American Fisheries Society Symposium 86:265–277, 2018

Methods to Quantify Recreational Angling Effort on Artificial Reefs off Florida's Gulf of Mexico Coast

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Abstract.—Florida boasts an abundance of natural and artificial reefs that support a large and diverse recreational fishery off the Gulf of Mexico coast. Recent efforts to mitigate the effects of the *Deepwater Horizon* oil spill have increased the number of artificial reefs deployed off Florida's Gulf Coast. Fisheries-dependent data are needed to assess whether artificial reef programs are meeting intended objectives and to understand changes in recreational angler behavior, which may influence catch per unit effort and biomass of landed fish. The objective of this study was to quantify the use of artificial reefs by recreational anglers targeting reef fishes in the Gulf of Mexico off the west coast of Florida. We utilized an existing survey designed to monitor recreational fishing effort by anglers that target reef fishes from private boats. Over a 20-month period, an estimated total of 776,026 (SD ±27,540) angler trips targeted reef fishes off the Gulf Coast of Florida, of which 46% utilized artificial reefs. Approximately two-thirds of all reef angling trips took place nearshore in state-managed waters, and 70% of trips that utilized artificial reefs occurred in this area. Regionally, the highest proportion of angler trips targeting reef-associated species on artificial reefs took place in the panhandle of Florida, where Red Snapper *Lutjanus campechanus* are most abundant. Seasonally, state and federal fishing regulations also had an apparent influence on fishing effort and artificial reef use by recreational anglers. The method of assessment we present here could be useful for monitoring future trends in recreational fishing effort with respect to artificial reefs.

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Introduction

Florida's mix of natural and artificial reef fish habitats along the coastal Gulf of Mexico provides for a diverse recreational reef fish fishery. Off the northwest panhandle of Florida (i.e., northern Gulf of Mexico), recreational anglers have nearshore access to deepwater reef habitat where Red Snapper *Lutjanus campechanus*, Vermilion Snapper *Rhomboplites aurorubens*, and Gray Triggerfish *Balistes capriscus* are abundant (Strelcheck et al. 2007; Saul et al. 2013). East of the panhandle (i.e., the Big Bend region), Gag *Mycteroperca microlepis* and Red Grouper *Epinephelus morio* are more abundant; however, Red Snapper abundance is increasing as the overfished stock continues to rebuild in the eastern Gulf of Mexico (Saul et al. 2013). In the Big Bend region, the nearshore area is dominated by expansive sea grass beds while reef habitats are further offshore and less accessible to recreational anglers (Coleman et al. 1996; Koenig et al. 2000; Switzer et al. 2012). Further south, the broad slope of the west Florida shelf is characterized by low-relief, natural hard-bottom habitats that support abundant grouper populations. The nearshore recreational fishery frequently targets grouper species in shallow water, but anglers must travel farther distances to access depths where Greater Amberjack *Seriola dumerili* and Red Snapper may also be caught.

Artificial reefs have been used to enhance stocks of marine fisheries, thus providing increased opportunities for the recreational angler. Various reef-associated fishes are attracted to high-relief structure (e.g., artificial reefs) that may be easily located with electronic fish finders and GPS coordinates and repeatedly targeted by recreational anglers. Generally, increased abundance of reef fishes on artificial reefs improves catch per unit effort (CPUE) and thus enhances recreational fishing for reef fishes (Grossman et al. 1997; Karnauskas et al. 2017). However, habitat preferences and life history strategies differ among species. Red Snapper and Gray Triggerfish exhibit an affinity for artificial reef structure with high site fidelity (Strelcheck et al. 2007), whereas pelagic amberjacks *Seriola* spp. are more transient (Dance et al. 2011). In contrast, groupers associate more with natural hard bottom. Red grouper have a high affinity for low relief limestone karst, and Gag are associated with small patches of hard bottom and rocky ridges (Lindberg et al. 2006; Coleman et al. 2010; Wall et al. 2011).

The establishment of artificial reefs in Florida began in the mid-1930s. The first permit was issued in 1936 by the U.S. Army Corps of Engineers (Seaman 1982), and the Florida Fish and Wildlife Conservation Commission's (FWC) Artificial Reef Program was initiated in 1982. Currently, FWC reports more than 2,200 artificial reef deployments in Florida's Gulf waters, including 1,222 within the boundaries of the state's fishery management jurisdiction (up to 9 nautical miles [16.7 km] from shore off the Gulf of Mexico coast) and 980 reefs in the exclusive economic zone. Artificial reefs are concentrated in the northwest panhandle region (Figure 1), where mitigation from potential environmental damage related to the *Deepwater Horizon* oil spill has increased deployment efforts. Artificial reefs are less concentrated in the Big Bend region, especially in state waters, and are widely dispersed off the southwest peninsula (Figure 1).

Understanding the human use of artificial reefs is required to measure both the economic and ecological success of an artificial reef program. In the past, perceived benefits have been assumed. However, there is an emerging need for studies that quantify

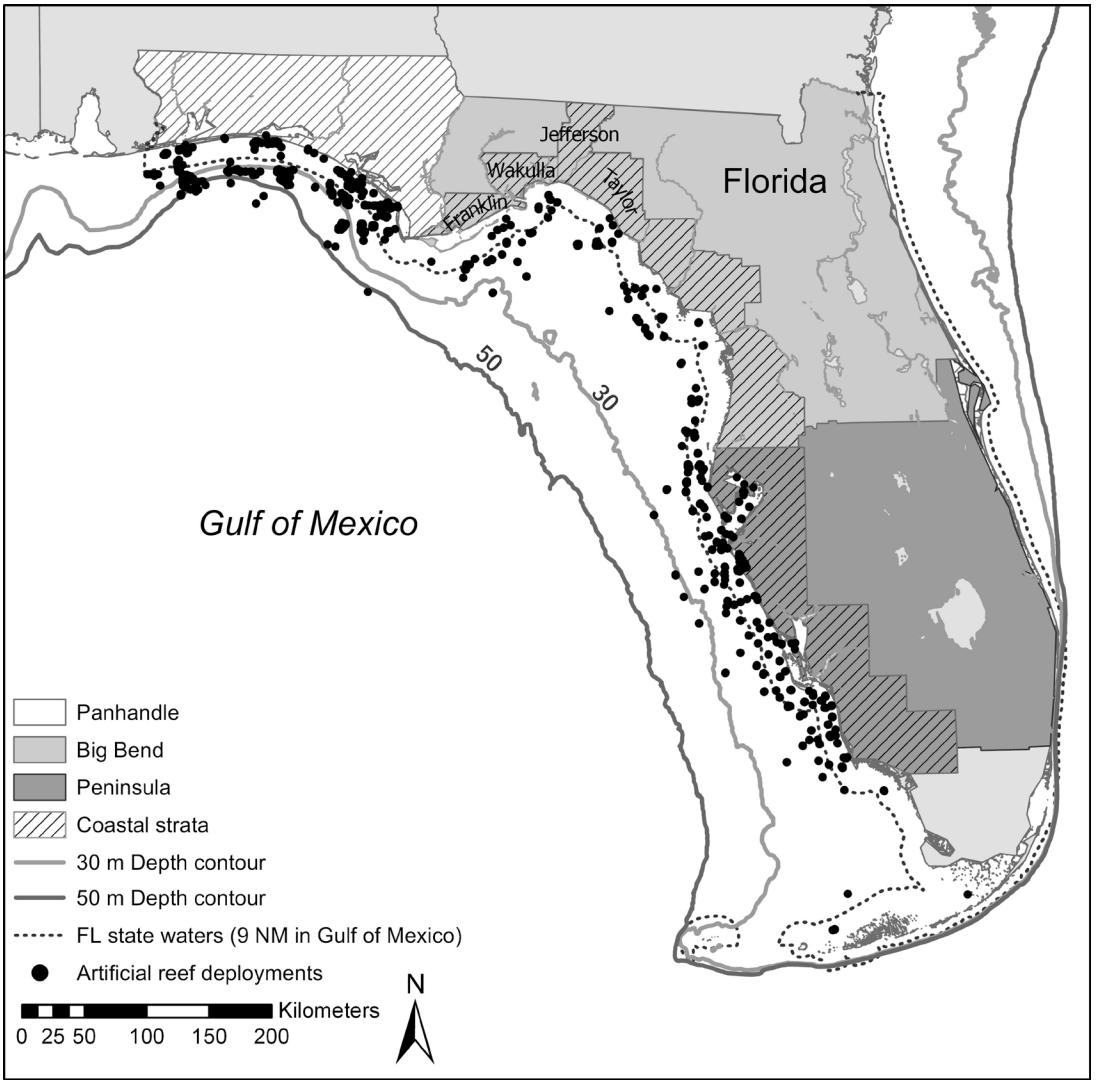

Figure 1. Filled circles represent artificial reef locations off Florida's Gulf Coast. State residents subscribed to the Gulf Reef Fish Survey were partitioned by region and subregion (coastal and noncoastal counties) prior to stratified random sampling for the mail survey. For each trip, respondents were asked to report whether fishing took place adjacent to the panhandle (white), Big Bend (medium gray), or peninsula (dark gray) regions. Hatched areas represent coastal counties adjacent to the Gulf of Mexico. Franklin, Wakulla, Jefferson, and Taylor counties in the Big Bend region have special regulations for Gag.

how well artificial reefs are meeting intended marine fisheries management objectives and evaluate whether the costs associated with implementing artificial reef programs are returned through economic benefits. Fisheries independent studies have evaluated fish distribution and production on artificial reefs (Grossman et al. 1997; Powers et al. 2003; Strelcheck et al. 2007; Dance et al. 2011; Addis et al. 2013; Karnauskas et al. 2017), and others still have assessed recreational vessel visitation rates at artificial reefs for use in

economic and ecological valuation of artificial reefs (Adams et al. 2006; Tinsman and Whitmore 2006; Huth et al. 2014; Simard et al. 2016). Monitoring the recreational fishing component of an artificial reef program is also important in gaining an understanding of how large-scale projects influence fishing behavior, change CPUE, and potentially alter the average size of fish caught. Additionally, investigations of recreational fishing on artificial reefs may explain trends in overall landings of various reef fish species, both in number and in biomass. To date, we are unaware of a study that has reported recreational fishing effort on artificial reefs.

To assess the value and success of Florida's artificial reef program, it is necessary to quantify human use of artificial reefs deployed off Florida's Gulf Coast. The objective of this study was to quantify artificial reef use by recreational anglers targeting reef fishes in the Gulf of Mexico off the west coast of Florida. Here, we took advantage of an existing survey designed to monitor recreational fishing effort for reef fishes off the west coast of Florida. The Gulf Reef Fish Survey was initiated by the state of Florida in 2015 to improve the timeliness and precision of recreational catch-and-effort statistics for a suite of reef fish species commonly targeted by anglers. The survey methodology utilizes an established database of saltwater anglers that participate in the fishery. In 2016, new questions were added to the questionnaire for the effort portion of the survey to quantify the portion of recreational fishing trips that take advantage of artificial reefs.

Methods

Gulf Reef Fish Survey

The Gulf Reef Fish Survey provides a directory of private boat anglers who fish for reef fishes in the Gulf of Mexico. Anglers, 16 years of age and older, fishing from private recreational boats off the west coast of Florida (excluding Monroe County) are required to register for the Gulf Reef Fish Survey to legally harvest 10 species in the reef fish complex that includes Vermilion Snapper, Gray Triggerfish, Gag, Red Grouper, Black Grouper *Mycteroperca bonaci*, and amberjacks, including Greater Amberjack, Lesser Amberjack *Seriola fasciata*, Almaco Jack *S. rivoliana*, and Banded Rudderfish *S. zonata*. Applicable state saltwater fishing license requirements and state and/or federal size and bag limits and harvest seasons also apply. Anglers are subscribed to the Gulf Reef Fish Survey during the purchase or renewal of a state of Florida saltwater fishing license for no additional fee, or as a separate and free transaction if no license was purchased. During a transaction through the state fishing license system, anglers are required to provide a driver's license number or other acceptable form of identification, which is used to confirm residency status (in state or out of state) and automatically populate the database with the current mailing address for individuals.

Each month, anglers with a current subscription to the Gulf Reef Fish Survey were randomly selected to receive a mail survey. Prior to sample selection, anglers were partitioned into 14 separate survey groups based on their residence and whether the address could be matched with a recreational boat registered in the state of Florida (Table 1). A sample of 10% or 500, whichever was less, was selected from each survey group. This stratified random sample design was developed to account for potential differences in response rates among anglers with different fishing avidities. For example, anglers that live near the Gulf Coast and have direct access to a registered boat may be more likely to participate in the reef fish fishery in the

Table 1. Mail survey strata, defined by residence of Gulf Reef Fish Survey subscribers. Regions and subregions for Florida residents (strata 1–12) are depicted in Figure 1.

Stratum	Region	Subregion	Boat registration
1	Florida NW panhandle	Coastal	No
2	Florida NW panhandle	Coastal	Yes
3	Florida Big Bend	Noncoastal	No
4	Florida Big Bend	Noncoastal	Yes
5	Florida Big Bend	Coastal	No
6	Florida SW peninsula	Coastal	Yes
7	Florida SW peninsula	Noncoastal	No
8	Florida SW peninsula	Noncoastal	Yes
9	Florida SW peninsula	Coastal	No
10	Florida SW peninsula	Coastal	Yes
11	Keys and SE Florida	Noncoastal	No
12	Keys and SE Florida	Noncoastal	Yes
13	Alabama and Georgia	Noncoastal	–
14	Other states	Noncoastal	–

Gulf of Mexico and may also show a higher propensity to respond to the voluntary survey (avidity bias). Stratification also accounts for regional variability (Figure 1). For example, fishing effort may vary regionally in response to seasonal openings and closures for different species that are abundant, such as Red Snapper in northern regions and Gag in southern regions. By surveying groups of anglers with different participation rates separately, survey responses may be weighted to account for potential bias associated with varied response rates.

Included in the packet mailed to selected anglers was a cover letter explaining the purpose for the survey, the questionnaire with a map to assist in reporting the general region where each trip took place, a full-color guide with pictures for each Gulf reef fish species to aid in positive identification, and a postage-paid return envelope. One week after the survey packets were mailed, a reminder postcard was sent to all selected anglers to prompt a timely response, and 2 weeks later, a second questionnaire was mailed to anglers that had not yet returned the first survey. Response to the mail survey was voluntary.

The survey questionnaire prompted anglers to recall their fishing activity over the previous month and provide specific details for up to 12 trips. For each trip, the angler was asked to report the region fished (Figure 1), the percent of time (if any) spent fishing within the state of Florida's jurisdictional boundary (defined as ≤9 nautical miles off the Gulf Coast), and the types of fish that the angler kept, released, or tried to catch (selected from a list provided). A reported trip was counted as a Gulf reef fish trip if one or more of the required species was selected.

In May 2016, additional questions were added to the Gulf Reef Fish Survey questionnaire to quantify artificial reef use during recreational fishing. One question asked whether the angler ever fishes recreationally on artificial reefs, and for each fishing trip reported for the survey month, respondents were also asked to record whether they fished on an artificial reef.

Effort Estimation

Survey responses were used to generate monthly estimates of the total number of Gulf reef fish trips taken by registered participants during a given month, as well as the number of those fishing trips that used artificial reefs, using the methods for stratified random sampling described by Kish (1965). The sample weight for individuals selected to receive a survey from a given stratum (h) was calculated as

$$W_h = \frac{N_h}{n_h},$$

where N_h is the total number of registered Gulf reef fish anglers in the angler population stratum, and n_h is the number of anglers selected from the stratum to receive the mail survey. To account for anglers that did not return the completed questionnaire, the survey response rate in each stratum was calculated as

$$R_h = \frac{\sum_{i=1}^{n_h} W_h r_{h,i}}{\sum_{i=1}^{n_h} W_h},$$

where r_i is the binomial variable indicating whether selected individual i responded to the survey (1 = yes, 0 = no).

The mean number of Gulf reef fish trips per response in each stratum was calculated as

$$\bar{y}_h = \frac{\sum_{i=1}^{n} y_{h,i}}{n_h},$$

where $y_{h,i}$ is the number of Gulf reef fish trips reported in state or federal waters by the ith respondent in stratum h and n_h is the number of people in stratum h that responded to the survey. This value was also calculated separately, including only reported trips where the respondent indicated that an artificial reef was utilized. Variance was calculated as

$$\mathrm{var}\left(\bar{y}_h\right) = \frac{\sum_{i=1}^{n}\left(y_{h,i} - \bar{y}_h\right)^2}{n_h - 1}.$$

The overall mean weighted number of trips per response across all 14 strata was calculated as

$$\bar{y} = \sum_{h=1}^{14} W_h \frac{1}{R_h}\bar{y}_h.$$

And overall variance was calculated as

$$\mathrm{var}\left(\bar{y}\right) = \sum_{h=1}^{14}\left(W_h \frac{1}{R_h}\right)^2 \mathrm{var}\left(\bar{y}_h\right).$$

The total number of trips taken by all anglers registered for the Gulf Reef Fish Survey during a given month was calculated as

$$\hat{Y} = N\,\bar{y},$$

where N is the total number of Gulf reef fish anglers that were registered during the survey month. Variance is calculated as

$$\mathrm{var}(\hat{Y}) = N^2 \mathrm{var}\left(\bar{y}\right).$$

Results

Each month, an average of 6,304 individuals were selected to receive an effort survey questionnaire in the mail, and the percentage that returned the survey ranged from 14.1% to 23.4% (Table 2). Between May 2016 and December 2017, anglers subscribed to the Gulf Reef Fish Survey took an estimated 776,026

Table 2. Total numbers of individuals registered for the Gulf Reef Fish Survey, sample sizes, and numbers of response rates by survey month and year.

Year	Survey month	Number registered	Sample Sample size	Number of responses	Raw response rate (%)	Weighted response rate (%)
2016	May	402,161	6,212	1,171	18.9	18.5
	June	412,084	6,184	1,120	18.1	19.2
	July	431,712	6,204	1,074	17.3	17.5
	August	410,066	6,151	1,088	17.7	16.9
	September	407,233	6,159	1,067	17.3	17.5
	October	405,002	6,159	1,114	18.1	17.7
	November	405,451	6,116	1,152	18.8	19.2
	December	401,418	5,835	1,031	21.7	23.4
2017	January	387,680	5,814	1,114	19.2	18.9
	February	413,807	5,856	1,132	19.3	19.0
	March	440,703	6,235	1,091	17.5	17.0
	April	445,885	6,249	1,093	17.5	18.1
	May	450,984	6,782	1,166	17.2	17.5
	June	458,700	6,434	1,122	17.4	17.4
	July	478,369	6,817	1,139	16.7	17.5
	August	451,708	5,797	889	14.4	14.1
	September	437,955	6,796	1,144	16.8	17.2
	October	431,341	6,778	1,139	16.8	16.5
	November	434,802	6,742	1,181	17.5	16.7
	December	421,391	6,762	1,214	17.4	15.9

recreational fishing trips from private boats (measured in angler trips, SD ±27,540) to target reef fishes off the west coast of Florida. The highest percentage of total fishing trips took place in the peninsula region (42%), followed by the panhandle (34%) and Big Bend (24%; Figure 2). Overall, artificial reefs were utilized during an estimated 46% of fishing trips (360,522 trips, SD ±18,098). Half of the estimated fishing effort on artificial reefs took place in the panhandle region (176,725 angler trips, SD ±12,012), 18% (66,436 SD ±8,133) took place in the Big Bend, and the peninsula region constituted 32% (114,820 SD ±10,314; Figure 3).

The majority of fishing trips that targeted reef fishes took place nearshore in state-managed waters, regardless of whether artificial reefs were visited (Figures 2 and 3). In the panhandle region, 77% of fishing trips that visited artificial reefs took place in state waters, followed by 69% in the peninsula and 59% in the Big Bend (Figure 3). In the panhandle, artificial reefs were visited during a majority of trips (68%), whereas anglers in other regions were less likely to report utilizing them (Figure 4).

Fishing seasons for reef fishes managed in state and federal waters off the west coast of Florida varied over the months of this study and apparently influenced artificial reef use by recreational anglers (Table 3). In the panhandle region, fishing effort on artificial reefs peaked during May through October, which coincided with open recreational harvest seasons for Red Snapper (Figure 5).

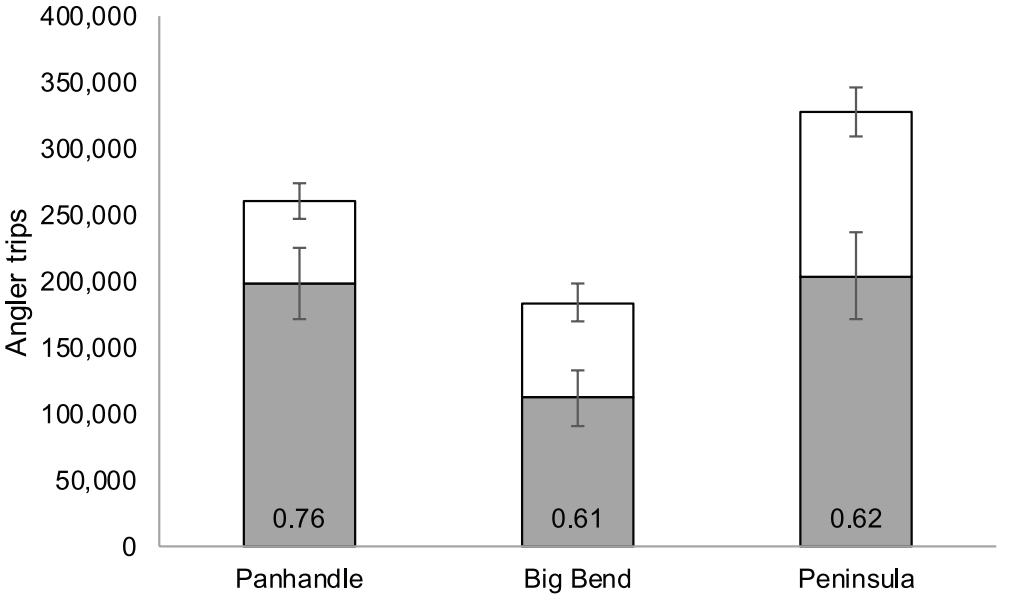

Figure 2. Total estimated recreational fishing effort for reef fishes (regardless of whether an artificial reef was visited) in each region over the 20-month study period by area fished. State (shaded bars) = trips taken in inland or state territorial seas, and exclusive economic zone (white bars) = trips taken in the exclusive economic zone. Proportion of trips that occurred in state waters are labeled.

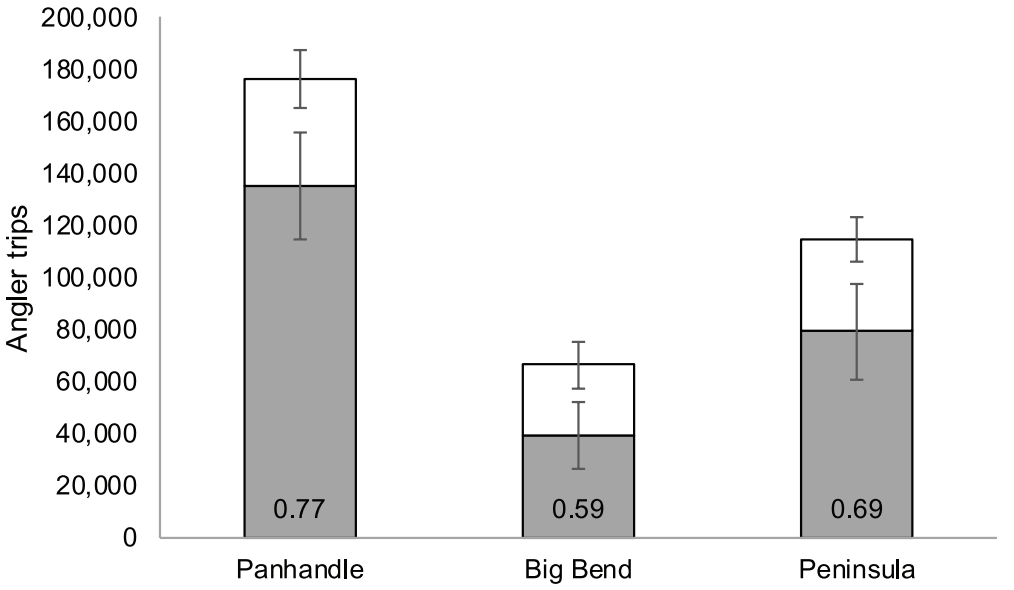

Figure 3. Estimated recreational fishing effort on artificial reefs in each region over the 20-month study period by area fished. State (shaded bars) = trips taken in inland or state territorial seas, and exclusive economic zone (white bars) = trips taken in federal waters of the exclusive economic zone. Proportion of trips that occurred in state waters are labeled.

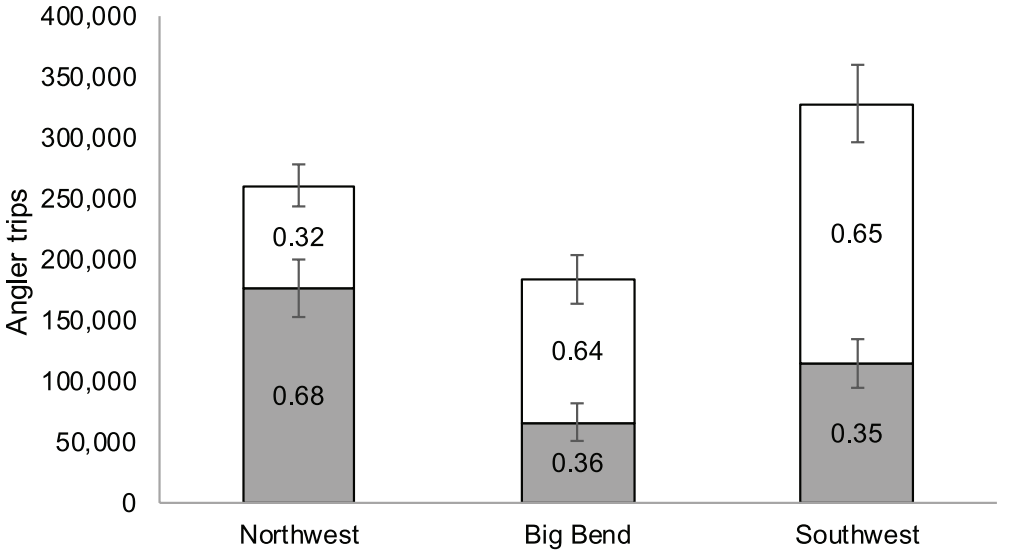

Figure 4. Estimated recreational fishing effort in each region over the 20-month study period where artificial reef habitat was reportedly used (shaded bars) or not (white bars). Relative proportions in each region are labeled.

Table 3. Months during the study period (May 2016 through December 2017, unshaded cells) when recreational harvest was open one or more days in all state waters (S), state waters adjacent to four northernmost counties in the Big Bend region (B), and the exclusive economic zone (E) for six frequently targeted reef fish species.

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Red Snapper	2016					S	S,E	S		S	S		
	2017					S	S,E	S,E	S,E	S,E			
Gag	2016					B	S,E	S,E	S,E	S,E	S,E	S,E	S,E
	2017				B	B	S,E	S,E	S,E	S,E	S,E	S,E	S,E
Greater Amberjack	2016					S,E			S	S			
	2017	S,E	S,E	S,E	S								
Gray Triggerfish	2016					S,E							
	2017									S	S	S	
Red Grouper	2016					S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E
	2017	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E
Vermilion Snapper	2016					S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E
	2017	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E	S,E

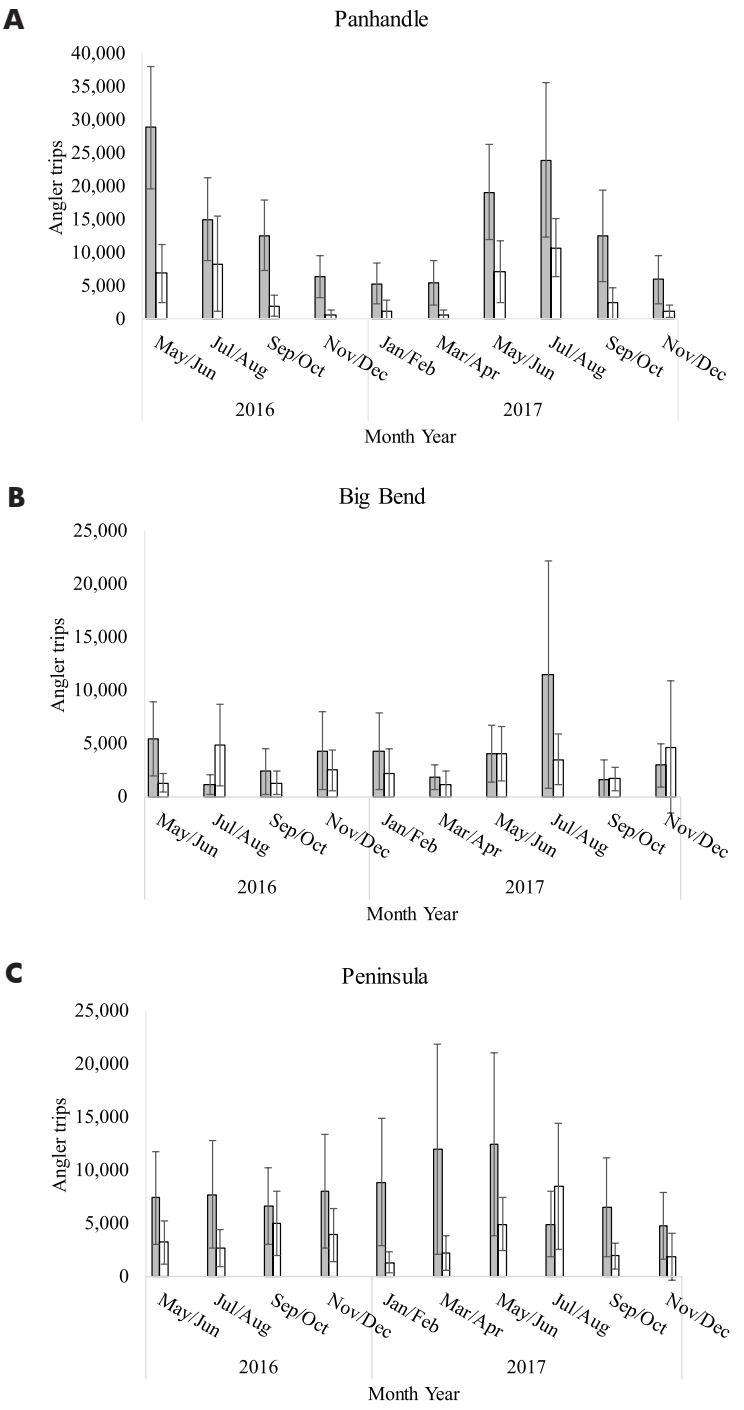

Figure 5. Bimonthly estimated fishing effort on artificial reefs in **(A)** the panhandle, **(B)** Big Bend, and **(C)** peninsula regions by area fished. State (shaded bars) = trips taken in inland or state territorial seas, and the exclusive economic zone (white bars) = trips taken in federal waters of the exclusive economic zone.

In 2016, recreational harvest of Red Snapper was permitted in federal waters during the first 11 d of June only but was more protracted during 2017 and encompassed the months of June, July, and August and the first 4 d of September. During July and August 2017, fishing effort on artificial reefs was elevated in the panhandle and Big Bend regions (Figure 5). In the peninsula region, where Red Snapper are not as abundant close to shore, fishing effort on artificial reefs also peaked in the exclusive economic zone during July and August 2017 (Figure 5).

Discussion

The results from this study indicate that a significant portion of recreational fishing effort for reef fishes along the Gulf Coast of Florida occurs at artificial reefs, particularly in the panhandle where Red Snapper is most abundant. The implications of this finding are many. Artificial reef programs have been implemented to enhance marine fisheries stocks as well as to increase recreational opportunities for anglers. Whether artificial reefs increase biomass in addition to attracting and aggregating reef-associated fishes is still debated, especially for Red Snapper in the Gulf of Mexico (Bohnsack 1989; Grossman et al. 1997; Pickering and Whitmarsh 1997; Dance et al. 2011). In their study at artificial reef sites in Florida's panhandle, Dance et al. (2011) found that Red Snapper was the dominant species across all reef types, though the majority (91%) were estimated to be below the legal size limit of 406 mm total length for recreational harvest. Karnauskas et al. (2017) also found that catch rates were 20 times higher on artificial reefs compared to natural reefs across similar depths, and age-1 and age-2 Red Snapper were the dominant age-classes. The absence of larger, older individuals across several important fishery species on artificial reefs may indicate that these habitats become less preferential with size or age or that fishing pressure is concentrated at artificial reef sites and fish are removed at higher rates (Dance et al. 2011). Thus, monitoring trends in recreational fishing effort among natural and artificial reefs is important for assessing changes in catch rates, discarding of undersized fish, and biomass of landed fish.

Potential shifts in recreational fishing effort toward more frequent usage of artificial reefs, which may also serve as attractants for some species such as Red Snapper, may have important implications for selectivity and catchability, both of which may profoundly influence the outcome of stock assessments (SEDAR 2009; Maunder et al. 2014). Selectivity is still poorly understood for reef fish stocks in the southeastern United States (Cowan 2011) and is often assumed to be constant over time in stock assessments. However, as artificial reefs have accumulated in the Gulf region, this may not be an accurate assumption. Catchability was also assumed constant until recently. In 2009, the Southeast Data, Assessment and Review (SEDAR) held a special workshop to address the influence of time-varying catchability in regional stock assessments (SEDAR 2009). Most of the discussion at the workshop focused on the influence of technological advances, such as electronic fish finders and GPS; however, the gradual accumulation of artificial reefs is an additional factor that should be considered when evaluating catchability back in time. The method we present here can be useful for monitoring future trends in recreational fishing effort with respect to artificial reefs.

A secondary component of Florida's Gulf Reef Fish Survey is a dockside intercept survey that collects information from

private boat parties as they return from recreational fishing trips targeting reef fishes. These data could not be evaluated in time for this publication but will be used in the future to account for additional fishing trips taken by anglers that are not subscribed to the mail survey. Anglers interviewed in the dockside intercept survey are also asked to report whether an artificial reef was visited during the trip, and catch data collected through this survey may be used in the future to evaluate potential differences in species composition, size and age composition, and CPUE for landings and discards when anglers take advantage of artificial reefs.

Acknowledgments

The authors express appreciation to Lynne Stokes, Jean Opsomer, Jay Breidt, and Virginia Lesser for their statistical expertise during the initial design and development of the mail survey of Gulf reef fish anglers. Funding for the mail survey was provided by the National Fish and Wildlife Foundation's (NFWF) Gulf Environmental Benefit Fund.

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