted number of boats observed per sample period in inlet h was calculated as

$$\bar{y}_h = \frac{\sum_{p=1}^{t}\sum_{i=1}^{n} P_{h,p}S_{h,p,i}y_{h,p,i}}{\sum_{p=1}^{t}\sum_{i=1}^{n} P_{h,p}S_{h,p,i}} \quad (6)$$

for periods 1 to t. Variance was calculated as

$$v(\bar{y}_h) = \frac{\sum_{p=1}^{t}\sum_{i=1}^{n} P_{h,p}S_{h,p,i}\left(y_{h,p,i} - \bar{y}_{h,p}\right)^2}{\sum_{p=1}^{t}\sum_{i=1}^{n} P_{h,p}S_{h,p,i}}. \quad (7)$$

To estimate the total number of boats that exited through an inlet sampled during a given season, the weighted mean for the sample inlet was multiplied by the total number of sampling periods (N) in the season, calculated as

$$\hat{Y}_h = \bar{y}_h N. \tag{8}$$

Since N was known, variance was calculated by

$$\mathrm{var}(\hat{Y}_h) = \mathrm{var}(\bar{y}_h)N. \tag{9}$$

Step 2.— To estimate the proportion of trips targeting Red Snapper, the seasonal estimated number of boats that made a trip into the Atlantic Ocean was adjusted using additional information collected during the access point trip intercept survey. Following Cochran's (1977) methods for estimating proportions and totals over subpopulations, the proportion of intercepted trips that targeted Red Snapper was calculated for each inlet by

$$p_h = \frac{t_h}{n_h}, \tag{10}$$

where t_h is the number of boats intercepted at access points adjacent to a given inlet h with at least one angler in the group who reportedly caught or tried to catch Red Snapper in the Atlantic Ocean, and n_h is the total number of intercepted boats that reportedly entered the Atlantic Ocean. Since $\hat{Y}_h$ does not account for trips that entered the Atlantic Ocean before sunrise (that occurs in step 3), only boat intercepts that reported exiting an inlet at 0700 hours or later were included in the calculation for equation (10). An unbiased estimate of variance was derived from the sample as

$$\mathrm{var}(p_h) = \frac{\hat{Y}_h - n_h}{(n_h - 1)\hat{Y}_h} p_h(1 - p_h). \tag{11}$$

The total number of targeted trips was then estimated by

$$\hat{T}_h = \hat{Y}_h \times p_h, \tag{12}$$

with error propagated for sample inlets (where $\hat{Y}_h$ is estimated) as follows:

$$\sigma(\hat{T}_h) = \hat{T}_h \sqrt{\left[\frac{\sigma(\hat{Y}_h)}{\hat{Y}_h}\right]^2 + \left[\frac{\sigma(p_h)}{p_h}\right]^2}. \tag{13}$$

For reference inlets, where Y_h was observed, the total number of angler trips was estimated by

$$\sigma(\hat{T}_h) = Y_h \sigma(p_h). \tag{14}$$

Step 3.— To adjust the estimated number of targeted trips for boats that departed before sunrise, the proportion given by equation (10) was recalculated by using (1) the number of intercepted trips that targeted Red Snapper and reported exiting through an inlet at 0700 hours or later as the numerator and (2) the total number of intercepted trips that targeted Red Snapper as the denominator. The estimated number of targeted Red Snapper trips was then adjusted,

$$\hat{T}_{h,\mathrm{adj}} = \hat{T}_h / p_h, \tag{15}$$

with error propagated as

$$\sigma(\hat{T}_{h,\mathrm{adj}}) = \hat{T}_{h,\mathrm{adj}} \sqrt{\left[\frac{\sigma(\hat{T}_h)}{\hat{T}_h}\right]^2 + \left[\frac{\sigma(p_h)}{p_h}\right]^2}. \tag{16}$$

Catch Estimation

The numbers of harvested and released Red Snapper that were reported from targeted trip interviews during the access point trip intercept survey were used to estimate the total harvest and discards. For each inlet, the number of Red Snapper caught per angler in targeted trip interviews was calculated as

$$\hat{c}_h = \frac{\sum_{i=1}^{n} f_{h,i}}{\sum_{i=1}^{n} a_{h,i}}, \tag{17}$$

where $f_{h,i}$ is the number of Red Snapper that were either retained (for harvest estimates) or released (for discard estimates) by all anglers on the boat as reported during trip interview i; and $a_{h,i}$ is the number of anglers in each interviewed party. Catch per unit effort was calculated at the angler level to account for variance in catch (partly due to the bag limit of one fish per person) among boats with varying numbers of anglers (Lockwood 1997). Variance was estimated as

$$\mathrm{var}(\hat{c}_h) = \left[\frac{1}{\sqrt{t_h a_h}} \sqrt{\frac{\sum_{i=1}^{n} f_{h,i}^2 - 2\hat{R}_h\left(\sum_{i=1}^{n} f_{h,i} a_{h,i}\right) + \hat{R}_h^2\left(\sum_{i=1}^{n} a_{h,i}^2\right)}{t_h - 1}}\right]^2, \tag{18}$$

where t_h is the total number of intercepted boat parties that were targeting Red Snapper. The number of anglers in each intercepted boat party was calculated as

$$\hat{e}_h = \frac{\sum_{i=1}^{n} a_{h,i}}{t_h} \tag{19}$$

and variance for party size was given by

$$\operatorname{var}(\hat{e}_h) = \frac{\sum_{i=1}^{n} a_{h,i}^2 - \left[\left(\sum_{i=1}^{n} a_{h,i}\right)^2 / t_h\right]}{t_h(t_h - 1)}. \quad (20)$$

To estimate total catch, the estimated number of boat parties that targeted Red Snapper was converted to angler trips,

$$\hat{E}_h = \hat{T}_{h,\mathrm{adj}} \hat{e}_h, \quad (21)$$

and variance was estimated via the methods described by Goodman (1960):

$$\operatorname{var}(\hat{E}_h) = \hat{T}_{h,\mathrm{adj}}^2 \operatorname{var}(\hat{e}_h) + \hat{e}_h^2 \operatorname{var}(\hat{T}_{h,\mathrm{adj}}) - \operatorname{var}(\hat{e}_h)\operatorname{var}(\hat{T}_{h,\mathrm{adj}}). \quad (22)$$

Last, total catch across the nine inlets was estimated by

$$\hat{C} = \sum_{h=1}^{9} \hat{E}_h \hat{c}_h, \quad (23)$$

with variance calculated as

$$\operatorname{var}(\hat{C}) = \sum_{h=1}^{9} \left[\hat{E}_h^2 \operatorname{var}(\hat{c}_h) + \hat{c}_h^2 \operatorname{var}(\hat{E}_h) - \operatorname{var}(\hat{E}_h)\operatorname{var}(\hat{c}_h)\right]. \quad (24)$$

RESULTS

For boat parties intercepted in the access point survey that took a trip into the Atlantic Ocean, the overall percentage that recreationally fished for Red Snapper ranged from 53% to 89% over the three seasons (Table 1). Among boat parties that were targeting Red Snapper, 49–67% reported exiting through an inlet during daylight hours, and estimated effort was adjusted upward to account for trips that departed before sunrise (Table 1). When the ratio estimator method was used to calculate the numbers of boat trips across all inlets, point estimates did not vary significantly with the choice of reference inlet, and this result was consistent across all years (Table 1; Figure 2). A paired t-test was used to compare the total estimated number of boat trips within years by using the two separate reference inlets, and the mean difference was not significant (mean difference = −77.7 trips, df = 2, t = −0.32, P = 0.777). Therefore, time of day appeared to be a reliable predictor of boat activity independent of the inlet to which estimates were referenced. Estimates of effort during the 2 years for which the expansion method could be used (discussed below) yielded results that were similar to those of the ratio estimator method (Figure 3). When a paired t-test was used to compare estimates within years from the two methods, the differences were not significant (mean difference = −194.5, df = 3, t = −1.67, P = 0.194).

To ground-truth the estimated number of boat trips, time periods were randomly sampled for reference inlets to produce estimates that could be compared with observed values. Due to the survey design employed during the first year of the study, the expansion method could not be used to estimate effort for the 2012 season. During 2012, inlets were sampled only on 3 of the 6 d; additionally, because the season was not open until later in the year (September), daily fishing activity was highly dependent upon offshore weather conditions. If a sampled time period was selected disproportionately on days during which almost no boats were observed due to unfavorable offshore conditions, then the expansion resulted in an underestimate. On the other hand, effort was overestimated if a period was sampled more frequently during days with favorable offshore conditions. During 2013 and 2014, the sampling frequency was increased to include one period each day in each inlet. Under this sample design, the expansion method yielded estimates that fluctuated within close range of observed values and were unbiased, with approximately equal numbers of points falling above and below the observed values (Figure 4).

From 364 to 1,371 private recreational boat parties that targeted Red Snapper were intercepted during access point surveys each season, and 620–2,686 harvested Red Snapper

TABLE 1. Total number of private recreational fishing boat trips targeting Red Snapper off the Atlantic coast of Florida, estimated either by comparison to a reference inlet or by expansion (no reference inlet).

Season	Reference inlet	Boat trips intercepted	Proportion targeting Red Snapper (±SE)	Proportion that departed before sunrise (±SE)	Targeted trips (±SE)
Sep 2012	St. Augustine	508	0.882 ± 0.031	0.660 ± 0.053	6,492 ± 517
	Sebastian Inlet		0.892 ± 0.027	0.665 ± 0.046	6,157 ± 422
Aug 2013	St. Augustine	803	0.648 ± 0.017	0.571 ± 0.133	3,854 ± 690
	Fort Pierce Inlet		0.684 ± 0.017	0.597 ± 0.044	3,926 ± 223
	None		0.698 ± 0.017	0.598 ± 0.053	4,181 ± 289
Jul 2014	St. Augustine	2,303	0.541 ± 0.011	0.504 ± 0.054	10,455 ± 844
	Fort Pierce Inlet		0.535 ± 0.011	0.500 ± 0.048	10,951 ± 750
	None		0.534 ± 0.011	0.494 ± 0.052	10,801 ± 902

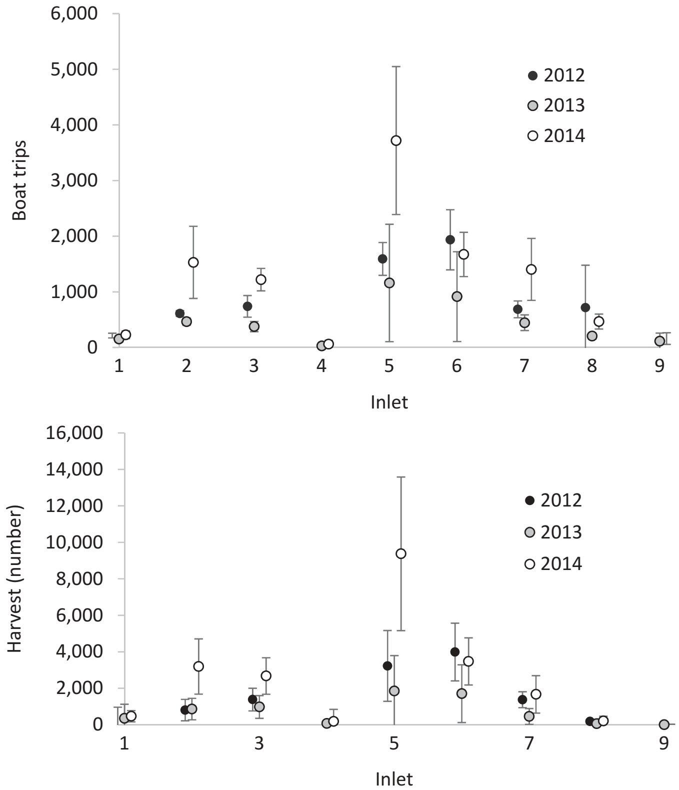

FIGURE 2. Total targeted effort (upper panel) and harvest (lower panel) of Red Snapper by private recreational fishing boats at each monitored inlet, as estimated using the ratio estimator method and the northern reference inlet (see Methods; inlet numbers are defined in Figure 1). Error bars represent 95% confidence intervals.

were observed during interviews. Fishing effort and landings were highest between Ponce Inlet and Cape Canaveral, whereas Red Snapper were less frequently harvested south of Cape Canaveral (Figure 2). Harvest of Red Snapper was virtually absent south of Fort Pierce Inlet. Over three seasons, only one Red Snapper was intercepted from a boat that departed through St. Lucie Inlet (the southernmost inlet in this study), and that party reportedly traveled north and fished offshore of Fort Pierce. More than 90% of aged Red Snapper were less than 10 years old, and the age distribution varied across the reported average depths fished. Just over half (54%) of fish sampled during 2013 and 2014 were from trips that took place in shallow depths (average depth fished < 29 m), and 44% were from trips fishing mid-level depths (29.0–48.9-m). Trips that took place in deeper waters (average depth fished ≥ 49 m) were not frequently intercepted, and only 34 out of 2,080 harvested Red Snapper that were sampled came from these trips. Approximately half (53%) of the Red Snapper caught during trips fishing shallow depths were younger than age 6, compared with 33% of those caught from mid-level depths and 32% of those caught from deep waters (Figure 5). Average depth fished was not recorded in 2012; therefore, depth-dependent age distributions could not be reported for that year.

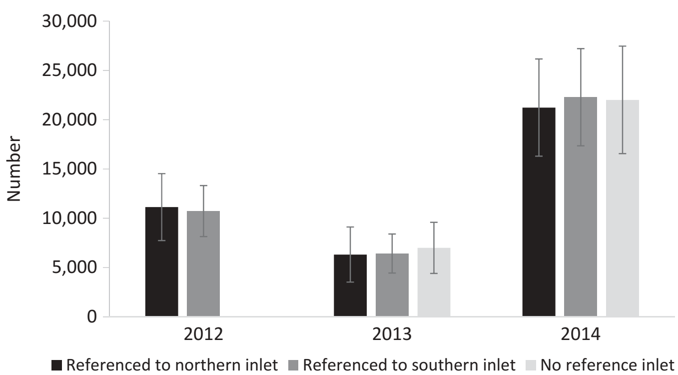

FIGURE 3. Estimated numbers of Red Snapper harvested by private recreational fishing boats off the Atlantic coast of Florida during each season.

Effort and harvest estimates varied with season length; the lowest levels were calculated for the 3-d season in 2013, and the highest values were obtained for the 8-d season in 2014 (Table 2; Figure 3). Harvest estimates generated from the present survey were more precise than those obtained via the MRIP survey of private recreational boat anglers fishing from the Atlantic coast of Florida (for the 2-month sample wave in which the annual Red Snapper season occurred; Figure 6). High uncertainty around MRIP estimates was likely due in part to the low number of assignments that fell on days when the Red Snapper harvest season was open, which resulted in low numbers of Red Snapper anglers intercepted during two out of the three sample waves. During the 6-d season in 2012, only three anglers (from a single boat party) that caught Red Snapper were interviewed during the MRIP survey in Florida. In 2013, the MRIP survey intercepted nine private boat anglers who caught Red Snapper during the harvest season, which likely contributed to the higher harvest estimate for that year than in 2012, even though the 2013 season was open for only 3 d. The largest number of Red Snapper anglers (n = 53) was intercepted by the MRIP survey during the 8-d season in 2014; however, the bimonthly harvest estimate was still imprecise (Figure 6).

DISCUSSION

The goal of this study was to develop and test new survey and estimation methods that may be employed to precisely monitor landings from a high-effort recreational fishery over an abbreviated harvest season. The primary benefit of using complementary on-site methods to estimate effort and catch is increased precision (Pollock et al. 1994), particularly for high-effort fisheries over short temporal scales (Essig and Holliday 1991). A review of programs developed over 20 years to monitor recreational fisheries across varied spatial scales in Australia and New Zealand found that off-site methods (e.g.,

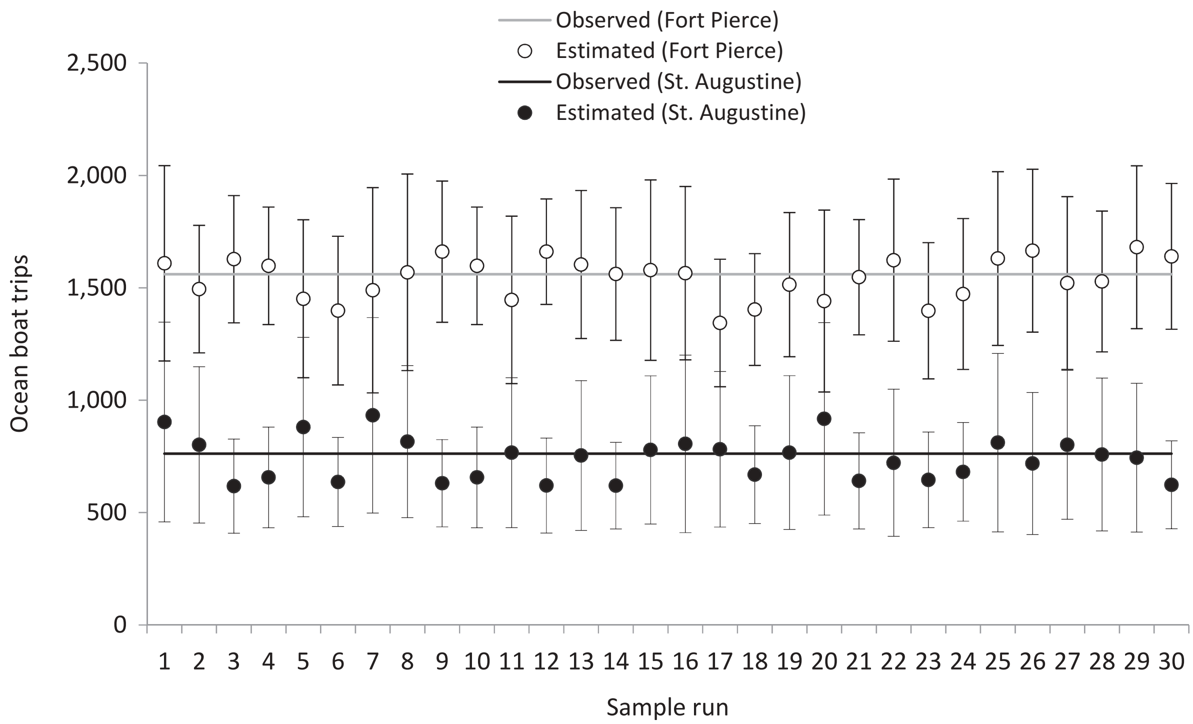

FIGURE 4. Observed (solid lines) and predicted (point estimates ± 95% confidence intervals) numbers of private recreational fishing boats exiting into the Atlantic Ocean during the 2014 Red Snapper harvest season, as calculated using the expansion method for random subsamples within each reference inlet (St. Augustine and Fort Pierce Inlet).

telephone or mail surveys) were more cost effective for large scales; however, at smaller scales (up to 1,000 km of coastline), on-site methods are affordable and generally preferred since they allow for direct observations from a fishery (Hartill et al. 2012).

The state of Oregon uses complementary on-site survey methods to conduct weekly monitoring of recreational salmon harvest from private boats in the Pacific Ocean. The Oregon Recreational Boat Survey design is similar to the present survey design in that (1) it uses boat exit counts from major ports to estimate fishing effort and (2) CPUE is estimated independently by use of a dockside intercept survey (NRC 2006). The statistical design of the Oregon Recreational Boat Survey was externally reviewed in 2012 and among the positive features identified were the fine spatial and temporal stratification and the use of geographic choke points to directly measure effort (Breidt and Opsomer 2010). Recommended improvements included the development of an appropriate weighting factor for calculating CPUE, and the reviewers suggested that the direct measure of fishing effort could be used for this purpose. In our study, proportional effort through each inlet was used as a weighting factor for calculating CPUE. This method allowed us to maximize productivity during the short sampling window by allowing staff to issue reserve assignments where manpower was available and by adjusting for uneven sampling effort after data were collected. Survey designs in which scheduled assignments are preselected with known probabilities are less flexible.

Resources for implementing additional fishery-dependent monitoring programs are extremely limited in the South Atlantic region, and the development of cost-effective methods was an important objective for this study. An essential first step was verifying the assumption that vessel activity through a single inlet was a reliable predictor of effort across the larger

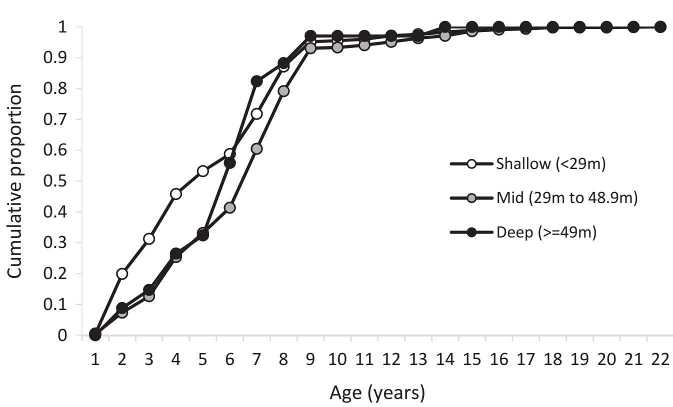

FIGURE 5. Cumulative proportion of aged Red Snapper that were caught during private recreational boat trips that took place in shallow (n = 1,120 fish), mid-level (n = 926 fish), and deep (n = 34 fish) average fishing depths.

TABLE 2. Total Red Snapper harvest and discards (number of fish) estimated for private recreational boats fishing off the Atlantic coast of Florida (CV = coefficient of variation).

Season	Reference inlet	Estimated harvest (±SE)	CV of harvest	Estimated discards (±SE)	CV of discards
Sep 2012	St. Augustine	11,136 ± 1,734	0.156	17,587 ± 9,031	0.513
	Sebastian Inlet	10,729 ± 1,629	0.152	17,033 ± 8,219	0.483
Aug 2013	St. Augustine	6,320 ± 1,426	0.226	4,567 ± 1,476	0.323
	Fort Pierce Inlet	6,428 ± 1,011	0.157	4,802 ± 1,453	0.303
	None	6,999 ± 1,321	0.189	5,033 ± 1,512	0.300
Jul 2014	St. Augustine	21,234 ± 2,517	0.119	9,658 ± 1,657	0.172
	Fort Pierce Inlet	22,282 ± 2,407	0.108	9,996 ± 1,724	0.173
	None	22,013 ± 2,782	0.126	9,755 ± 1,741	0.178

geographic area. Estimates of fishing effort did not differ with the choice of reference inlet used, and the more traditional method—in which instantaneous count data for an observed area were used to expand effort across a larger area—also produced similar results. Therefore, either method is acceptable. The expansion method, however, required high sample coverage across all egress points to account for variable boating conditions offshore, which influenced daily effort. The expansion method is more cost effective and acceptable when daily variability can be averaged over an extended fishing season, but to accurately estimate effort across a season constituting only 3–8 d, it is essential to account for short-term variability. For short seasons, the alternative ratio estimator method allows daily fluctuations in effort to be measured at a single reference inlet and accounted for, while sample coverage at the remaining egress points can be adjusted to balance costs with desired precision.

Little information exists on fishery interactions for Red Snapper in the South Atlantic region (Rindone et al. 2015), and this study serves as an important contribution of knowledge and provides new insight into a fishery that has experienced a rapid transition from year-round harvest to seasonal pulsed harvest with regulatory discarding during the remainder of the year. Catch estimates from the MRIP survey are generally precise on an annual scale, whereas within-year estimates on a bimonthly scale are not as robust. Our specialized survey demonstrates that precise estimates of Red Snapper harvest can be obtained for the high-effort private boat recreational fishery in the region, and information collected through this survey proved to be an important supplement to the large-scale, general MRIP survey. Due to the larger sample sizes and the precision of estimates achieved by our survey, Red Snapper harvest estimates were used by NMFS to account for recreational harvest during each of the three seasons, while the MRIP survey continued to provide year-round estimates of the out-of-season harvest, which is occasionally observed, and year-round estimates of regulatory discards (NMFS SEFSC 2013, 2014; SEDAR 2014). Discard mortality is depth dependent and ranges as high as 40% for Red Snapper released from the recreational hook-and-line fishery (Campbell et al. 2014), and a percentage must be applied to discards to account for the total removals that count toward the annual catch limit. Therefore, it is important that the MRIP survey is conducted simultaneously along with a specialized survey such as this to monitor Red Snapper discards and harvest out of season, which may occur year round, and obtain precise estimates for the large harvest that occurs during the pulsed open seasons.

Increased precision of recreational harvest estimates did not necessarily equate to less-restrictive regulations. During the first season (2012), our point estimate was more precise and higher than that generated from the MRIP survey, and a shorter season was adopted the next year. However, the MRIP point estimate for harvest in 2013 was substantially higher and less precise than ours, and sole reliance on the MRIP estimate would likely have triggered accountability measures to make up for the potential overage, such as implementing a full-year closure of the fishery

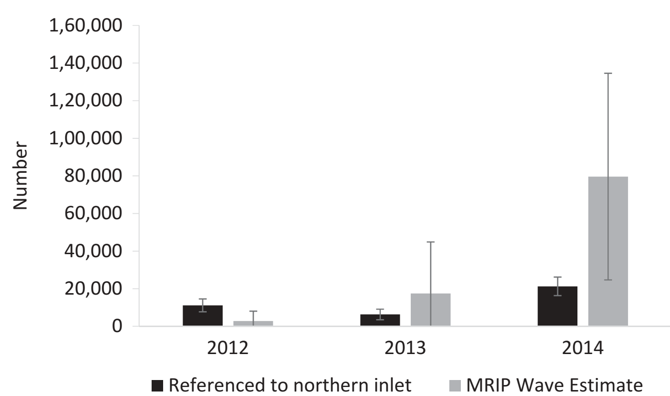

FIGURE 6. Estimates of Red Snapper harvest (number of fish) during each season based on the present study results (referenced to the northern inlet) and based on the Marine Recreational Information Program (MRIP) survey conducted during the 2-month sample wave in which the Red Snapper harvest season occurred.

in 2014. In contrast, our 2013 estimate was almost half that obtained for 2012. Point estimates for both surveys peaked during 2014, when the season was lengthened to 8 d. By combining precise harvest estimates during the pulsed fishing season (present study) with year-round estimates for discards and out-of-season harvest (MRIP survey), fishery managers were able to make well-informed decisions each year regarding whether a harvest season could be allowed and, if so, the number of days for which the season should be open.

This study also revealed important spatial patterns in the private boat segment of the recreational fishery off Florida's Atlantic coast that might not have been apparent in a general survey. Effort observed through ocean inlets was highly variable among days and was dependent upon whether offshore conditions were favorable to recreational boating. Effort was centered between Ponce Inlet and Cape Canaveral, and the majority of Red Snapper were harvested by boats fishing shallow depths (<29 m). Fish caught from shallow depths were approximately equally distributed among younger (1–5 years) and older age-classes. However, as fishing moved into mid-level depths and deep waters, a greater proportion of Red Snapper were older than 5 years. This finding deviates from the results of a fishery-independent trap survey conducted off Georgia and northeastern Florida, which found that younger Red Snapper were disproportionately more abundant in shallow depths and older fish were more equally distributed across depths (Mitchell et al. 2014). Therefore, selectivity in the Red Snapper fishery may be influenced by confounding factors that interact with the depth-dependent distribution of the fish. For example, anglers reported anecdotally that stronger-test line was used when fishing in greater depths, which could have increased their ability to land large fish. Anglers may also reach the harvest limit of one Red Snapper per person before an older fish is encountered, and this could occur more often in shallow depths if younger fish are disproportionately more abundant. Assumptions surrounding the selectivity of Red Snapper fisheries in southeastern U.S. Atlantic waters and the Gulf of Mexico are a subject of much debate (Cowan 2011), and we recommend further research focusing on the mechanisms that influence the size and age distributions of Red Snapper removed by the recreational hook-and-line fishery. In conclusion, we have demonstrated the utility of supplementing large-scale surveys of recreational fisheries with more specialized surveys to improve the spatial and temporal resolution of information that is available for use in management decisions and in stock assessments.

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