ESTIMATION OF TOTAL RED SNAPPER ABUNDANCE IN LOUISIANA AND ADJACENT FEDERAL WATERS

Final Report

For

LDWF Purchase Order No. 2000461788

Attn: Andrew Fischer, Contract Monitoring and Liaison Representative
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TABLE OF CONTENTS

INTRODUCTION

On 1 November 2019, the Louisiana Department of Wildlife and Fisheries (LDWF) entered into a Contract (Purchase Order No. 2000461788) with LGL Ecological Research Associates, Inc. (LGL) to estimate total Red Snapper *Lutjanus campechanus* abundance in Louisiana waters. The specific objectives of the contract were to:

- Determine species composition at 106 sampling sites at predetermined locations in the Gulf of Mexico per approved sampling methodology.
- Conduct hydroacoustic, Submersible Rotating Video (SRV), and composition sampling for finfish at 106 sampling sites at predetermined locations in the Gulf of Mexico offshore Louisiana.
- Conduct water column surveys at 106 sampling sites at predetermined locations in the Gulf of Mexico offshore Louisiana.
- Conduct a mark/recapture study at a subset of six sites (1 platform and 1 artificial reef site in each of three regions).

As indicated in the Request for Proposal, the selection of the 106 sites resulted from several months of collaboration between Louisiana Department of Wildlife and Fisheries (LDWF) with researchers throughout the Gulf states, and these data were used by a contracted ecological consulting firm to assist LDWF in the development of a research protocol and study design. The resulting design was described in the Request for Proposal found on pages 32-35 and detailed in the corresponding Table 2 (RFP is attached as Appendix 9). Table 1 provides an overview of the distribution of the final sampling design as subdivided by habitat type, region and depth.

Of importance, the study was required to be compatible with the “Great Red Snapper Count” (Stunz et al. 2021). As acknowledged by Stunz et al. (2021), unusual complications prevented their initial scope of sampling for Louisiana to be accomplished. Therefore, a Louisiana-specific study was necessary and was accomplished over the period 1 November 2019 - 30 June 2021.

Prior to initiation of the formal Red Snapper survey, a Proof-of-Concept Study was conducted, primarily to 1) test the utility of using trammel nets as a non-size-selective sampling device, and 2) finalize all field sampling protocols. The results (LGL 2020) suggested trammel nets would not be practical for this purpose. A longline sampling program was developed as an alternative method for sampling widely-dispersed Red Snapper over uncharacterized bottoms (UCBs). The final methods for field sampling used hydroacoustic methods to count fish, supplemented by camera surveys (Submersible Rotating Video Cameras [SRV] at discrete sites and Towed Video [TV] cameras over UCBs) which were used to apportion counts to individual species or taxa. Hook-and-line (vertical lines and longlines) methods were used to collect fish to quantify selected biological attributes (e.g., length, weight, sex, age).

We first describe our Study Area (the Louisiana State Red Snapper Management Area) and provide a characterization of the major types of habitats represented within the area. We then describe the 106 designated sampling sites that were located within this area. Next, we describe our field sampling strategies for each habitat which were divided into discrete sites (e.g., artificial reefs, petroleum platforms, pipeline crossings, and natural banks) and UCBs. The field methods section is followed by a section describing our approaches for handling Data and Statistical Analyses. Results of our study are then described and discussed. Lastly, a Summary and Conclusions Section provides an executive-level description of key findings.

STUDY AREA AND HABITATS

The Louisiana Red Snapper Management Area (the study area) was divided into three regions (West, Central and East) each of which was divided into four depth zones (shallow, 10- to 25- m deep; mid depth, 25- to 45- m deep; deep, 45- to 100- m deep and shelf, 100- to 150- m deep) (Figure 1). A total of 106 sites were sampled in summer and fall of 2020. In addition, data for 37 platforms that were present in the study area and sampled as part of our recent Bureau of Ocean Energy Management (BOEM) study were also included (Gallaway et al. 2020). Before describing the specific sampling sites, we will first provide an overall background of Red Snapper habitats found in the study area.

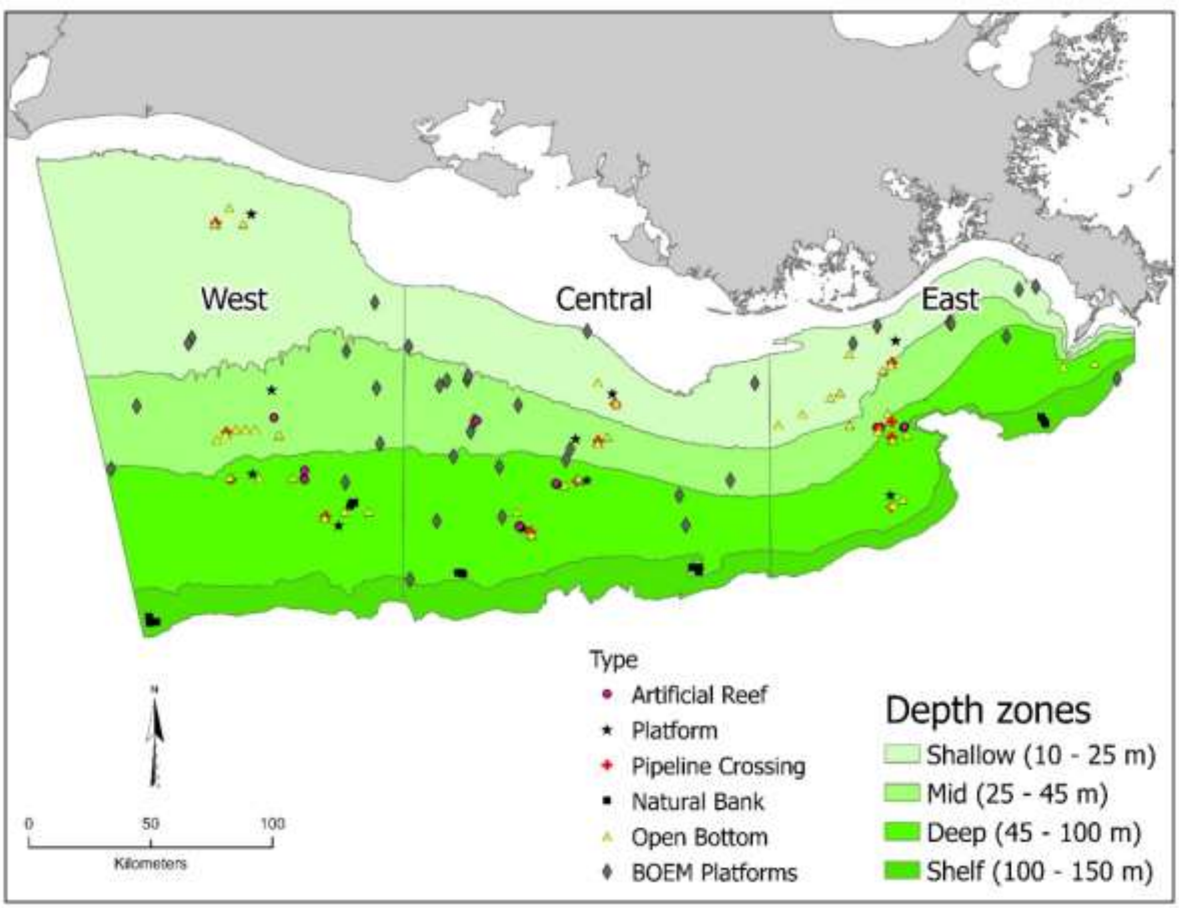

Figure 1. Louisiana study area. A total of 106 new sites were sampled and data from 37 platforms sampled by Gallaway et al. 2020 were also incorporated.

Habitat Areas and Discrete Structures

Areal coverage of all discrete and UCB habitats within each region and depth zone was determined using GIS. We used an Albers Conic Projection with North American Datum of 1983 (NAD83). This projection is centered at 91.5° W, 28.0° N on the area offshore of Western Louisiana and encompasses the study area. This reduces distortion when calculating areal coverage of bottom habitats.

The extent of UCB habitat was estimated from the usSEABED bottom sediment database (Buczkowski, 2006). This is a gridded database that estimates percent coverage of bottom sediment (rock, mud, sand, and gravel) within each grid cell (2.22 km by 1.96 km). We considered UCB as being those grid cells that had less than 66% rock (Table 1). Natural bank habitat was estimated using a natural bank coverage obtained from Gulf States Marine Fishery Commission (Jeff Rester, pers. com). Aerial extent of natural bank habitat was calculated by combining the natural bank coverage with those areas from the usSEABED dataset with 66% or greater rock coverage (Table 2).

Locations of standing oil and gas platforms (Fixed leg, Well Protectors and Caissons) were obtained from the Bureau of Ocean Energy Management (BOEM 2021, accessed March 2021). This database includes all historical installations of offshore structures and was filtered to remove those platforms that had a removal date prior to January 1, 2021 in its attribute table. The remaining structures are considered standing structures. Artificial reef locations were obtained from the Louisiana Department of Wildlife and Fisheries (LDWF 2021). Pipeline locations were obtained from the Bureau of Ocean Energy Management (BOEM 2018) and were filtered to identify and quantify the intersections of pipelines 20 inches in diameter or greater. Wrecks and Obstructions were accessed from the National Oceanic and Atmospheric Administration Office of Coast Survey (NOAA OCS 2021).

Each of the datasets was clipped to show spatial coverage within the defined study area. Spatial joins were utilized to calculate the number of discrete structures within each regional depth zone. Geometry for aerial extent was calculated for UCB habitat within each regional depth zone combination after removal of rock habitat defined previously. We followed the same methodology to calculate the aerial coverage of natural bank.

UCB habitat (49,000 km^2) dominates most of the study area and is comprised mainly of mud substrate, although sandy areas are well represented in the Western shallow region, and some rock/gravel patches occur at greater depths (Figure 2, Panel A). Natural bank habitat is much smaller in total area (724 km^2) than UCB habitats and occurs mainly in the shelf depth zone (Figure 2, Panel B).

A total of 821 petroleum platforms and well protectors were present in the study area as of January 1, 2020 and they constituted the dominant artificial reef type (Panel A,

Figure 3) In addition there were 147 single-pipe caissons standing in 2020 (Panel B, Figure 3). Caissons were not sampled as part of our program.

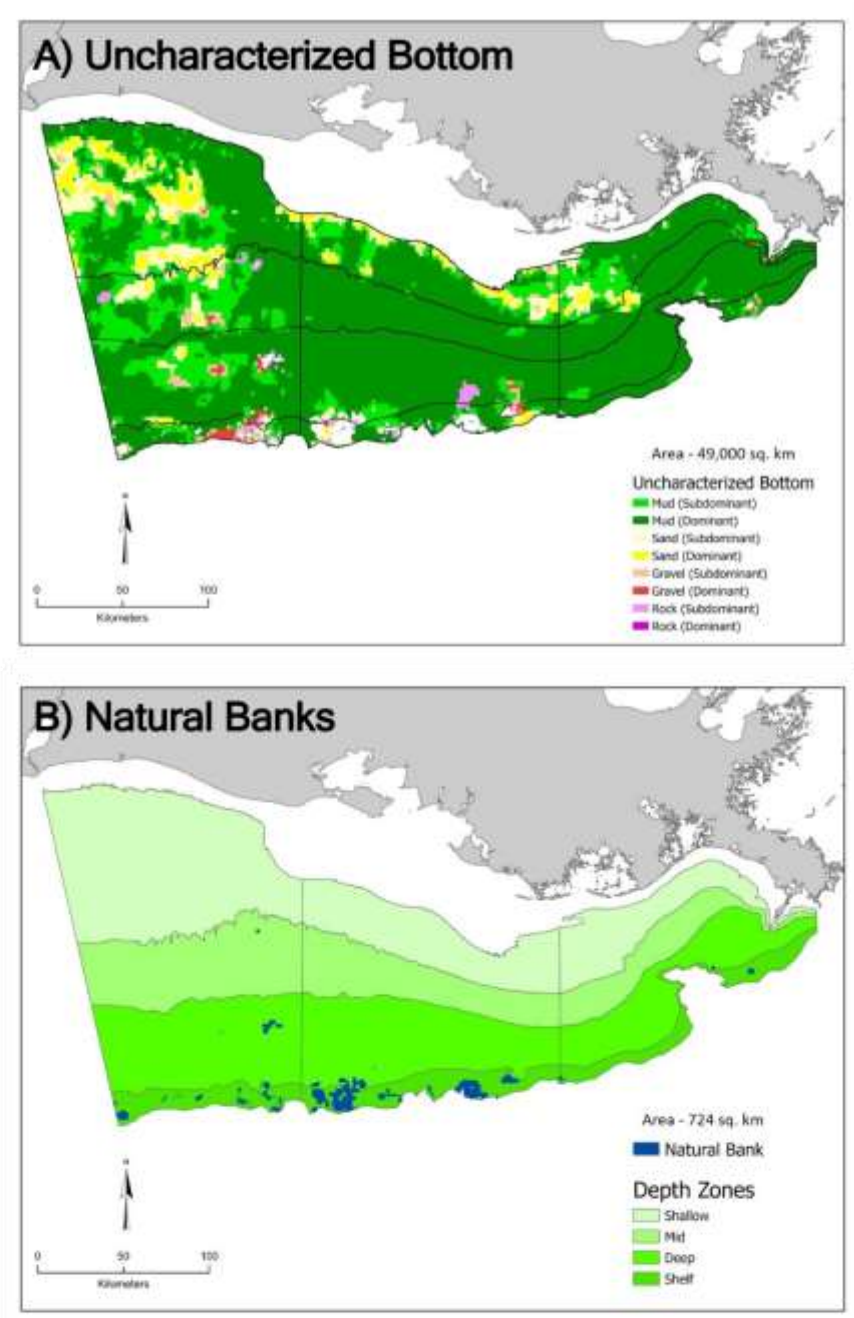

Figure 2. Distribution and special extent of (A) uncharacterized bottom habitat (shown as areas shaded in color) and (B) natural bank habitat (shown in blue) within the study area.

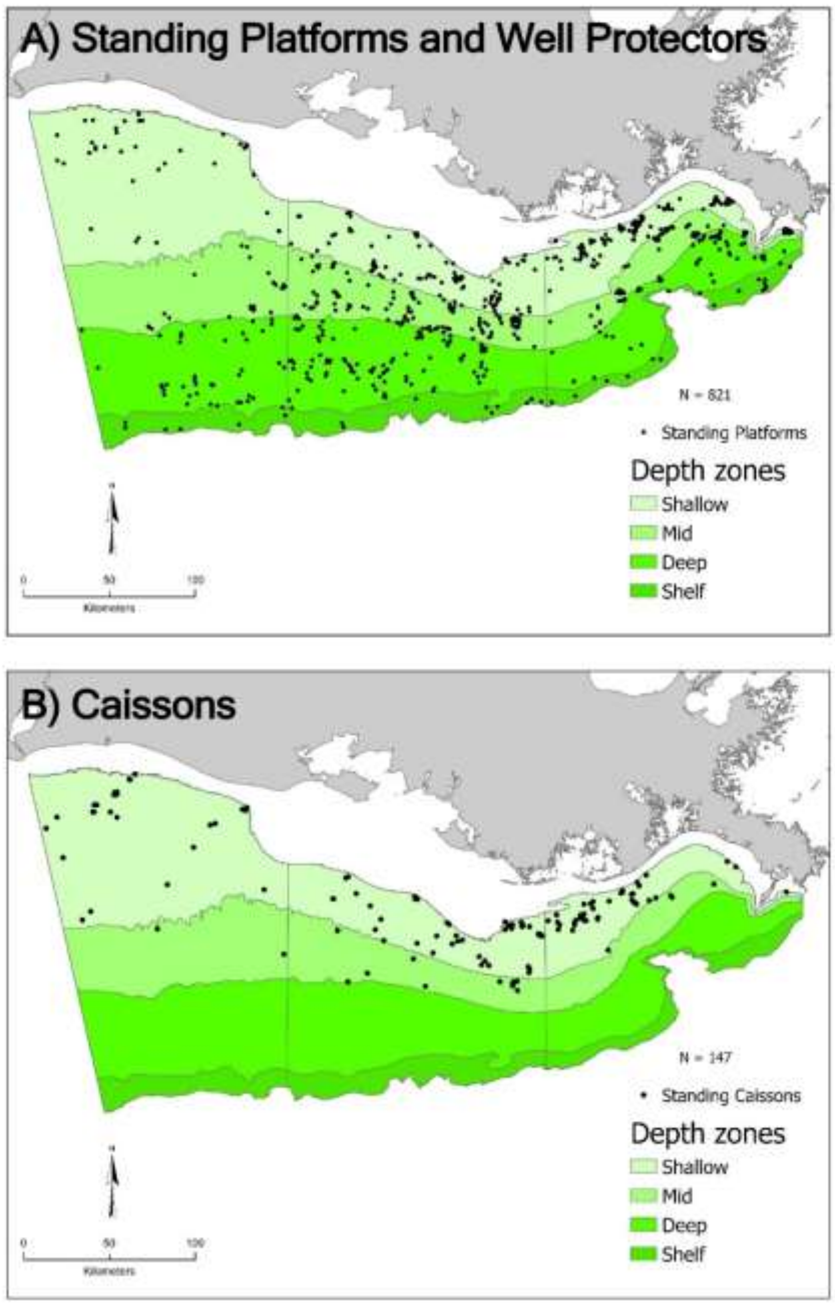

Figure 3. Number and distribution of (A) standing platforms (filled circles) and (B) caissons (filled circles) present within the study area.

In summer/fall of 2020 there were on the order of 442 reefed platforms in the Louisiana Artificial Reef Program (Figure 4A) and these were supplemented by 514 oil and gas pipeline crossings where each of the pipes were greater than 20” in diameter (Figure 4B).

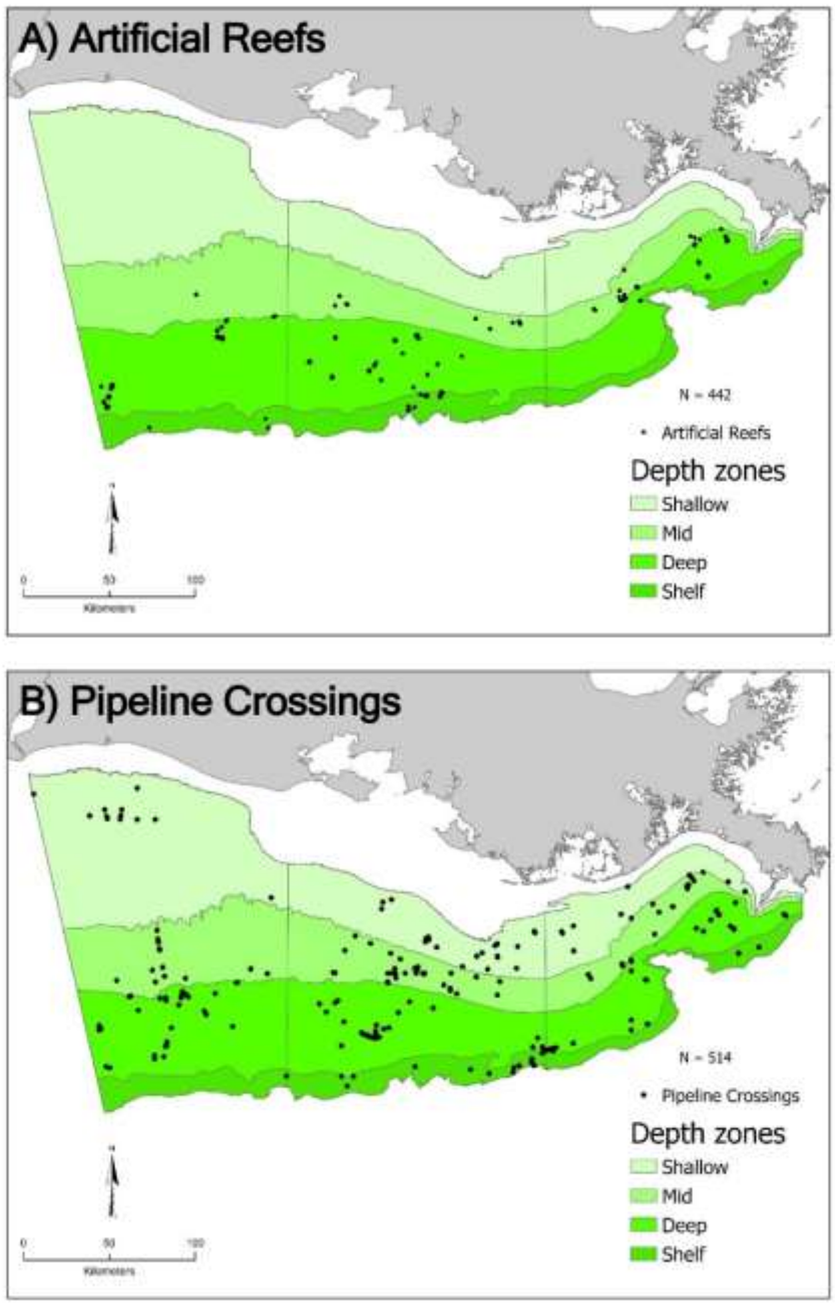

Figure 4. Number and distribution of (A) reefed oil and gas platforms (filled circles) and (B) major pipeline crossings (filled circles) within the study area.

In addition to the natural banks and artificial reefs described above there were 132 obstructions (Figure 5A) and 56 wrecks that have been documented to occur within the study area (Figure 5B). These habitat types were not sampled as part of this program.

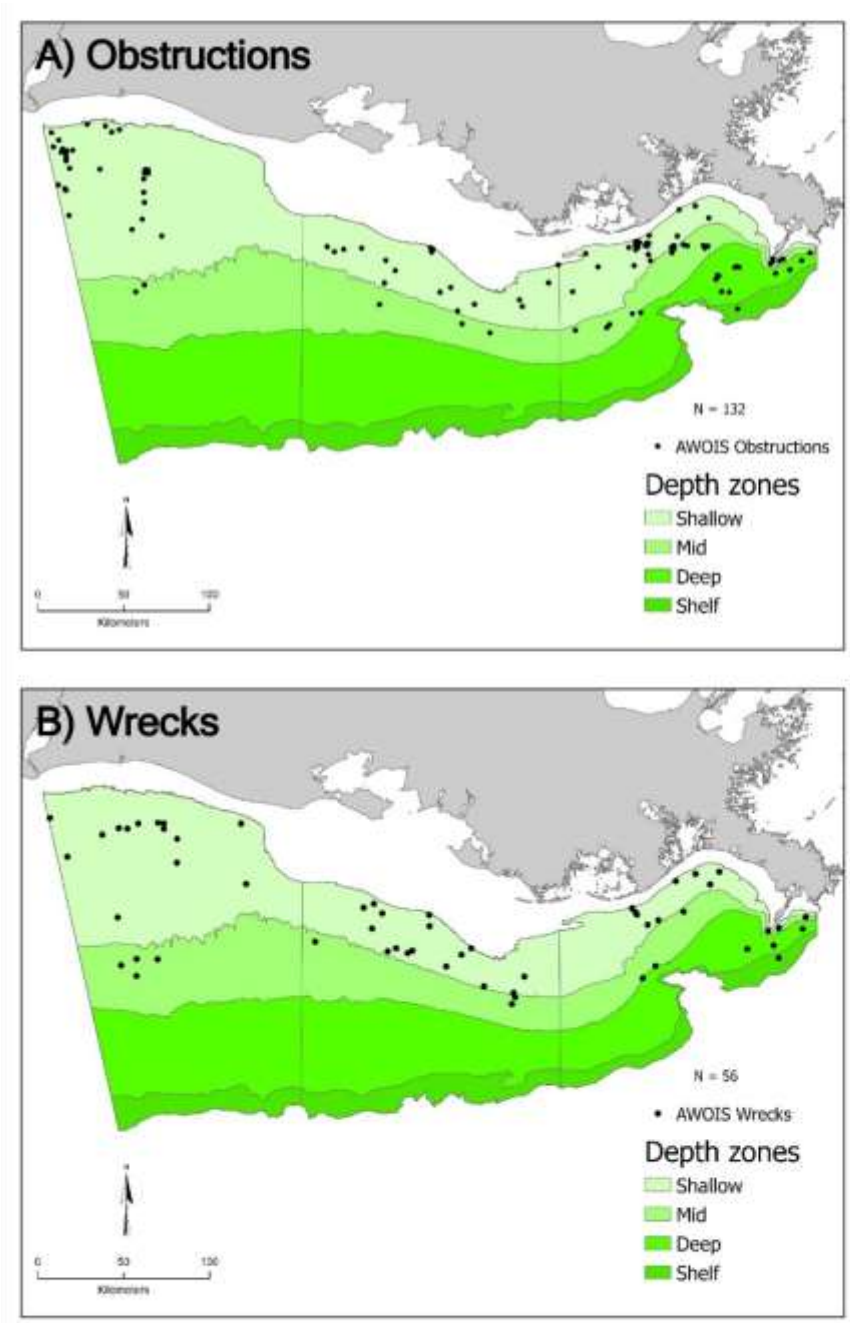

Figure 5. Number and location of documented (A) obstructions (filled circles) and (B) wrecks (filled circles) in the study area.

All of the habitats described above are used as habitat by Red Snapper.

Sampling Sites

Of the 106 total sampling sites, 37 were located in the West Region, 33 were in the Central Region and 36 were in the East Region (see Figure 1 and, for more detail, Appendix 1). Of these, 55 were discrete reef sites whereas 51 were UCB sites. The UCB surveys included only 39 unique sites, but paired sampling was performed at 12 sites .The 12 sites where paired samples were taken at the same substrate with and without pipeline present included site numbers 41 and 42 (West Shallow), 46 and 47 (West Mid), 52 and 53 (West Deep), 56 and 57 (West Deep), 61 and 62 (Central Shallow), 64 and 65 (Central Mid), 66 and 67 (Central Deep), 70 and 71 (Central Deep), 73 and 74 (East Shallow), 82 and 83 (East Mid), 85 and 86 (East Deep) and 88 and 89 (East Deep).

It should be noted that UCB hydroacoustic surveys were conducted by Auburn University. Alternative site numbers (1-39) were assigned for internal tracking purposes. A key for relating the Auburn site numbers to the original, LDWF site number locations is also included in Appendix 1.

The number of sites sampled for each habitat was chosen to balance the need for representative sampling across multiple habitats and geographic regions within specified cost constraints. Our samples for UCB habitat did not include any taken from the deepest shelf zone. The shelf zone constituted about 8% of the total sampled area. Our sampling covered about 0.37% of the total remaining area:

Table 1. Total area of UCB and area sampled for this habitat.

Name	Zone_ID	Area_km^2	Num Sites Uncharacterized Bottom	Area sampled _km^2	Percent sampled
West Shallow	1	10,267.60	3	12.94	0.13
West Mid	2	5,297.20	6	25.87	0.49
West Deep	3	5,892.60	6	25.87	0.44
Central Shallow	5	4,407.10	2	8.62	0.20
Central Mid	6	3,760.00	2	8.62	0.23
Central Deep	7	6,043.10	4	17.25	0.29
East Shallow	9	3,058.40	7	30.18	0.99
East Mid	10	2,326.70	3	12.94	0.56
East Deep	11	3,853.00	6	25.87	0.67
West Shelf	4	1,269.70	0	0.00	0
Central Shelf	8	1,468.30	0	0.00	0
East Shelf	12	1,359.50	0	0.00	0
Total - Shallow, Mid,Deep		**44,905.70**	**39**	**168.17**	**0.3745%**

Likewise, we sampled a total of 2.4 km^2 of Natural Bank habitat which constituted 0.33% of the total Natural Bank area. Note that the depths within a defined zone differ based on the location of the Natural Bank within the zone.

Table 2. Total and sampled area (in parentheses) of natural bank habitats in the study area.

Natural Bank Area (km^2)	
Natural Bank Region	**Total**
West Mid/Deep (Sonnier)	45.85 (0.48)
West Shelf/Deep (Bright)	133.97 (0.48)
Central East Deep/Shelf	544.42 (1.44)
Total	**724.25 (2.4)**
% Sampled = 0.33	

Sampling effort included 5.8% of the Standing Platforms, 2.3% of the Pipeline Crossings and 3.6% of the Artificial Reefs documented to have been in the Study Area during the summer and fall of 2020 (Table 3).

Table 3. Numbers of artificial reefs present and the number of each reef type sampled. For standing platforms (A), the first number in parentheses represents the number of sites sampled in the present study, the second number represents the additional BOEM sites from a previous study, and the third is the total number of samples (see text).

A) Standing Platforms

Depthzone	West	Central	East
Shallow	62 (1+3=4)	118 (1+3=4)	182 (1+4=5)
Mid	25 (1+5=6)	133 (1+9=10)	58 (1+2=3)
Deep	45 (2+2=4)	107 (2+8=10)	55 (1+1=2)
Shelf	7 (0)	10 (0)	19 (0)
Region Total	139 (14)	368 (24)	314 (10)
Total			**821 (48)**
			% Sampled= 5.8

B) Pipeline Crossings

Depthzone	West	Central	East
Shallow	24 (1)	93 (1)	18 (1)
Mid	28 (1)	70 (1)	49 (1)
Deep	61 (2)	50 (2)	61 (3)
Shelf	2 (0)	50 (0)	8 (0)
Region Total	115 (4)	263 (4)	136 (5)
Total			**514**
			% Sampled=2.3

C) Artificial Reefs

Depthzone	West	Central	East
Shallow	0 (0)	0 (0)	0 (0)
Mid	5 (1)	35 (1)	57 (3)
Deep	117 (3)	129 (6)	59 (2)
Shelf	4 (0)	31 (0)	5 (0)
Region Total	126 (4)	195 (7)	121 (5)
Total			**442**
			% Sampled=3.6

In comparison to the GRSC study, our overall sampling intensity is relatively robust. For example, we sampled 0.33% of the total 724 km^2 of Natural Bank Habitat within the study area. In comparison, the total area of Natural Bank Habitat offshore Mississippi/Alabama was reported by Stunz et al. (2021) to be 211 km^2. A total of 32 sites were sampled, each site consisting of an average area of 417 m^2. This reflects a sampling intensity of 0.0063%, two orders of magnitude less than our sampling intensity for Louisiana.

FIELD SURVEYS AND SAMPLE PROCESSING

Our field surveys included hydroacoustic sampling to enumerate the fish associated with each of the defined habitat categories, camera surveys to estimate species composition of the fish communities represented at a site, and hook-and-line sampling to determine length, weight, sex and age of Red Snapper in the resident community.

Prior to departing the dock, Field Team Leaders were required to file a Float Plan (Appendix 2), with the Project manager, the Field Coordinator, and specified office staff designated as safety contacts. The Float Plan described the locations and activities to be performed. The Field Team Leader then conducted a pre-trip meeting with the vessel captain, the deckhand(s) and scientific staff, covering sampling objectives for the day as well as an overview on the location of safety equipment aboard the vessel. The Field Team Leader notified the designated safety contact of departure and successful return to dock. A copy of the Letter of Authorization (LOA) from NOAA was present during all field activities (Appendix 3).

Water column measurements were taken in conjunction with each type of sampling using a YSI EXO3 CTD which measured dissolved oxygen saturation (ODO %), dissolved oxygen concentration (ODO mg/L), specific conductance (SpCond µS/cm), conductivity (µS/cm), salinity (psu), total dissolved solids (TDS mg/L), turbidity (FNU), total suspended solids (TSS mg/L), and temperature (°C) (Figure 6). All data were downloaded to a notebook computer, converted to .csv files and backed up on an external hard drive on board, immediately after being recorded. These data were used for the calibration of the echosounders applied in the hydroacoustic analyses and for the statistical model of Red Snapper abundance, as described below.

Surface conditions were measured using the vessel's instruments at each sampling station. We recorded air temperature (°F), wind speed (kts) and direction, atmospheric pressure (mbar), and water depth (ft). In addition, wave height (ft), current speed (kts) and direction were estimated by the captain of the vessel and recorded. CTD data were restricted to just the data for the downward drop. Prior to binning the data into 10 m increments, the top 3 meters and the bottom 1 meter of the water column were excluded to correspond to hydroacoustic exclusion zones. The 1-m depth-interval data were then binned to 10 m increments and averaged for each depth bin.

Figure 6. Deployment of the EXO3 CTD used to obtain seawater properties.

Hydroacoustic Field Surveys and Initial Data Processing

Hydroacoustics has been used in the Gulf of Mexico for the assessment of fishes around platforms for many years (e.g., Stanley and Wilson 1996, Boswell et al. 2010, Reynolds et al. 2018).

Hydroacoustic surveys were conducted using a multi-frequency series of three BioSonics DT-X split beam transducers - 38 kHz (10-degree beam angle), 70 kHz (5.0 degree beam angle), and 120 kHz (7.8 degree beam angle). Echosounder transducers were pole mounted over the side of the survey vessel using a customized bracket, with the transducer faces located approximately 1 m under the surface of the water aimed directly downwards (Figure 7). Prior to each survey event, each transducer was calibrated using standard methods (Foote et al. 1987). Any offsets between the actual and expected acoustic response from the calibration sphere were applied during data processing. The specified ping rate was set to “max,” depending on site water depth, and pulse duration was set to 0.2 ms. More detail is provided below.

Figure 7. Echosounder transducers pole mounted over the side of a survey vessel, 1 m under the surface of the water.

In hydroacoustic fish surveys, adequate coverage of the survey area is needed to achieve a reliable estimate of fish abundance. Degree of coverage (Λ) is defined as: $\Lambda = D/\sqrt{A}$, where D is the cruise track length, and A is the size of the survey area. Empirical data from Aglen (1989) showed the ratio needs to be 6:1 or greater. This was planned and achieved at all survey sites (Table 4).

Table 4. Hydroacoustic site numbers and survey areas and methods.

Site Type	Habitat Type	Number of Hydroacoustic Sites	Number of Transects	Sampling Area Dimensions	Area Sampled (m^2)	Aglen Ratio (>6)	Analysis Grid Applied	Analysis Grid Cell Size
Discrete	Platform	11 + 37 (BOEM)	11*	250m x 250m	62,500	11	5x5	50m x 50m
	Artificial Reef	16	11	250m x 250m	62,500	11	5x5	50m x 50m
	Pipeline Crossing	13	11	250m x 250m	62,500	11	5x5	50m x 50m
	Natural Bank	15	11	500m x 500m	250,000	11	5x5	100m x 100m
UCB	Uncharacterized Bottom	39	9	2000m x 2000m	4,000,000	10	5x5	400m x 400m

*Additional spiral transects conducted in order to maneuver around standing structures.

The hydroacoustic surveys at all sites were conducted in a parallel transect pattern, covering different total areas depending on habitat type (Table 4). Discrete artificial structure sites were centered on the central point of the structure itself, and additional spiral transects were conducted around standing platforms in order to maneuver around above-water structures and capture fish present in these proximal locations. A sample area of 250 m by 250 m (eleven transects, 250 m long) was chosen for discrete artificial sites, resulting in a radius of at least 100 m around the structure. This was chosen to ensure the entire reef-associated fish community was captured, as previous studies have found that fish densities further than 50 to 80 m from platforms were comparable to background levels (Stanley and Wilson 1996, 1997, 2000, Szedlmayer et al. 2019)). Discrete natural bank sampling transects were expanded to 500 m by 500 m (eleven transects, 500 m long) to encompass greater variability of rugosity and fish assemblages found in this habitat type. UCB sites were based on 2.22 km by 1.96 km usSEABED database cell sizes (Buckowski et al. 2006), and surveys sampled an approximate 2 km by 2 km area over these sites (nine transects, 2 km long).

Hydroacoustic Data Processing Methods

Our approach in the hydroacoustic surveys utilized the process of 'decibel differencing,' using data from the three transducers of differing frequencies; 38kHz, 70kHz and 120kHz. This approach has gained momentum in recent years with the major benefit being able to separate acoustic signals of swimbladdered fish from those organisms without swimbladders (both fish and plankton) (Madureira et al., 1993; Mosteiro et al. 2004; Korneliussen et al., 2009, De Robertis et al., 2010), as different types of organisms produce different strengths of acoustic return at different frequencies (Reynolds et al., 2018). Our focus in this study was placed on the swimbladdered Red Snapper, and the decibel differencing approach greatly assisted with 'cleaning' the data to leave only fish of interest (primarily mixed reef fish assemblages), reducing the risk of inflated values from non-target species.

The decibel differencing methodology was combined with "echo integration," a technique that divides the total energy reflected from fish (proportional to fish biomass (Boswell et al. 2007)), called "Sv" (in this case from those fish with swimbladders) by the known amount of energy reflected by a single fish (Target Strength (TS)), in order to calculate fish density (MacLennan and Simmonds, 1992). This method (as opposed to "echo counting") is necessary when fish are not adequately dispersed enough to count individuals. TS is known for various fish species of different sizes through established TS to Length (L) equations in the published literature, so it can be applied via the size distributions resulting from catch data. This method (*ex situ* TS) works well with single species stocks but is problematic in mixed species communities. The use of *ex situ* TS is difficult in situations such as this, where TS-L equations are unknown for most of the species present, and while species composition could be estimated over a site as a whole, the species community present in any one acoustic cell is practically impossible to determine.

TS and Sv are also known to vary considerably with aspects of fish behavior such as tilt angle and condition (Love, 1971). Therefore, our approach was to use mean *in situ* TS to calculate density within each acoustic cell. This approach follows Rudstam et al. (2009) and has been used in studies and environments similar to this (e.g., Stanley and Wilson, 1996, 1997, 2000, Boswell et al. 2007; Zenone et al. 2019, Egerton et al. 2021). This approach is, however, also subject to biases if valid mean TS cannot be extracted from the data within an acoustic cell, such as in situations where fish occur in dense schools (see below). Due to the challenging nature of deriving fish density in mixed species communities such as this (Gastauer et al., 2017), final abundance estimates should be considered as estimates.

As an overview the following approach was taken: System calibration → Data cleaning and noise removal → Decibel differencing to extract Sv of swimbladdered fish → valid TS from swimbladdered fish extracted→ Echo integration (Sv/TS) → Data exported to spreadsheet in units of fish per m^3→ multiply by acoustic cell thickness (data converted to fish per m^2) → GIS →mean fish per m^2 value multiplied by area of grid cell → final abundance of swimbladdered fish.

<u>Calibration</u> - Before every survey event the echosounders were calibrated following standard methods (Foote et al. 1987). The 38kHz and 70kHz transducers were calibrated using a 38.1 mm tungsten carbide sphere, and the 120kHz transducer was calibrated with a 33.2 mm tungsten carbide sphere. These offsets were applied in the data processing in addition to the mean temperature and salinity measurements taken at each site with a YSI EXO3 sonde. Temperature and salinity are necessary to calculate the speed of sound through the water column.

<u>Data processing</u> - Data were analyzed in 20 m x 20 m horizontal, and 10 m deep cells, chosen as a balance between suitable spatial resolution and the number of valid Single Targets (ST) available for valid *in situ* target strength (TS) measurements (see below). In each of these cells, fish density (in units of fish per m^3) was calculated via echo integration (Sv/TS scaling). To deal with the absorption of sound through water, a Time Varied Gain

(TVG) correction of 40log(R) for TS values and 20log(R) for Sv values was applied. The bottom was detected via the Echoview algorithm and checked by eye to ensure that the algorithm correctly detected the seabed. A bottom exclusion line of 1 m was also applied to ensure echoes from the seabed were not included in the analysis and to avoid sampling in the “acoustic dead zone” (Ona and Mitson, 1996). If individual fish could clearly be seen within this exclusion zone with ‘a visibly distinct gap’ between the fish and the bottom, they were also included in the analyses. Any other remaining noise visible in the echogram, such as surface bubbles and leaking gas plumes, was removed by eye. At the platform and artificial reef sites, the structures were identified by eye and blanked out in the echograms (set to “no data”). A dataflow of all processing steps was constructed in Echoview (ver. 11.1) to process the raw data (Figure 8).

Noise removal - Prior to the decibel differencing, data at all frequencies were cleaned to remove any noise that can come from a variety of sources. In order to do this the following steps were taken:

1. The impulse noise (IN) removal filter removes sound spikes that may be resultant from other sound sources such as an unsynchronized echosounder (Ryan et al., 2015). This operator identifies and adjusts sample values that are significantly higher than those of surrounding samples at the same depth. Within this filter, a threshold of -170 dB was used, with a vertical window size of 3 samples and a horizontal window size of 3 pings for the smoothing. Samples with a 20 dB threshold difference from the adjacent samples were removed and a mean value from these adjacent samples was used instead.
2. After the IN filter, transient noise (TN) removal was applied following Ryan et al, (2015). This operator identifies and adjusts sample values that are significantly higher than those of surrounding samples. Within this filter, data was thresholded at -170dB, the context window was 3 pings by 3 samples. Sample values had a threshold of 20 dB, and when identified, these mean values were taken from the context window.
3. Finally, a Background noise (BN) filter was used, which estimates the background-noise level and subtracts it from the value of each sample. Within this, Sv values that were below the defined Signal to Noise Ratio (SNR) level were set to -999dB re 1 m^2 (Ryan et al., 2015), with a maximum noise value of -125dB and a minimum SNR of 10. Averaging parameters set within the filter used a horizontal extent of 3 pings and a vertical extent of 1 m. Smoothing does not affect the noise removal but reduces the variance among ping by ping measurements (De Robertis and Higginbottom, 2007). This smoothing of the data occurred above and below the bottom exclusion line separately, so that the seabed signal is not combined

with near-bottom data above the Signal to Noise Ratio SNR (De Robertis and Higginbottom, 2007).

4. In the last step the 'processed data' variable was applied to remove all data below the bottom exclusion line at 1 m and above the surface exclusion line at 3 m depth. The data at each frequency were then smoothed using the XxY Echoview operator (5x5 pings). This is needed to average the acoustic measurements to reduce natural stochastic variations in the data (Korneliussen et al. 2009, Lezama-Ochoa et al. 2011). The data from the different frequencies were then matched in terms of ping times and geometry to ensure accurate comparison.

<u>Decibel differencing</u> - Next decibel differencing techniques were used to mask all but the data related to swimbladdered fishes. To achieve this, 70 kHz echogram data were subtracted from 120 kHz echogram data. Data resulting in a difference in dB ranging between -15 and 1 were classified as fish with swimbladders, whereas results ranging from 2 to 25 were classified as organisms lacking swimbladders (Reynolds et al. 2018; Simonsen 2013). Additionally, 38kHz Sv data subtracted from 120kHz Sv data were also used to classify swimbladdered fish (Ballon et al. 2011; Lezama-Ochoa et al. 2011). Here a criterion of Sv 120kHz-38kHz resulting in a <3dB difference was used to apportion swimbladdered fish. These two decibel differencing categories were used to create Boolean (True/False) masks, which were used to only allow valid data to persist for subsequent analyses. In order to avoid masking valid fish data, data were acceptable that satisfied either decibel differencing criteria (Sv 120-38 <3dB or Sv 120-70 <2dB). (Initially the plan was for the data to have to satisfy Sv 120-38 <3dB AND Sv 120-70<2dB; however, this was seen to be too conservative and some valid data were masked. Scrutiny of the data showed Sv 120-38 <3dB OR Sv 120-70<2dB to be more appropriate.)

In addition to the decibel differencing criteria described above, the data also had to satisfy the criteria of 120kHz+70kHz+38kHz<-170dB, the value of which was determined by scrutinizing the resulting data in the echograms. This summation assists in determining fishes of interest, as it retains only those that exist on all frequencies (Fernades 2009, Ballon et al. 2011). This criterion was also used to create a Boolean True/false mask which was applied to the data at 120kHz for subsequent processing. The 120kHz data was chosen for the main analyses in order to facilitate incorporation of data from the BOEM study platform surveys that also used this frequency.

Following the application of these masks, it could be seen that there were occasionally gaps in the acoustic record within fish schools that did not satisfy the criteria, i.e., valid fish data was on occasion also masked. Therefore, following Ballon et al. (2011) and Lezama-Ochoa et al. (2011), the resultant fish data were smoothed with the XxY operator on a 3x3 basis to fill these gaps. This resulted in the creation of an expanded fish echogram, which was used as a mask on the original (noise removed) 120kHz data. This

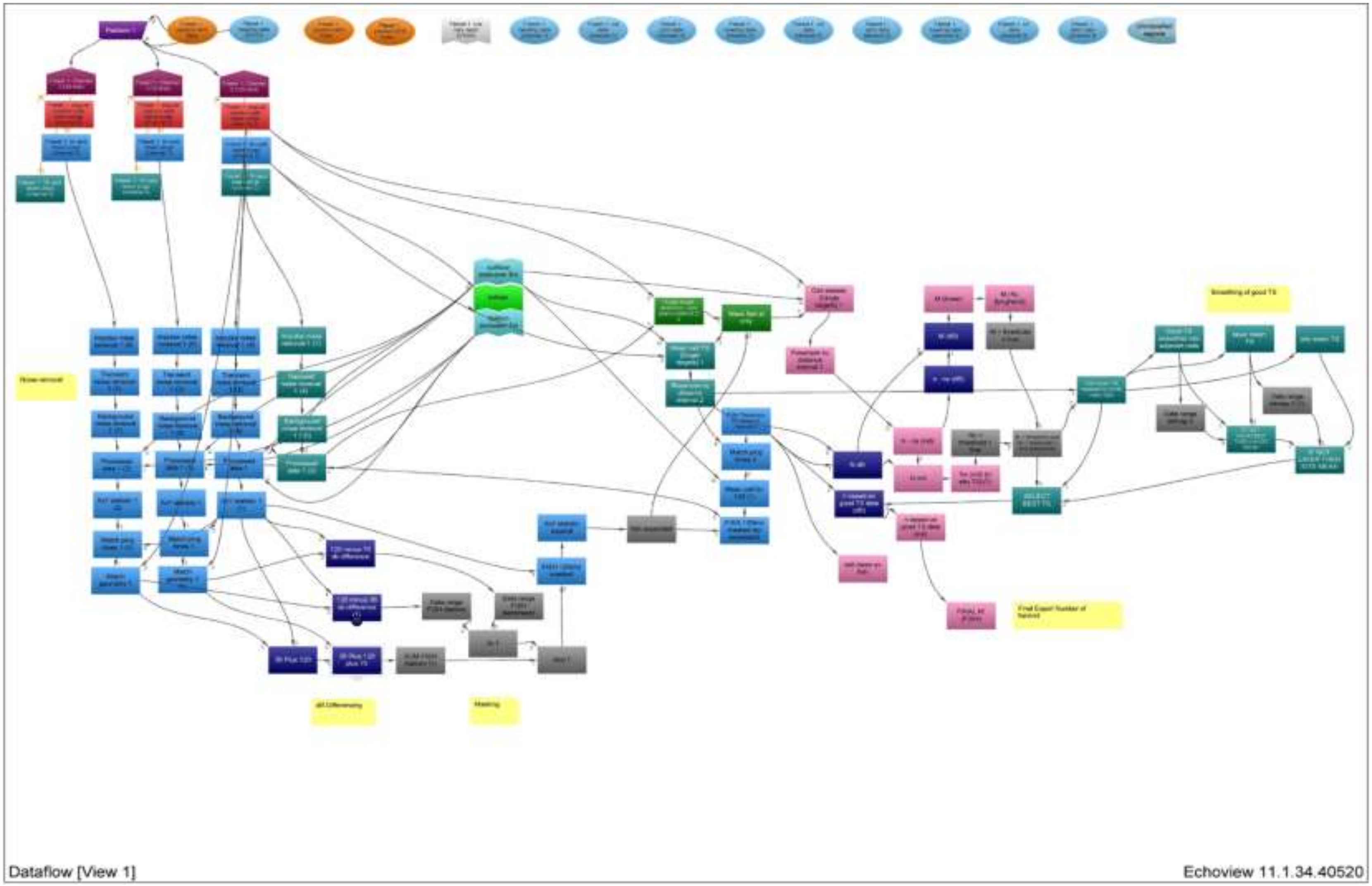

Figure 8. Hydroacoustic post-processing dataflow in Echoview (ver 11.1).

final mask was also applied to the single targets data so that only targets from swimbladdered fish were used in the echo integration process. Following the masking process, data were thresholded at an Sv of -50dB, with a minimum threshold TS of -50dB also applied in order to further assist in the removal of any remaining non-swimbladdered fish scatterers.

Determining valid TS from single targets - Single echoes were detected and accepted using the split beam single targets detection algorithm in Echoview, with a TS threshold of -50 dB, pulse length determination level of 6dB, minimum normalized pulse length of 0.7, maximum normalized pulse length of 1.5, and a maximum standard deviation of 0.6 degrees for the minor-axis and major-axis angles. To ensure that the TS of the single echoes was not artificially inflated by the issue of multiple echoes, following Sawada et al. (1993), the Nv index and the M% of multiple echoes criteria were employed to mask cells that compromised the criteria of Nv < 0.1 and M < 70% (Parker-Stetter et al. 2009; Kocovsky et al. 2013). This was important because, if not accounted for, these 'multiple echoes' cause TS to be overestimated, resulting in an underestimation of fish density (Kocovsky et al. 2013).

Following the removal of multiple echoes as described above, TS data were taken from the valid *in situ* Single Targets (ST). In echo integration, the objective was to use the TS of valid ST within the same cell as the Sv data being scaled. If this was not available, TS data was taken from ST from adjacent cells through the use of the "XxY" variable in Echoview with values of 3 by 3 cells. If there were none available in adjacent cells, a mean TS from within the same depth layer was used (1 by 999 cells), and finally if not available within the layer, a site mean (10 by 999 cells) had to be used.

Fish Density Calculations - Final density values were obtained by dividing Sv by the best available *in situ* TS. These values were extracted in units of numbers of fish /m^3 within the 20 m x 20 m horizontal by 10 m deep cells to a spreadsheet. Within the spreadsheet, the numbers of fish were converted to fish number/m2 within a depth layer by multiplying the fish number/m^3 value by the thickness of the layer (normally 10 m, except in the layer closest to the bottom which was sometimes less). These fish number/m^2 values were then exported to GIS for subsequent analyses. In areas of the echogram where there were no data, for example within the matrix of a platform, then the mean value of horizontally adjacent cells was used.

Geographic Information System (GIS) Analyses - The fish number/m^2 values were imported to a Geographic Information System (GIS) (QGIS ver 3.14) for each acoustic cell within a site. A grid was placed over these cell values to obtain averages and abundance data (absolute number of fish per site). Three different sizes of grids were used:

- Discrete Artificial sites – 250 m x 250 m block comprising 25 50 m x 50 m grid cells.
- Natural Bank sites – 500 m x 500 m block, comprising 25 100 m x 100 m grid cells.

- Uncharacterized bottom sites – 2000 m x 2000 m block, comprising 25 400 m x 400 m grid cells.

A spatial join was then performed in the software, so that the point cell data within each grid cell were extracted.

Camera Surveys

As noted above, SRV surveys were taken at discrete habitats and opportunistically at UCB habitats, and TV surveys were taken only over UCB habitat. The purpose of these surveys was to allocate the total fish counts to individual fish species or taxa occurring at a site.

SRV Surveys - Design of the SRV was patterned to be consistent with (Koenig and Stallings, 2015). The SRV consisted of a waterproof canister housing that encased a gear motor run by a rechargeable battery (Figure 9). The motor shaft extended through the top of the canister and was attached to a round platform that served as the mounting point for a GoPro (Hero 7 Black) digital HD camera in an appropriately rated dive housing. GoPros were set to record at 60 frames per second (fps), “Hypersmooth” video stabilization, 4:3 Aspect Ratio, 1920 x 1444 resolution, wide field of view (FOV), and zoom = 0%. A 360° view of fish fauna was captured as the camera rotated, completing two 360° rotations ever minute. The 30 second rotation simulates the stationary visual point count method, the most commonly used method to count reef fish (Bohnsack and Bannerot 1986), where each rotation can serve as a subsample or replicate count for repeated measures of the fish density at the site, if desired.

The SRV was deployed at each discrete site at a stationary point as close to the targeted fish assemblage as possible without risking entanglement of gear. The camera was lowered in 10 m intervals, corresponding to hydroacoustic analysis layers, in order to obtain accurate species proportions used to partition hydroacoustic abundance data. A minimum of 5 minutes of footage was recorded at each depth layer. This time was selected based on the exponential decay curve of new species detected over survey time in similar temperate reef systems (Koenig and Stallings 2015). We expected to capture all non-cryptic taxa including Red Snapper and other important federally-managed species, as well as their relative distribution by depth.

Figure 9. Deployment of Submersible Rotating Video (SRV) System.

The SRV was additionally deployed in UCB sites immediately after conducting hydroacoustic transects. If fish aggregations were observed during hydroacoustic surveys, a location was marked on the vessel's GPS and was subsequently surveyed with a targeted SRV drop, using the methodology described above. This allowed visual census data to be captured on significant fish assemblages and "patch reef" habitats in an otherwise relatively low-density environment. Data were recorded in the field on mini-SD cards then returned to the laboratory for analysis, backup, and archiving. All videos were examined on a high-resolution monitor with multiple reviewers. All fish species were identified to the lowest possible taxon and enumerated in ten 360° revolutions at each depth interval using MaxN, defined as the maximum number of a taxon seen in a single frame. The MaxN method is a commonly used relative abundance metric which provides a conservative estimate that avoids double counting fish (Schobernd et al. 2014, Bacheler et al. 2013, Campbell et al. 2015). These relative abundance data were used to calculate species percentage compositions at each depth layer and subsequently to apportion hydroacoustic abundances to species. Species that were considered cryptic or that did not have swimbladders were excluded from hydroacoustic apportionment, due to the acoustic dead zone and decibel differencing hydroacoustic methodologies.

Towed Video Transects - For each of the designated "UCB" sites (n=51), we deployed a towed video camera (GoPro Hero 7 Black) in either a standard GoPro dive housing in waters less than 60 m, or an Isotta housing, rated to 200 m (Figure 10). The cameras were all set to record at 60 frames per second (fps), "Hypersmooth" video stabilization, 4:3 Aspect Ratio, 1920 x 1444 resolution, wide field of view (FOV), and zoom = 0%. These settings correspond with directional FOV angles as follows: Vertical FOV 94.4°, Horizontal FOV 122.6° and Diagonal FOV of 149.2°.

Figure 10: Towed video camera sled made of ½" aluminum rod and plate, with 25 pounds of lead bolted to the bottom, a current vane at the back, and a GoPro Hero 7 Black (set at 1440, 120 fps, 4x3 wide) in an Isotta housing rated to 200m. The camera is mounted upside down but can be angled between straight forward and 45o down.

The towed video sled was custom built by LGL Animal Care Products. The sled frame was constructed from 1/2” aluminum 6061 T6511 rod and the vein from 0.080” aluminum 5052 H32 Sheet and fitted with a ¼” x 2” stainless steel eyebolt for attachment. The sled was designed to be towed from the surface to record video in straight, near-bottom transects while avoiding bottom snags and turbidity within 1 m of the bottom, where visibility was assumed to negligible and hydroacoustic methods were unable to distinguish fishes from the bottom (Figure 11). The video camera angle was gradually adjusted to account for deployment depth whereby the camera was near forward-looking in shallower waters and near downward-looking in deeper waters (Figure 11). All videos were downloaded to a computer and backed up to an external hard drive onboard the vessel, immediately after recording.

All videos were analyzed in full using a VLC video player on an ASUS notebook computer with an external 27” Apple thunderbolt flat panel display with a resolution of 2560 × 1440 pixels. The videos were generally reviewed at 1x speed. When possible images of fish came into view, the video was carefully reviewed at 0.25x speed. The maximum number of fish of each species observed in each video was derived using MaxN by enumerating every observed fish with time stamps. All fish were subsequently identified to the level of species or the lowest taxonomic level possible or, if unknown, recorded as unidentified. Still images of most fish detected were extracted and saved to confirm identifications. One viewer analyzed all videos and two additional observers analyzed three of the videos independently for verification. Finally, all species identifications were confirmed by three biologists.

Visibility varied among sampling sites and at times was reduced to zero, e.g., in those sites nearest to the outfall of the Mississippi River. It was assumed that catchability (i.e., visual detectability) was constant within each transect and among all species. We assumed that there was no bias for either avoidance or attraction to the sampling gear for any species. Visually derived fish counts were not used to estimate the total numbers of fish in each transect. Instead, the data were used to apportion abundance detected using hydroacoustic methods as the proportion of Red Snapper to the total number of fish detected, as described in SRV methodology. Therefore, while visibility varied among transects, it was relatively constant within transects and the relative apportioning was unaffected.

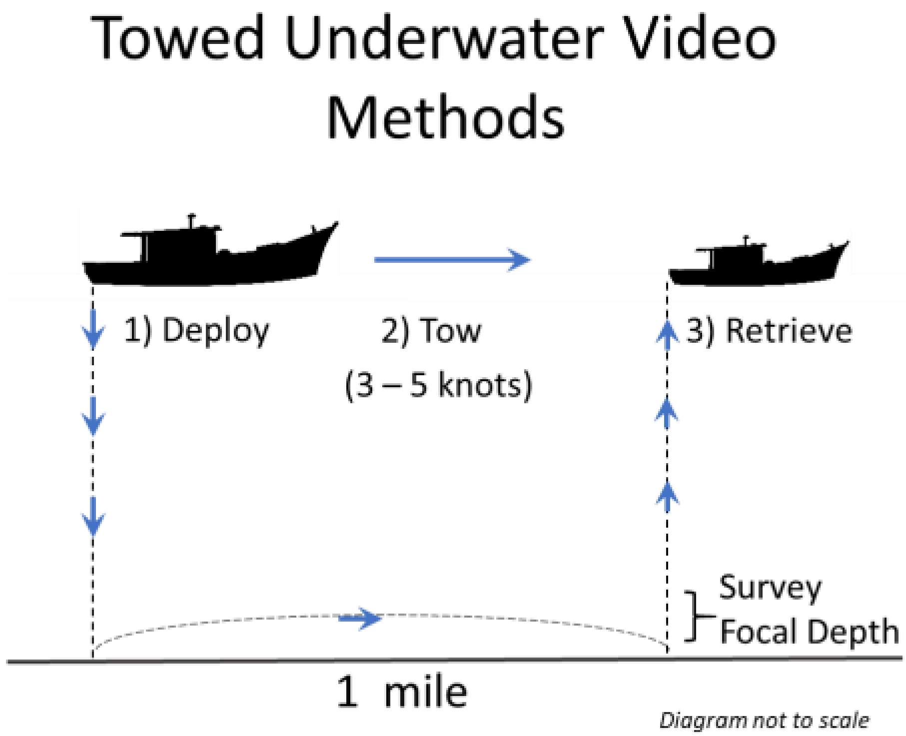

Figure 11: (A) Towed video cameras were deployed by (1) lowering the camera sled straight to the bottom from a stationary vessel, (2) towing the sled along the 1 mile transact at speeds of 3-5 knots without adding additional scope to the tow line, (3) allowing the sled to touch bottom at the end the transect and retrieving vertically. (B) The field of view captured the survey focal depth in shallow waters by angling the GoPro straight ahead and in deeper waters by angling the camera downwards at ~ 45°.

Hook and Line Surveys

Vertical hook-and-line sampling was conducted at discrete sites, and longlines were fished on UCB habitats.

<u>Vertical Hook-and-Line Effort</u> - This method was used at discrete sites (platforms, artificial reefs, pipeline crossings and natural banks) and used 2 hook sizes. The first was a Mustad 6/0, Model # 39948NP-BN, 2X strength, and the second, was a Mustad 11/0, Model # 39965-DT, 2X strength. Bait types consisted of squid and menhaden, with squid size cut to match menhaden size. Each bait type was fished on each hook size giving 4 combinations of hook and bait type. Only one bait-hook combination was fished on an individual pole, and each bait-hook combination was fished an equal number of drops at each site. As fish were brought on board, they were placed into 1 of 4 shrimp baskets specific to hook and bait combination (Figure 12).

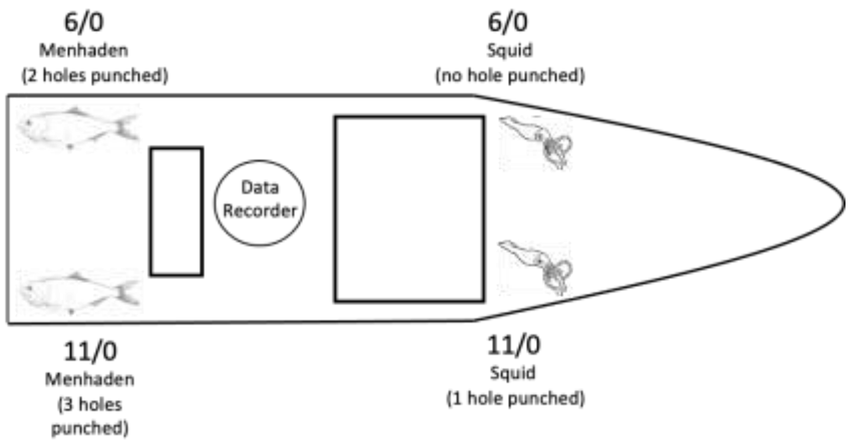

Figure 12. Diagram of vessel setup for sampling at discrete sampling sites.

To indicate the hook and bait combination used to catch an individual fish, holes were punched in the operculum for processing dockside (Figure 13). To maintain consistency throughout the field season, hole punches specific to hook and bait combinations were as follows:

- Combination 1 - 6/0 - Squid – No hole
- Combination 2 - 11/0 - Squid – 1 hole
- Combination 3 - 6/0 - Menhaden – 2 holes
- Combination 4 - 11/0 - Menhaden – 3 holes

Figure 13. Hole punching a Red Snapper to indicate bait-hook combination utilized for capture.

Start and end times for composition sampling were recorded on a catch data sheet. Composition sampling lasted for 1.5 hours or ended whenever 40 Red Snapper were caught on a given site. When multiple sampling sites were visited during a day, fish from different sites were marked to site and separated in the ice hold for dockside processing. Upon completion of on-water field sampling activities, vessel and crew returned to port for dockside workups that evening. Once at dock, specimens were unloaded by site, iced down, and prepared for workups. All specimens had bait-hook combination of capture recorded and whole weight measured to the nearest 0.001 kg using an Adam's 165 lb. warrior wash-down scale. Fork and total lengths were measured to the nearest millimeter using a Wildco measuring board, Model # 118-B30. Sex was recorded for every specimen. Red Snapper otoliths were then extracted, cleaned, dried, and stored in a labeled coin envelope specific to each individual and site for age determination (Figure 14). Gutted, whole fish were iced and donated to charity.

Figure 14. Dockside sampling after field sampling activities for the day.

<u>Longline Effort</u> - We deployed bottom longlines from the F/V Hull Raiser at 51 UCB sites in the study area (Figure 1). Longlines were deployed using a hydraulic winch mounted on the bow of the vessel. The main line was made of 1,400 lb. test monofilament with 74 hooks per set; 80 lb. test monofilament gangions, 3 feet in length with Mustad circle hooks alternating between 6/0 and 11/0 (Figures 15, 16). All hooks were baited with squid. Longlines were deployed by three persons, one driving the vessel, one baiting the hooks and one attaching gangions to the main line as it was fed out. The longlines were set using standard methods with one buoy on each end, with weights (20-40 lbs. depending on current) below the buoys and one mile (1.6 km) of line between them (Figure 16). The mainline was cut after attaching the second buoy so the gear was detached from the vessel during the set. Longlines were set parallel to latitude or longitude lines, N-S or E-W, through the center point of each pre-designated 2 km^2 sampling site. Set direction was selected by the captain based on his assessment of currents, winds, depth, obstructions and other factors. We deployed a total of 51 miles of longline, with a total of 60 hours of soak time during the course of the study.

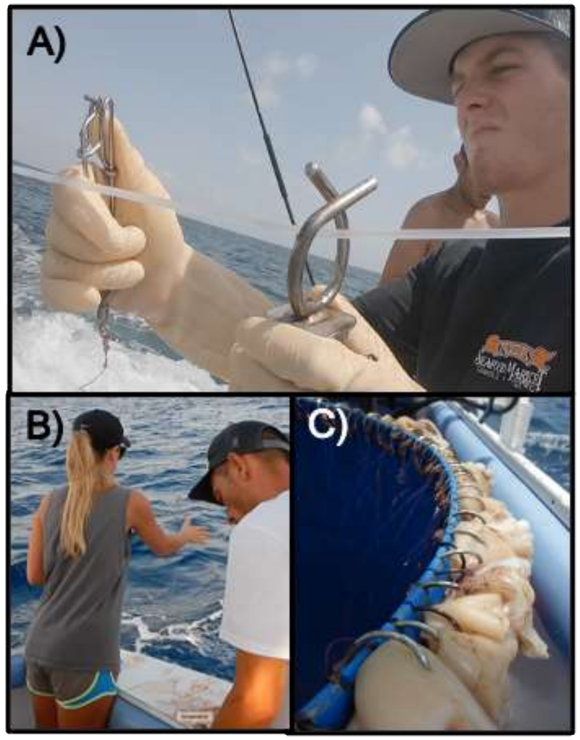

Figure 15. Longline deployment. A. Attaching gangions to the mainline, B. Feeding out the mainline, 3. Hooks, alternating 6/0 and 11/0, baited with squid.

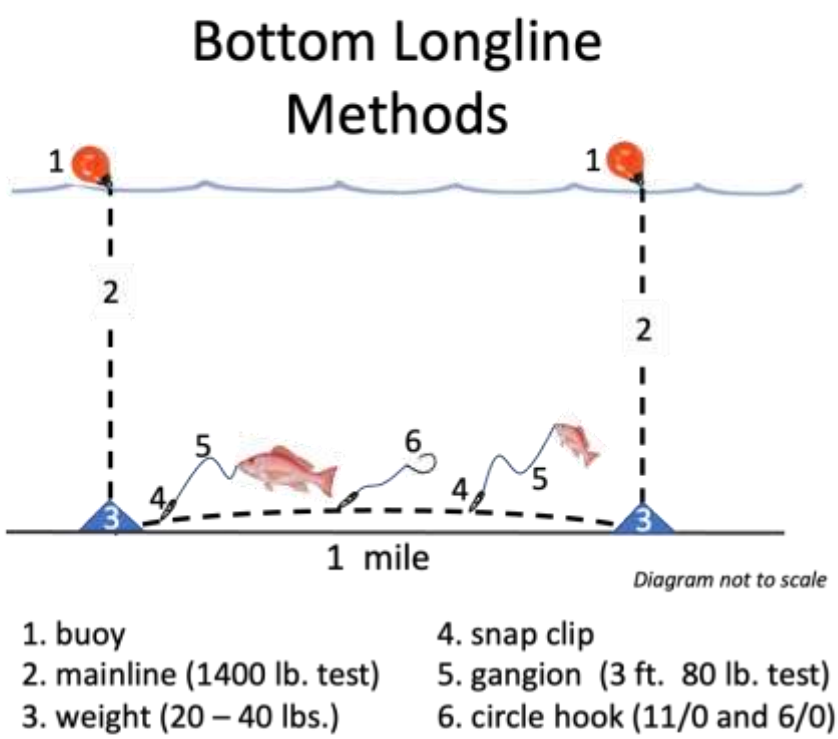

Figure 16: Bottom longline deployment for composition sampling over uncharacterized bottom.

Longlines were soaked for approximately one hour from the start of the deployment to the time the entire line was back on deck. Deployment times ranged from 9 – 21 minutes with a mean of 13 minutes (n=51). Total soak times ranged between 30 and 107 minutes, with a mean of 70 minutes (n=51) and a total soak for all samples of 60 hours. The longline was retrieved with the hydraulic winch in the same direction that it was deployed to standardize the amount of time each hook on the line was fished. The line was "peeled" off the bottom by backing the vessel towards the line to avoid dragging the line along the bottom. As the line was retrieved, all gangions were unhooked from the main line and all fishes were removed from the hooks.

All captured fish were retained and marked at sea to distinguish site and hook size. Fish were marked with a leather punch by punching holes through the gill plate of those fish captured on 11/0 hooks. All fish were stored on ice until the vessel reached port. At dockside, all fish were sexed, measured (FL and TL in mm) and weighed to the nearest 0.001 kg following methods described above. Sagittal otoliths were extracted from all Red Snapper, cleaned, dried and stored in a labeled coin envelope for aging purposes.

Mark/Recapture Studies

As an independent assessment of Red Snapper abundance, a mark/recapture study was conducted at 3 of the 11 of standing platforms and 3 of the 16 artificial reefs sampled during this study. Each of the 3 platforms and 3 artificial reefs were located in the mid-depth zone of each region (Table 5).

Table 5. Regional distribution, habitat type, depth zone, dates and elapsed time between mark and recapture efforts.

				Date (2020)		Elapsed Days
Region	Site	Habitat	Depth Zone	Mark	Recapture	Days
West	3	Platform	MID	5/29	6/14	16
West	13	Artificial Reef	MID	5/29	6/14	16
Central	7	Platform	MID	5/28	6/16	19
Central	17	Artificial Reef	MID	5/28	6/16	19
East	8	Platform	MID	5/21	6/17	29
East	26	Artificial Reef	MID	5/21	6/18	28

Note that, due to logistical constraints, the sites in the east (Sites 8 a nd 26) were sampled first and last with almost a month between mark and recapture. The elapsed days ranged between 15 and 19 days for the other four sites.

Red Snapper were captured by hook and line and then anesthetized with tricaine methanesulfonate (MS-222, 150 mg L^{-1} seawater for 90 sec.). The length (mm) and weight (0.1 kg) of each fish was recorded before being doubled tagged dorsally with Hallprint PDAT 135 mm dart tags. Before release, the fish were held in a 110 L container until they showed substantial recovery, that is, active fin and gill movements. Active fish were then transferred to a release cage and lowered to the bottom. Contact with the bottom caused a door to open so that the fish could exit the cage on their own initiative.

Recapture sampling was also conducted using hook-and-line. All fish caught were measured and, if not a recapture, were released at the surface. Recaptures were weighed, measured and the otoliths removed for aging in the laboratory. A photographic depiction of the mark-recapture process is provided in (Figure 17).

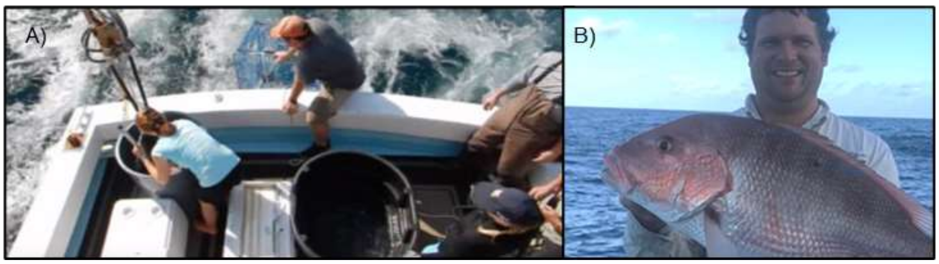

Figure 17. Photographic depiction of the mark-recapture process showing (A) the release of tagged fish and (B) recapture of a doubled tagged Red Snapper.

Age Determinations

Otoliths provided from field sampling were mounted in the laboratory and thin sectioned in a transverse plane with a Pace Technologies, Pico 155 sectioning machine outfitted with 2, 4" diamond embedded wafering blades with a 0.75 mm spacer between the blades. Sections were polished on 2,000 grit wet-dry sandpaper. Otoliths sections were submerged in water in a clear dish and read under transmitted light using a dissecting microscope outfitted with a Tucsen Bioimager camera. This method allowed us to read the annuli along the dorsal margin of the sulcus acousticus from the core to the proximal edge (GSMFC 2009). Edge condition was documented as having an opaque margin or a translucent margin, and depending on width of the margin and time of year at capture compared to the next expected annulus deposition period, an edge code of either 0 (opaque margin present or annulus deposition already completed that year) or 1 (annulus deposition yet to be completed) was assigned. Ages were advanced by one year for an assigned edge code of 1 to standardize ages among fish at different stages of annulus deposition during the year. Two independent readers counted annuli and assigned edge codes without knowledge of morphometric data. Instances of disagreement in initial counts resulted in a second count by both readers and consensus was reached.

STATISTICAL ANALYSES AND MODELING

Two approaches were taken to estimate Red Snapper abundance in the Louisiana State Management Zone. The initial approach was to calculate mean site abundance or density for a given habitat type and then expand this number to a total estimate by multiplying the mean count or density by the total number or area of the respective habitats. This is, in general, the approach used by Stunz et al. (2021) in the Great Red Snapper Count. The second approach used was to model abundance across all habitats, taking depth zone, region and average environmental conditions into account. As an independent assessment of these methods, we also estimated abundance at standing platforms from mark/recapture data. We believe that the modeled site abundance estimates as presented in Table 12 below are the best estimates.

Mean Site Abundance of Red Snapper

Discrete, Artificial Habitats - Each of the discrete artificial sites were characterized from hydroacoustic sampling of 25 polygons, each 50 m by 50 m with a variable number of ~10 m depth layers (up to 11 layers) that depended upon water depth (Table 4). Total fish density estimates (*TFD*) within each polygon and layer were multiplied by the area of each polygon (A_{Pn}) to convert to total fish abundance for that polygon (*TFA*).

In equation 1, *Pn* is polygon (numbers 1 to 25) and *Ld* is depth layer (layers 1 to $\leq$11).

$$[1]\ TFA_{Pn,Ld} = TFD_{Pn,Ld} \times A_{Pn,Ld}$$

Red Snapper abundance (*RSA*) at each polygon and depth layer was determined by multiplying the percent composition of Red Snapper (*PRS*) at each depth layer from Submersible Rotating Video surveys by total fish abundance.

$$[2]\ RSA_{Pn,Ld} = TFA_{Pn,Ld} \times PRS_{Ld}$$

For each polygon Red Snapper abundances were summed over all depth layers.

$$[3]\ RSA_{P1\text{-}25} = RSA_{P1\text{-}25,L1} + RSA_{P1\text{-}25,L2} + \ldots RSA_{P1\text{-}25,L11}$$

Then the Red Snapper abundances for each polygon were summed to generate the abundance for a site (RSA_S).

$$[4]\ RSA_S = RSA_{P1} + RSA_{P2} + RSA_{P3} + \ldots RSA_{P25}$$

Site abundances were stratified by structure type (reefed platforms, pipeline crossings, and standing platforms) and depth zone (shallow, mid, and deep) (Table 3). For reefed platforms and pipeline crossings the arithmetic means and 95% Confidence Intervals at each depth zone were calculated from the corresponding RSA_S's. For standing platforms (n=11) additional data were incorporated from surveys conducted in 2017 and 2018 across the northern Gulf of Mexico (Gallaway et al., in revision). From this larger dataset, we took Red Snapper abundance estimates from only those standing platforms sampled within Louisiana waters (n=37). The arithmetic means and 95% Confidence Intervals for standing platforms (n=48, total) were computed for each depth zone. With the exception of the deepest depth zone (the shelf edge), Red Snapper abundances for each structure type within a given depth zone ($RSA_{structure,\ depth}$) were multiplied by the total number of those structures for that depth zone ($Struct_{depth}$) and summed to produce the mean, lower, and upper estimates of Red Snapper abundance for each structure type across Louisiana waters ($RSA_{structure,LA}$).

$$[5]\ RSA_{structure,LA} = (RSA_{structure,\ shallow} \times Struct_{shallow}) + (RSA_{structure,\ mid} \times Struct_{mid}) + (RSA_{structure,\ deep} \times Struct_{deep})$$

For platforms on the shelf edge depth zone, we used the modeled median and confidence limits presented in Gallaway et al. (in revision). Given the low sample size for this depth stratum (n=3 structures) and highly variable abundance estimates (0 Red Snapper on two platforms and 12,926 on the other platform) we decided that the more representative modeled abundance value (median = 133 Red Snapper) was more appropriate to use than the observed value (mean = 4,309 Red Snapper).

<u>Natural Bank Habitats</u> - Natural bank sites were characterized by hydroacoustic sampling across three strata (West Mid/Deep – Sonnier Bank; West Shelf – Bright Bank; Central/East Deep/Shelf – Alderdice, Ewing, Sackett Banks). For each stratum, total fish densities (*TFD*) were determined within 100 m by 100 m polygons at ~10 m depth layers (Table 4). Submerged Rotating Video data were used to determine the percent composition of Red Snapper (*PRS*) in each 10 m depth interval to calculate Red Snapper density per polygon, per layer (*RSD*). Where *Pn* is a given polygon and *Ld* is the depth layer.

$$[6]\ RSD_{Pn,Ld} = TFD_{Pn,Ld} \times PRS_{Ld}$$

Owing to the positive skew of these data (in some cases, a large portion of polygons had no fish detected and a few polygons with large numbers of fish detected), density data were summarized using the geometric mean. This involves computing the log_{10}-transformed mean of non-zero polygons ($n_{non\text{-}zero}$), back-transforming the mean, and then multiplying by the ratio of non-zero polygons and total polygons sampled (*n*). This procedure to compute the geometric mean of Red Snapper density (RSD_{GM}) was conducted for each depth layer (*d*). Thus, for each depth layer,

$$[7]\ RSD_{GM,Ld} = 10\text{^}((log_{10}(RSD_{P1,Ld}) + log_{10}(RSD_{P2,Ld}) + \dots log_{10}(RSD_{Pn,Ld})) / n_{non\text{-}zero}) \times (n_{non\text{-}zero} / n)$$

Red Snapper densities were then summed over all depth layers and multiplied by total bank areas ($BA_{Stratum}$) in each stratum to calculate Red Snapper abundances for the stratum ($RSA_{Stratum}$).

$$[8]\ RSA_{Stratum} = (RSD_{GM,L1} + RSD_{GM,L2} + \dots RSD_{GM,L11}) \times BA_{Stratum}$$

<u>Uncharacterized Bottom Habitats</u> - For UCB sites, total fish density was summed over the bottom two depth layers so that estimates of fish density corresponded to the same survey area viewed by the Towed Video for determining species composition. Additional depth layers were included where Red Snapper were documented higher in the water column over "patch reef" areas; in these instances, SRV drops were made over the patch reef areas to determine species composition and fish density was summed over all depth layers. This occurred on three sites in the West Deep stratum (hydroacoustic sites designated A10, A11, and A13). Following Equation [7], the geometric mean of total fish

density (TFD_{GM}) was calculated using all polygon total fish density (TFD) estimates in each Region-Depth Zone stratum (Table 1).

$$[9]\ TFD_{GM,R\text{-}D} = 10\text{^}((log_{10}(TFD_{P1}) + log_{10}(TFD_{P2}) + \ldots\ log_{10}(TFD_{Pn})) / n_{non\text{-}zero})$$

$$x\ (n_{non\text{-}zero} / n)$$

Red Snapper densities ($RSD_{R\text{-}D}$) were determined by proportioning the geometric means of total fish density using MaxN data that were compiled across each stratum from the Towed Video of the bottom two depth layers or, in the three instances where patch reefs were encountered, targeted SRV surveys throughout the water column:

$$[10]\ RSD_{R\text{-}D} = TFD_{GM,R\text{-}D}\ \ x\ (RS_{MaxN,R\text{-}D} / TF_{MaxN,R\text{-}D})$$

where $RS_{MaxN,R\text{-}D}$ is the maximum number of Red Snapper observed in a single video frame across a given Region-Depth stratum and $TF_{MaxN,R\text{-}D}$ is the sum of the maximum number of other applicable fish species observed in a single video frame across that stratum.

The resultant Red Snapper densities were then multiplied by the area of similar habitats ($HA_{R\text{-}D}$) within the same stratum (see Table 1) to calculate total Red Snapper abundance ($RSA_{R\text{-}D}$).

$$[11]\ RSA_{R\text{-}D} = RSD_{R\text{-}D}\ x\ HA_{R\text{-}D}$$

Modeled Abundance of Red Snapper

The abundance estimation approach combining hydroacoustic and SRV data had to be carefully evaluated. For example, at a given site an estimation of Red Snapper abundance could be accomplished by combining total fish abundance estimated from the hydroacoustic survey with species relative abundances estimated concurrently with an SRV (Koenig and Stallings 2015). This abundance estimate would be wrong if either the total fish abundance or the proportion attributed to Red Snapper was in error. For instance, the hydroacoustic density estimate may have accurately estimated a total abundance of 2,000 fish and was unknowingly comprised of 1,000 Atlantic Bumper *Chloroscombrus chrysurus* and 1,000 Red Snapper. However, if the SRV sample only recorded 10 fish because of, say poor visibility, nine of which were Atlantic Bumper and only one was a Red Snapper, then the Red Snapper abundance estimate would be biased low (i.e., 200 instead of 1,000). Thus, at a given site, error in the species apportionment would be magnified by the respective estimated total abundance. Averaging across site-specific estimates could then result in a biased overall estimate if an especially egregious apportionment error were unduly weighted by a large total abundance estimate for one of the sites. For this reason, site-specific estimates were notestimated. Instead, we modeled the average proportion of the assemblage structure comprised of Red Snapper for a given habitat type, region, depth zone, and vertical depth band given average environmental variables. Then, we used this output to apportion the corresponding model output of average total fish abundance. In so doing, random errors in species apportionment (i.e., proportion that were Red Snapper) had a greater chance of canceling each other across sites before being multiplied by the total abundance estimates. The same was true for site-specific errors in the total abundance estimates.

For standing platforms, variables quantifying the number of legs descending from the surface and categorizing a given platform as manned/unmanned were considered but were not used in the final model. The number of legs did not capture the number of total pipes descending to the ocean floor nor the complexity of cross structures beneath the surface. We reasoned that the fish assemblage on a manned platform would be exposed more to fishing pressure. However, during field activities, crew boats were sometimes observed tied to and actively fishing platforms designated as "unmanned" in the BOEM database. For these reasons, these variables were considered poor descriptors and were ultimately dismissed as misleading.

Below we describe how relative abundance of Red Snapper and total fish abundance were modeled separately. For each habitat type-region-depth zone-vertical depth band combination, predictions from both models were combined to provide Red Snapper abundance estimates with confidence intervals.

Assemblage Structure from Submersible Rotating Video (SRV) Surveys

At each site, a survey of assemblage structure was available from the SRV MaxN count observations for each vertical depth band. From these data, the relative abundance of Red Snapper was estimated as its MaxN count divided by the sum of the MaxN counts for all species in the sample. This binomial response was modeled using the logit link function:

$$[12]\ log_e\left[\frac{Prop\ Red\ Snapper_i}{1-Prop\ Red\ Snapper_i}\right] = \alpha + x_i\beta$$

where, α = the intercept, x_i=the vector of fixed effects explanatory variables for the ith sample, and β= their corresponding vector of coefficients. Hence, we modeled the log odds of a fish in the assemblage structure being a Red Snapper rather than being something else.

Possible fixed effect variables included the categorical variables DepthZone (10-25 m, 25-45 m, or 45-150 m), Region (East, Central, and West), and HabitatType (Artificial Reef, Natural Bank, Uncharacterized Bottom, Pipeline Crossing, or Standing Platform). Available covariates were DistFromBottom (meters from the bottom to the center of each vertical depth band), salinity, temperature, and dissolved oxygen (DO). Salinity was correlated (Pearson's r > 0.7) with temperature and DO and therefore dropped from the analysis to prevent collinearity. Based on Akaike's Information Criterion (AIC), the most parsimonious model retained Region, HabitatType, temperature and DistFromBottom. Temperature was included as extraneous/nuisance variable to reduce noise and confounding influences. DistFromBottom was entered as a covariate to allow change in Red Snapper relative abundance along the vertical depth gradient. The assumption of linearity for this covariate was relaxed by entering this term as a thin plate smoothing spline; furthermore, this term was allowed to interact with HabitatType. All covariates were converted to standard normal deviates (z-scores) before modeling. Ignoring subscripts and parameters, fixed effects for the final model were specified as follows:

$$[13]\ Prop\ Red\ Snapper = Region + zTemp + HabitatType|\ s(zDistFromBottom)$$

where the operator "|" indicates an interaction of two or more terms and all of the corresponding main effects, "z" indicates normal deviate standardization, and s() indicates a thin plate smoothing spline was used. We attempted to let the intercept and covariates vary randomly across sites, but this specification did little to improve model fit and the random effects were not significant; thus, all effects remained fixed. This specification formed a generalized additive model (GAM) for which we estimated parameters using the gam function in the mgcv Package Version 1.8-36 (Wood 2003) for the R statistical programming language implemented with RStudio (R Core Team 2021).

Total Fish Density from Hydroacoustic Surveys

The hydroacoustic surveys provided observations of total fish density (TFD; fish per m^3) for each site-depth band combination. This response was assumed to be from a Tweedie distribution, which uses the log link function:

$$[14]\ log_e(TFD_i) = \alpha + x_i\beta + z_i b$$

where, TFD_i=predicted total fish per m^3 for the i^{th} sample, α = the intercept, x_i=the vector of fixed effects explanatory variables for the i^{th} sample, β= their corresponding vector of coefficients, and Z_i and b = the random effects and coefficients. The same fixed effects variables were considered as was described above for modeling Prop Red Snapper (salinity was dropped from consideration due to collinearity with temperature and DO). Again, the final model was based on the mix of variables rendering the lowest AIC value. Ignoring subscripts and parameters, fixed effects for the final model were specified as follows:

$$[15]\ TFD_i = zDO + zTemp + HabitatType|\ s(zDistFromBottom) + Region|s(zDistFromBottom) + DepthZone|\ s(zDistFromBottom)$$

The intercept was allowed to vary randomly across sites. Furthermore, the volume of water sampled at each site-depth band combination was entered as an offset. This specification formed a generalized additive mixed model (GAMM) whose parameters were also estimated with the gam function in the mgcv Package Version 1.8-36 (Wood 2003).

Red Snapper Abundance and Associated Variance Propagation

For each Region-Depth Zone-Habitat Type-Vertical Depth Band combination, Prop Red Snapper and TFD were predicted from their respective models described above based on the average observed covariates within each stratum combination. Density of Red Snapper was then predicted as the product of their predicted proportions from the binomial model output and the predicted TFD from the Tweedie model output. The arithmetic variance of TFD was given by the method of moments estimator:

$$[16]\ Var[TFD] = e^{2\mu+\sigma^2}\left(e^{\sigma^2} - 1\right)$$

Where, μ and σ were the respective prediction and its associated standard error (SE) in log space (i.e., on the link scale). Variances from TFD and Prop Red Snapper were then combined using Goodman's (1960) variance of products estimator:

$$[17]\ Var[PropRS * TFD] = PropRS^2 Var[TFD] + TFD^2 Var[PropRS] - Var[TFD] * Var[PropRS]$$

Red Snapper per m^3 was converted to per m^2 based on the average width of each vertical depth band for each stratum combination with the variances expanded accordingly. Then, total Red Snapper abundance for each habitat type was estimated by extrapolation based on the total area or number of structures within each Region-Depth Zone combination. For Natural Banks and Uncharacterized Bottom, the total areas of these habitats were used as multipliers. For Platforms, Artificial Reefs, and Pipeline Crossings the respective total number of structures were multiplied by the predicted number of Red Snapper per respective structure. Red Snapper per structure was estimated by assuming the average area covered at a sampling site subsumed all Red Snapper present at a typical site. These areas were 62,500 m^2 for Artificial Reefs and Pipeline Crossings and 42,000 m^2 for Platforms (equates to a sampling radius of about 115 m from the center). Again, variance estimates for Red Snapper abundance were propagated through all extrapolations.

Mark/Recapture Population Estimates

The purpose of the mark/recapture studies was to obtain the basis for an independent evaluation of the population estimates for Red Snapper that were derived from hydroacoustic and camera surveys. The mark-recapture population estimates for each site were made using the sequential Bayes algorithm described by Gazey and Staley (1986). We selected this method rather than the traditional Petersen approach as modified by Chapman (1951) and Bailey (1951). While the traditional methodologies perform well if large samples are obtained relative to the population level, they have difficulty when the sample size is small (see Corwack 1968). Ricker (1975) and others have pointed out that a pronounced negative bias will occur if the combination of the number of animals marked and the total number later examined for marks falls too low.

Gazey and Staley (1986) addressed the problems associated with small sample sizes using a sequential Bayes algorithm. While the approach is intensive in computation, the advent of cheap, universally-available computing power has made the algorithm both tractable and convenient. The method requires that one first sets the smallest feasible population size (must be at least equal to the number of animals marked); then provide a feasible upper bound to the population which can be finitely large; and lastly, establish K (the number of discrete population levels to be considered within the range of possible population sizes). The Gazey and Staley (1986) Bayes' method can be applied to both single-census type estimates (e.g., Petersen method) as well as to multiple-census type estimates without replacement (e.g., Schnable-type estimates as described by Ricker 1975).

The only known data are M (the marked animals at large), C (the total number of individuals caught in the recapture event) and R (number of recaptures in sample C). Equation 2 of Gazey and Staley (1986) allows calculation of the probability of observing all the R's given some population level N (the sampling distribution); and their Equation 3 calculates a "noninformative" discrete uniform distribution called the prior distribution. The sampling and prior distributions are combined to form the posterior distributions (probability of each N given the data) by using the Bayes' algorithm (Equation 4 from Gazey and Staley 1986). Gazey and Staley (1986) also provide a simple algorithm for computation of the posterior distribution and statistics of interest.

Growth and Condition

Growth was modeled for observed TL (cm) with Von Bertalanffy growth equation.

$$TL_t = L_\infty \left(1\text{-}e\ \text{-}K(t\text{-}\ t_\theta\ )\right)$$

Where;

TL_t = TL at age t;
L_∞ = TL asymptote;
K = growth coefficient;
t = age in years;
t_θ = age at length 0;

A Von Bertalanffy growth model was estimated for the entire sample population and subsequent growth models were not forced through t_θ and allowed to estimate age at TL = 0.

RESULTS

All sites were successfully sampled as planned (Appendix 4) and analysis of all hydroacoustic, SRV, TV, age and mark/recapture samples was completed by the end of April 2021 (Appendix 5). Length and age distribution summaries for Red Snapper are provided in Appendices 6 and 7, respectively. Appendix 8 compares the similarities and differences in the hydroacoustic approaches used here versus those used by Stunz et al. (2021). Overall, we encountered a total of 88 unique taxa (Table 6). Below, we first describe the results obtained from our mean site abundance approach, followed by the results obtained using our modeling approach.

Table 6. A list of the species collected by habitat type (Discrete or UCB) and sampling gear within habitat type. The numbers in the table represent the MaxN Counts observed for a taxa across all habitats and sampling gears used within the overall habitat category.

		Discrete		Uncharacterized Bottom		
Common Name	Scientific Name	SRV	Hook and Line	Towed Video	SRV	Longline
African Pompano	*Alectis ciliaris*	4				
Almaco Jack	*Seriola rivoliana*	3	8		1	
Amberjack sp.	*Seriola sp.*				3	
Angelfish sp.	*Pomacanthidae*	1				
Atlantic Creolefish	*Paranthias furcifer*	150				
Atlantic Croaker	*Micropogonias undulatus*		2			2
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*	1	1			19
Atlantic Spadefish	*Chaetodipterus faber*	66			1	
Bandtail Pufferfish	*Sphoeroides spengleri*	1				
Bar Jack	*Carangoides ruber*	4				
Bermuda Chub	*Kyphosus sectatrix*	171	1		3	
Bicolor Damselfish	*Stegastes partitus*	14				
Black Drum	*Pogonias cromis*		1			
Black Grouper	*Mycteroperca bonaci*	2				
Black Jack	*Caranx lugubris*		4			
Black Margate	*Anisotremus surinamensis*	12				
Blackedge Moray	*Gymnothorax nigromarginatus*					1
Blackfin Snapper	*Lutjanus buccanella*	1	1			
Blackjack	*Caranx lugubris*	4				
Blacktip Shark	*Carcharhinus limbatus*		2	1		3
Blue Angelfish	*Holacanthus bermudensis*	2				
Blue Runner	*Caranx crysos*	76	2	2	60	4
Bluefish	*Pomatomus saltatrix*		1			
Bonnethead Shark	*Sphyrna tiburo*		1			
Bottlenose Dolphin	*Tursiops truncatus*	1		1		
Brown Chromis	*Chromis multilineata*	1				
Bull Shark	*Carcharhinus leucas*	1				
Butterflyfish sp.	*Chaetodon sp.*	1				
Cero Mackerel	*Scomberomorus regalis*			1		
Cherubfish	*Centropyge argi*	2				
Cobia	*Rachycentron canadum*	1	2		1	1
Crevalle Jack	*Caranx hippos*	12	1		21	
Cubera Snapper	*Lutjanus cyanopterus*	2			1	
Damselfish sp.	*Stegastes sp.*	136				
Doctorfish	*Acanthurus chirurgus*	1				

		Discrete		Uncharacterized Bottom		
Common Name	Scientific Name	SRV	Hook and Line	Towed Video	SRV	Longline
Eel sp.						1
Filefish sp.	*Monacanthidae*	1				
French Angelfish	*Pomacanthus paru*	2				
Gafftopsail Catfish	*Bagre marinus*		4			
Giant Snake Eel	*Ophichthus rex*		8			1
Gray Snapper	*Lutjanus griseus*	162	3		2	
Gray Triggerfish	*Balistes capriscus*	4			6	
Great Barracuda	*Sphyraena barracuda*	4			1	
Greater Amberjack	*Seriola dumerili*	12	7		3	
Grouper sp.	*Epinephelinae*	2				
Grunt sp.	*Haemulon sp.*	31				
Hammerhead Shark sp.	*Sphyrnidae sp.*	2				
Hardhead Catfish	*Ariopsis felis*		18			2
Horse-eye Jack	*Caranx latus*	80			1	
Jack sp.	*Carangidae sp.*	20			1	
Jolthead Porgy	*Calamus bajonado*		1			
King Mackerel	*Scomberomorus cavalla*	28			1	
Knobbed Porgy	*Calamus nodosus*	1				
Lane Snapper	*Lutjanus synagris*		3			4
Leatherjack	*Oligoplites saurus*	27				
Little Tunny	*Euthynnus alletteratus*					1
Longsnout Butterflyfish	*Prognathodes aculeatus*	3				
Lookdown	*Selene vomer*		1			
Mackerel sp.	*Scomberomorus sp.*			9	2	
Mahi Mahi	*Coryphaena hippurus*		3			1
Ocean Triggerfish	*Canthidermis sufflamen*	2				
Porgy sp.	*Calamus sp.*	3				
Puffer sp.	*Tetraodontidae*	1				
Queen Angelfish	*Holacanthus ciliaris*	1				
Rainbow Runner	*Elagatis bipinnulata*	16			1	
Ray sp.						1
Red Drum	*Sciaenops ocellatus*				10	
Red Porgy	*Pagrus pagrus*	7				
Red Snapper	*Lutjanus campechanus*	66	47	5	31	27
Reef Butterflyfish	*Chaetodon sedentarius*	2				
Remora	*Remora remora*		1			
Rock Beauty	*Holacanthus tricolor*	1				
Rock Sea Bass	*Centropristis philadelphica*					3

		Discrete		Uncharacterized Bottom		
Common Name	Scientific Name	SRV	Hook and Line	Towed Video	SRV	Longline
Round Scad	*Decaptertus punctatus*	1481				
Sailor's Choice	*Haemulon parra*		1			
Sand Seatrout	*Cynoscion arenarius*					4
Sand Tilefish	*Malacanthus plumieri*	1				
Saucereye Porgy	*Calamus calamus*	2				
Scad sp.	*Decaptertus sp.*	387				
Scalloped Hammerhead	*Sphyrna lewini*					2
Scamp	*Mycteroperca phenax*	6	3		2	
Seargent Major	*Abudefduf saxatilis*	1				
Shark sp.	*Carcharhinidae*	3	1	1	1	2
Sharksucker	*Echeneis naucrates*	1		2		1
Silver Seatrout	*Cynoscion nothus*		1			
Smooth Pufferfish	*Lagocephalus laevigatus*					5
Smoothhound	*Mustelus sp.*					4
Snapper sp.	*Lutjanus sp.*	20		1	1	
Southern Kingfish	*Menticirrhus americanus*					3
Spanish Hogfish	*Bodianus rufus*	4				
Spinner Shark	*Carcharhinus brevipinna*	1			1	2
Spotfin Hogfish	*Bodianus pulchellus*	3				
Squirrelfish	*Holocentrus adscensionis*	1				
Squirrelfish sp.	*Holocentridae sp.*	1				
Stingray sp.	*Dasyatidae sp.*	1				
Sunshinefish	*Chromis insolata*	1				
Tiger Shark	*Galeocerdo cuvier*					1
Triggerfish sp.	*Balistes sp.*	1				
Mackerel Tuna sp.	*Scombridae sp.*	21				
Vermilion Snapper	*Rhomboplites aurorubens*	255	10		61	
Whitebone Porgy	*Calamus leucosteus*		1			
Wrasse sp.	*Halichoeres sp.*	3				
Yellow Jack	*Carangoides bartholomaei*	9				
Yellowmouth Grouper	*Mycteroperca interstitialis*	1				
Yellowtail Reeffish	*Chromis enchrysura*	27				
Baitfish	*Unidentified small silvery*	727				
UnID	*Unidentified*	796		8	30	
		60	**29**	**6**	**19**	**21**
	Total Unique Taxa across entire study			**88**		

Mean Site Abundance Results

Overall, estimates of Red Snapper abundance based on mean abundance suggest that the total population of Red Snapper in the Louisiana State Management Program for Recreational Red Snapper area is about 4,180,643 fish (Table 7). On the order of 62% of the population is estimated to occur in association with UCB habitat and 37% of the total fish occurred at artificial reefs. Only about 1% of the Red Snapper population in West Louisiana occurred at natural banks and most of these (28,159 of the total 39,556) occurred at Sonnier Bank. This bank is much shallower and smaller than the other natural banks offshore of West Louisiana (Table 7, see also Figure 2, Panel B). As will be elaborated below, the Red Snapper population within the study area is characterized by a wide size and age range; i.e., older and larger fish are common. As a result, the total biomass of Red Snapper within the study area is large (32,227,099 lbs., Table 7). For reference purposes, the Overfishing Limit (OFL) for Red Snapper for the entire Gulf of Mexico during the period 2016 through 2021 was 15.5 million pounds, roughly half the biomass estimated to occur offshore Louisiana alone (NMFS 2021). Of interest, about 24.4 million pounds (82% of the Louisiana total biomass) occurs over UCB habitat (Table 7). Because the fish are widely dispersed over this area, they are largely unavailable to the vertical line fisheries. The UCB may functionally serve as a large marine protected area for Red Snapper offshore.

Discrete Habitats

A total of 55 discrete sites were sampled in our program, and these efforts resulted in 154 km of hydroacoustic survey transects and 72 individual SRV surveys. The SRV surveys yielded a total of 39,014 fish counted of which 2,813 were Red Snapper. A total of 69 h of hook-and-line fishing effort was expended at discrete sites. These efforts yielded a total of 996 Red Snapper of which 993 were used for age composition.

Natural Banks - Overall, we estimated that the area of natural bank habitat in the study area was on the order 724 km^2. Density of Red Snapper was observed to be highest at the shallowest bank (Sonnier Bank, density of 0.0614 Red Snapper/100m^2) which also had the smallest area (45.9 km^2). Density on the deep banks was slightly higher in the West region (0.0022 Red Snapper/100 m^2) than observed in the Central/East region (0.0015 Red Snapper/100 m^2). Using these density estimates and the respective areas in each strata yields a total of 39,556 Red Snapper (Table 7). In contrast, had the overall mean density (0.0217 Red Snapper/100 m^2) observed for natural banks been applied to the estimate of total area, we would have obtained an estimate of 157,151 Red Snapper. We believe this approach would have yielded a large overestimate because density was not homogeneous over the area.

The Red Snapper at natural banks within the study area typically included large fish, and most were between 470 mm and 690 mm TL, and from 5 to 9 years in age (Figure 18). Good numbers of fish were also observed in the 10- to 17- year old age categories. We estimate that Red Snapper biomass at natural banks within the study area was on the order of 238,550 lbs.

<u>Standing Platforms</u> - Based on mean abundance, a total of 1,322,670 Red Snapper were estimated to occur in association with the 821 remaining offshore oil and gas structures in the study area in 2020. The total biomass of Red Snapper at standing platforms was 6,722,541 lbs. (Table 7). In 2018, the study area had 882 oil and gas platforms which harbored an estimated 1,353,061 Red Snapper (Gallaway et al. 2020). In our current study, the highest numbers of Red Snapper (2,734 fish per platform) occurred at platforms in the Mid strata (25- to 45- m deep) followed by 2,329 Red Snapper per platform in the Deep Strata (45- to 100- m deep).

Red Snapper on platforms, overall, were characterized by a wide length range (270 mm TL to 770 mm TL) and most of the fish were between 3 and 8 years in age (Figure 19). More smaller and younger fish were present on the platforms than were observed on the deeper natural banks.

Table 7. Estimates of absolute abundance and biomass of Red Snapper in Louisiana waters, 2020. 95% CI below each estimate in parenthesis.

Panel A Natural Banks and UCB				
Habitat Type	Area (km^2)	Density ($Fish/100m^2$)	Abundance	Biomass (lbs.)
1) Natural Banks	**724.2**		**39,556**	**238,550**
			(12,896 - 134,749)	
West Deep (Sonnier)	45.9	0.0614	28,159	
		(0.0217 - 0.176)	(9936 - 80,737)	
West Deep/shelf (Bright)	134.0	0.0022	2,969	
		(0.00040 - 0.0122)	(538 - 16,389)	
Central/East-Deep shelf	544.4	0.0015	8,428	
		(0.00044 - 0.00691)	(2422 - 37,623)	
2) UCB	**44,906**		**2,605,697**	**24,421,007**
			(1,594,497 - 4,298,756)	
West Shallow	10,267.6	0.00000	-	
		-	-	
West Mid	5,297.2	0.00067	35,386	
		(0.00031 - 0.00145)	(16,352 - 76,575)	
West Deep	5,892.6	0.00269	158,768	
		(0.00160 - 0.00453)	(94,370 - 267,111)	
Central Shallow	4,407.1	0.00000	-	
		-	-	
Central Mid	3,760.0	0.01625	611,079	
		(0.00948 - 0.0279)	(356,551 - 1,047,305)	
Central Deep	6,043.1	0.00055	33,191	
		(0.00040 - 0.00076)	(23,930 - 46,036)	
East Shallow	3,058.4	0.02555	781,400	
		(0.01712 - 0.03812)	(523,717 - 1,165,870)	
East Mid	2,326.7	0.01063	247,253	
		(0.00518 - 0.0218)	(120,415 - 507,695)	
East Deep	3,853.0	0.01917	738,620	
		(0.0119 - 0.0308)	(459,162 - 1,188,164)	

Continued on following page

Panel B. Artificial Reefs				
Habitat Type	**Structure Count**	**Number/ Structure**	**Abundance**	**Biomass (lbs.)**
Artificial Reefs	**1,777**		**1,535,390**	**7,567,542**
			(413,921 - 2,649,435)	
Standing Platforms (821)			**1,322,670**	**6,722,541**
			(411,623 - 2,235,588)	
Shallow	362	678	245,343	
		(139 - 1216)	(50,413 - 440,273)	
Mid	216	2734	590,481	
		(905 - 4562)	(195,558 - 985,405)	
Deep	207	2329	482,057	
		(788 - 3870)	(163,060 - 801,055)	
Shelf	36	133	4,788	
		(72 - 246)	(2592 - 8,856)	
Reefed Platforms (442)			**170,363**	**613,652**
			(2299 - 316,374)	
Shallow	0	-	-	
		-	-	
Mid	97	1,491	144,651	
		(0 - 2755)	(0 - 267,248)	
Deep	305	74	22,446	
		(7 - 140)	(2053 - 42,838)	
Shelf	40	82	3,267	
		(6 - 157)	(246 - 6288)	
Pipeline Crossings (514)			**42,357**	**231,349**
			(0 - 97,473)	
Shallow	135	0	-	
		-	-	
Mid	147	125	18,370	
		(0 - 261)	(0 - 38,333)	
Deep	172	103	17,784	
		(0 - 255)	(0 - 43,845)	
Shelf	60	103	6,204	
		(0 - 255)	(0 - 15,295)	
		Grand Total	**4,180,643**	**32,227,099**
			(2,021,314-7,082,940)	

**95% Confidence Intervals below each estimate in parentheses*

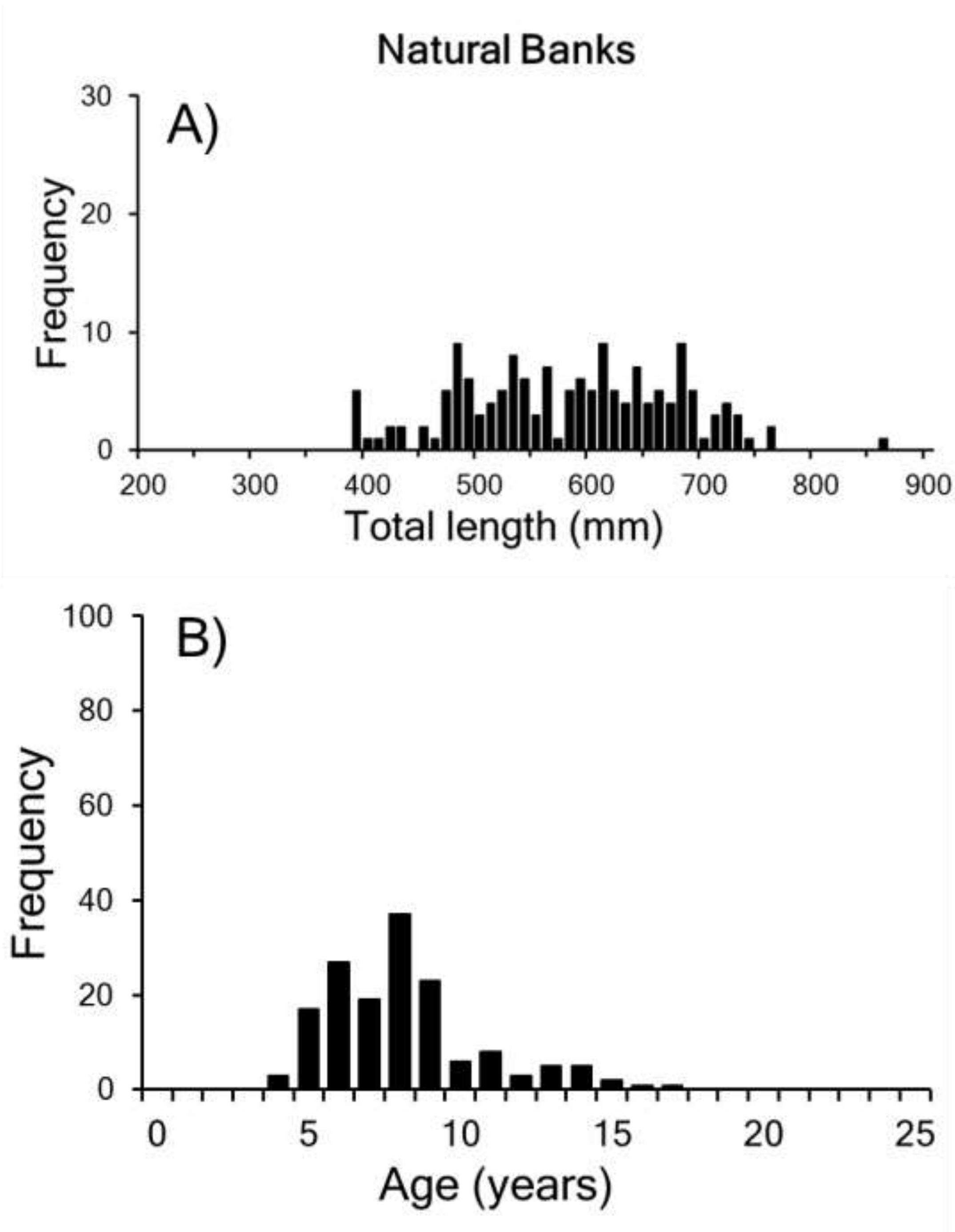

Figure 18. (A) Length and (B) age frequency of Red Snapper on natural banks within the study area 2020.

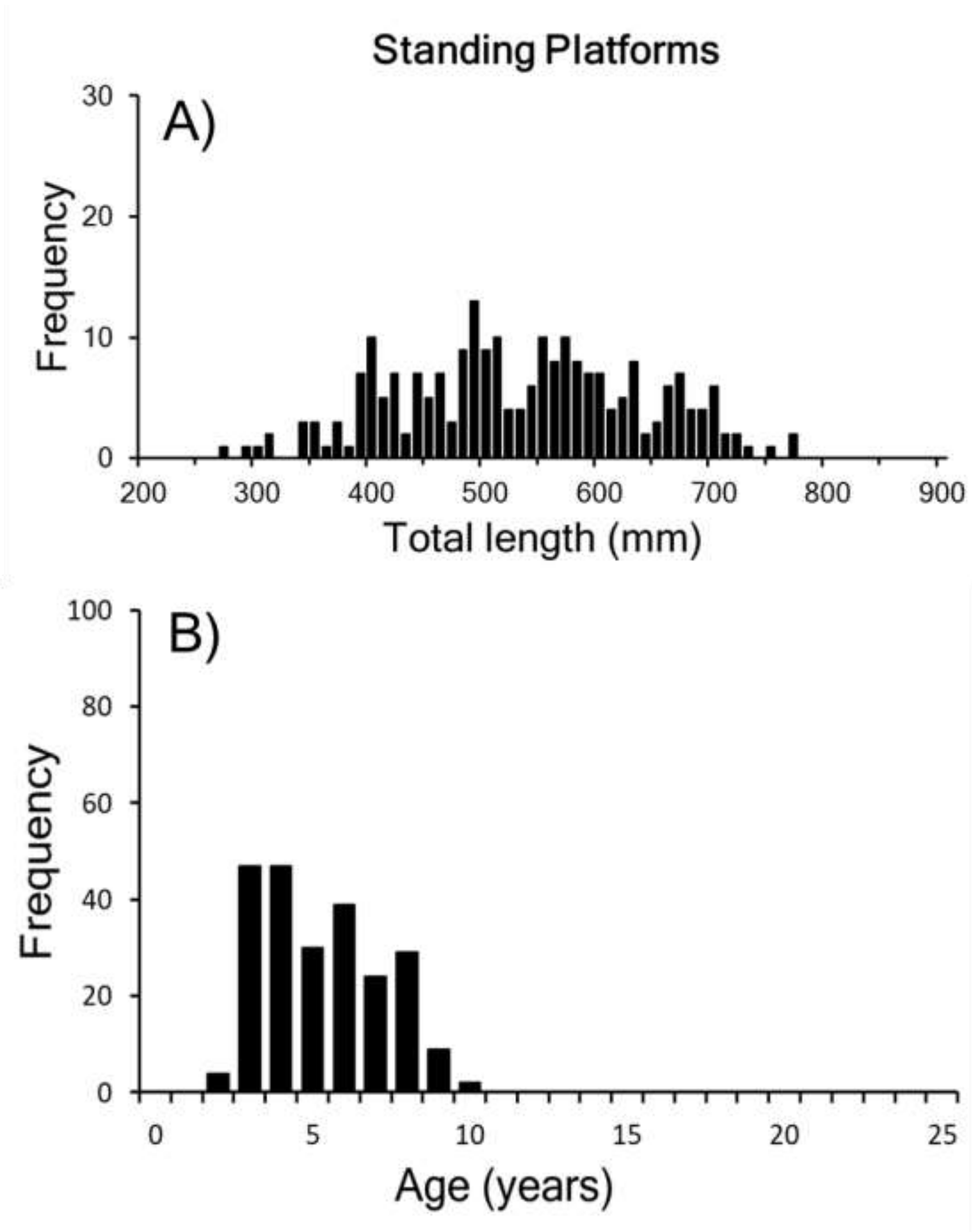

Figure 19. (A) Length and (B) age frequency of Red Snapper on offshore oil and gas platforms within the study area 2020.

<u>Mark/Recapture Studies.</u> A summary of the mark/recapture results show that sample sizes at mid-depth sites in the East Region (Sites 8 and 26) were small and that Site 8 had 0 recaptures and only 1 recapture was made at Site 26 (Table 8).

Table 8. Summary of mark/recapture data by region, site, depth zone and elapsed days. (see Table 5 for more information, e.g., dates of mark and recapture).

				Numbers		
Region	Site	Habitat	Depth Zone	Mark	Recapture	Tags
West	3	Platform	MID	30	117	2
West	13	Artificial Reef	MID	45	45	3
Central	7	Platform	MID	28	89	4
Central	17	Artificial Reef	MID	31	81	4
East	8	Platform	MID	4	35	0
East	26	Artificial Reef	MID	16	58	1

Sites 8 and 26 were also characterized by the largest sampling interval between mark and recapture efforts (see Table 5).

Both of the mark/recapture estimates obtained for the remaining platforms (West Site 3, Figure 20 and Central Site 7, Figure 21) indicated that the hydroacoustic/SRV estimate was within the 95% Highest Posterior Density (HPD) region of the Bayesian Mark Recapture estimates. The HPD is considered to be the range of the most likely values (95% certain that the true value lies within this range) and that any value within this range has a higher probability of being the true value than any point outside this range.

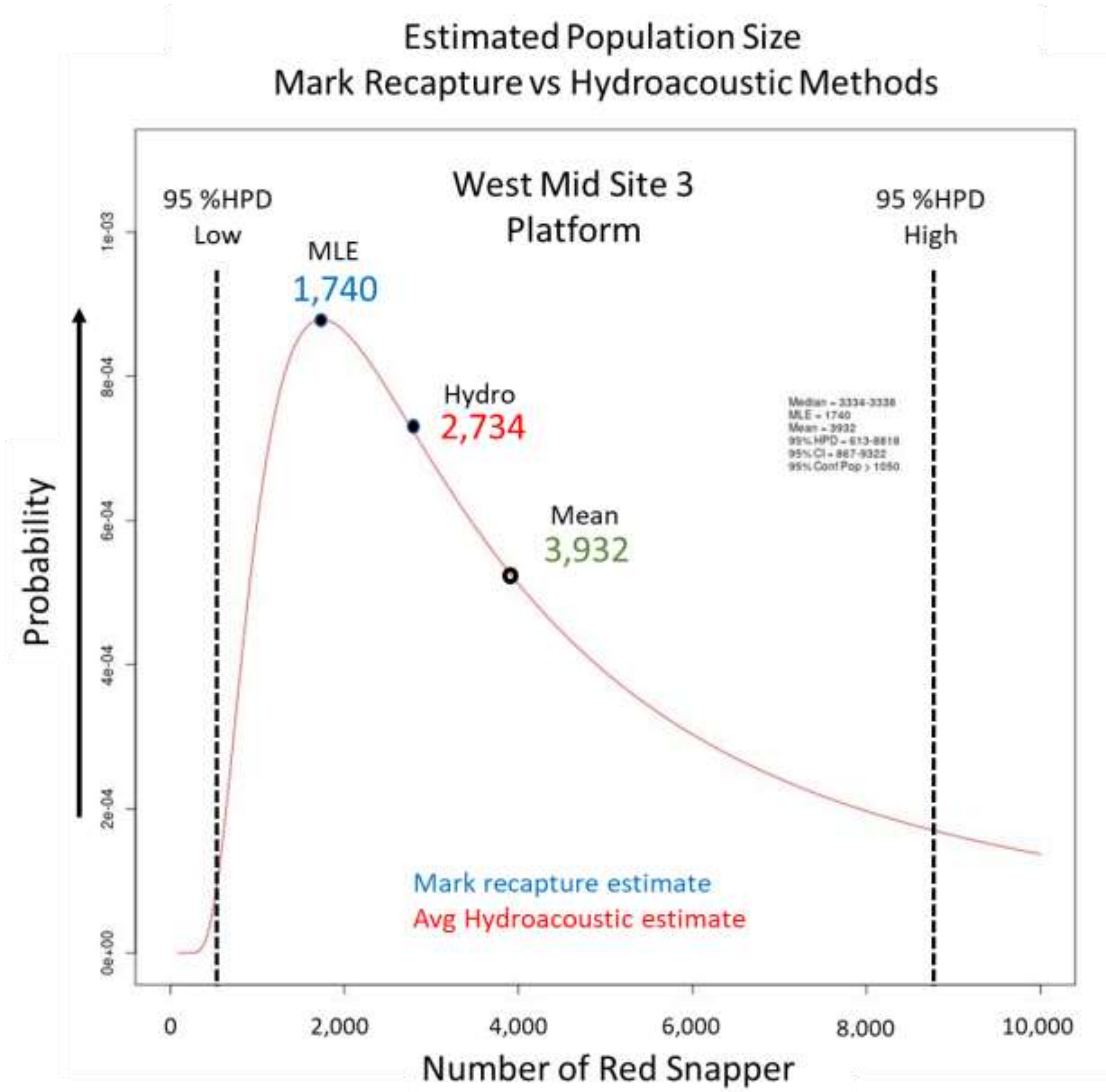

Figure 20. Comparison of the respective hydroacoustic population estimate to the mark/recapture population estimate for the Platform Site 3. MLE and mean population estimates are plotted; MLE, mean and median estimates are shown in table.

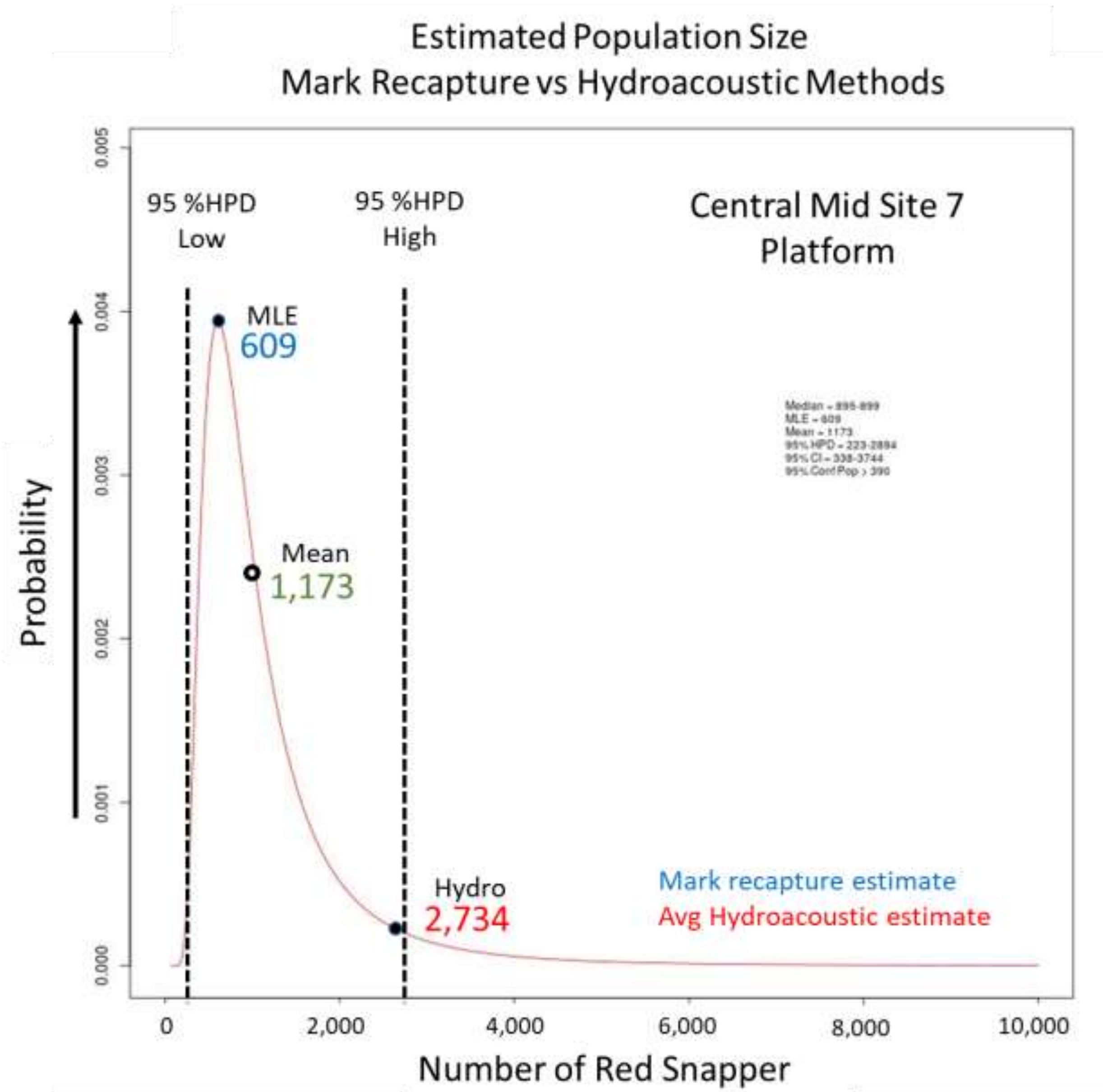

Figure 21. Comparison of the respective hydroacoustic population estimate to the mark/recapture population estimate for the Platform Site 7. MLE and mean population estimates are plotted; MLE, mean and median estimates are shown in table.

Reefed Platforms – As shown by Figure 4, Panel A above, 442 artificial reefs consisting of reefed offshore oil and gas platforms were present within the study area in 2020 and all were located at depths ≥ 25 m. These structures provided habitat for an estimated 170,363 Red Snapper having an associated biomass of 613,652 lbs. A broad range of sizes were observed at these habitats (e.g., 300- to 740- mm TL) and most of the fish were between 3 and 6 years in age (Figure 22).

The largest populations of Red Snapper (1,491 fish per reefed platform) based on hydroacoustic estimates were associated with the reefed platforms in the 25- to 45- m depth zone (Table 7). The corresponding population estimates for Red Snapper based on mark/recapture studies conducted at mid-depth reefed platform sites were all smaller than the corresponding hydroacoustic estimates (Figures 23-25). However, the generic hydroacoustic estimate (1,491 Red Snapper per site) was within the 95% HPD range for the mark/recapture estimates in all cases.

<u>Pipeline Crossings</u> – We identified some 514 crossings of large pipelines (see Figure 4, Panel B). We found that population sizes of Red Snapper at these structures to vary only slightly with all estimates being on the order of 100 or so fish (103 to 125, Figure 5). This results in a total estimate of some 42,357 Red Snapper at the defined pipeline crossings having an associated biomass of 231,349 lbs.

Sizes of Red Snapper at pipeline crossings located within the study area at depths between 25 and 150 m exhibited a broad size range (270-770 mm TL) (Figure 26). Most of the fish were between 2 and 8 years of age and the maximum age observed in this habitat was a 15- yr. old fish.

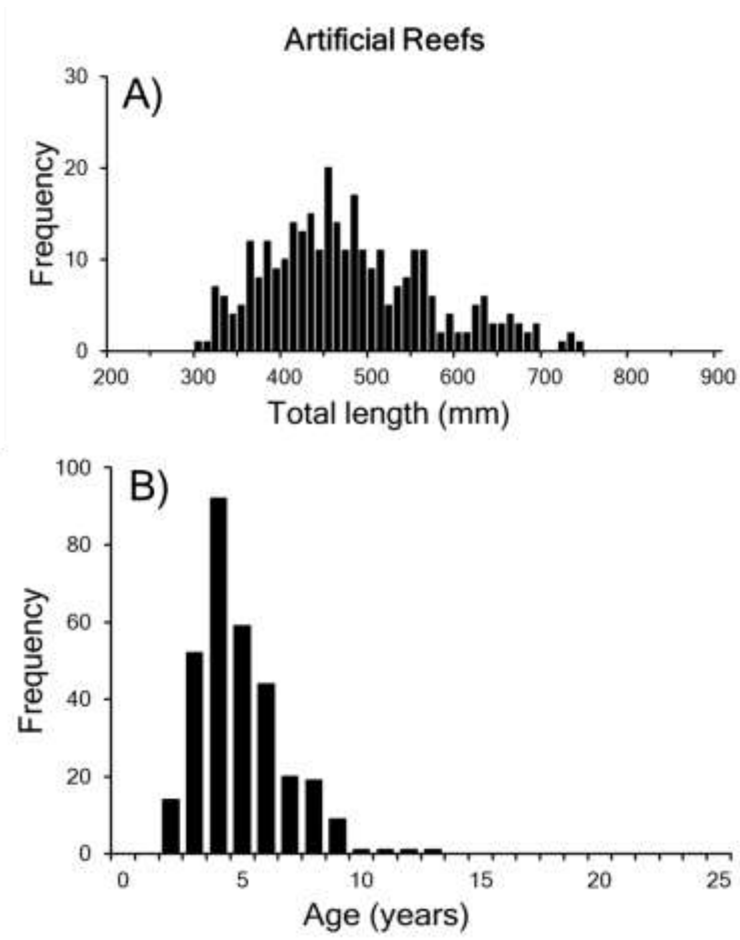

Figure 22. (A) Length and (B) age Frequency of Red Snapper on reefed platforms within the study area 2020.

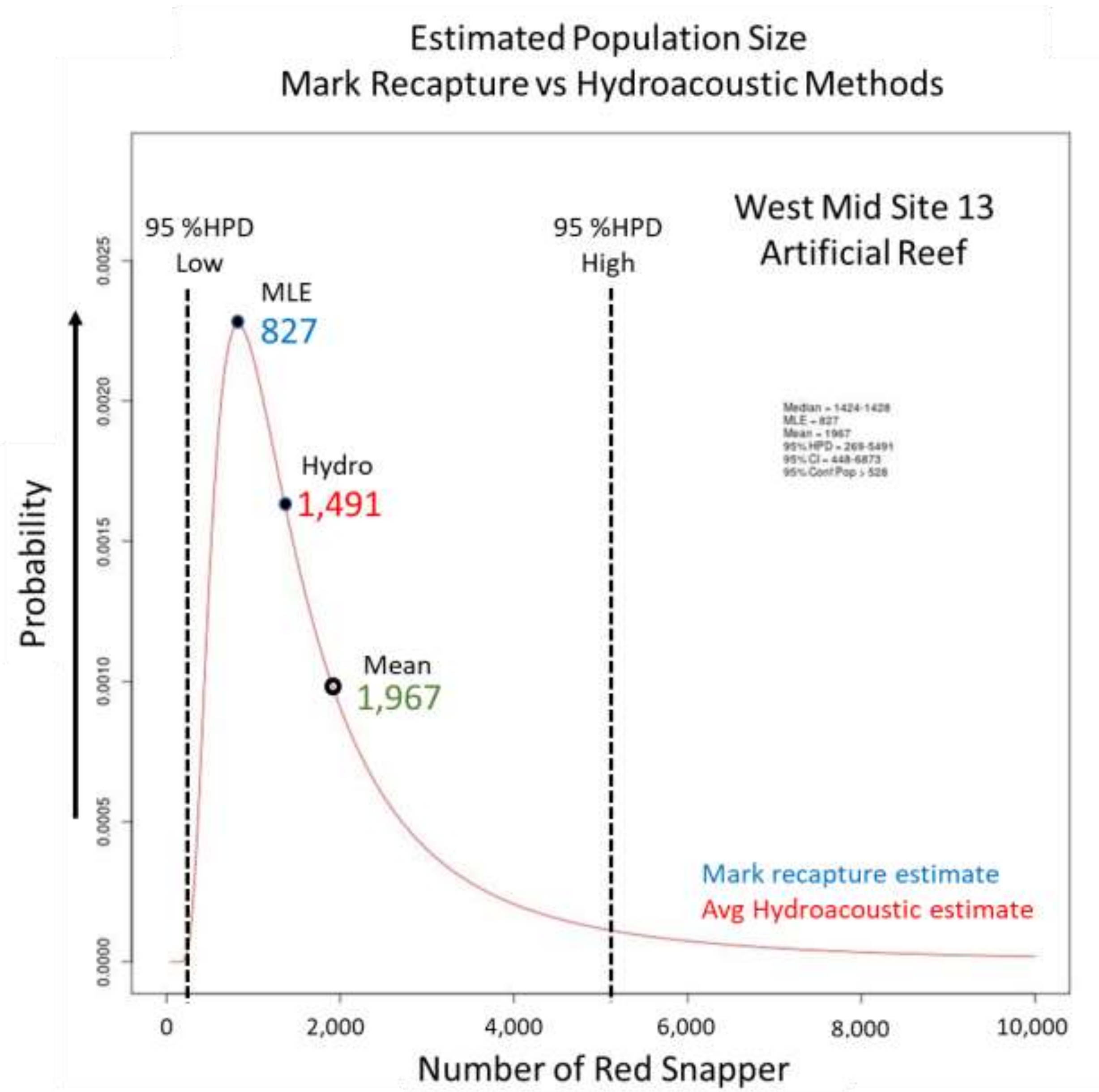

Figure 23. Comparison of the hydroacoustic population estimate for Red Snapper at a reefed platform site in the mid-depth site in the mark/recapture estimate for Site 13, a mid-depth site in the West Region. MLE and mean population estimates are plotted; MLE, mean and median estimates are shown in table.

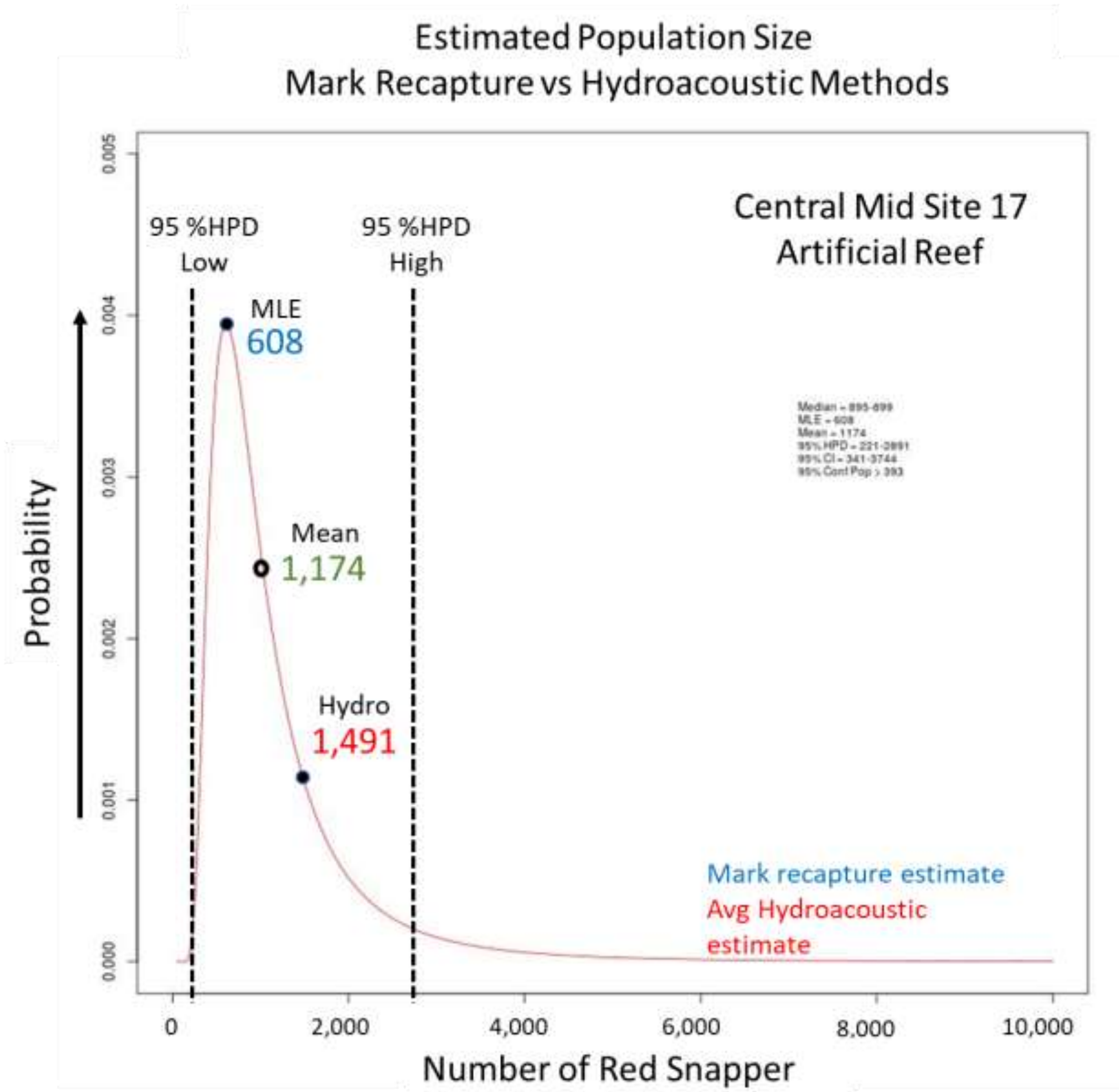

Figure 24. Comparison of the hydroacoustic population estimate for Red Snapper at a reefed platform site in the mid-depth range to the mark/recapture estimate for Site 17, a mid-depth site in the Central Region. MLE and mean population estimates are plotted; MLE, mean and median estimates are shown in table.

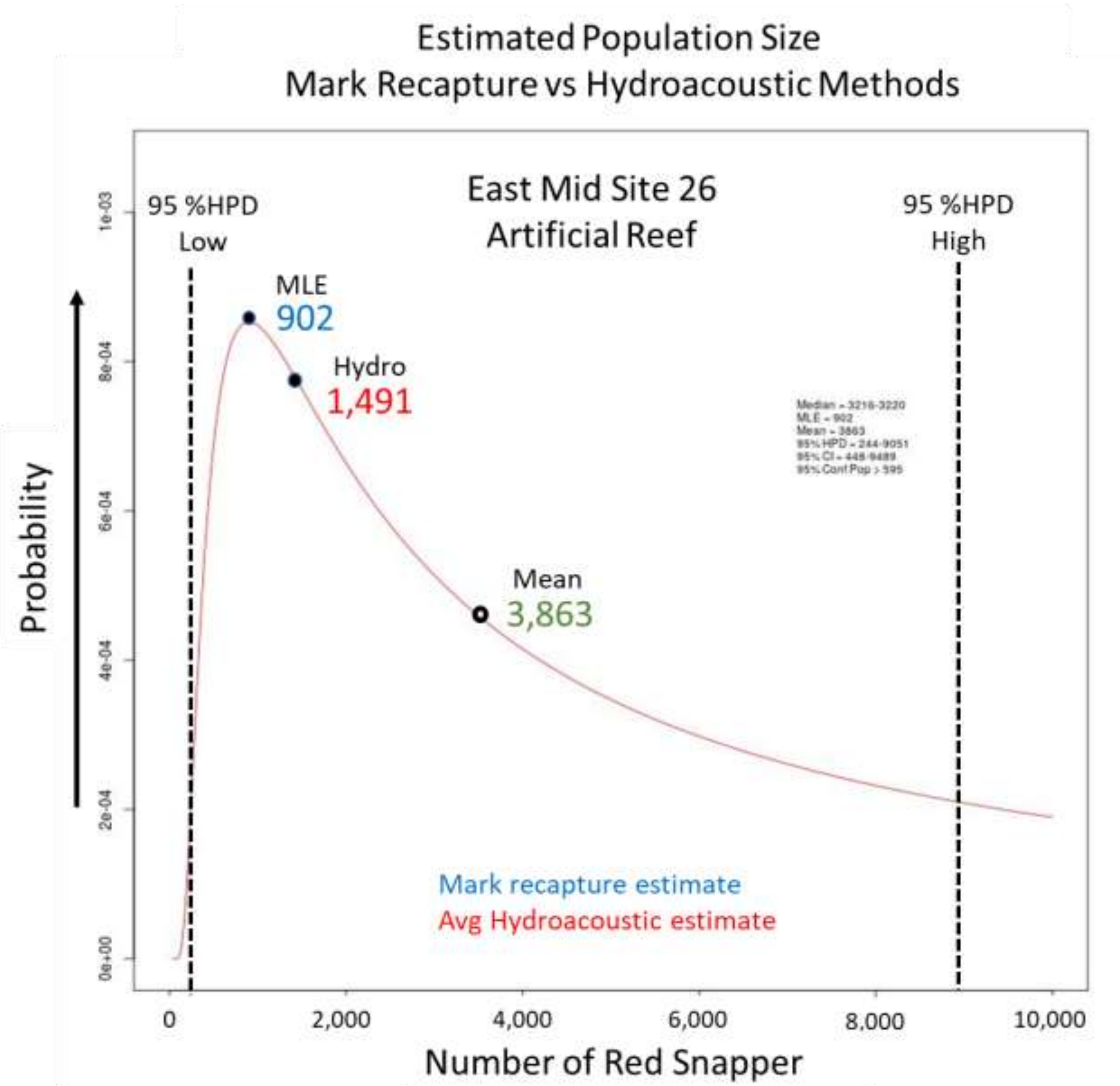

Figure 25. Comparison of the hydroacoustic population estimate for Red Snapper at a reefed platform site in the mid-depth range to the mark/recapture estimate for Site 26 in the East Region. MLE and mean population estimates are plotted; MLE, mean and median estimates are shown in table.

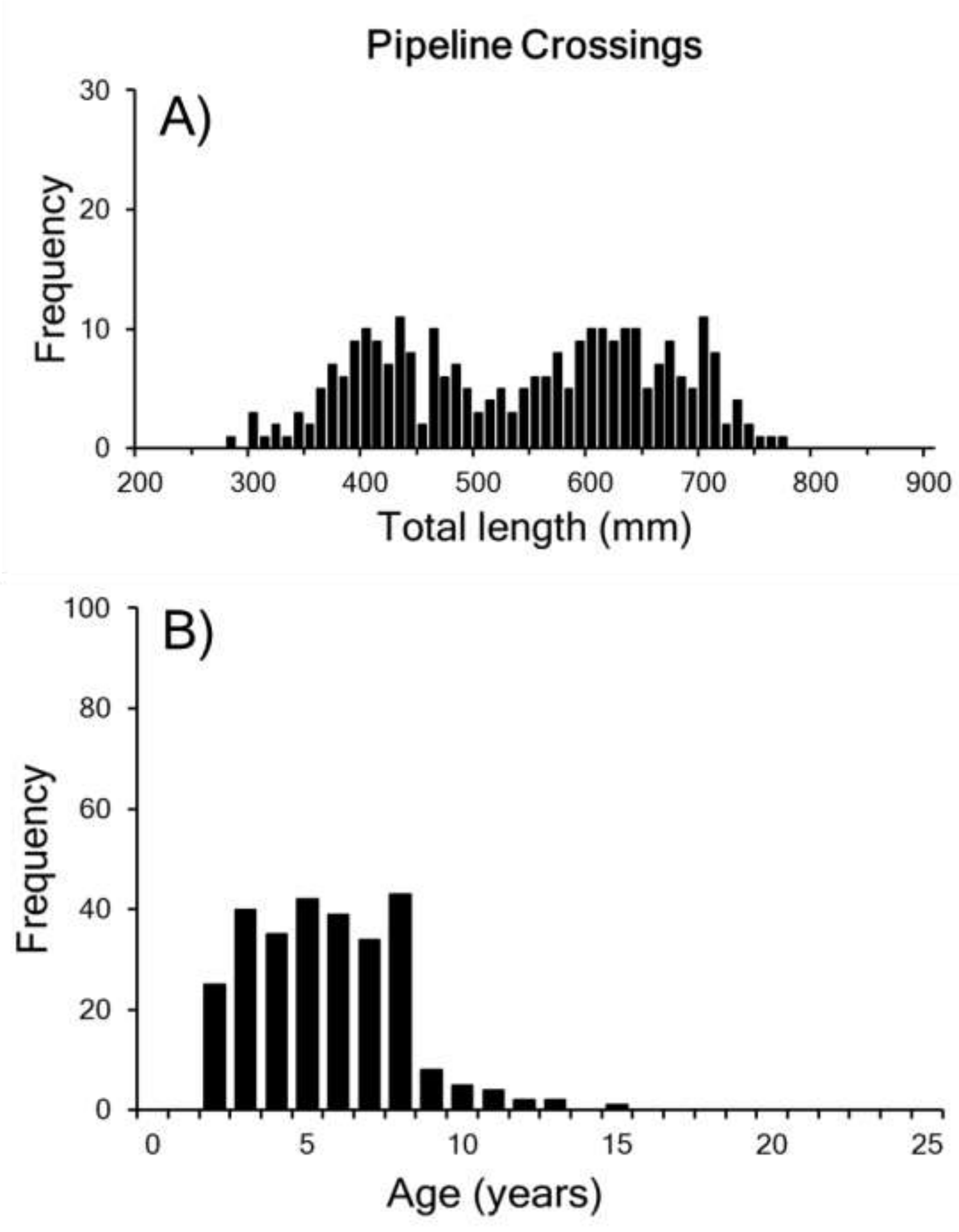

Figure 26. (A) Length and (B) age frequency of Red Snapper on pipeline crossings, within the study area 2020.

Uncharacterized Bottom Habitat

A total of 51 total samples were taken from 39 unique UCB sites. These surveys included 702 km of hydroacoustic transects supplemented by 90 linear miles (49 km) of towed video transects and 51 miles (28 km) of bottom longline sets. In addition to these, 14 SRV surveys were made at locations where bottom obstruction features were discovered along the transects. These SRV surveys contained the observations of 3,234 fish suspended above the features of which 1,433 were Red Snapper. For comparison, Towed Video surveys contained a total of only 101 fish of which 11 were Red Snapper. The 60 hours of bottom longlining effort yielded 190 Red Snapper. Red Snapper were not uniformly distributed along the transects but occurred in "clumps" of fish associated with the occasionally-observed, small uncharted bottom features (Figure 27).

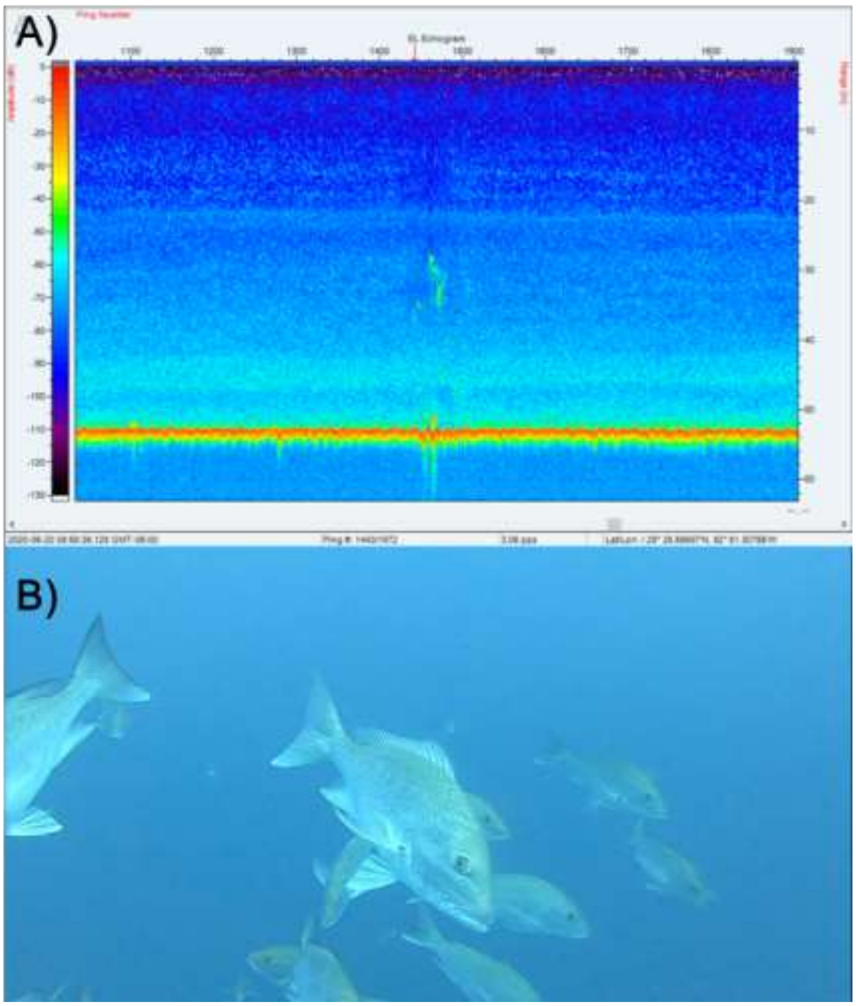

Figure 27. Cloud of Red Snapper suspended above a small bottom feature at Site A11 as detected by (A) hydroacoustic data and (B) SRV.

As pointed out above, about 62% (2,605,697 of 4,180,643) of the Red Snapper within the study area were estimated to occur over UCB habitats, mainly on small patch reefs. We were able to present data for 9 strata (3 regions by 3 depth zones) as shown by Table 7. Mean Density (fish/100 m^2) was not homogeneous within strata, ranging from 0 to a maximum value 0.02555 Red Snapper/100 m^2 (Table 6). However, only one of the nine estimates exceeded 0.02.

Overall, density of Red Snapper over UCB habitat was higher in the East than in the West and Central Regions (Figures 28-30). Red Snapper were absent from the shallow zones of both the West and Central Regions (Figures 28 and 29) but were particularly abundant in the shallow zone of the east region (Figure 30). Sites designated with an (ST) were areas where shrimp trawling was low or absent. The distribution of trawl effort may provide an index to uncharted obstructions. Review of the individual site data presented for individual cells within a site also varied greatly—from 0 to as high as 3.66974 Red Snapper per 100 m^2. As can be seen, the data are quite “patchy”.

However, the unstratified mean for the total area of UCB sampled was 0.00466/100 m^2. Appling this mean to the total UCB area of 44,906 km^2 yields an estimate of 2,093,456 fish, remarkably close to the stratified estimate of 2,605,697 Red Snapper. Overall, density of Red Snapper in UCB was low as compared to Texas. In Texas, the overall estimate was 0.03 Red Snapper/100 m^2 (Stunz et al. 2021).

Red Snapper over UCB habitats were typically larger (610-888 mm TL) and older fish than seen elsewhere (Figure 31 as compared to Figures 18, 19, and 22). Many of these fish were observed to have had fully developed gonads and many showed signs of imminent spawning (Figure 32). Fish in these habitats may represent an unexploited breeding stock.

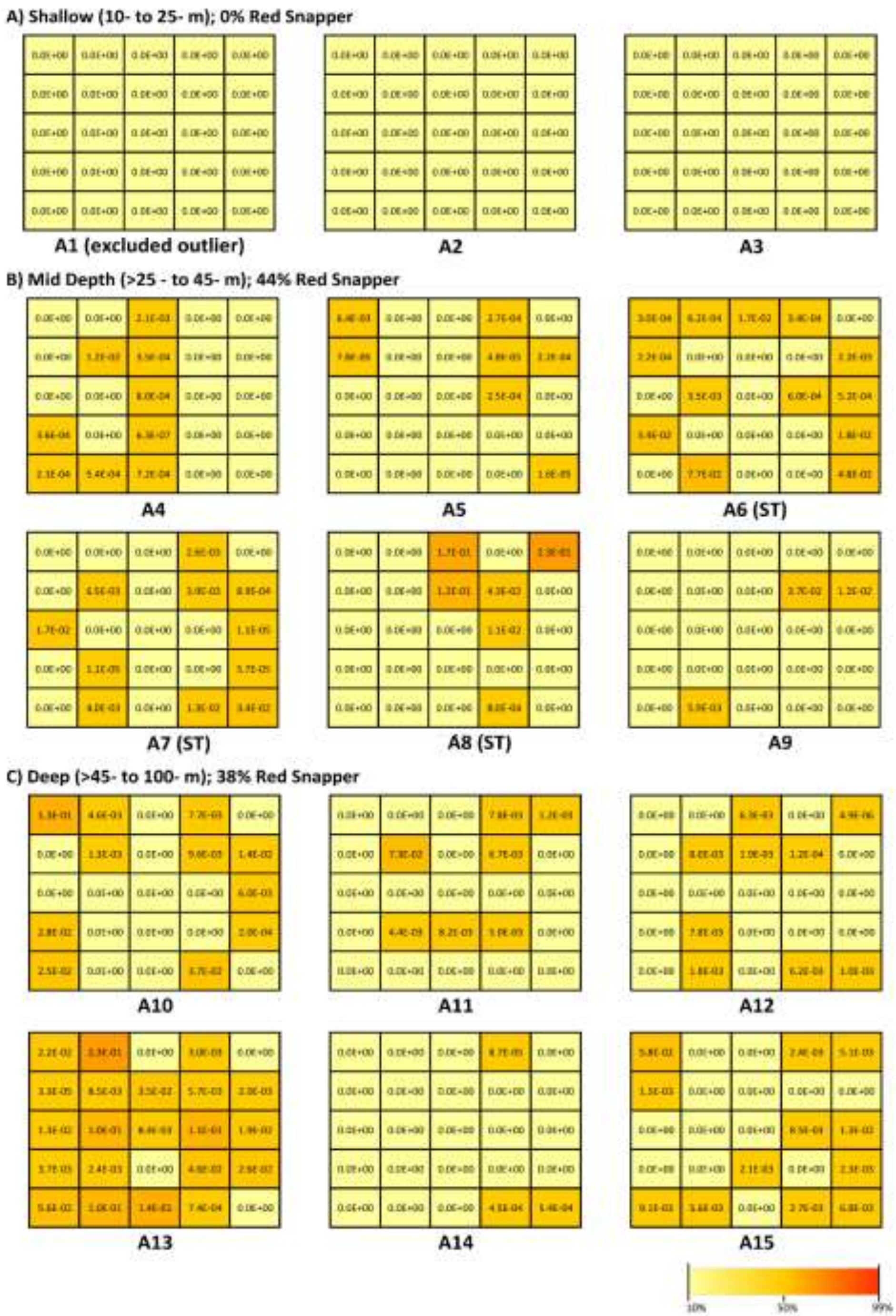

Figure 28. UCB Hydroacoustic site heat maps in the West Region, illustrating Red Snapper density (fish per 100 m^2). ST designates areas with little or no shrimping effort. Each sampling site is represented by a 2 km x 2 km square. Within a site, each cell represents a 400 m x 400 m sampling polygon. Colors indicate the relative density of Red Snapper within each of the polygons (light yellow = polygons are in the bottom 10th percentile of sampled densities; orange = polygons are within the 50th percentile of sampled densities, red = polygons are in the upper 99th percentile of sampled densities).

Figure 29. UCB Hydroacoustic site heat maps in the Central Region, illustrating Red Snapper density (fish per 100 m^2). Other conventions as in Figure 28.

Figure 30. UCB Hydroacoustic site heat maps in the East Region, illustrating Red Snapper density (fish per 100 m^2). Other conventions as in Figure 28.

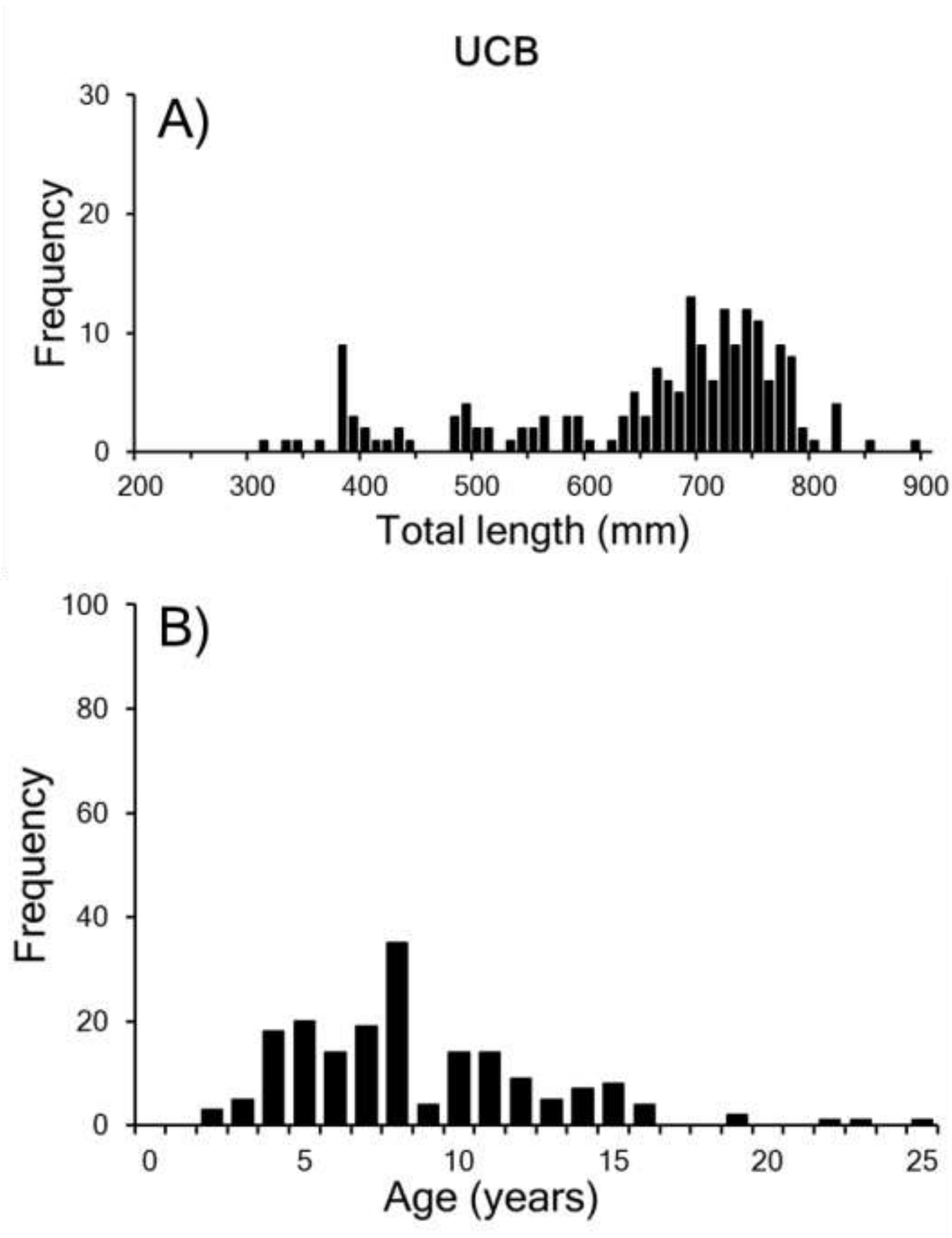

Figure 31. (A) Length and (B) age frequency of Red Snapper on UCB.

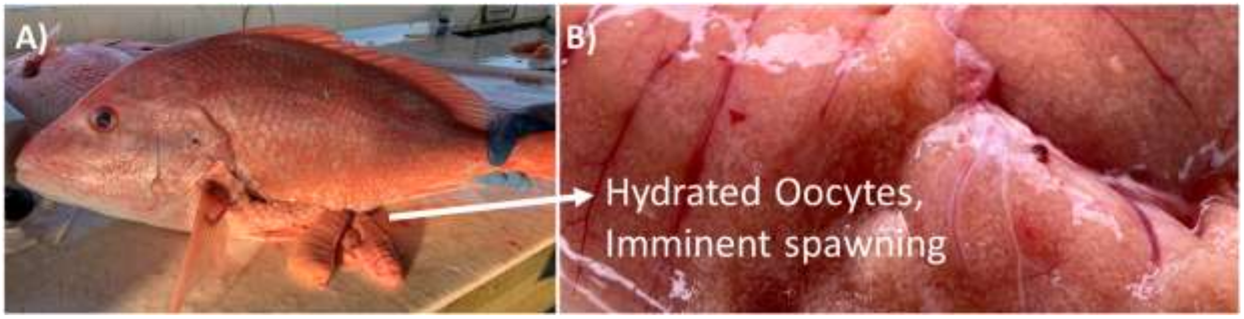

Figure 32. (A) A female Red Snapper collected from the mid-depth area of the East Region. (B) A magnified view of hydrated oocytes of this Red Snapper, indicative that this individual was in spawning condition.

Modeled Site Abundance

The final GAM of Red Snapper proportion had an explained deviance of 46% and included the fixed categorical effects of Habitat Type and Region, as well as the covariates water temperature and Distance from the Bottom. The final GAMM of total fish density (TFD) had an explained deviance of 79% and included these effects as well with the additional fixed categorical effect of Depth Zone, the fixed covariate Dissolved Oxygen, and each Site having a random intercept. Overall, the residual plots indicated adequate fits and no major misspecifications (Figures 33, 34). Furthermore, both models yielded similar predicted and observed values, which coaligned when compared across the various strata (Figures 35, 36).

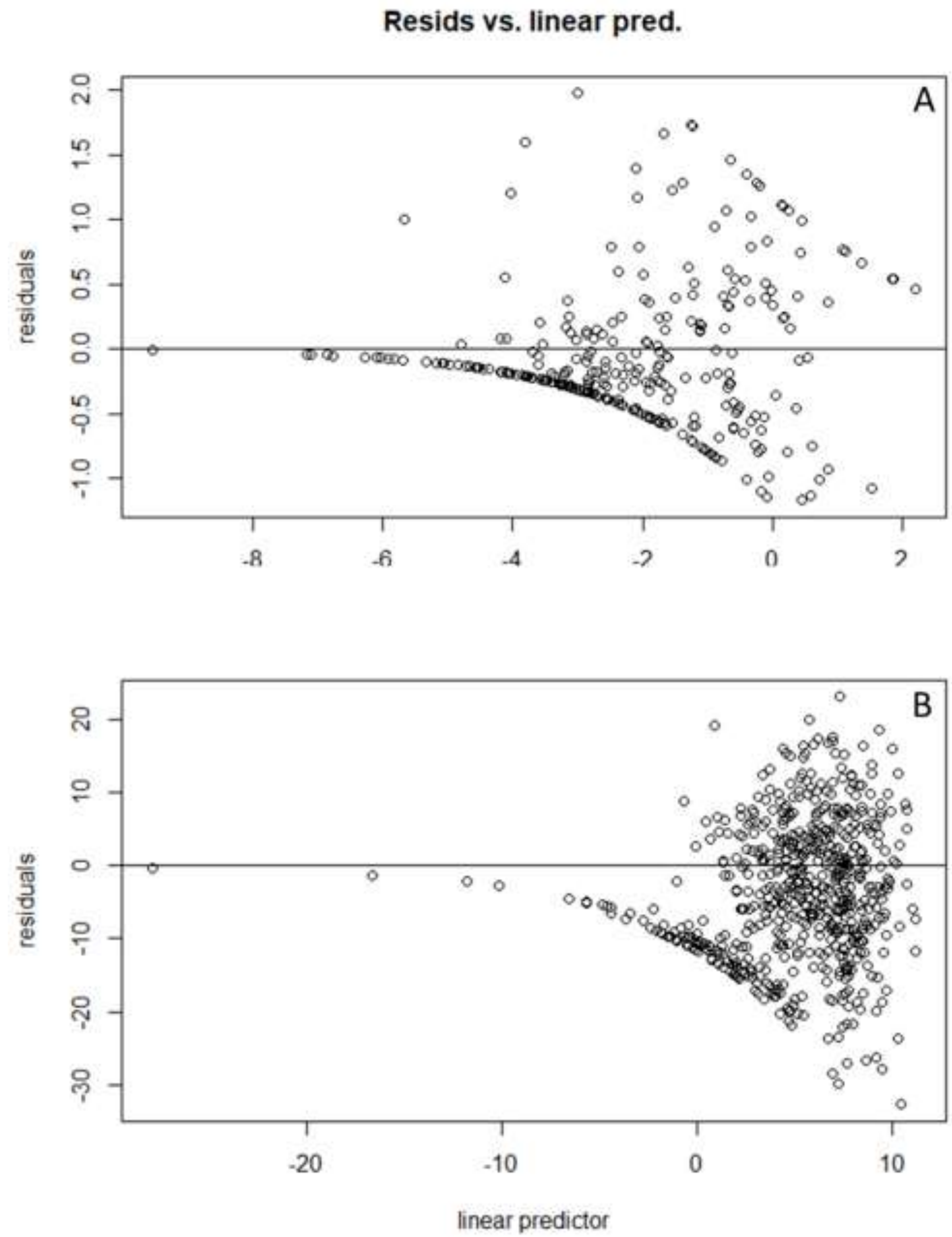

Figure 33. Deviance residuals versus the linear predictor for (A) the binomial GAM output of Red Snapper proportions based on the SRV data (B) the Tweedie GAMM output of total fish density based on the hydroacoustic data.

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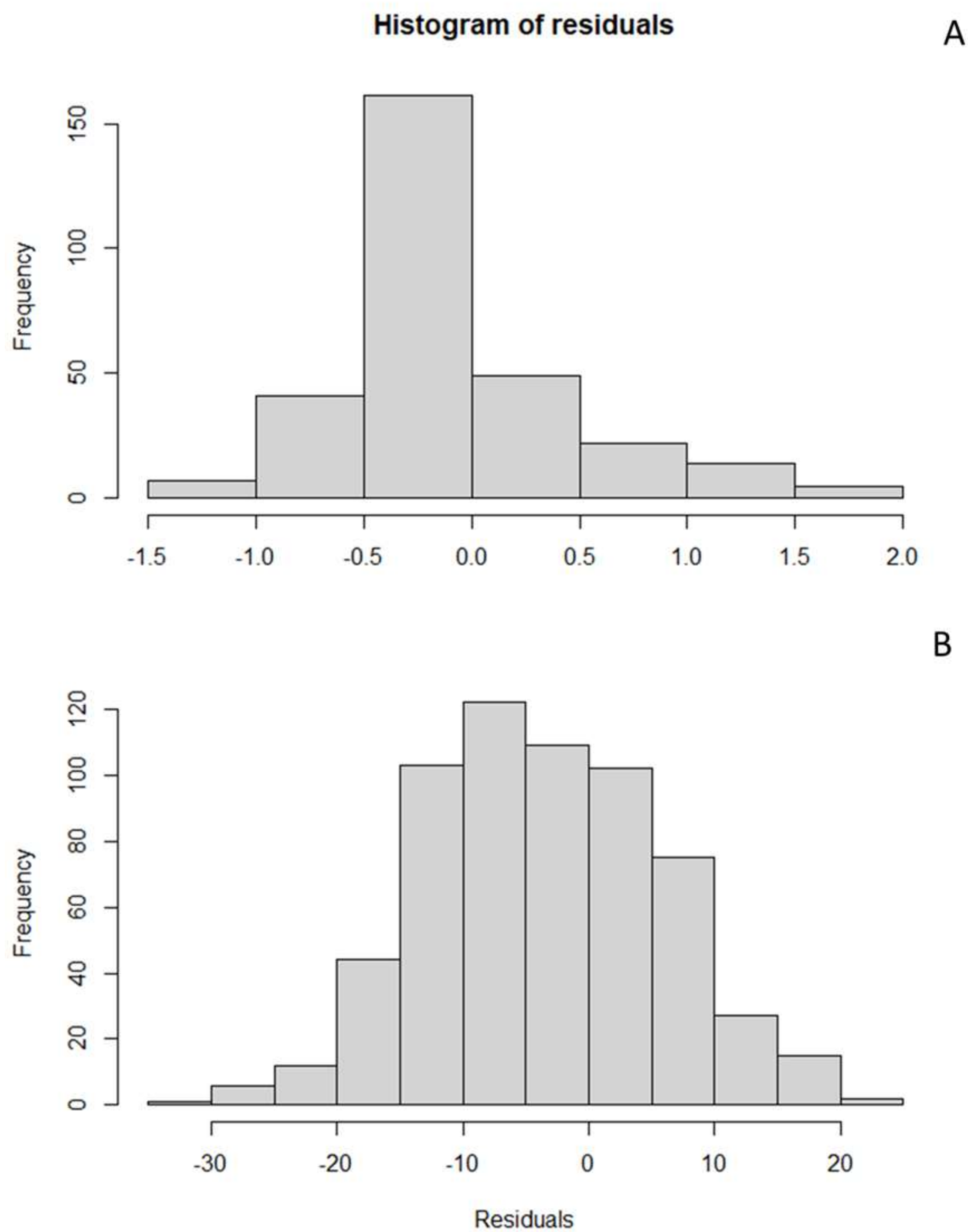

Figure 34. Histogram of deviance residuals for (A) the binomial GAM output of Red Snapper proportions based on the SRV data (B) the Tweedie GAMM output of total fish density based on the hydroacoustic data.

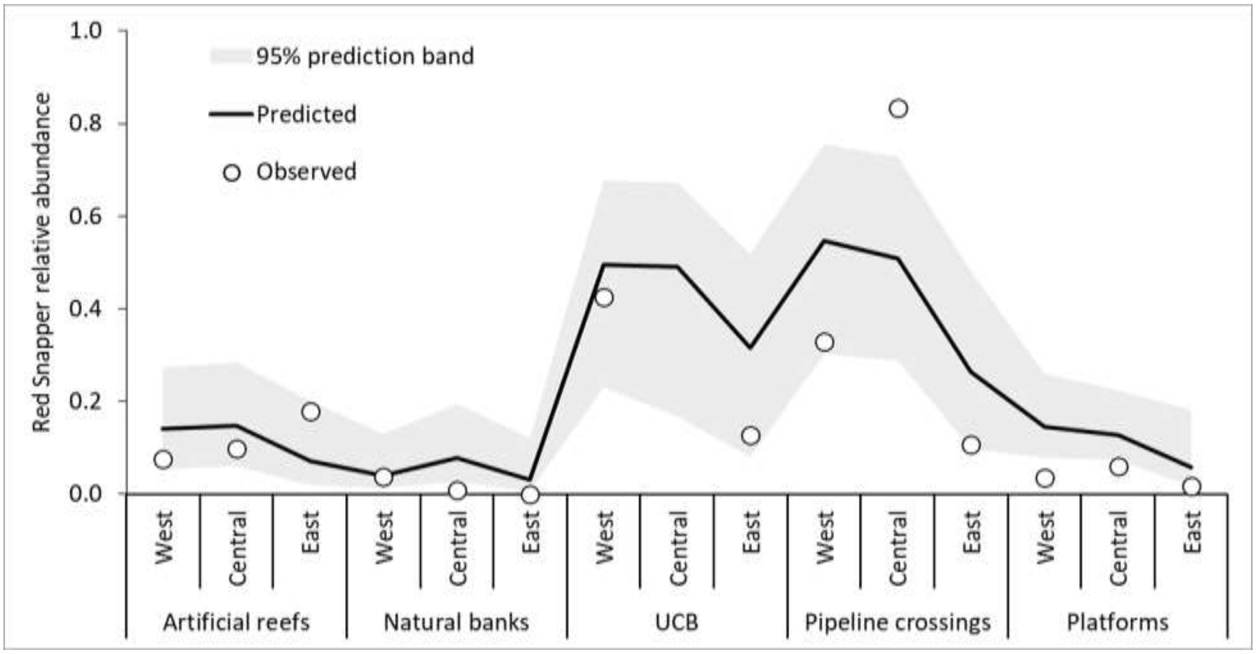

Figure 35. Predicted (black line) and observed (circles) values of Red Snapper proportions by Region and Habitat Type averaged across the Vertical Depth Bands based on the SRV data.

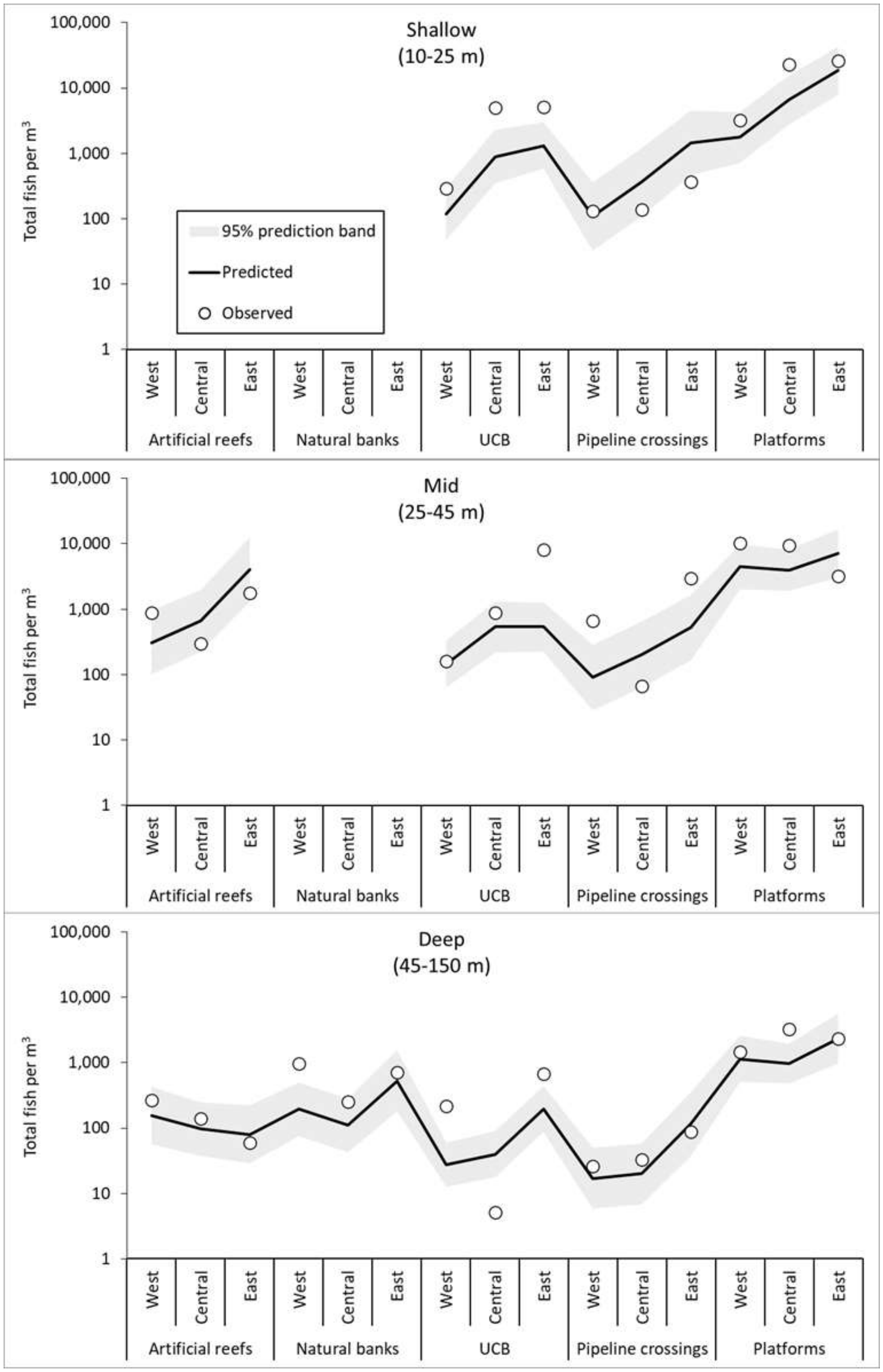

Figure 36. Predicted (black line) and observed (circles) values of total fish density (fish per m^3) by Region and Habitat Type (x-axis) and by Depth Zone (top, middle, and bottom panels) averaged across the Vertical Depth Bands based on the hydroacoustic data.

The overall estimate of total Red Snapper Abundance came to just over 6 million, with the 95% prediction limits ranged from about 4.7 to 7.8 million (Table 9). The exact estimate (6,027,890) had a SE of 791,199 and a corresponding CV of 13.1%. Most of this abundance occurred over uncharacterized bottom (63%), followed by standing platforms (22%), natural banks (10%), pipeline crossings (3%), and artificial reefs (2%). Across all habitat types, greater Red Snapper densities were observed in the mid depth zone (25-45 m) in general; exceptions included the east region for pipeline crossings and uncharacterized bottom. Except for natural banks and platforms, the trend in Red Snapper density declined from east to west.

Table 9. Predicted Red Snapper densities and total abundances by habitat type, region, and depth zone (shallow=10-25 m, mid=25-45 m, and deep=45-150 m). Horizontal bars indicate relative magnitude within each habitat type.

Habitat type	Region	Depth zone	Red Snapper per km^2 (*) or per structure (**)	LCL	UCL	Area km^2 (*) or structure count (**)	Total abundance	Subtotal (% of overall)	LCL	UCL
Natural Banks*	West	Deep	816	306	2,178	180	146,820	621,133	302,439	1,275,649
	Central		876	348	2,206	521	456,500	(10%)		
	East		766	255	2,300	23	17,812			
Platforms**	West	Shallow	405	163	1,005	62	25,136	1,328,714	970,066	1,819,959
		Mid	1,838	958	3,528	25	45,954	(22%)		
		Deep	1,033	592	1,803	52	53,742			
	Central	Shallow	1,741	745	4,071	118	205,473			
		Mid	3,002	1,680	5,365	133	399,307			
		Deep	1,511	985	2,317	117	176,805			
	East	Shallow	1,369	483	3,876	182	249,131			
		Mid	1,556	665	3,644	58	90,277			
		Deep	1,120	636	1,973	74	82,889			
Artificial reefs**	West	Mid	171	71	414	5	856	99,733	59,662	166,718
		Deep	123	53	285	121	14,857	(2%)		
	Central	Mid	430	155	1,194	35	15,045			
		Deep	165	78	350	160	26,396			
	East	Mid	617	197	1,932	57	35,190			
		Deep	115	46	291	64	7,391			
Pipeline crossings**	West	Shallow	162	41	649	24	3,894	195,778	117,983	324,870
		Mid	261	97	701	28	7,299	(3%)		
		Deep	79	31	202	63	4,991			
	Central	Shallow	442	105	1,867	93	41,096			
		Mid	545	215	1,383	70	38,151			
		Deep	131	54	321	100	13,149			
	East	Shallow	1,180	310	4,486	18	21,238			
		Mid	908	305	2,700	49	44,494			
		Deep	311	115	844	69	21,467			
Uncharacterized bottom*	West	Shallow	25	9	72	10,268	259,907	3,782,532	2,609,274	5,483,345
		Mid	58	25	134	5,297	308,386	(63%)		
		Deep	24	12	47	7,162	168,574			
	Central	Shallow	96	24	380	4,407	424,184			
		Mid	188	68	523	3,760	708,309			
		Deep	51	25	108	7,511	386,279			
	East	Shallow	117	39	345	3,058	356,491			
		Mid	138	56	340	2,327	322,242			
		Deep	163	72	369	5,213	848,160			
							Overall total	6,027,890	4,665,675	7,787,825

Age, Growth, and Condition

In all, 1,152 fish were aged from otolith cross sections and used in the growth model after removal of outliers. As shown above and by Appendix 7, Red Snapper ages ranged from 2 to age 25. Overall, fish averaged a total length of 21.24 inches, weighed 5.58 lbs., and had an average age of 6.16 years. Larger average sizes were found on UCB habitats, TL was 25.57 inches, and average weight was 9.41 lbs. The average age of Red Snapper on UCB habitat was 8.6 years. On artificial reefs, Red Snapper had an average TL of 18.52 inches, weighed 3.59 lbs. in weight and had an average age of 4.89 years (Table 10). Geographically, average size and age increased from east to west. Our growth parameter estimates were lower than those reported in SEDAR 52 (2018) (Figure 37), but were similar across regions (Figure 38), and varied somewhat among habitat type (Figures 39 and 40).

There were 1,149 Red Snapper with WT-TL pairings after outlier removal. Overall, predicted mean weight for all sites compared favorably to SEDAR 52 estimates for intercepts and slopes, 1.55E-05, 2.97 and 1.67E-05, 2.95, respectively (Figure 41, Table 11). Predicted mean weight was similar across regions and habitat types (Figures 42-45).

Table 10. Length and weight summary for Louisiana Red Snapper by region, depth and habitat.

Habitat	Avg Length (in)	Avg Weight (lbs)	Avg Age
Overall	21.24	5.58	6.16
West	22.58	6.31	7.22
Central	20.58	5.09	5.52
East	20.01	5.03	5.30
Shallow	19.86	4.83	4.14
Mid	19.94	4.87	5.17
Deep	21.99	6.11	6.74
Shelf	21.87	5.27	8.40
Artificial Reef	18.52	3.59	4.89
Platform	20.71	5.07	5.29
Pipeline Crossing	21.03	5.47	5.60
Natural Bank	22.69	6.04	8.13
UCB	25.57	9.41	8.60

Table 11. Slope and intercept values for length weight regressions for Louisiana Red Snapper. Values shown by habitat type and region.

Habitat/Region	Intercept	Slope
SEDAR 52	1.67E-05	2.95
All sites	1.55E-05	2.97
Platform	1.71E-05	2.95
Artificial Reef	1.67E-05	2.95
Pipeline Crossings	1.87E-05	2.93
Natural Bank	1.76E-05	2.93
UCB	1.28E-05	3.02
Artificial Structures	1.60E-05	2.96
West	1.99E-05	2.91
Central	1.81E-05	2.93
East	1.29E-05	3.02
UCB West	1.22E-05	3.03
UCB Central	1.87E-05	2.93
UCB East	1.24E-05	3.03

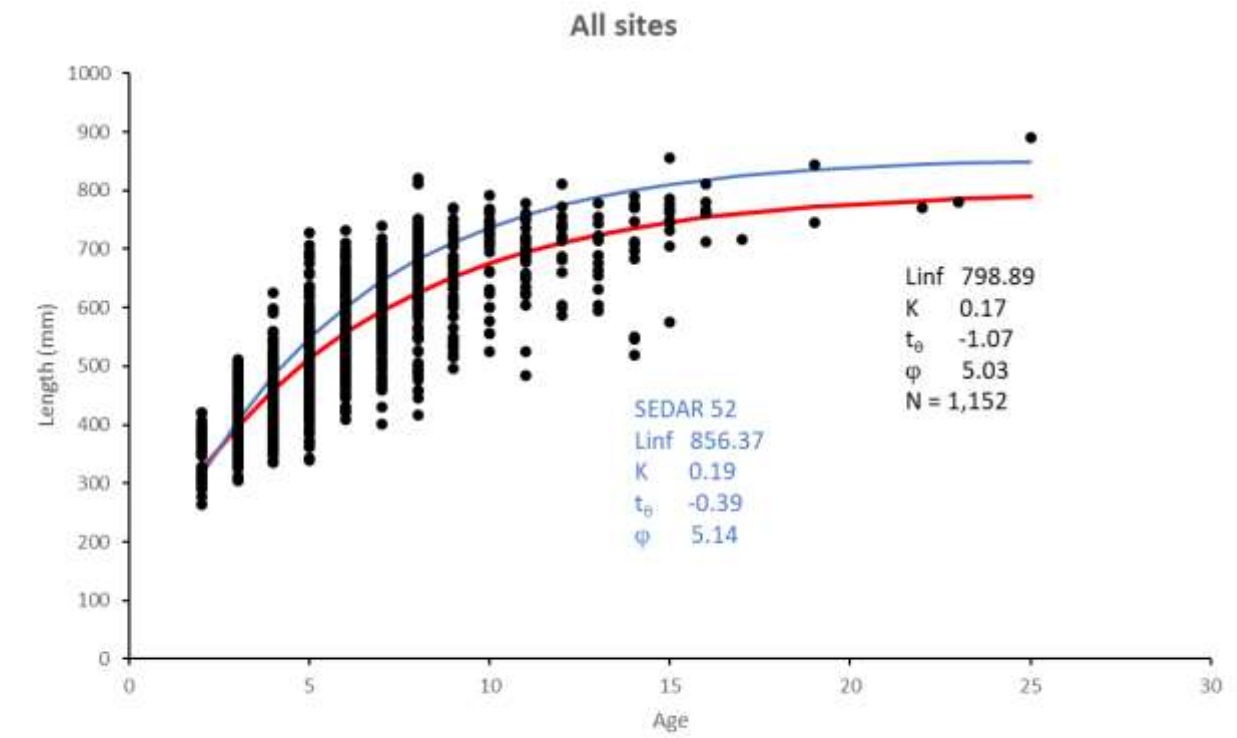

Figure 37. Von Bertalanffy growth curves for all sites within the study area (3 outliers removed, red line) and the most recent stock assessment, SEDAR 52 (blue curve).

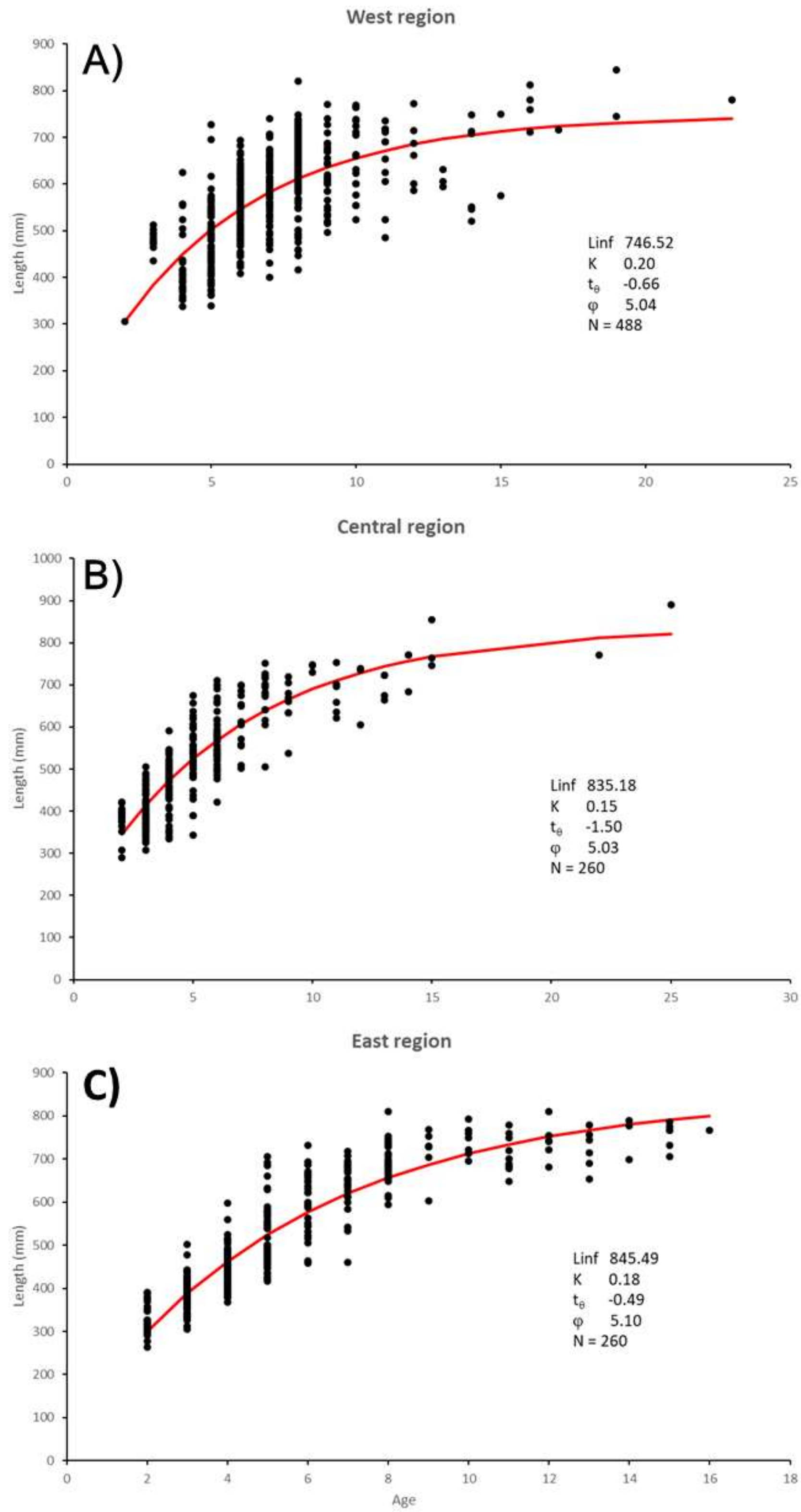

Figure 38. Von Bertalanffy growth curves for (A) all sites in the West Region, 1 outlier removed, (B) Central Region and (C) East Region, 2 outliers removed.

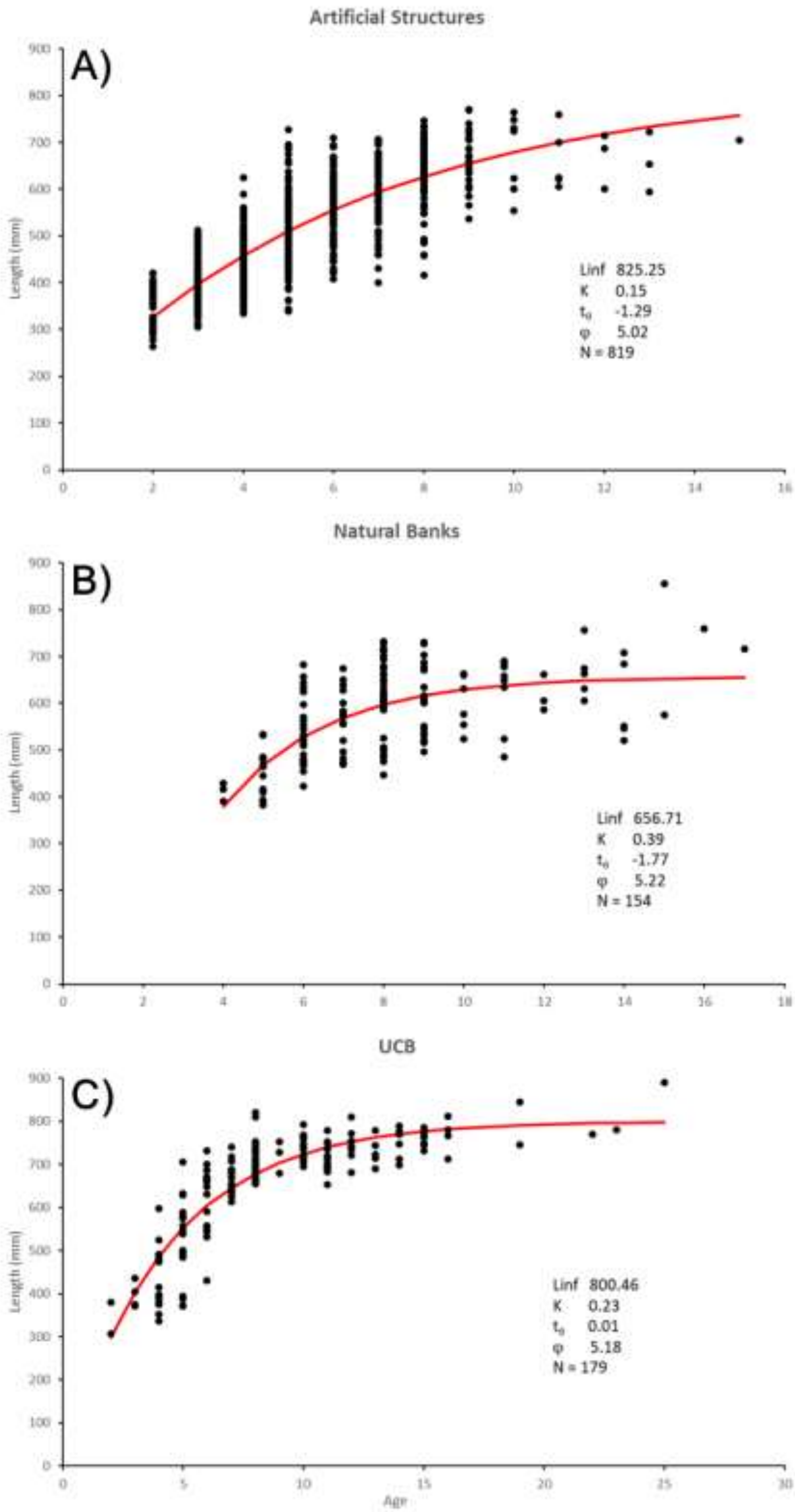

Figure 39. Von Bertalanffy growth curves by habitat. (A) Artificial structures (artificial reefs, platforms and pipeline crossings combined), (B)natural banks and (C) UCB, 3 outliers removed.

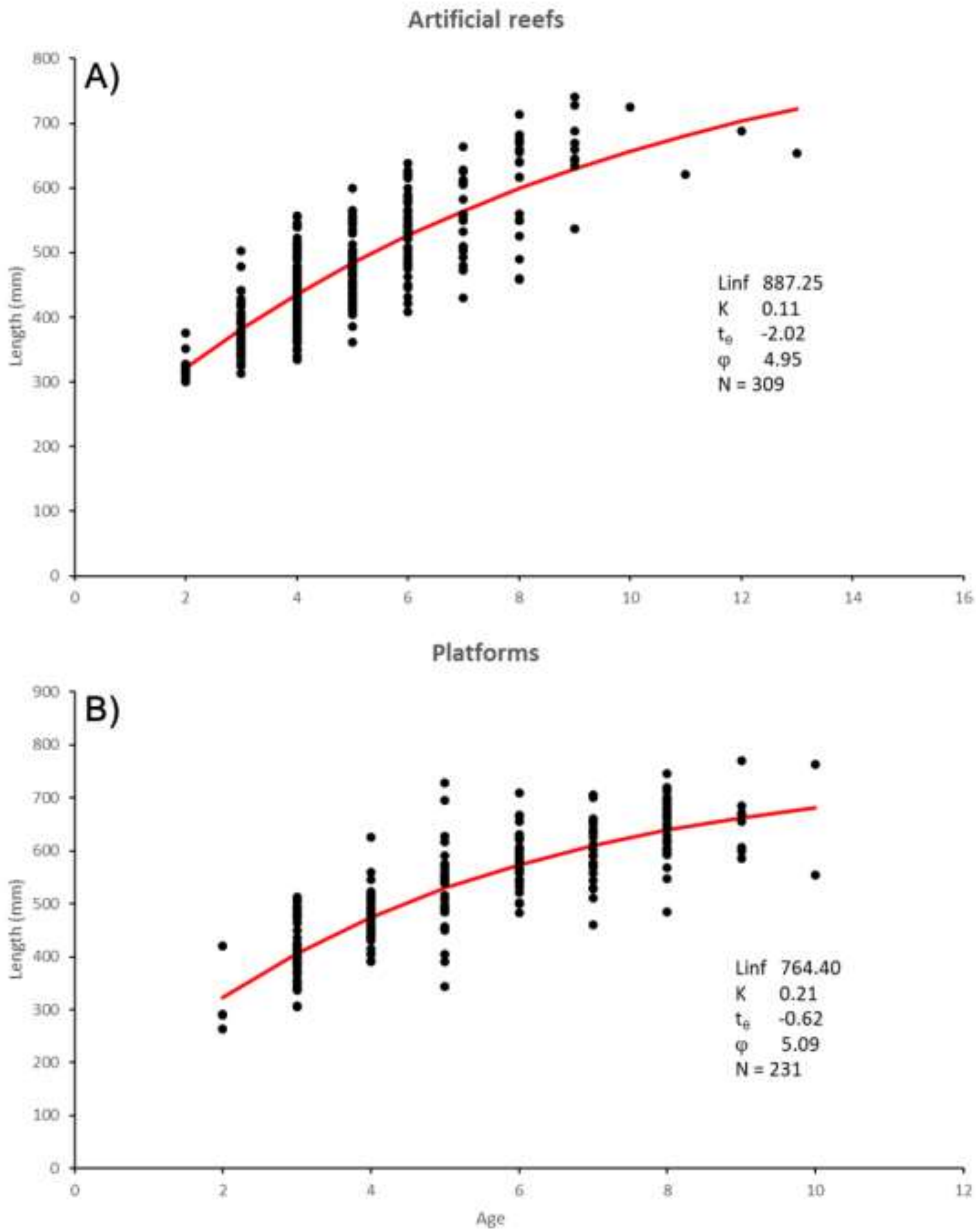

Figure 40. Von Bertalanffy growth curves for (A) artificial reefs) and (B) platforms.

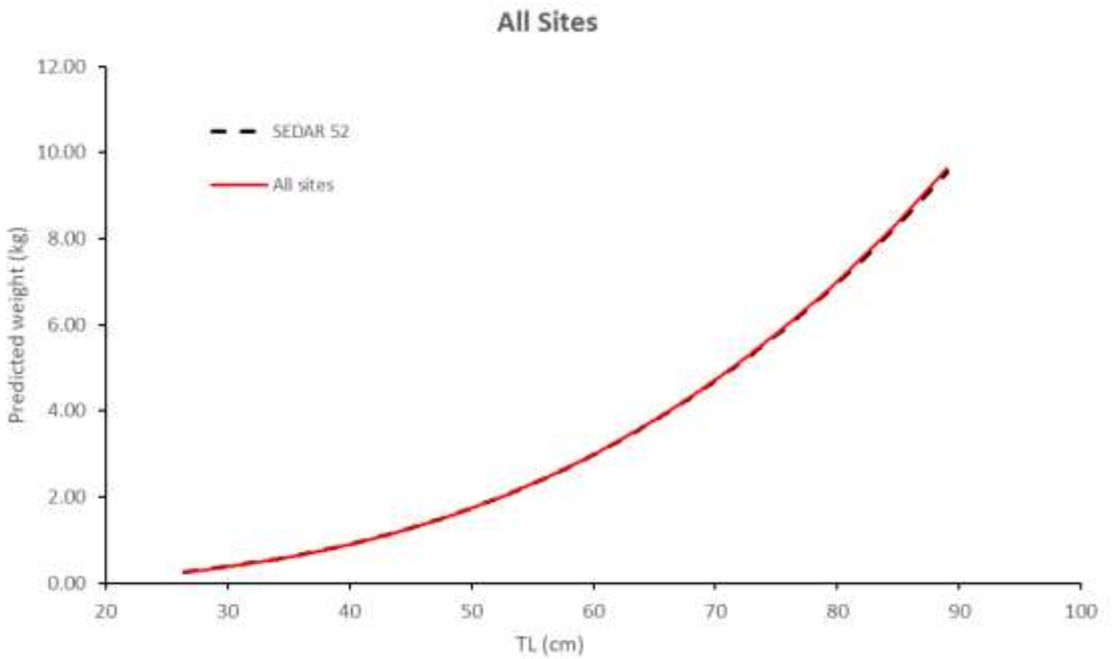

Figure 41. Predicted mean weight (kg) as a function of TL (cm) for all sites between the current study and SEDAR 52.

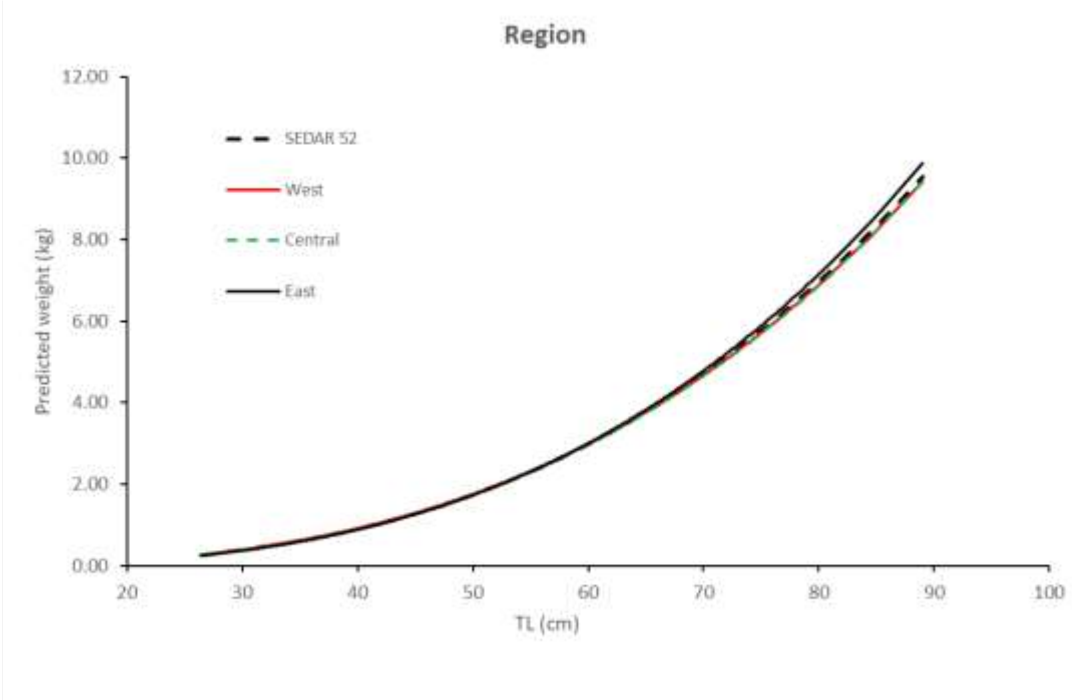

Figure 42. Predicted mean weight (kg) as a function of TL (cm) by geographic region between the current study and SEDAR 52.

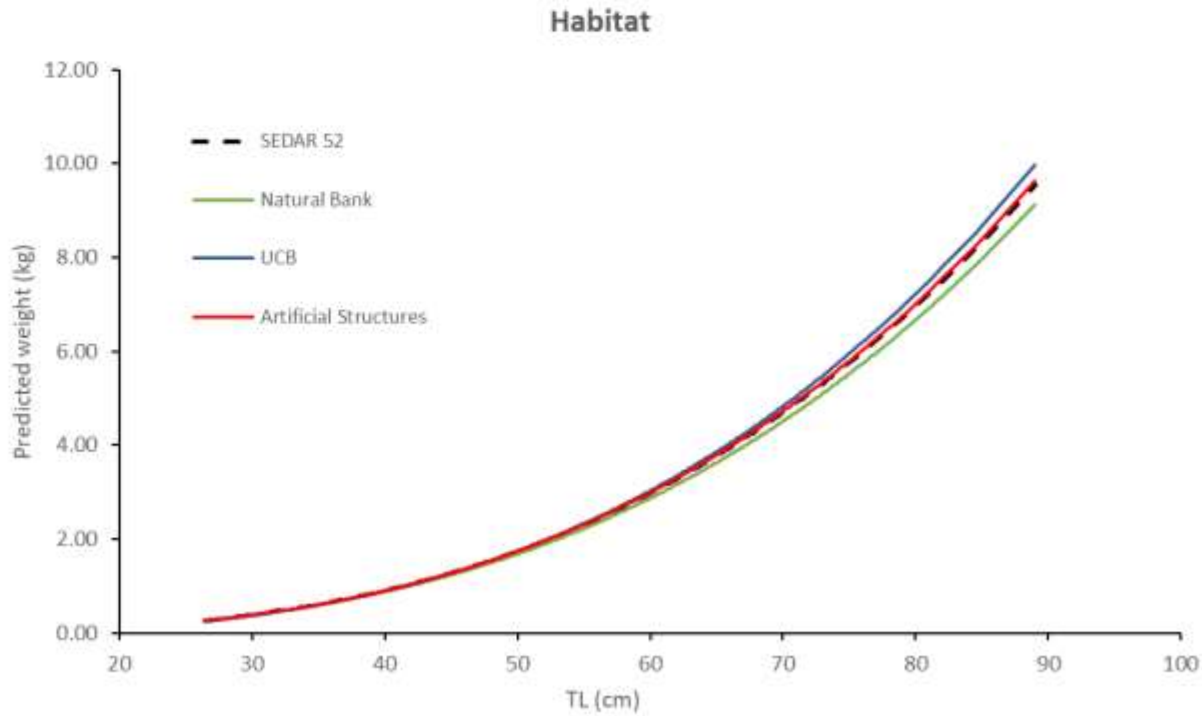

Figure 43. Predicted mean weight (kg) as a function of TL (cm) by habitat (natural banks = green, UCB = blue, artificial structures = red). Data from SEDAR 52 (dashed black line) are plotted for reference.

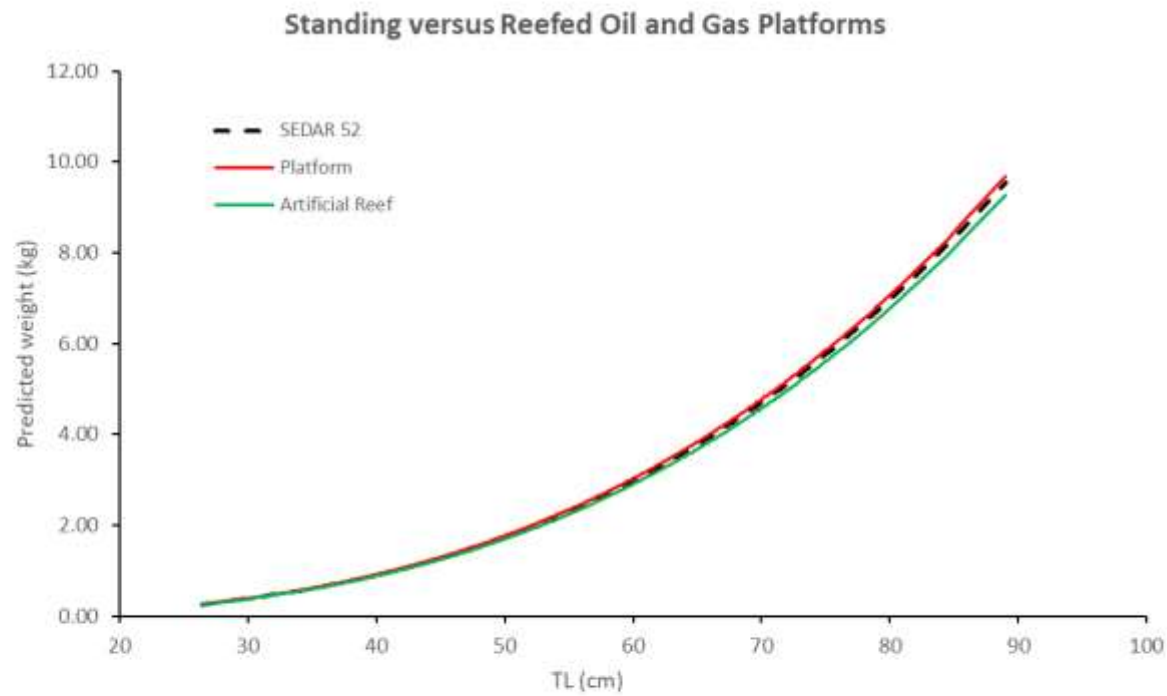

Figure 44. Predicted mean weight (kg) as a function of TL (cm) for standing platforms (red), reefed platforms (green) and SEDAR 52 (dashed black).

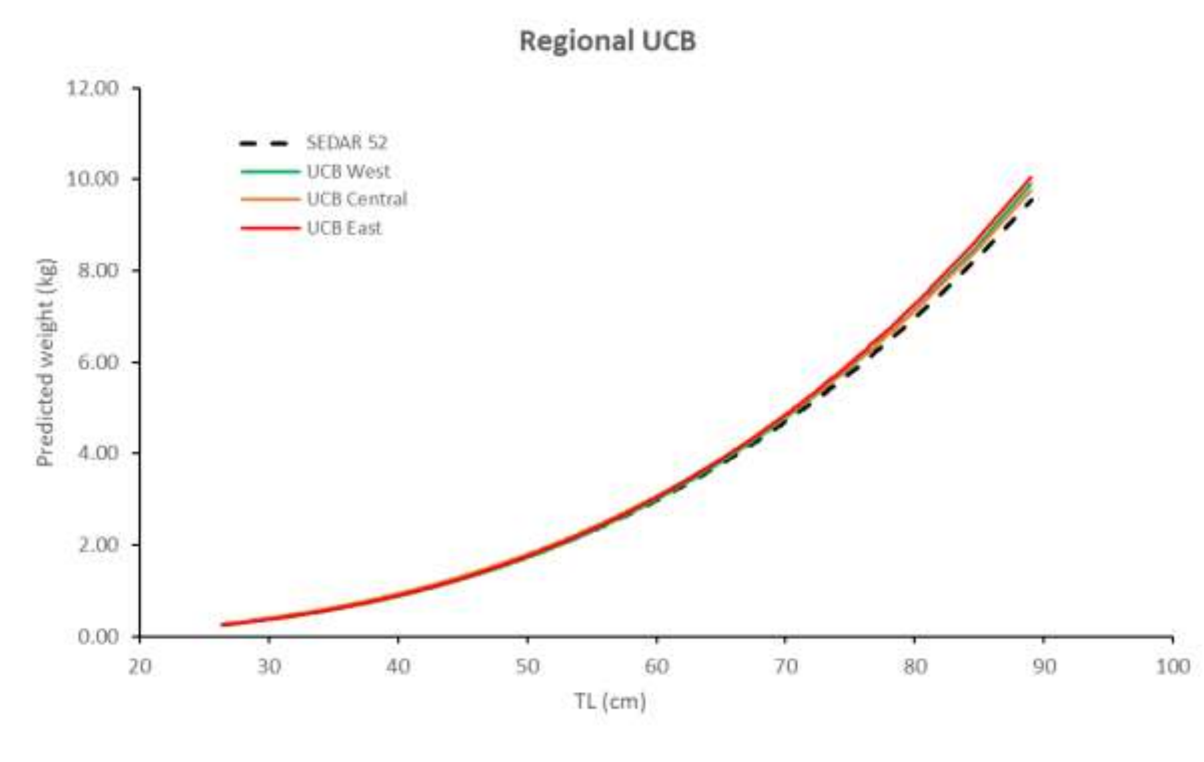

Figure 45. Predicted mean weight (kg) as a function of TL (cm) for UCB by geographic region (green = West, orange = Central, red = East) and SEDAR 52 (black dashed).

DISCUSSION

As described above, the results of the comprehensive statistical modeling assessment shows that an estimated 6.0 million (95% CI: 4.7–7.8 million; SE=791,199; CV=13.1%) Red Snapper occupy the Louisiana State Red Snapper Management Area and that these fish have a corresponding total biomass of over 47 million pounds. While these estimates are about 3 times less than estimated by Stunz et al. (2021b), their original Louisiana estimates were extrapolated based on data obtained from eastern Texas. Some unusual circumstances occurred which prevented their completion of the originally planned field-sampling program for Louisiana.

Overall Abundance

A summary of Red Snapper abundance and biomass (lbs.) by habitat type and/or areas for Louisiana is summarized (Table 12):

Table 12. Summary of Red Snapper abundance and biomass in Louisiana, 2020.

	Habitat Type	Area (km^{2x})/Count	Abundance	Biomass
1)	Natural Bank	724 km ^{2}	621,133	3,745,866
2)	Uncharacterized Bottom	49,003 km^2	3,782,532	35,450,492
3)	Artificial Reefs	1,777	1,624,225	8,181,819
	Platforms	821	1,328,714	6,753,260
	Artificial Reefs	442	99,733	359,241
	Pipeline Crossings	514	195,778	1,069,318
	TOTALS		6,027,890	47,378,177

Stunz et al. (2021b) provide a corresponding estimate 17,431,364 Red Snapper in the Louisiana Red Snapper State Management Area (see Table 5 on page 87 of their report). This estimate is about 3 times larger than our estimate of 6,027,890 million Red Snapper in the same area. The differences seem largely related to catch rates rather than differences in area of habitat or number of habitats. (Table 13):

Table 13. A comparison of the nature of the differences between estimates of total Red Snapper in Louisiana based on Stunz et al. (2021b) verses this report. Numbers in parentheses reflect the Stunz estimate divided by the LGL estimate.

Habitat	Study	Area(km^2)	Catch Rate	Total
Natural Bank	Stunz	821 (x 1.13)	4,693/km^2 (x 5.5)	3,852,652 (x 6.2)
	LGL	724	858/km^2	621,123
Artificial Reef	Stunz	* 1,771 (x 0.99)	2,174/reef (x 2.4)	3,849,325 (x 2.4)
	LGL	* 1,777	914/reef	
UCB	Stunz	53,052 (x 1.08)	183/km^2 (x 2.3)	9,729,387 (x 2.6)
	LGL	49,003	77/km^2	3,782,532

* Number of reefs

The area or count of habitats are similar between the two studies with the Stunz et al. (2021b) estimates being from 0.99 to 1.13 times the LGL estimates. In contrast, the catch rates of Stunz et al. (2021b) were from 2.3 to 5.5 times higher than the corresponding LGL catch rates and the total estimates ranged from 2.4 to 6.2 times higher than the LGL estimates. These differences could be attributed to a number of factors, but as one reviewer stated: "However, since the Louisiana estimates in LGL are based solely on sampling in Louisiana and adjacent Federal Waters, whereas Stunz et al. used extrapolated samples from outside that area, this provides some *prima fascia* support for using the LGL results in support of management."

IMPACT ON STOCK STATUS

The Stunz et al. (2021b) estimate of the absolute abundance of Red Snapper in the Gulf of Mexico was estimated to have been about 118 million fish in 2019 as compared to about 36,738,063 fish estimated to be present by the SEDAR 52 Stock Assessment (SEDAR 2018). SEDAR 52 estimated that 23,643,192 age 2+ Red Snapper were present in the Western Gulf (Texas and Louisiana) as compared to 39,456,399 estimated to be present in the Western Gulf by Stunz et al. (2021b). The new estimate for the West Gulf was about 1.7 times as high as suggested by SEDAR 52. For the East Gulf, Stunz et al. (2021b) estimated 78,507,594 Red Snapper were present, nearly 6 times as many as estimated for the Eastern Gulf by SEDAR 52 (13,094,871). A graphic comparison of the respective estimates is shown by Figure 46.

However, if our Louisiana estimates, are combined with the Texas estimates from Stunz et al. (2021), the overall estimate, of Red Snapper in the Western Gulf was very close to the SEDAR 52 estimate. The SEDAR 52 estimate for the West Gulf was 23,643,192 and the modified Stunz et al. (2021b) estimate plus this study estimate was 28,052,925 fish (Figure 46).

The size differences for Red Snapper in the Eastern Gulf (Florida, Figure 48) differ greatly from the Western Gulf (Louisiana, Figure 47). In Florida, most of the Red Snapper are small; 62% of the fish appear to be below the legal size limit of 16 in. In Louisiana, a wide size range was evident in 2020 with 87% of the fish being above the legal size limit (Figure 47).

The size/age distributions for Red Snapper observed in Louisiana suggest that approximately 6 million age 2+ Red Snapper are present in the Louisiana Recreational Red Snapper Management Area and that they have a very high biomass, on the order of 47 million pounds. To put this in perspective, the most recent recreational fishery quota for Louisiana was 784,332 lbs., about 1.7% of the Louisiana Red Snapper stock size estimated for 2020. Platforms alone, the most heavily fished habitat in Louisiana, were estimated to harbor about 6.8 million pounds of Red Snapper. Further, 35.5 million pounds of Red Snapper were estimated to occur over UCB habitats and these fish appear largely unexploited.

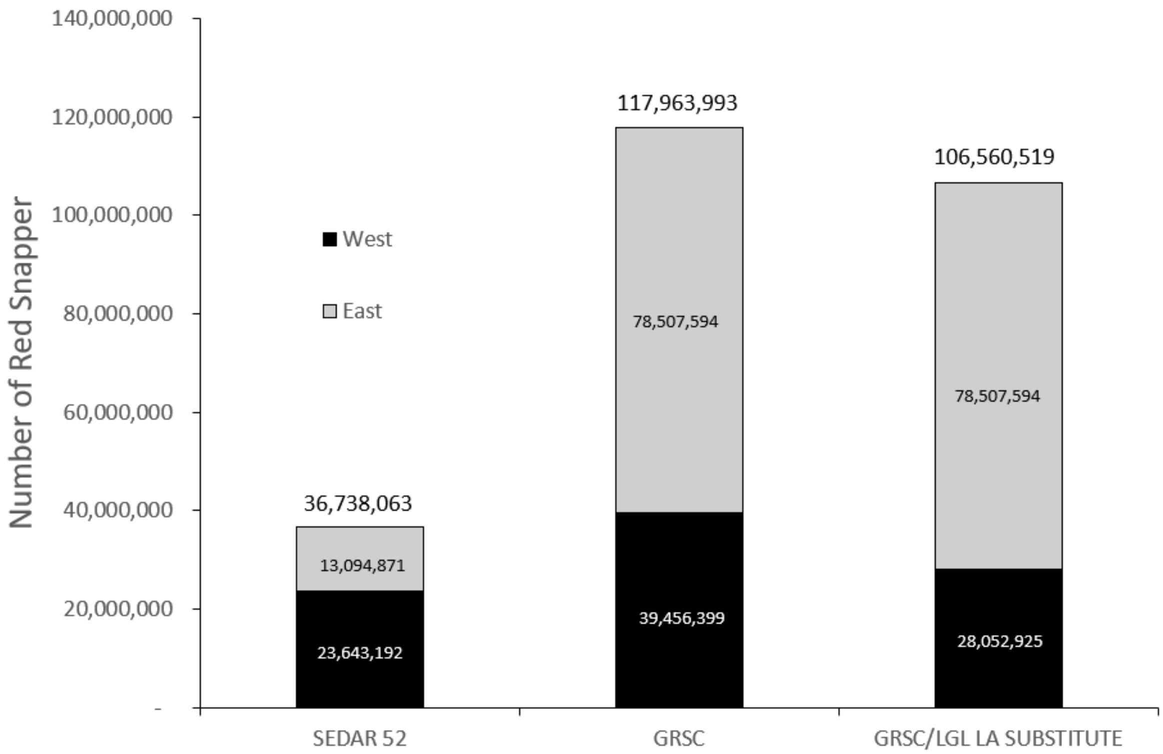

Figure 46. Red Snapper population estimates for the Red Snapper in the Gulf of Mexico based on the SEDAR 52 Red Snapper stock assessment, Stunz et al. (2021b) and this study.

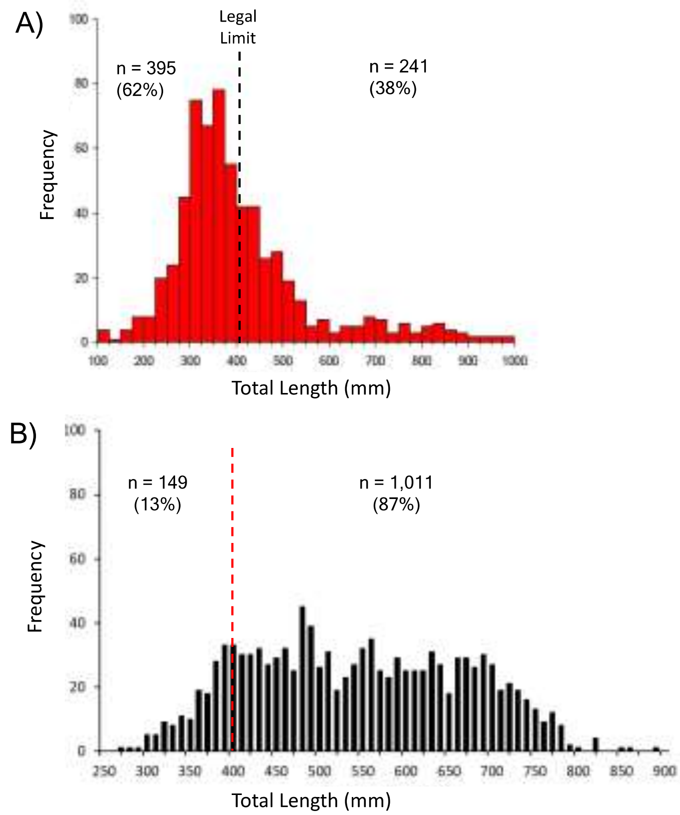

Figure 47. Red Snapper in the Louisiana study area had a higher percentage of legal sized fish than those from Florida. (A) Red Snapper from Florida sampling sites (n = 637) illustrates that only 38% were of legal size (16 inches) (adapted from Figure 6 in Stunz et al. 2021). (B) Length frequency of all Red Snapper from Louisiana measured directly in this study (n = 1160) showing that 87% were above the legal size.

SUMMARY AND CONCLUSIONS

A study to estimate the absolute abundance of Red Snapper in the Louisiana Red Snapper Fishery Management zone (the study area) was conducted over the period 2019-2021. The base sampling approach included investigations of Red Snapper over uncharacterized bottoms (UCB) and natural banks, as well as at standing oil and gas platforms, pipeline crossings and artificial reefs. Hydroacoustic surveys were used to estimate fish densities over UCB and natural banks and obtain total counts of fish at standing oil and gas platforms, pipeline crossings and artificial reefs. Submersible Rotating Videos (SRVs) and Towed Videos (TVs) were used to determine the proportion of Red Snapper detected by hydroacoustic surveys, thereby producing Red Snapper abundance estimates. Hook-and-line and longline sampling were used to collect Red Snapper for determination of length, weight, and age composition.

Overall, the study area was estimated to contain on the order of 6.0 million Red Snapper having an associated total biomass of over 47 million pounds. About 63%

(3,782,532 fish) of the population was estimated to occur in association with UCB habitat, and about 27% (1,624,225 fish) occurred at artificial reefs. Only about 10% (621,133 fish) of the Red Snapper population in the study area occurred on natural banks.

Our estimate (6 million fish) while lower than the estimated 18 million Red Snapper extrapolated to occur in the study area by Stunz et al. (2021b) suggests a healthy stock is present. Due to unforeseen difficulties, the original scope of work planned by Stunz et al. (2021b) for Louisiana did not occur. Therefore, the Stunz et al. (2021) estimates were largely extrapolations based on Texas data. Despite our estimate that the Red Snapper population of the study area was only about 6.0 million fish, the biomass was high (>47 million pounds) due to the abundance of relatively large, old fish. For context, the most recent recreational fishing quota for Louisiana was about 784,332 lbs. or about 1.7% of the total Red Snapper stock size in the study area.

The Red Snapper in the Gulf of Mexico are divided into West Gulf and East Gulf stocks. The West Gulf stock includes our Louisiana study area plus Texas and the East Gulf stock includes Louisiana east of the mouth of the Mississippi River, Mississippi, Alabama and Florida. We combined our Louisiana estimate with the Stunz et al. (2021) Texas estimate to obtain a total West Gulf stock size of 28,052,925 Red Snapper. This compares closely to the most recent Red Snapper stock assessment (SEDAR 52) that estimated that the West Gulf stock contains 23,643,192 Red Snapper.

The size distribution for Red Snapper in Western Louisiana, reported herein, differs greatly from the size distribution reported for the Eastern Gulf (Florida) by Stunz et al. (2021). In Florida most of the Red Snapper are small; i.e., 62% of the measured fish appeared to be below the minimum size limit of 16 in. In Louisiana, a wide size/age range was evident in 2020, with 87% of the measured fish being above the minimum size limit.

Offshore oil and gas platforms appear to be the most heavily fished habitat in our study area. In 2020, this habitat had a standing stock of about 1.3 million Red Snapper with an associated biomass of 6.7 million pounds. The average weight of Red Snapper at platforms was about 5 lbs., and the average length of the fish was about 21 in, well over the minimum size limit.

Of importance, over 63% of the total population of Red Snapper in West Louisiana occurred over UCB habitat. In these habitats, the Red Snapper present were generally larger than elsewhere, averaging about 26 in. in total length, 9.4 lbs. in weight and about 9 years in age. Because Red Snapper are widely distributed over large areas of UCB, fishing pressure is likely reduced compared to more dense aggregations over habitats with structure in charted locations. Thus, UCB habitats have, in essence, served as **de facto** "Marine Protected Areas".

Overall, the Louisiana Red Snapper stock appears to be in excellent condition and is experiencing very low levels of recreational fishery mortality. The recreational fishing quota is only about 2.4% of the total stock biomass.

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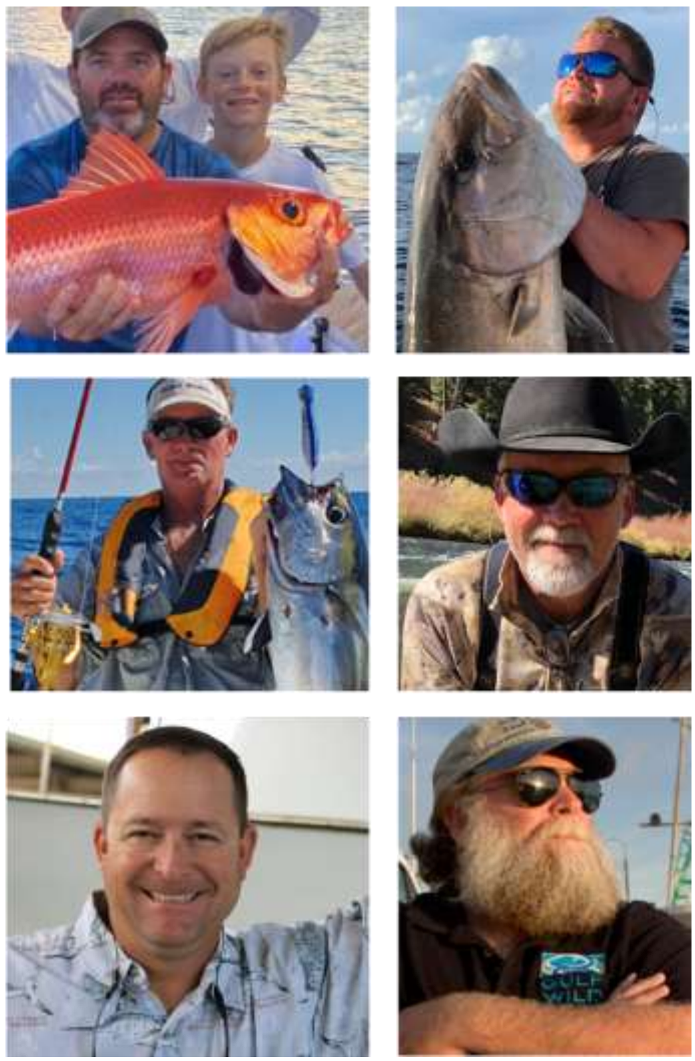

The results of this study are based on data gathered at 100% of the 106 intended sampling sites during summer 2020, despite a historic hurricane season and various restrictions from COVID-19. Our success is due in large part to our trusted captains (clockwise from top left): Jamie Gaspard, Hans Guindon, Mike Jennings, Buddy Guindon, Scott Hickman, and Bill Butler.

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