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Validating Sidescan Sonar as a Fish Survey Tool over Artificial Reefs

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ABSTRACT

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Visual observation methods *via* SCUBA are commonly used to survey artificial reef fish, although conditions in the Gulf of Mexico often make surveys difficult or even dangerous for divers. In this study, sidescan sonar was used to quantify water-column fish abundance and was compared to the established visual observation methods on SCUBA over four reef sites. Calibrated intensity values measured from sidescan sonar echo returns were used to estimate fish body length and to calculate scaled biomass (g/m^2 reef) from a pooled fish length–weight relationship of commonly observed reef fish in the area. Sidescan sonar methods were equivalent to SCUBA surveys for measuring fish abundance over the same reef areas; however, overall reef-associated abundances measured with sidescan were significantly higher because the sidescan could measure a larger water-column area and furthermore allowed for a rapid assessment of abundance on a greater number of reefs in a single sampling day. Scaled abundance and biomass differed significantly between structural types, with the reefed oil-jacket structures in deeper, federally managed waters showing the highest scaled abundance and biomass. With sidescan methods, five reef sites could be surveyed in one day, demonstrating the capability for macroscale comparisons of fish abundance, biomass, and structural preference among sites.

ADDITIONAL INDEX WORDS: *Fish quantification, acoustics, biomass, reef comparison*.

INTRODUCTION

There are over 4000 oil and gas structures in the Gulf of Mexico and hundreds of artificial reefs comprising numerous structural types, which are challenging to assess and monitor efficiently. Many of these oil-drilling structures are being decommissioned and converted into artificial reefs *via* the Rigs to Reefs program (Dauterive, 2000). Artificial reefs serve an essential function as fish habitats (Brickhill, Lee, and Connolly, 2005). While these reefs generally harbor large fish populations (Bohnsack, 1989), questions remain regarding their costs and benefits. In addition, it is still unclear which types of structure provide the best outcomes over the long term and which factors drive differences between reef configurations. These questions remain difficult to answer because of the extreme size of some artificial reef complexes and the depths at which they lie. The increased availability and advances in processing of sidescan sonar data make it a good candidate for artificial reef survey and assessment.

Currently, the Texas Parks and Wildlife Department (TPWD) Artificial Reef Program (ARP) monitors 76 permitted reef sites along the Texas coast. These artificial reef sites greatly vary in size from 40–381 acres. Current monitoring protocols for artificial reefs include vertical longline fishing for size metrics of red snapper (*Lutjanus campechanus*; Poey, 1860), remotely operated vehicle surveys, and visual SCUBA surveys. SCUBA surveys remain the most common survey method to quantify fish abundance and biomass but can only be performed under limited conditions (Edgar, Barrett, and Morton, 2004; Froehlich and Kline, 2015; Hicks *et al*., 2016; Watson, Carlos, and Samoilys, 1995). SCUBA visual census techniques are only useful in the range of tens of meters in the clearest waters, and the presence of a nepheloid layer (stratified layer of suspended sediments in the water column) (Shideler, 1981) in the western Gulf makes visual surveys challenging during certain times of year (McGrail and Carnes, 1983; Shideler, 1981). Divers are also severely limited regarding both the time spent at depth and the reef area that can be covered and compared.

Artificial reefs off the Texas coast contain many essential recreational and commercial fish species. In terms of biomass, most of the economically important fish species reside in the water column above reef structures; a fact that lends itself to the use of sonar monitoring (Simmonds and MacLennan, 2005). The red snapper is one of the most recreationally and commercially harvested fish species (Gillig, Griffin, and Ozuna, 2001; Southwick Associates Staff, 2012) that typically inhabits depths from 10 m to 130 m in the Gulf of Mexico (Allen, 1985; Gallaway, Szedlmayer, and Gazey, 2009). Other common species include grey snapper (*Lutjanus griseus*), grey triggerfish (*Balistes capriscus*), sheepshead (*Archosargus probatocephalus*), Atlantic spadefish (*Chaetodipterus faber*), cobia (*Rachycentron canadum*), greater amberjack (*Seriola dumerili*), and African pompano (*Alectis ciliaris*) (Ajemian *et al*., 2015a).

Sidescan sonar was created in the 1940s when relatively high frequency echosounders were positioned to ensonify a wide area of the seafloor (Fish and Carr, 1990). Side scan sonar

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Table 1. *Study sites showing different types of artificial reefs sampled. The structure at each reef site coupled with the reef date and depth suggest successional state and ecological niche of each reef.*

Site	Latitude	Longitude	Dist Offshore (n.m.)	Depth (m)	Mean Surface Area Reefed (m^2)	Structure	Year Deployed
Concrete Culverts (PS-1047)	26.525583	−97.153583	6.5	21	300	4922 concrete drainage culverts	2011
Three-Pile Jacket Reef (PS-1169L)	26.215033	−96.982416	7.1	24	192	2 three-pile oil-rig-drilling jackets, one tugboat	1994
Four-Pile Jacket Reef (PS-1070)	26.424983	−97.020950	15.4	31	240	four-pile oil-rig-drilling jackets	1994
Texas Clipper Artificial Reef (PS-1122)	26.186450	−96.855700	17.2	35	3600	single ship (144 m)	2007
Natural Reef (Big Sea Bree)*	26.435450	−96.010216	16.5	33	300	natural reef (max 4 m relief)	N/A

**The natural reef was used only in the rapid assessment.*

technology developed rapidly in the 1970s and 1980s and has since been used as a high resolution imaging device to search for shipwrecks, to look at sea-floor configuration for the oil industry, and to map benthic habitats (Cuevas, Buchanan, and Moss, 2002; Fish and Carr, 1990). The wide angle of emitted sound (beam angle) of sidescan sonar allows a greater volume of water to be sampled than is possible with vertical-single beam echosounders (Trevorrow, 1997, 1998; Trevorrow and Pedersen, 2000). Sidescan units produce high-quality images, and sidescan sonar transducers can be either attached to the hull of a vessel or mounted on a towfish. Several studies have utilized sidescan to observe fish populations. Specifically, these studies have focused on the migration of salmon (Salmonidade) and herring (Clupeidae) in Canadian channels (Trevorrow, 1997, 1998; Trevorrow and Claytor, 1998; Trevorrow and Pedersen, 2000), the surveying of sturgeon (Acipenseridae) in the rivers of North Carolina (Flowers and Hightower, 2013, 2015), and the counting and mapping of pelagic fish schools (Smith, 1970). While size classifications have been conducted with sidescan sonar, no biomass estimates have been noted.

Some of the most important applications of fisheries acoustics are estimations of density, abundance, and biomass of fish (MacLennan, Fernandes, and Dalen, 2002). Biomass is commonly estimated as an integration of acoustic energy scattered from discrete targets per unit volume of water, where each discrete target's acoustic intensity is its target strength (TS). Fish length has been estimated with TS in several studies (Boswell *et al*., 2008; Foote, 1987; Love, 1977; MacLennan and Holliday, 1996) using an equation originally presented by Love (1969). Fish length is then converted to weight using known length-to-weight relationships for commonly sampled fish species within the survey area (Boswell, Wilson, and Wilson, 2007). An essential requirement of estimating biomass with sonar is the use of solid sphere calibration (Foote, 1990; MacLennan, 1981). Because of the lack of information regarding species identification from individual sonar returns, biomass estimates are generalizations based on the fish community sampled (Boswell, Wilson, and Wilson, 2007). Another challenge when estimating biomass is the lateral position of the fish when surveyed. Fish that shoal or school can be expected to face multiple directions that can lead to errors in fish-size classifications (Boswell *et al*., 2008; Boswell, Wilson, and Cowan, 2008; MacLennan, Hollingworth, and Armstrong, 1989). Therefore, estimations using any sonar technique in the field likely underrepresent total biomass present.

Sonar-based research is becoming more prevalent as the cost of equipment decreases and as the technology improves. Early versions of sidescan units that printed echograms on paper have been supplanted by ones that use convenient data-recording methods and higher frequencies (400–900 kHz). They have become popular for both recreational and commercial fishing applications, and they function as a tool readily adapted to survey reef-associated fish (Daniels *et al*., 2009). In addition to covering vast areas, sidescan sonar can be used to assess reef function by determining fish use of habitat both spatially and temporally, metrics that have posed constant challenges to researchers in the past.

Sidescan sonar has been used to locate and characterize artificial reef structures (Arney, Froehlich, and Kline, 2017; Froehlich and Kline, 2015), and work has been done to characterize the fish over these habitats (Alexander, 2015; Garcia, 2013); it is clear that additional tools to quantify and compare the abundant fish populations across entire reef areas are needed. The aim of this research is to validate sidescan sonar as an artificial reef survey method by comparing abundances obtained *via* SCUBA observations to those obtained *via* sidescan sonar echo returns. Going a step further, this study used abundance data and calibrated sidescan sonar biomass estimates to compare a variety of reef structure types and temporal differences in these same reefs. Biomass data and fish-length size classes were used to analyze differences in the fish community across structure type and time of day.

METHODS

This study was conducted in the western Gulf of Mexico between May 2014 and June 2015 at five representative reef structural types to evaluate the efficacy of using sidescan sonar as a reef fish survey tool (Table 1; Figure 1). The surface area reefed for each structure was calculated from sidescan sonar images using structure length and width approximated as a rectangle.

Sonar Equipment

The sidescan sonar used in this study was a Humminbird 1198c SI (Johnson Outdoors Marine Electronics, Inc., Eufaula, Alabama, U.S.A.; Figure 2) with a transducer mounted on a towfish (Part # FRO-HST, First Response Outfitters, Willis, Texas, U.S.A.). The 200-kHz down imaging (20° @ –10 dB re 1 μPa) and 455-kHz side imaging (86° @ –10 dB re 1 μPa; total 180° of overall coverage) frequencies were used. The sonar equipment was calibrated using solid, nonresonant, tungsten

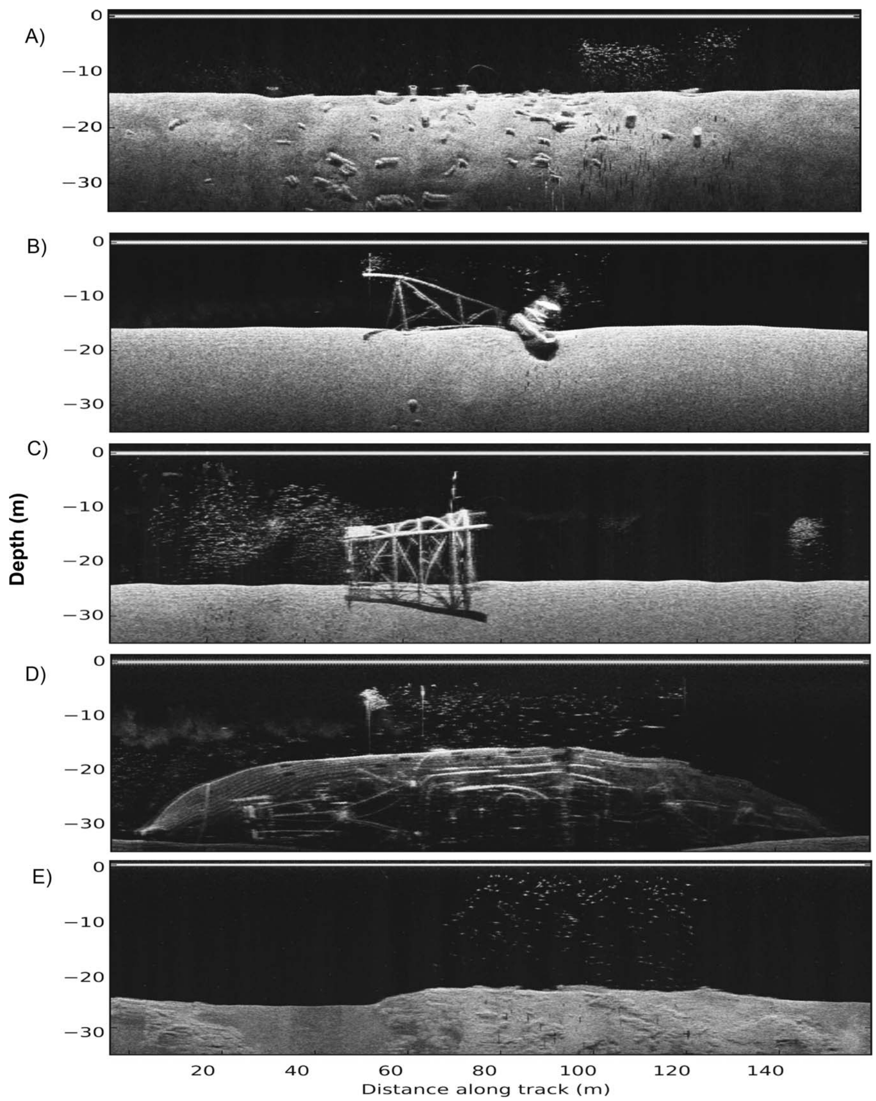

Figure 1. Sidescan images of the five structural types sampled in this study. (A) Port Mansfield, concrete culverts. (B) Port Isabel Reef, three-pile oil-drilling jacket. (C) Port Mansfield Liberty Ship Reef, four-pile oil-drilling jacket. (D) Texas Clipper Reef, ship. (E) Big Sea Bree, natural reef.

spheres (22.23 mm, 20.00 mm, 19.05 mm, 15.00 mm, and 12.70 mm), as described by MacLennan (1981).

SCUBA Surveys

Thirty-six SCUBA surveys were conducted over four, out of the five, reef types to compare these data with paired fish-quantification data from sonar. A diver survey at each location was conducted within 30 minutes of recording sonar surveys. Only one paired survey at each location was compared per day at each reef location because of concerns with differential fish positioning on the reef over extended time periods. Surveys were conducted by sending a pair of divers down the line of a marker buoy. One diver, trained in identifying all local fish species, was tasked with quantification of all fish in the water column, while the other diver was tasked with navigation, estimating water-column visibility, and ensuring that the starting and stopping points of the survey were located. Linear roving diver surveys with two segments that corresponded to the left-hand and right-hand transducer distances were conducted. The surveyor counted

Figure 2. The Humminbird 1198c head unit and towfish with sidescan transducer used in this study.

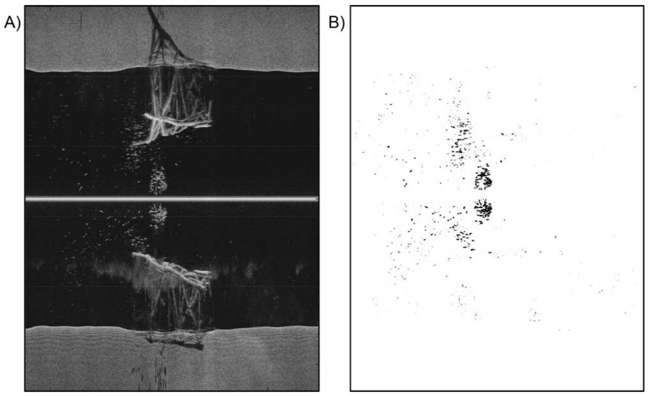

Figure 3. (A) Example of a raw sidescan sonar image. (B) Example of a processed image with a threshold applied in ImageJ. Fish counted manually = 340. Automated fish count = 305 × 1.1417 (correction factor) = 348.

only the fish in the water column along a transect with start and stop landmarks that corresponded to start and stop landmarks identified in the sonar surveys. These surveys varied in time from 20 to 35 minutes, depending on the reef size being surveyed. At the concrete culvert reef, the diver surveyed two parallel 50-m linear transects. The three-pile and four-pile oil-rig-jacket structures had higher open vertical relief and required parallel transects on both the upper and lower portions of the structure. The Texas Clipper Reef was surveyed by two parallel 100-m transects—along the length of the ship, up the hull side and down the rigging side—as the ship lays on its side (Figure 1D).

Sonar Surveys

Recordings from 36 sonar surveys were collected over the same four reefs and within 30 minutes of the SCUBA surveys. Only fish residing in the water column and between easily recognizable landmarks identified on each structure were compared between the two methods. As the sidescan sonar could easily cover areas much larger than SCUBA, recordings of each transect continued until reef-associated fish returns stopped for use in a second analysis.

Sonar surveys comprised three consecutive passes recorded over each reef structure or section of reef to ensure that the desired transect was captured in the recordings using identifiable landmarks in sonar returns and on SCUBA at each reef site. These passes were later processed on a computer workstation where only the most direct pass over the center line in the longest direction of the structure was used in analyses, as it consistently had the highest fish counts based on preliminary experiments. Vessel speed was kept below 5 knots to ensure that the towfish with transducer remained at a depth approximately 6 m below the surface to avoid the effects of air bubbles from propwash and the influence of the sea surface.

Fish echo returns were compared in two analyses: (1) with sonar quantification limited to the boundaries of the structure and (2) with an expanded survey that included sonar quantification of all fish returns associated with the reef structure. Transect length varied depending on structure type or in the case of expanded surveys, until reef-associated fish returns stopped. Full sonar transects averaged 239.6 (±72.9) m in length. To scale for differences in area surveyed during SCUBA surveys, transects were limited to the area directly over each structure (the area that was surveyed with SCUBA) to enable direct comparison with SCUBA surveys.

Sonar Processing

Images of the water column were generated from raw sonar files using the PyHum program (v1.3.3, U.S. Geological Survey, Flagstaff, Arizona, U.S.A.; Buscombe and Hamill, 2015). Tungsten solid sphere calibration was completed *in situ*, similarly to MacLennan (2011), by hanging spheres at midwater column and passing over the top of them in the same manner as the fish surveys. Resulting intensity values were set to the calculated echo intensities of the spheres, and those calibrated intensity adjustments were used in processing the fish survey data. Attenuation of intensity with distance was corrected using a cosine-range correction in PyHum. Images were edited in Photoshop (CS6, Adobe Systems Inc., San Jose, California, U.S.A.) to remove high-intensity returns, such as bottom structure and water-column interference, that were not fish. ImageJ (v.1.48p, National Institutes of Health, Bethesda, Maryland, U.S.A.) was used to quantify fish-echo returns using the count tool, and intensities of each discrete echo return were recorded (Figure 3). ImageJ setting combinations as compared to manual counting results and image processing macro are detailed in the git repository (Bollinger, 2015).

Abundance Estimation

A minimum fish TS threshold of –60 dB was used to filter low-intensity noise, and only particles larger than 20 in pixel area (1 pixel = 4.5 cm) and 0.05 circularity were counted (where 1.0 circularity = a perfect circle and 0.0 circularity = elongated rectangle shape [Ferreira and Rasband, 2012]). In a linear regression (Sokal and Rohlf, 1995) of automated counts of fish conducted in ImageJ *vs*. manual Photoshop counts, a slight underestimation of automated ImageJ counts was noted, and a correction equation was applied to all sonar count data ($y = 1.1417x$; $r^2 = 0.864$; $n = 36$; $p < 0.001$). Fish abundances were scaled to surface area of each reef structure (m^2) as fish density (D_F; Equation [1]):

$$D_F = \text{Total number of fish/reef area}(\text{m}^2). \qquad (1)$$

Biomass Estimation

After abundance estimation, ImageJ was used to calculate maximum individual TS from all targets in the image. Fish standard length (L_{cm}) was calculated for all individuals using Equation (2) (Love, 1969), and a mean standard length (cm) was determined:

$$\text{TS} = 24.1 \times \log_{10}(L_{\text{cm}}) - 61. \qquad (2)$$

Next, a mean weight (g) was calculated using published length-to-weight relationships of commonly sampled fish species occurring over reefs in the Gulf of Mexico (Table 2).

A fish community length (L)–weight (W) relationship (Table 1; Figure 4; Equation [3]) was calculated by averaging log-transformed data from individual species growth curves:

Table 2. *Parameters used in calculating the mean weight-to-length ratio for common Gulf fish species, where weight* = a × *(length)*^{b}. *All functions were recalculated so that length was in cm and weight was in g.*

Species	Max L (cm)	A	B	Source
Selene vomer	48	0.018	3.01	(Oliveira Freitas *et al*., 2011)
Lutjanus griseus	89	0.0156	2.93	(Powers *et al*., 2003; SAFMC [South Atlantic Fishery Management Council], 1983)
Caranx crysos	70	0.0306	2.86	(Frota, Costa, and Braga, 2004)
Lutjanus campechanus	100	0.0135	3.05	(McInerny, 2007)
Balistes capriscus	60	0.0361	2.78	(Ismen, Muhammet, and Yigin, 2004; SAFMC, 1983)
Chaetodipterus faber	91	0.0392	2.94	(Wigley, McBride, and McHugh, 2003)
Archosargus probatocephalus	91	0.0342	2.89	(Dutka-Gianelli and Murie, 2001; SAFMC, 1983)
Seriola dumerili	190	0.0174	2.86	(Manooch III and Potts, 1997)
Rhomboplites aurorubens	60	0.0135	3.01	(Wigley, McBride, and McHugh, 2003)

$$W = 0.0232 \times L^{2.9088} \tag{3}$$

Biomass (g/m^3) over the reefs was estimated using Equation (4) by multiplying fish density (D_F) by mean fish community weight (Equation [4]):

$$\text{Biomass} = W \times D_F \tag{4}$$

Methodology Comparison

Water-column visibility was not a significant covariate in the multivariate analysis of variance (ANOVA) comparing SCUBA and full transect sonar surveys or structure limited surveys (sonar, $F = 0.050$, df $= 35$, $p = 0.824$; SCUBA, $F = 2.127$, df $= 35$, $p = 0.155$). Consequently, paired t tests were used in further comparisons. The SCUBA abundance was compared to sonar abundance limited to the area over the structure that a diver surveyed, using a paired t test. In addition, SCUBA abundance was compared to sonar abundance utilizing an expanded survey length (until structure associated fish returns stopped) with a paired t test. All analyses were done in SPSS (v. 21 IBM Statistics, Armonk, New York, U.S.A.) unless otherwise stated, and statistical significance was determined at $p < 0.05$ for all tests.

Reef-Structure Comparisons

Abundance and biomass estimates calculated from sonar returns were scaled to each reef area and compared using an ANOVA with a Scheffe *post-hoc* test. All data were verified for normality using Q-Q plot analysis and homoscedasticity using Levine's test (Sokal and Rohlf, 1995).

Rapid-Reef Assessment

All reef comparisons were accomplished with the sidescan sonar methodology detailed above. In the first comparison, four artificial reefs and one natural reef were sampled on the same day. Three distinct sites within each reef were sampled, with the exception of the submerged ship reef where only one structure exists. Three 200-m passes were taken at each site, and only the most direct pass over the structure was used in analysis. The reefs were compared by abundance and biomass using a multivariate ANOVA with a Scheffe *post-hoc* test and verified for normality using Q-Q plot analysis and homoscedasticity using Levine's test (Sokal and Rohlf, 1995) in SPSS (v. 21). Fish lengths were calculated by applying the Love (1969) equation to each calibrated fish TS, provided in ImageJ. Fish lengths were then binned into 30-cm-size classes (<30 cm, 30–59 cm, 60–90 cm, >90 cm) at each reef and calculated as a percentage of the total fish abundance (Figure 5). These data were analyzed with a Bray-Curtis similarity, multidimensional scaling plot, and cluster analysis in PRIMER-E v6 (Clarke and Gorley, 2006).

Temporal Comparison

Because preliminary surveys showed high abundances associated with four-pile oil-drilling-jacket structures at PS-1070 (Table 1), a temporal comparison was conducted to test the hypothesis that fish exhibit a preference for a particular side of the structure throughout the day. Three 200-m passes were taken at three four-pile jacket structures during three time periods (1000, 1300, 1800 h) where only the pass from each

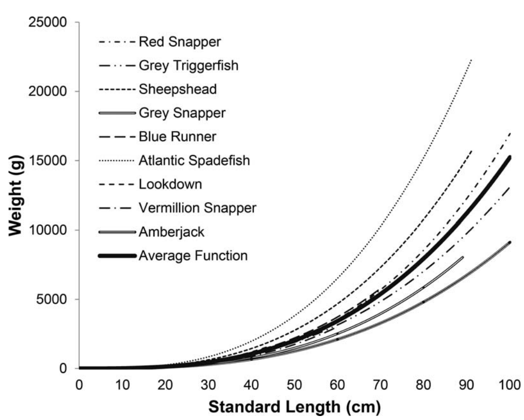

Figure 4. Weight (g)–length (cm) ratios for common midwater column fish (nine total) in the Western Gulf of Mexico (Ajemian *et al*., 2015a). The average of the ratios was calculated and plotted in bold.

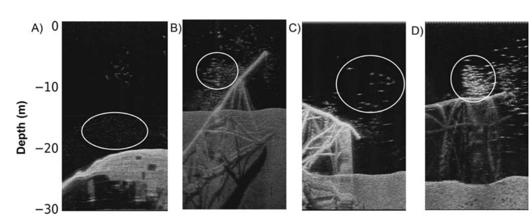

Figure 5. Examples of sidescan imagery with fish from each size class: (A) small = <30 cm, (B) medium = 30–60 cm, (C) large = 60–90 cm, and (D) extra-large = >90 cm.

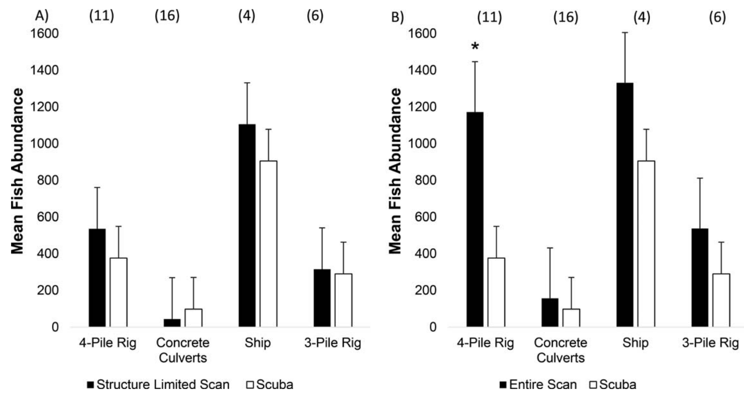

Figure 6. Comparison of survey methods used over artificial reefs. (A) Sidescan surveys limited to structural area (structure limited scan) compared with SCUBA surveys of structural area ± SE (bars). (B) Sidescan transects quantifying all fish returns within 100 m of the structure area, utilizing entire range of sidescan sonar as compared to SCUBA surveys of structural area ± SE (bars). A paired *t* test for limited scan and SCUBA were not significantly different ($t = 0.259$, df = 35, $p = 0.797$) while a paired *t* test for the entire scan and SCUBA was significantly different ($t = -3.653$, df = 35, $p = 0.001$). Further site specific paired *t* tests show the four-pile oil-drilling structure was the only structure driving the significance. Sample size included in parenthesis.

structure and time period with the highest abundance was used in analysis. Each scan of an individual structure was divided into three sections based on cardinal direction and prevailing currents (NW, SE, and over reef structure) in postprocessing. Repeated measure ANOVAs were used to compare abundance and biomass both within each section of the structure for time of day and between sections of the structure for time of day.

RESULTS

Counts directly over the structures by sidescan sonar (326.52 ± 65.65 [mean ± standard error (SE)]) were not significantly different than the paired SCUBA surveys (297.25 ± 50.09) ($t = 0.259$, df = 35, $p = 0.797$; Figure 6A). However, sidescan sonar could cover a larger volume of the water than what was immediately around the reef structure. When considering the entire sonar transect that contained reef-associated fish returns (239.6 ± 72.9 m), sonar abundance (633 ± 120.91) was significantly different from paired SCUBA counts ($t = -3.653$, df = 35, $p = 0.001$; Figure 6B).

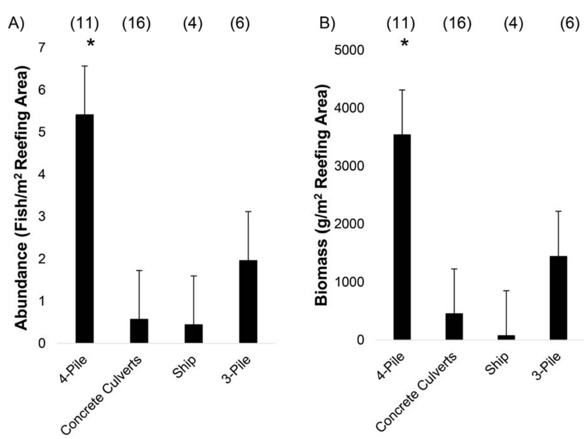

Figure 7. Abundance (A) and biomass (B) estimates (±SE bars) per reefing area footprint for each of the artificial reef structures averaged over the study time. The ANOVA (abundance: $F = 14.752$, df = 4, $p < 0.001$; biomass: $F = 7.200$, df = 4, $p < 0.001$). Sample size included in parenthesis.

Reef-Structure Comparisons

Abundance per area reefed was significantly different among structure types ($F = 10.311$, df = 3, $p < 0.001$; Figure 7A). The four-pile jacket had significantly more associated biomass (5.41 ± 1.20 g/m^2) than the ship (0.44 ± 0.03 g/m^2, $p = 0.009$), the culverts (0.57 ± 0.25 g/m^2, $p < 0.001$), and the three-pile oil-drilling jacket (1.96 ± 0.24 g/m^2, $p = 0.028$).

Fish biomass estimates per area reefed were significantly different among structure types ($F = 7.280$, df = 3, $p < 0.001$; Figure 7B). The four-pile jacket had significantly more biomass associated with it (787.3 ± 177.7 g/m^2) than the ship (22.7 ± 8.9 g/m^2, $p = 0.018$) and the culverts (131.3 ± 61.6 g/m^2, $p = 0.02$); however, no significant difference was detected between the four-pile jacket and the three-pile jacket (288.3 ± 127.5 g/m^2, $p = 0.069$).

Rapid Reef Assessment

An ANOVA and Scheffe *post-hoc* test revealed that the four-pile oil-drilling jacket had significantly higher mean fish abundance per reef area (4.603 ± 0.966, $F = 14.752$, df = 4, $p < 0.001$) than the natural site (0.154 ± 1.762 fish/m^2, $p < 0.001$), the three-pile oil-drilling jackets (0.357 ± 0.406 fish/m^2, $p < 0.001$), the culverts (0.180 ± 1.717 fish/m^2, $p < 0.001$), and the ship (0.050 ± 1.030 fish/m^2, $p = 0.003$) (Figure 8A).

In addition, the four-pile oil-drilling jacket had significantly more biomass (1445.8 ± 113.2 g/m^2) associated with it than the three-pile oil-drilling jacket (2.7 ± 0.6 g/m^2, $p = 0.031$) and the culverts (33.5 ± 15.3 g/m^2, $p = 0.036$) but not the natural site (121.8 ± 113.1 g/m^2, $p = 0.057$) or the ship site (2.4 ± 1.1 g/m^2, $p = 0.233$) during the rapid assessment (Figure 8B).

The three-pile oil-drilling-jacket reef-fish assemblage was smaller than other structures, with only 1% of fish larger than 30 cm compared to other structures, where between 45–55% of the assemblage was over 30 cm (percentage greater than 30 cm:

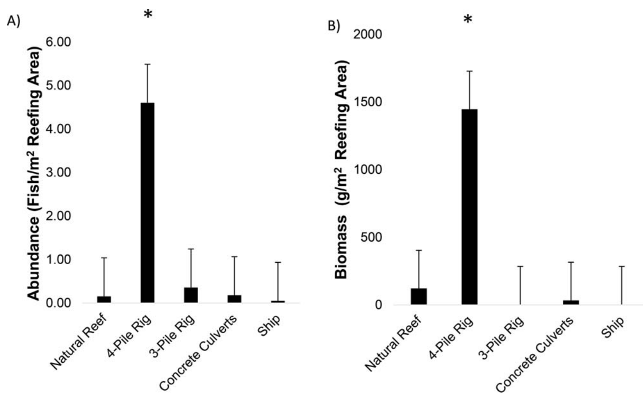

Figure 8. Abundance (A) and biomass (B) measures for each reef structure ± SE (bars) for the rapid reef assessment. (A) The four-pile oil-drilling-jacket structures (a) had significantly higher abundance than the other structures besides the ship (Natural Reef [NR]: $p = 0.001$; three pile [3-P]: $p = 0.012$; concrete culverts [CC]: $p = 0.002$; ship: $p = 0.334$). (B) A similar trend was observed in biomass with higher biomass on the four-pile oil-drilling jacket than the other structures except for the ship (NR: $p = 0.01$; 3-P: $p = 0.004$; CC: $p = 0.008$; ship: $p = 0.075$).

natural 55.2%, four pile 46.8%, culverts 45.1%, and ship 43.4%; Figure 9).

Temporal Comparison

The comparison of the four-pile oil-drilling-jacket reef structures over an 8-hour period showed a decrease in reef fish abundance directly over the structure as the day progressed (repeated measures ANOVA, within; over: $F = 31.034$, df = 1, $p = 0.001$; Figure 10A), while no significant change in fish abundances was noted on the NW and SE ends of the structure throughout the day (NW: $F = 0.654$, $p = 0.450$; SE: $F = 0.05$, $p = 0.948$). Total abundance showed a decreasing trend that was not significant regardless of position over the structure ($F = 0.639$, df = 2, $p = 0.531$; means: morning, 0.758 ± 0.082; noon, 0.711 ± 0.105; evening, 0.471 ± 0.043).

Overall, biomass decreased 34% (±0.21) over all sections as the day progressed, but biomass directly over the structure peaked at midday (895.4 ± 305.3 g/m^2). Biomass on the SE side increased, although not significantly (repeated measures ANOVA within; over: $F = 4.849$, df = 2, $p = 0.070$; NW: $F = 0.853$, $p = 0.391$; SE: $F = 0.044$, $p = 0.841$; Figure 10B). No significant differences were observed within sections of the reef. The structures showed a decrease of 42% (±0.17) in the proportion of fish above 30 cm as the day progressed (Figure 11).

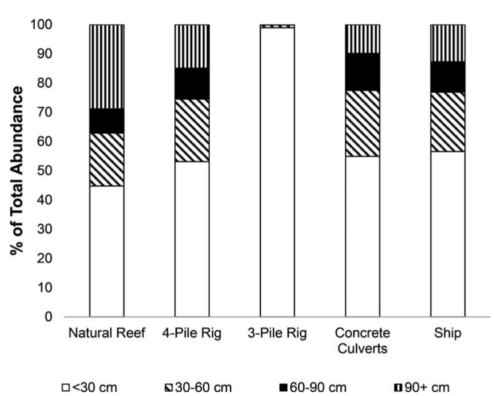

Figure 9. Fish abundance by size class for each reef structure scaled to 100% of the total abundance.

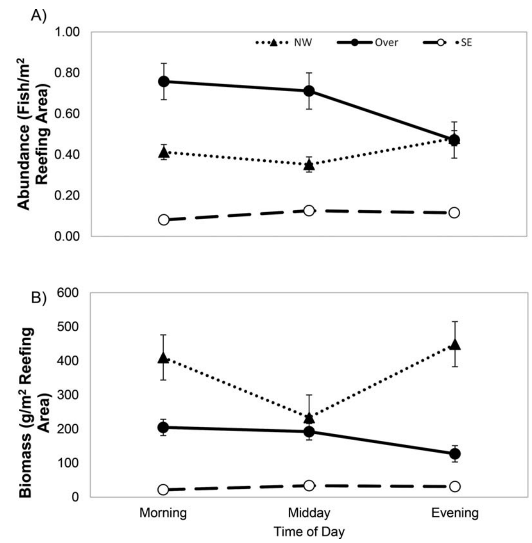

Figure 10. Abundance (A) and biomass (B) estimates on the SE side, NW side, and over the top of four-pile oil-drilling-jacket structures at the Port Mansfield Liberty Ship Reef (PS-1070) ± SE (bars). The overstructure abundance decreased during a daily sampling regime (repeated measures ANOVA: $F = 31.034$, df = 1, $p = 0.001$), while biomass decreased slightly during the midday samples. Fish abundance and biomass on either edge of the structure did not change significantly with time.

DISCUSSION

In this study, sidescan sonar was used to quantify abundance, biomass, and size categories of reef fish. Abundance

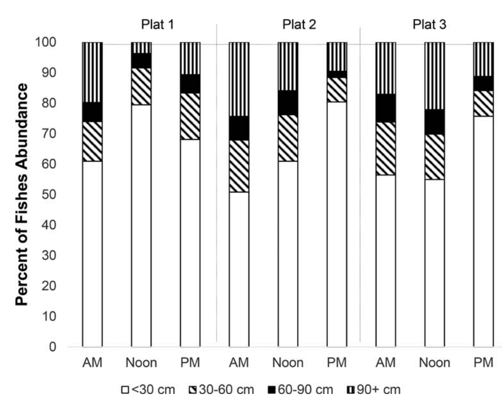

Figure 11. Fish abundance by size class for each platform (plat) structure and time scaled to 100% of the total abundance.

estimates of reef fish using the sidescan sonar method were comparable to SCUBA surveys when restricted to the same coverage area, proving its utility in reef surveys. Previous acoustic studies of this nature have used single- and split-beam sonar for biomass estimation (Boswell *et al*., 2010; Boswell, Wilson, and Wilson, 2007; Hightower, Taylor, and Degan, 2013; Misund, 1997; Misund *et al*., 1996); however, the sidescan sonar methodology defined here is preferable because it can cover more of the water column than single- and split-beam sonars (<20° for split beam depending on transducer *vs*. 180° for sidescan sonar) in a single pass. Some authors have ground-truthed their sonar surveys with trawl net tows (Misund, 1997), a technique that would be impossible over artificial reef structures in the present study. A main advantage of sidescan sonar and other sonar methods is that they are not limited to the area directly over the structure as with SCUBA surveys. The temporal comparison over the four-pile jacket showed high fish abundance toward the edges of the structure, possibly indicating a behavioral preference for position on the structure that warrants further investigation.

The sonar methodology quantified more fish than SCUBA when extending the survey into a larger water volume, indicating that in some cases, reef-associated fish aggregations cannot be accurately quantified using SCUBA survey methods. A few studies have taken advantage of this large-scale water-column sampling technique (Trevorrow, 1997; Trevorrow and Claytor, 1998) and have been successful in enumerating fish. Trevorrow (1997) was able to generalize migrating salmon abundances using a stationary sidescan sonar to resolve backscatter relative levels but stopped short of individual fish counts. Other studies have used a split-beam or dual-beam echo sounder (Misund, 1997; Simmonds and MacLennan, 2005; Stanley and Wilson, 1995, 1996), but sidescan's fanlike beam pattern used in the present study allows a much larger water volume to be observed in a single pass (Trevorrow, 1997).

In the present study, biomass was calculated using TS to estimate body length and a mixed-species group average length-to-weight ratio was used to estimate biomass. While these are methods that have been utilized in several studies where biomass could not be ground-truthed for all species present, it would be preferable to directly measure biomass from a subsample of species directly; this is a limitation of the results presented here. In addition, species identification, through sidescan, was not possible in this study. This poses a problem for management of target species, such as red snapper that commonly occur in mixed-species aggregations (Boswell *et al*., 2008; Massé and Retière, 1995). Using simple abundance or biomass of these mixed groups could be misleading; therefore, a combination of sonar with another technique to identify the species composition such as SCUBA or video could provide enhanced resolution to the methods presented here.

The present study categorized reef fish into 30-cm increments based on calibrated TS, similar to other acoustic surveys (Borstad, Lemon, and Martinez, 2009; Walline, Pisanty, and Lindem, 1992) and visual survey techniques (Edgar, Barrett, and Morton, 2004; Jordan, Gilliam, and Spieler, 2005). In management situations where species identification is key, a limited area visual survey could be paired with a large-scale sonar survey using the present methodology to answer management questions. The present study saw clear differences in fish community between structure types with the largest percentage (28.8%) of 90-cm+ size class fish at the natural reef and only 1.1% of fish larger than 30 cm at the three-pile jacket. Further research is warranted to investigate seasonal trends in these fish communities.

Habitat Comparisons

The four-pile oil-platform jacket structures in this study had higher abundances than any other structural type (Figure 11). Oil-platform jacket structures have been reported to hold high abundance and diversity of fish (Ajemian *et al*., 2015a,b) and appear to make good artificial reef material; however, location may also play a role in the higher abundance observed. Garcia (2013) suggested inshore sites, such as the culvert reef, are more heavily fished because of their location in state-managed waters than offshore reefs, such as the ship reef, which is located in federally managed waters. The four-pile structures may have had reduced fishing pressure because of the lack of a surface marker buoy and extended closures of the U.S. federal fishing seasons for red snapper (10-day season) and amberjack (30-day season) (GMFC [Gulf of Mexico Fisheries Council], 2016). The size class differences observed at the three-pile jacket in this study also support that fishing pressure may be the cause of the differences observed. The three-pile jacket sites showed no fish larger than 60 cm during the reef comparison analysis, which may indicate predator depletion, likely from fishing (Jennings and Polunin, 1997).

The temporal comparison showed clear differences in fish abundances on different sides of the structures (Figure 11), and over the course of this research, the authors commonly observed higher fish numbers on the sides of structures. Boswell *et al*. (2010) showed that fish abundance decreased as distance from the reef complex increased. Decreasing fish abundance with distance away from the structure was noted in most cases during the present study; fish were consistently more numerous on one end of the structure than the other. A potential reason for this side preference could be feeding patterns of the reef species, such as red snapper and Atlantic spadefish, in relation to prevailing currents. Hamner *et al*. (1988) found that planktivorous fish on the Great Barrier Reef (Australia) form a "wall of mouths" on the upstream (*i.e*. the side of the reef where larger fish would be farther from and smaller fish would be closer to the reef).

Fish abundance at the structures tended to decrease as day length progressed (Figure 10). It is well documented that fish show diel feeding patterns (Helfman, 1986; Hobson, 1972; Ouzts and Szedlmayer, 2003). This results of the present study show that comparisons of fish populations over large artificial reefs need to be accomplished over similar timeframes and over areas larger than a diver can cover to accurately assess the resident population. This is an aspect easy to accomplish with sidescan sonar but very difficult to accomplish with visual methods.

Sampling and Processing Efficiency

The rapid assessment of reef structures with sidescan sonar described in this study would allow multiple sample sites in a single day, creating a large data set of comparable data. The present method used a semiautomated method to process the sidescan sonar data. Boswell, Wilson, and Cowan (2008) outlined methodology to partially automate processing of dual-frequency identification sonar (DIDSON) data. Automating the data processing streamlined the method and reduced the labor needed to obtain results using this method. Recently, Buscombe, Grams, and Smith (2015) used a Humminbird sidescan sonar and the PyHum program to classify sediments on a riverbed. The present methodology for estimation of fish abundance and biomass, as well as the classification method presented in Buscombe's study, illustrate the adaptability of sidescan sonar.

CONCLUSIONS

The results of this study showed that rapid assessments of reef-associated fish communities using sidescan sonar methodology is possible and may be used to answer macroscale questions impossible with visual methods. The concordance in abundance estimates from visual SCUBA surveys and from sidescan sonar show promise for automation of the sonar data comparisons of reef structures using sidescan sonar. The adaptability and affordability of sidescan sonar makes it an attractive option for researchers all over the world, and future studies can accomplish large-scale comparisons of numerous reef habitats for reef fish abundance, size classes, and biomass in a variety of sea states and visibility levels with the methodology reported here.

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