5-2017

Investigating the Application of Multibeam Sonar and Remotely Operated Vehicles in Fish Population Monitoring on Artificial Reefs

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Recommended Citation

Figueroa-Downing, Robert, "Investigating the Application of Multibeam Sonar and Remotely Operated Vehicles in Fish Population Monitoring on Artificial Reefs" (2017). *Theses and Dissertations*. 193.
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INVESTIGATING THE APPLICATION OF MULTIBEAM SONAR AND REMOTELY OPERATED VEHICLES IN FISH POPULATION MONITORING ON ARTIFICIAL REEFS

A Thesis

by

ROBERT FIGUEROA-DOWNING

Submitted to the Graduate College of
The University of Texas Rio Grande Valley
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2017

Major Subject: Biology

INVESTIGATING THE APPLICATION OF MULTIBEAM SONAR AND REMOTELY OPERATED VEHICLES IN FISH POPULATION MONITORING ON ARTIFICIAL REEFS

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ROBERT FIGUEROA-DOWNING

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May 2017

ABSTRACT

Figueroa-Downing, Robert, Investigating the Application of Multibeam Sonar and Remotely Operated Vehicles in Fish Population Monitoring on Artificial Reefs. Master of Science (MS), May, 2017, 38 pp., 5 tables, 9 figures, references, 46 titles.

Implementation of ROVs and multibeam imaging sonar in fisheries research has the potential to improve the accuracy and efficiency of current monitoring practices. This study aimed to 1) compare ROV video and diver abundance estimates; 2) evaluate fish length measurement accuracy from sonar; 3) investigate key differentiating sonar characteristics. Results indicate: 1) Diver surveys captured greater diversity of species; survey methods were comparable with regards to conspicuous species ($r = 0.089$, $p = 0.074$); 2) Length measurements from multibeam imaging sonar had high predictive power ($Rho = 0.998$; $p < 0.001$) of actual standard lengths and; 3) variations between samples were largely due to swim bladder echo, relative position of the target fish, and schooling characteristics. We conclude that 1) ROVs are less apt at observing cryptic species; 2) The Blueview P900-90 sonar can accurately measure fish length; and 3) swim bladder morphology plays an important role in fish identification.

DEDICATION

I would like to dedicate this masters thesis project to my loving and supportive parents, Derise Figueroa and Robert James Downing, my sister, Daniella Figueroa-Downing, and the graduate students of the University of Texas Rio Grande Valley.

ACKNOWLEDGEMENTS

I would like to thank Texas Parks and Wildlife, the National Oceanic and Atmospheric Administration, and the Environmental Cooperative Science Center for funding this research. I would like to give special thanks to my advisor and committee chair, Dr. David Hicks, for everything he has done in aiding in the planning and execution of this masters thesis project. I would also like to recognize my committee members, Dr. Richard Kline, Dr. Diego Figueroa, Dr. Laura Kracker, and Bryan Legare, who were always available and willing to give sound advice. I thank captains Andres Garcia and Johnny Yerner, who helped in deploying and retrieving the ROV in addition to piloting the Vollert. I also thank Ricky Alexander, Michael Bollinger, Catheline Froehlich, Al Alder, Adam Lee, and Ethan Getz who played a crucial roll in data collection. Thank you to my lab assistants: Shelby Bessette, Ashley Moreno, and Heather Otte. Finally, I would like to thank my family and the Brownsville grad community for their incredible support throughout this process.

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CHAPTER I

INTRODUCTION

The Gulf of Mexico has the largest number of artificial reefs in the world (Dauterive 2000). An artificial reef is any man-made structure submerged in the ocean for the purpose of increasing the available hard substrate for fish and invertebrate species (Baine 2001). While artificial reefs do offer habitat for fish and invert species (Ditton et al. 2002), there is a debate as to whether artificial reefs facilitate increases in fish biomass or if they concentrate individuals from the surrounding area (Grossman et al. 1997; Polovina 1991). The impact of artificial reefs on commercially and recreationally valuable species, such as red snapper (*Lutjanus campechanus*), is of great interest, as artificial reefs have the potential to increase the fishing pressure on fish communities (Grossman et al. 1997). In the case of red snapper (*Lutjanus campechanus*), recreational fishing accounts for more than 60% of the total fishing effort (Coleman et al 2004). If artificial reefs are, in fact, concentrating individuals from the surrounding area, these populations could be under greater stress than we currently believe. Therefore, it is of critical importance that we better understand how these structures are incorporated into the life histories of reef fish.

A majority of current methods of monitoring fish populations and performing stock assessments on artificial reefs are indirect, invasive, and species-specific. Stock assessments are currently estimated from a combination of fisheries-dependent and fisheries-independent data. Fisheries dependent data is sourced from the commercial and recreational fishing sectors including landing records, portside sampling, onboard observers, log books, and telephone surveys (Cooper 2006). The majority of data comes from landing records, resulting from the sale of caught fish, or portside sampling, in which catches are analyzed as fishermen unload (Cooper 2006). A large portion of stock assessment data is collected from recreational fishermen (Maunder and Piner 2015). The creation of stock assessments based on fisheries dependent data is problematic, as reports from fishermen have been shown to be inaccurate (SEDAR 2009). Fishermen tend to understate the amount of bycatch (SEDAR 2009), and are reluctant to disclose the amount of high-grading performed at sea (SEDAR 2009; Harrington et al. 2005). Bycatch, or the capture of non-target species, results in a degradation of overall ecosystem health. High-grading occurs when smaller fish are exchanged for larger fish that are caught later. This results in the death of the discarded individual in most cases (Harrington et al. 2005). Fisheries independent data is obtained in a more direct and selective manner, reducing the amount of potential error associated with fisheries dependent data, yet failing to cover the same scope and scale as fisheries dependent data.

Fisheries independent data is more reliable, but remains species-specific and fails to overcome the inherent assumption that the subset sampled is representative of the entire population. Scientists tasked with monitoring fish populations use various methods including but not limited to vertical long lines, bottom long lines, trawls, and/or seines to collect individuals from a target species (Foley and Gelband 2001). Most of these methods, being species-specific by nature, cause harm to the areas sampled, especially trawls and seines, which have high levels of bycatch (Harrington et al. 2005). Of these methods, vertical long lines are most effective and low impact for artificial reefs (Gregalis et al. 2012) yet, this data can vary (Harley and Meyers 2001) as the chances of capturing a target species (i.e. “catchability”) are prone to change unrelated to stock size. Furthermore, caught individuals need to be representative of the population as a whole, since biomass estimates are based on their biometrics. At the heart of a stock assessment is the notion that the sample set will represent the population as a whole. While removal of this assumption is impossible, the direct measurement of fish communities and the reefs they inhabit would help to reduce assumptions and therefore the potential error of stock assessments. One method of directly measuring fish communities, diver surveys, has been adopted in the past 20 years.

Diver surveys represent a direct, non-invasive means of assessing the reef ecosystem as a whole. In diver surveys, scuba divers are used to perform visual counts of all fish species inhabiting a reef. Divers trained in the roving diver technique (Edgar and Smith 2013) offer a noninvasive means of monitoring artificial reefs. While a direct means of monitoring fish populations, diver surveys are prone to many limitations and inaccuracies. Diver surveys are limited by depth, visibility and duration (Edgar and Smith 2013). Additionally, research has shown that diver surveys can be biased, resulting in inaccurate estimations of counts (Assiss et al 2013). Issues faced by diver surveys could be improved with emerging technologies, such as remotely operated vehicles and sonar. Multibeam sonar, in conjunction with ROVs, does not share these environmental and time limitations of diving. The combination of sonar and ROVs allows for greater coverage, depth, and accuracy over a greater range of visibility and sea-state conditions. While sonar and ROVs exceed the capabilities of diver surveys, there are obstacles to the technology that must be overcome if they are to replace or enhance current monitoring methods. These include limited field of view (Tessier et. al. 2005), decreased resolutions (Assis et al. 2013), and the cost of purchasing and maintaining the technology (Langlois et al. 2010). This study seeks to investigate the use of ROVs in conjuction with multibeam imaging sonar technology to monitor fish populations of artificial reef habitats as a means to produce more accurate data in a noninvasive and cost efficient manner.

Sonar History and Biomass Estimation

The potential application of sonar in fisheries management and research is largely dependent on the characteristics of sound in water. Early sonar units were single, narrow-beam echosounders originally designed to map the ocean floor and detect objects in the water column, such as submarines. Such units were effective at depicting the density differential between the sea floor or a submarine and the water column, but faced obstacles when applied to fisheries monitoring (Chu 2011). These obstacles arose due to the fact that the body density of fish is roughly equivalent to the surrounding seawater (Klemm et al. 1995). Underwater, high frequency sound waves are able to image smaller areas versus longer, lower sound waves that propagate further in the water column. This is due to the fact that the intensity of the returning echo is dependent on the ratio of the size of the object to the wavelength of the incident wave, which is altered according to the frequency of the incident sound wave, via the equation wavelength = c/f (c= speed of sound; f = frequency) (Urick 1987). Therefore, low frequency sound waves fail to produce a strong enough echo off the bodies of fish for detection, relying instead on the air filled swim bladders of fish, which produce stronger echoes due to their density differential versus the surrounding water column. Thus, early sonar units (<100khz) were effective at detecting the presence of fish, yet gave little to no data on the size or species of the target. Subsequent higher frequency sonars (>100khz), coupled with a transition from analog to digital, have allowed for more detailed images of fish and brought about research relating the target strength, or echo intensity, to the overall length of the individual. In order to accurately measure target strengths, more beams were necessary, as single beam units had the tendency to produce overlapping echoes that would result in inconsistent measurements. As sonar technology evolved in light of fisheries research and management, units utilizing higher frequencies were invented.

Fish Identification

Fish identification is being explored as the next potential leap in sonar application to fisheries. Modern sonar units fall into four general categories which are differentiated by the frequency and number of beams utilized by each unit. Echosounders, sidescan sonars, multibeam echosounders, and multibeam imaging sonars and all are being investigated for fish identification. Of these four main sonar groups, multibeam imaging sonars are the only ones developed with the main intention of high definition imagery of objects including fish in the water column. Technologies within this group include Blueview, DIDSON, and ARIS units.

Certain parameters are crucial to standardize reflectivity of a target fish in sonar images, including depth, orientation of target, location of target in the field of view (FOV) of sonar, and distance from the sonar unit (Horne 2000).

Objectives and Research Questions

The objectives are as follows: 1) Compare ROV surveys to diver surveys; 2) Determine what role multibeam-imaging sonar (Blueview P900-90) can play in the estimation of fish biomass; and 3) Identify the most impactful differentiating characteristics between species in multibeam imaging sonar images

This study addresses three main questions:

1) How do abundance and diversity estimates from a ROV compare to those gathered from roving diver surveys?

2) Can multibeam imaging sonar be used to accurately measure fish length, therein enabling biomass estimation via length to biomass equations?
3) What are the key differentiating characteristics seen in multibeam imaging sonar images that would aid in future identifications of fish species?

CHAPTER II

METHODS

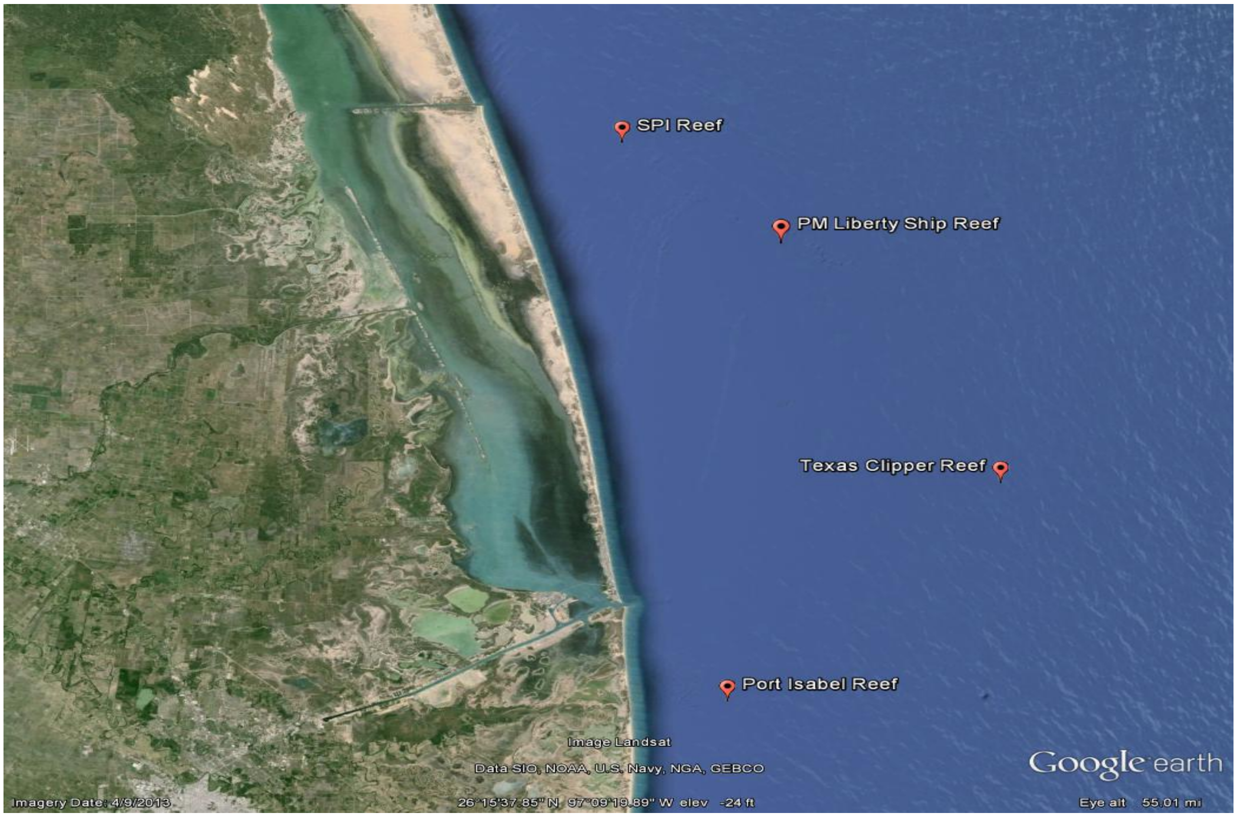


Figure 1. Locations of the sampling sites used for comparisons (Texas Clipper, PS-1122; South Padre Reef, PS-1047; Port Isabel Reef, PS-1169L; and Port Mansfield Liberty Ships, PS-1070) in the northwestern Gulf of Mexico.

Study sites

Data was collected at four artificial reef sites off the south Texas coast (Figure 1): the Texas Clipper (PS-1122), South Padre Reef (PS-1047), Port Isabel Reef (PS-1169L), and Port

Mansfield Liberty Ships (PS-1070). The Texas Clipper (PS-1122) is a 144 m ship, located 17nm from shore, which became an artificial reef in 2007, at a depth of 35m. South Padre Reef (PS-1047) is composed of 4,922 concrete culverts and one tugboat at a depth of 21 m and 6.5 nm from shore. The Port Isabel Reef (PS-1169L) is composed of two, 3-pile oil rig jackets and one tugboat at a depth of 24 m, 7.11 nm from shore. The Port Mansfield Liberty Ships (PS-1070) site is composed of 4-pile oil rig jackets and three liberty ships at a depth of 31 m, 15.4 nm from shore.

Sampling Equipment

Sonar data was collected via a Blueview (Teledyne Blueview Inc, Bothell, WA) P900-90 multibeam forward-looking sonar unit attached to a Videoray (Videoray LLC Pottstown, PA) PRO4 ROV. The Blueview P900-90 multibeam sonar unit operates at 900 kHz and has a 90-degree field of view. It has a max range of 100 m, with an optimal range of 4-60 m. The Blueview P900-90 has 512 beams spaced at 0.18 degrees per beam.

Simultaneous video recordings were collected via the Videoray Pro 4 ROV to aid in identification of fish species. The Videoray Pro 4 houses a high-resolution, color, wide angle camera that can rotate 180 degrees vertically and zoom. The forward-facing camera has about 570 lines of resolution and wide dynamic range. The Videoray Pro4 ROV has a maximum depth rating of 305 m. The data collected for this study occurred in 10-30 m of seawater, corresponding to the depths of the artificial reefs in South Texas. The ROV has two horizontal thrusters and one vertical thruster, each capable of varying degrees of thrust. It is operated via a command center module that displays real time video captured by the ROV’s front camera. The ROV has two forward-facing 1,600 lumen lamps. The ROV is equipped with a directional compass and depth sensor.

Comparison of Diver and ROV Surveys

The roving diver technique (RDT) survey methodology utilized in this study followed Texas Parks and Wildlife-Artificial Reef Program (ARP) protocol for surveying reef fish communities which has been in use since 1995. The RDT is a rapid visual census method wherein divers freely roam reef environments and record all fish species that can be positively identified in logarithmic abundance categories: Single (1 fish), Few (2-10), Many (11-100), or Abundant (>100); hereafter referred to as SFMA data (www.REEF.org). In this study, two consecutive paired-diver, RDT fish surveys, separated by a 2 h surface interval, were conducted during each site visit. Dives extended 30-40 min within sport diving depths (18-35 m).

The Videoray PRO4 surveys were performed immediately after both roving diver surveys for a specific site were completed, in a similar fashion (i.e. two 30 minute transects covering the same areas). The Videoray ROV was equipped with directional and depth sensors that enabled a close representation of diver surveys. Fish species identification and enumeration from the ROV were performed from the video recording.

ROV video and diver survey methodologies were compared by ANOSIM (PRIMER, Clarke et al., 2015). Non-metric multidimensional scaling (MDS) based upon Bray-Curtis similarity measures (group averaged) were used as an additional analysis tool for comparing survey methodologies. Data transformations varied from presence/absence to original scale counts to emphasize varying components of the fish assemblage from rare to abundant fish species. Method comparisons based on diversity were made by reducing the abundance matrices to presence-absence. To compare survey methodologies in terms of contributions of rare and abundant species, SFMA diver counts were compared to the ROV video exact counts binned into the SFMA categories. For the latter, SFMA count-categories were converted to a simple log-scale abundance by taking the natural log of the category midpoint values according to the log-normal distribution. The ln(X+1) transformed values of SFMA midpoints were rounded to the nearest whole number resulting in log-normal abundances of 0, 1, 2, 4, or 6 for the zero (0 fish), Single (1 fish), Few (2-10), Many (11-100), and Abundant (101-1,000) groupings, respectively (Hicks et al. 2016).

To compare the two survey methods in terms of capturing similar relative abundances of the more conspicuous and abundant species, the untransformed ROV counts were compared with the untransformed SFMA log-normal category midpoints. For this comparison, both datasets were standardized prior to multivariate analyses.

Length and Biomass Determination Using Sonar

The standard lengths of fish species from sonar images were estimated using the measurement tool in Blueview Proviewer 4.6 software. Fish were caught on long-line or spear gun and suspended in the water column, then insonified at varying distances (2-10m). Fish were then brought aboard, identified to species and measured. Sonar video was analyzed in the lab by matching video timestamps to sonar timestamps in Proviewer 4.6. Length measurements were made for each fish in Proviewer 4.6 when the maximum lateral aspect was observed. This was confirmed by watching for movement of the caudal fin of the individual in sonar video. The actual standard lengths of each individual were compared to their sonar image lengths. A type II linear regression was used to test the accuracy of the actual standard length and lengths measured in sonar images.

Fish Identification via Sonar Images

Distance, orientation, and location in the sonar FOV were collected from Proviewer 4.6 software. Depth was measured with the Videoray Pro4 depth sensor. Timestamps on both video and sonar footage enabled accurate measurements of depth that could be applied to each individual fish.

The maximum, minimum and mean intensity of the area of highest intensity of an individual fish was measured using ImageJ 1.48v software. The area of the highest intensity, or the area of the swim bladder echo, was measured using the Maximum Entropy tool of ImageJ software and compared to the overall length of the fish (explained below). A combination of certain parameters, such as the length of the fish divided by the area of the highest target strength, were additionally calculated as potential predictor variables. A full list of the parameters examined is as follows:

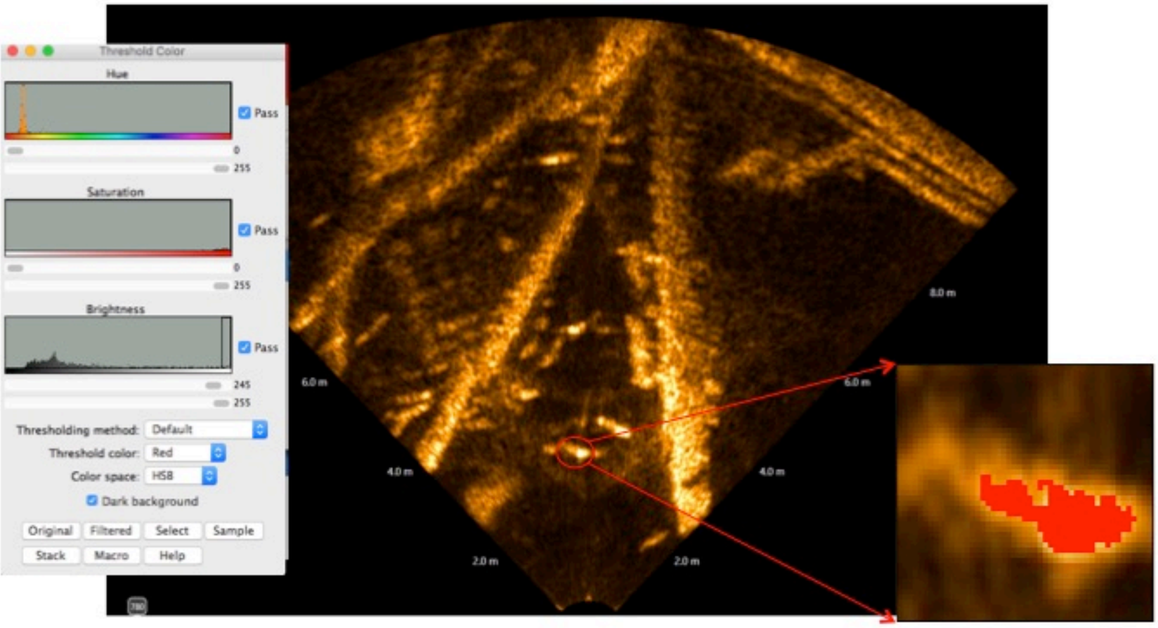
- Maximum, minimum, and mean intensity within the area of highest intensity
- Area of the highest intensity
- Center of mass coordinates (xm, ym) of the area of highest intensity
- Length of individual
- Distance of individual from sonar transducer
- Position of individual in the sonar field of view
- Area of highest intensity/(length of individual + distance from transducer)
- Area of highest intensity/length of individual
- Mean intensity of the area of highest intensity/area of highest intensity
- Mean intensity of the area of highest intensity/length of the individual

- Mean intensity of the area of highest intensity/distance from the transducer
- Depth
- Distance to nearest neighboring fish

A list of the fish species measured is as follows:

- Almaco Jack (*Seriola rivoliana*)
- Atlantic Spadefish (*Chaetodipterus faber*)
- Barracuda (*Sphyraena barracuda*)
- Blue Runner (*Caranx crysos*)
- Crevalle Jack (*Caranx hippos*)
- Grey Snapper (*Lutjanus griseus*)
- Lookdown (*Selene vomer*)
- Red Snapper (*Lutjanus campechanus*)
- Sheepshead (*Archosargus probatocephalus*)
- Triggerfish (*Balistes capriscus*)

ImageJ Max Entropy Tool Measurements:



Thresholding method: Default
Threshold color: Red
Color space: HSB
☑ Dark background

The maximum entropy tool in ImageJ 1.48v was used to isolate the area of highest intensity. Sonar images of fish (confirmed by ROV video footage) were processed in ImageJ and the target fish was isolated using the “box” tool. The Maximum Entropy Tool was set at 245 (out of 255) brightness to isolate the area of highest intensity. This area was then selected and measured.

A principal component analysis (PCA) was performed in Primer (ver. 7) to identify which factors account for the variability among species. A log-transformation of the following right-skewed variables was performed:

- Area of highest reflectivity
- Minimum reflectivity
- Center of mass coordinates (xm, ym)

- Perimeter
- Length of individual
- Distance from transducer
- Area/(Length + distance from transducer
- Distance to nearest neighbor

The left-skewed variable, Max Reflectivity (Mx), was transformed using log (256-V) where the value 256 is just higher than the maximum value in the variable array, to achieve data symmetry.

Following transformations, the entire dataset was normalized.

The goal was to find a factor, or combination of factors, that shows little variation within species and large variation between species.

CHAPTER III

RESULTS

ROV vs. Diver Surveys

Average occurrences of fish species in the presence-absence analysis were higher for diver surveys across all major discriminating species (Table 1). The top contributors to average dissimilarity between ROV and diver surveys were Gag (2.85%), Rock Hind (*Epinephelus adscensionis*) (2.78%), Tomtate (*Haemulon aurolineatum*) (2.72%) and Blue Angelfish (*Holacanthus bermudensis*) (2.69%) (Table 1). Average dissimilarity across all samples was 67.80% (Table 1). Among the species contributing at least 70% average similarity, twenty-six species were observed in diver surveys, while only 17 species were seen in ROV surveys (Table 1). ANOSIM analysis indicated that the survey methods yielded markedly different fish communities (R = 0.701, P = 0.001, Figure 2).

Diver average abundances were consistently higher than ROV average abundances among major discriminating species in the log-midpoint transformation method (SFMA) (Table 2). Top contributors to the average dissimilarity among methods were Seaweed Blenny (*Parablennius marmoreus*) (3.61%), Atlantic Spadefish (*Chaetodipterus faber*) (3.38%), Gray Snapper (*Lutjanus griseus*) (3.0%) and Tomtate (*Haemulon aurolineatum*) (2.86%) (Table 2). Average dissimilarity across all samples was 70.29% (Table 2). Among the species contributing at least 70% average similarity, twenty-two species were observed via diver, while 17 were observed in ROV surveys. ANOSIM analysis indicated that the methods yielded different fish communities (R = 0.678, P = 0.001, Figure 3). ROV average abundances were higher than diver average abundances among major discriminating species in the untransformed analysis for Red Snapper (*Lutjanus campechanus*), Atlantic Spadefish (*Chaetodipterus faber*), Gray Snapper (*Lutjanus griseus*), Gray Triggerfish (*Balistes capriscus*), and Crevalle Jack (*Caranx hippos*) (Table 3). Top contributors to average dissimilarity were Red Snapper (15.1%), Sheepshead (9%), Atlantic Spadefish (7.6%), and Gray Snapper (6.9%) (Table 3). Average dissimilarity across all samples was 70.5% (Table 3). Among the species contributing at least 70% average similarity, eight species were observed via diver, versus 7 species observed via ROV (Table 3). ANOSIM analysis indicated that the methods yielded similar fish communities (R = 0.089, P = 0.074, Figure 4).

Overall, the number of species recorded by the diver survey method was consistently higher (Figure 5).

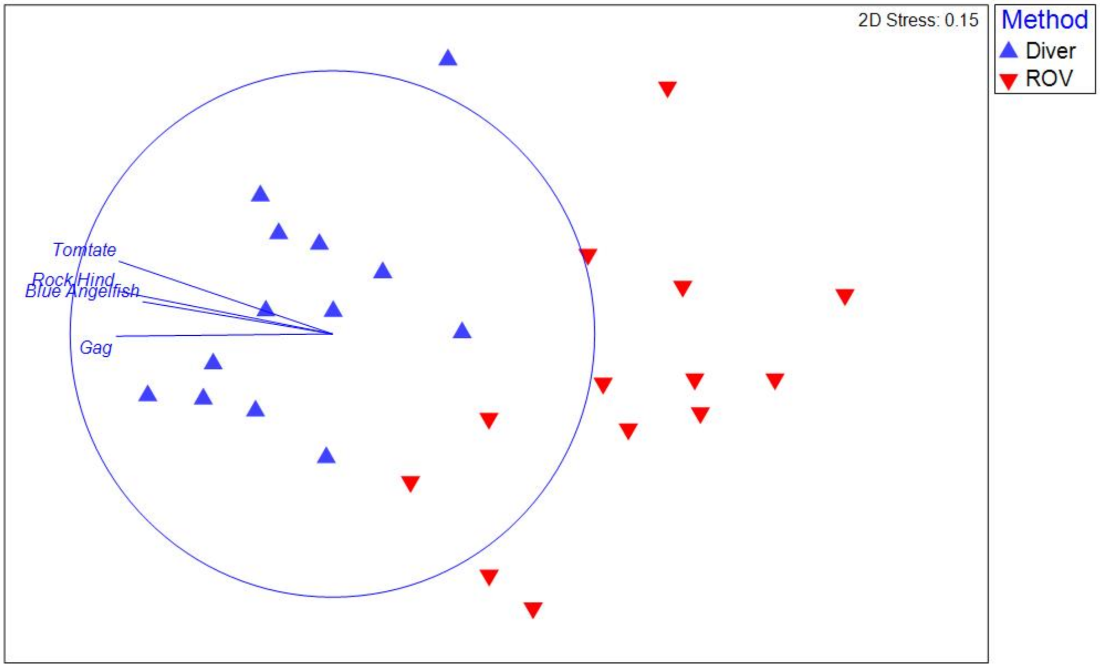


Figure 2. MDS analysis comparing ROV and diver surveys based on presence/absence. Vectors point in the direction of increasing occurrence of major discriminating species with more impactful species reaching closer to the surrounding circle. Average dissimilarity among samples =67.8%.

Table 1. Results from Similarities Percentages (SIMPER) analysis of ROV vs diver presence-absence fish surveys.

Species	Diver Av.Abund	ROV Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gag	0.92	0.08	2.85	1.84	4.2	4.2
Rock Hind	1	0.23	2.78	1.4	4.11	8.31
Tomtate	0.92	0.15	2.72	1.5	4.01	12.32
Blue Angelfish	0.85	0.08	2.69	1.58	3.97	16.29
Whitespotted Soapfish	0.77	0	2.54	1.52	3.74	20.03
Seaweed Blenny	0.77	0	2.5	1.49	3.68	23.71
Scamp	0.69	0	2.4	1.22	3.55	27.26
Belted Sandfish	0.77	0.08	2.35	1.28	3.47	30.73
Cocoa Damsel	0.77	0	2.27	1.61	3.35	34.08
Cubbyu	0.69	0	2.15	1.19	3.17	37.26
Spotfin Butterfly Fish	0.69	0	1.94	1.4	2.86	40.12
Gray Trigger	0.69	0.54	1.72	0.86	2.54	42.66
Spanish Hogfish	0.54	0.31	1.62	0.95	2.38	45.04
Vermillion Snapper	0.54	0.15	1.58	0.97	2.34	47.38
Blue Runner	0.54	0	1.55	1.02	2.28	49.66
Reef Butterfly Fish	0.46	0.31	1.51	0.89	2.22	51.89
Pork Fish	0.46	0.08	1.47	0.88	2.16	54.05
Gray Snapper	0.85	0.69	1.45	0.7	2.13	56.18
Atlantic Spadefish	0.85	0.69	1.39	0.68	2.05	58.24
Lookdown	0.38	0.23	1.38	0.8	2.04	60.27
Greater Amberjack	0.38	0.23	1.38	0.79	2.03	62.3
Spotted Scorpion Fish	0.31	0.08	1.3	0.64	1.91	64.22
Spotfin Hogfish	0.38	0.23	1.29	0.82	1.9	66.12
Comb Grouper	0.31	0	1.25	0.61	1.84	67.96
Tessellated Blenny	0.31	0	1.15	0.62	1.7	69.66
Cobia	0.38	0.08	1.12	0.79	1.66	71.31
Average dissimilarity = 67.80						

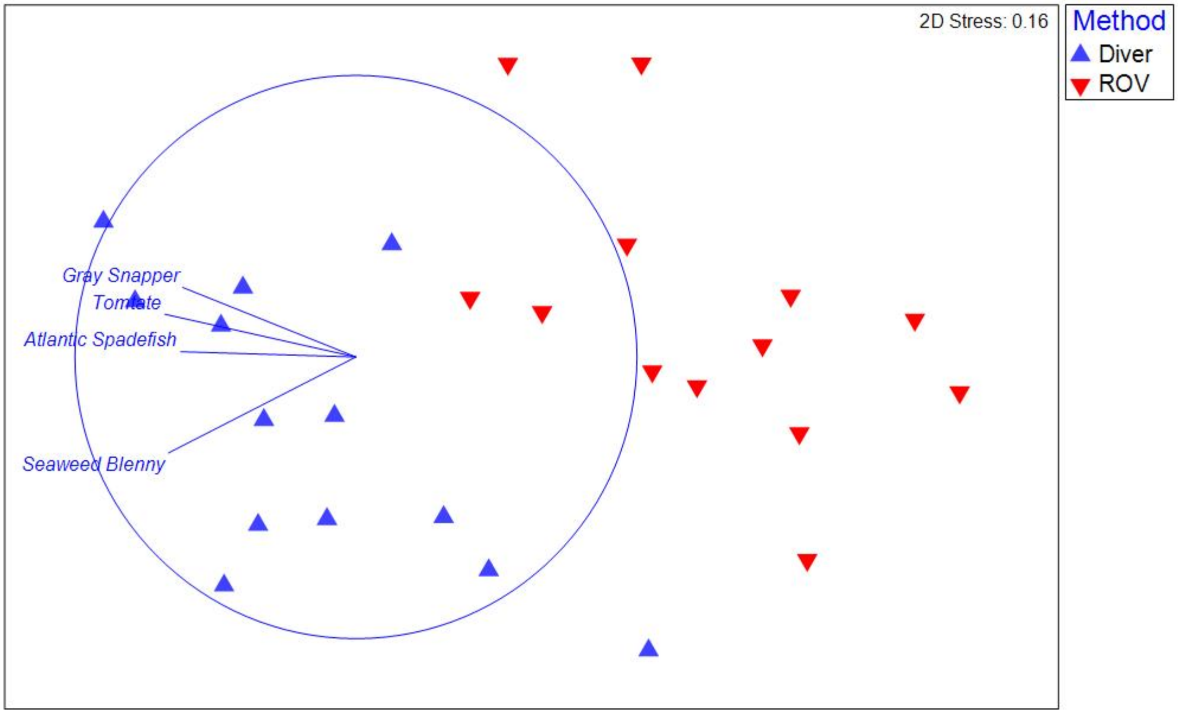


Figure 3. An MDS plot comparing ROV and diver surveys performed according to the categorical (SFMA) method. Vectors point in the direction of increasing abundance of the major discriminating species with more impactful species reaching closer to the circle. Average dissimilarity = 70.29.

Table 2. Results from SIMPER analysis of ROV vs diver fish surveys based on the SFMA (Log-Midpoint) abundances.

Species	Diver Av.Abund	ROV Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Seaweed Blenny	3.08	0	3.61	1.27	5.13	5.13
Atlantic Spadefish	4.15	2.31	3.38	1.15	4.81	9.93
Gray Snapper	3.69	2.62	3	1.1	4.27	14.21
Tomtate	2.62	0.69	2.86	1.44	4.07	18.28
Whitespotted Soapfish	2.31	0	2.86	1.11	4.06	22.34
Rock Hind	2.69	0.23	2.74	2.01	3.9	26.24
Sheapshead	4	2.38	2.7	0.93	3.84	30.08
Gray Trigger	2.31	1.31	2.56	1.15	3.65	33.73
Spanish Hogfish	2.31	0.77	2.37	1.08	3.38	37.1
Red Snapper	4.92	3.85	2.33	1.16	3.32	40.42
Cubbyu	2.15	0.15	2.28	1.17	3.24	43.66
Lookdown	1.85	0.92	2.23	0.82	3.17	46.84
Cocoa Damsel	2.31	0	2.17	1.29	3.09	49.93
Blue Runner	2.31	0	2.16	1.01	3.07	53
Belted Sandfish	2	0.08	2.09	1.13	2.97	55.97
Vermillion Snapper	2.15	0.31	1.97	1.1	2.8	58.77
Gag	1.77	0.08	1.95	1.44	2.78	61.55
Blue Angelfish	1.46	0.08	1.7	1.55	2.42	63.97
Reef Butterfly Fish	1.31	0.54	1.38	1	1.97	65.94
Scamp	1.08	0	1.34	1.19	1.91	67.84
Common Jack	1	0.69	1.33	0.67	1.89	69.73
Spotfin Hogfish	1.23	0.46	1.32	0.86	1.88	71.61
Average dissimilarity = 70.29						

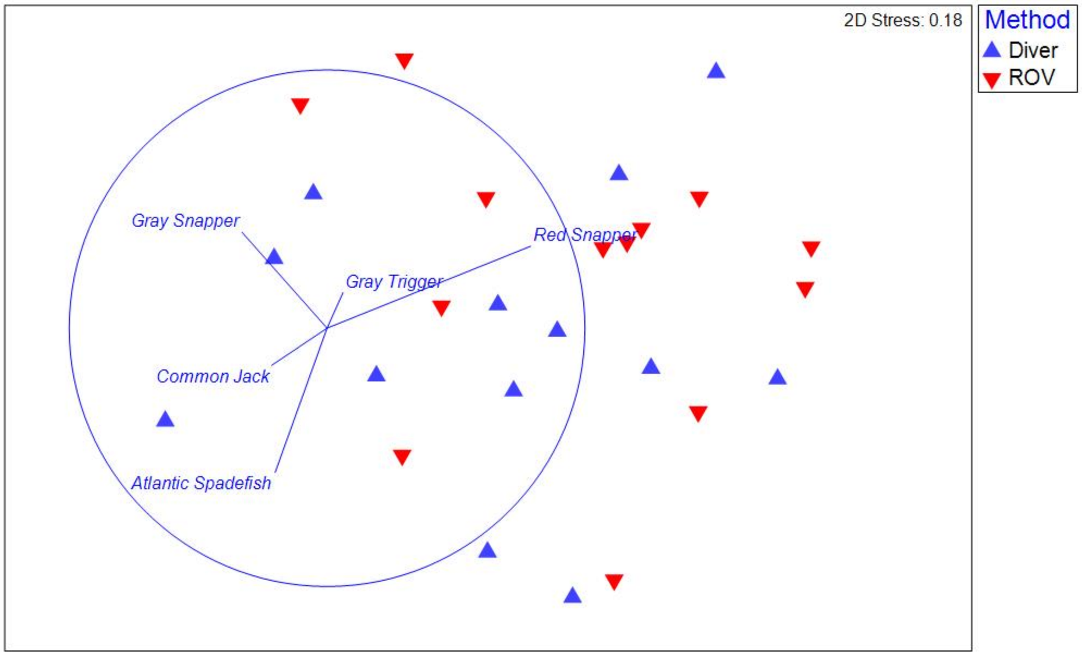


Figure 4. An MDS plot comparing ROV and Diver surveys based on the midpoints method. Vectors point in the direction of increasing abundance of the major discriminating species with more impactful species reaching closer to the circle. Average dissimilarity = 70.5%

Table 3. Results from SIMPER analysis of ROV and diver surveys based on the midpoint method.

Species	**Diver Av.Abund**	**ROV Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Red Snapper	18.63	37.28	15.12	1.3	21.44	21.44
Sheapshead	14.05	12.38	8.96	0.88	12.71	34.14
Atlantic Spadefish	12.15	12.8	7.57	1.1	10.74	44.88
Gray Snapper	7.67	15.16	6.88	1.29	9.75	54.63
Lookdown	6.06	6.05	5.24	0.57	7.44	62.07
Seaweed Blenny	5.93	0	2.97	0.76	4.21	66.28
Gray Trigger	2.68	3.24	2.24	0.74	3.18	69.46
Common Jack	1.95	2.63	2.01	0.58	2.85	72.31
Average dissimilarity = 70.51						

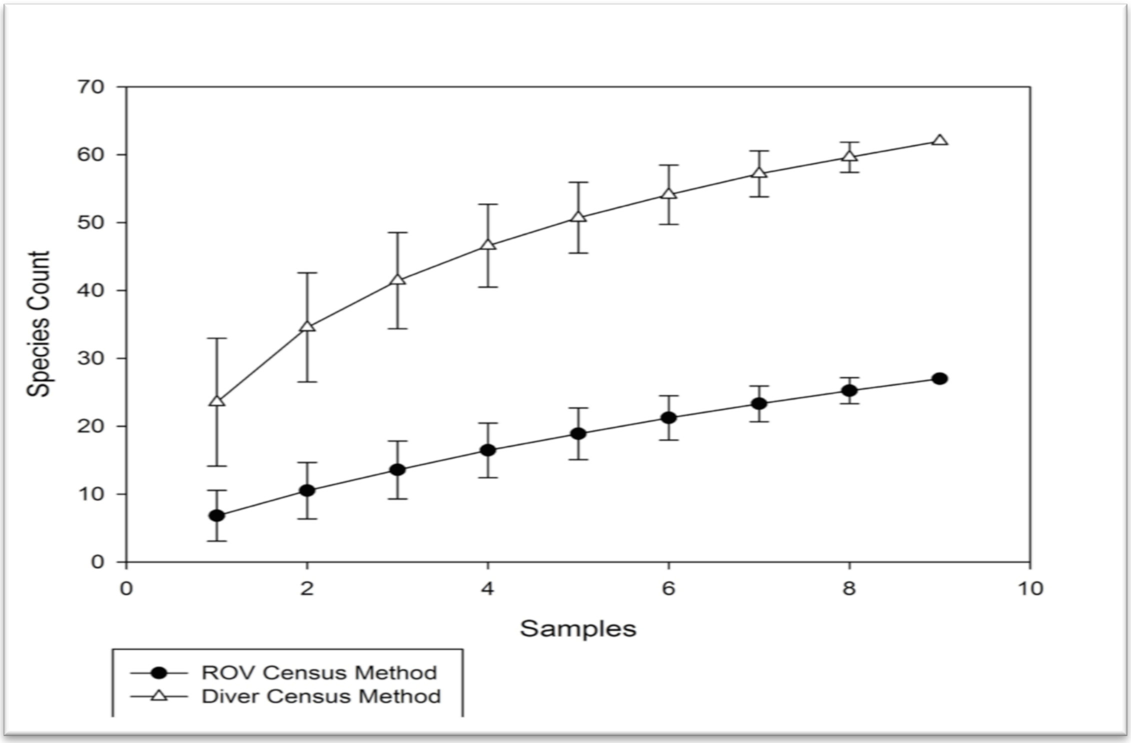


Figure 5. A Species Accumulation plot comparing fish community visual assessments by ROV (solid circles) and diver (open triangles) survey methods.

Sonar Fish Lengths vs. Actual Standard Length

A total of 25 individuals were measured including 15 Red Snapper (*Lutjanus campechanus*), 3 Sheepshead (*Archosargus probatocephalus*), 3 Atlantic Spadefish (*Chaetodipterus faber*), 2 Mangrove Snapper (*Lutjanus griseus*), 1 Comb Grouper (*Mycteroperca acutirostris*), and 1 Rainbow Runner (*Elagatis bipinnulata*). Lengths measured in sonar images via the length tool provided by Blueview Proviewer software were highly correlated to actual standard lengths across all species examined. (F = 1104.7; df = 24; P < 0.001; r^2 = 0.98) (Figure 6).

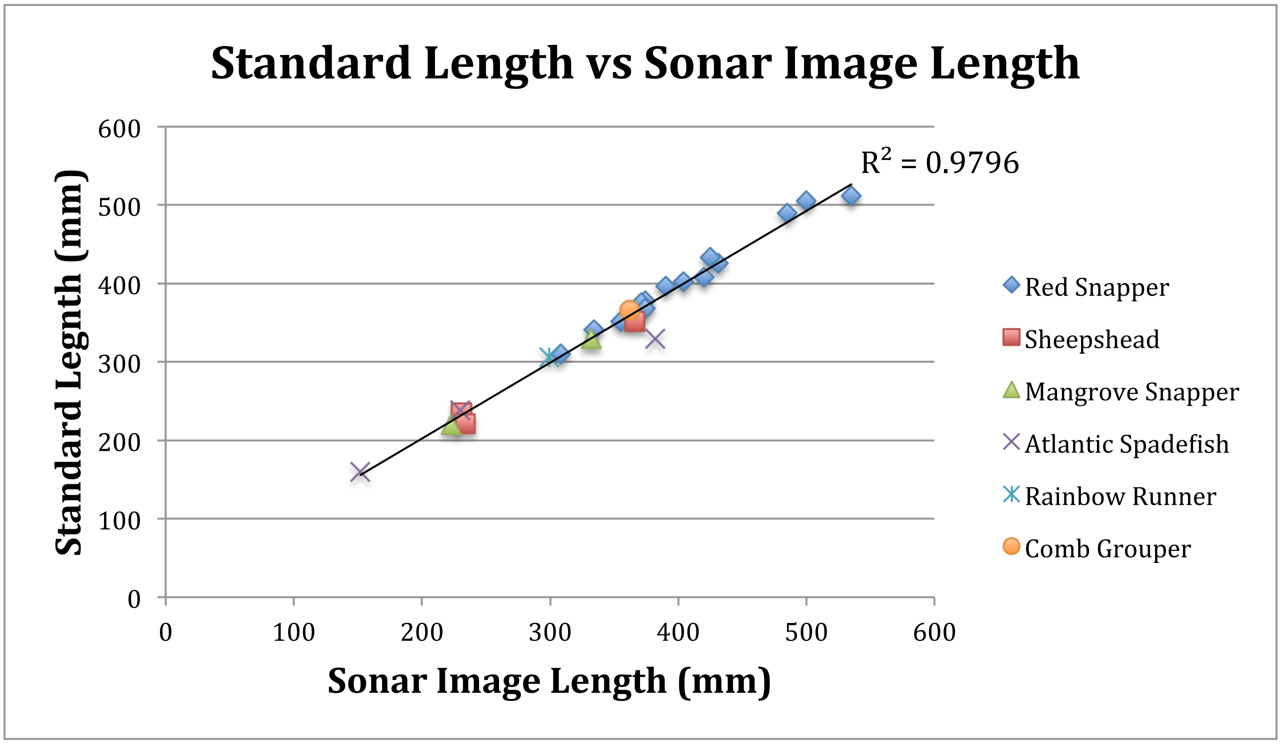


Figure 6. A Type II Linear Regression comparing fish lengths measured from sonar images with actual standard lengths. Sonar fish lengths were measured using Proviewer 4.6 software's ruler tool. Sonar measured lengths had high predictive power of actual standard lengths (f = 1104.7; df = 24; $p < 0.001$; $r^2 = 0.98$).

Sonar Characteristics

The principal component analysis of sonar characteristics required 3 PCs to account for 65% of the variation (Table 4). The first principal component (PC 1) accounted for 30.8% of the variation and was dominated by variables related to swim bladder morphology including Area (-0.344), center of mass x-coordinate (XM) (-0.379), Perimeter (-0.386), mean/area (0.345), and mean/length (0.315) (Table 5; Figure 7,8, and 9). PC2 accounted for 23.1% of the variation based on morphology and relative position versus the sonar unit. PC2 was a weighted combination of max reflectivity (Max) (-0.304), Area/Length (0.394), Area/Length + Distance(0.449) and mean/distance (0.317) (Table 5; Figure 7,8, and 9). PC 3 accounted for 11.1% of the variation based on relative position and schooling characteristics. PC3 was a weighted combination of mean (-0.347), Max (0.305), Distance (-0.375), Left Angle (0.353), mean/distance (0.302), distance to nearest neighbor (0.435) and depth (0.310) (Table 5; Figure 7,8, and 9).

Table 4. Principal Components Analysis of sonar and environmental variables applied to assess differences in fish species.

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.23	30.8	30.8
2	3.93	23.1	53.9
3	1.89	11.1	65.0
4	1.44	8.5	73.4
5	1.07	6.3	79.7

Table 5. Loadings from a Principal Components Analysis of sonar and environmental variables measured in both ImageJ and Proviewer applied to assess differences among fish species. Mean intensity, Max intensity, Min intensity, Perimeter, and Area are measurements of the area of highest intensity. Length refers to length of the individual. XM and YM are x-coordniates and y-coordinates (respectively) of the center of mass of the area of highest intensity.

Variable	PC1	PC2	PC3
Log(Area)	-0.344	0.290	-0.004
Mean	0.190	0.286	-0.347
Log(Min)	0.219	0.073	-0.134
log(256-Max)	-0.063	-0.304	0.305
Log(XM)	-0.379	0.009	-0.052
Log(YM)	-0.270	0.068	-0.103
Log(Perim.)	-0.386	0.127	0.055
Log(Length)	-0.298	-0.201	0.130
Log(Distance)	-0.188	-0.292	-0.375
Angle(Left)	0.025	0.059	0.353
Area/Length	-0.088	0.394	-0.022
Log(Area/Length + Distance)	-0.104	0.449	0.233
Mean/Area	0.345	-0.245	-0.014
Mean/Length	0.315	0.228	-0.195
Mean/Distance	0.227	0.317	0.302
Log(Distance to Nearest Neighbor)	-0.110	0.127	-0.435
Depth	0.057	0.013	0.310

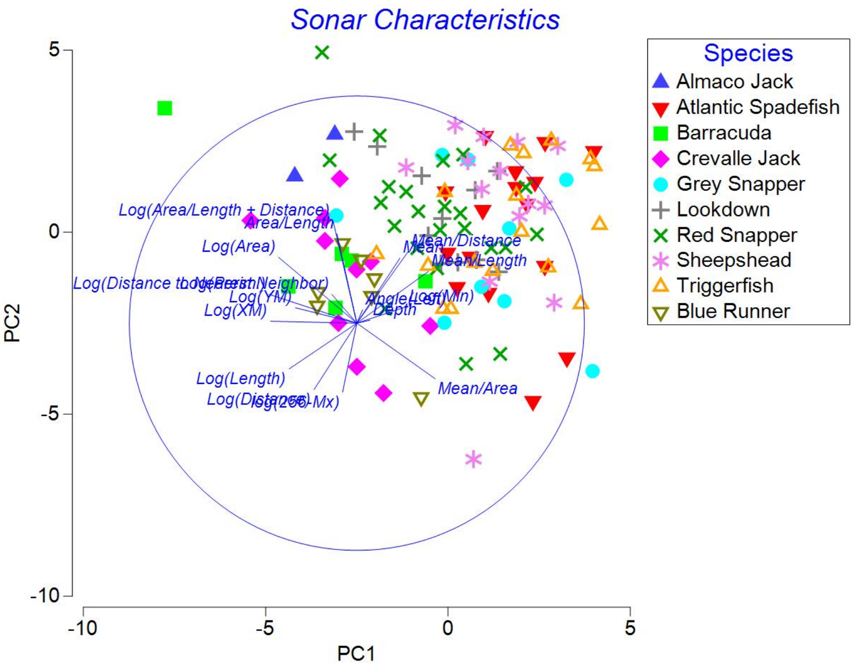


Figure 7. Principal Component Analysis of sonar and environmental variables graph by species. The loadings of the most influential variables are indicated by vectors.

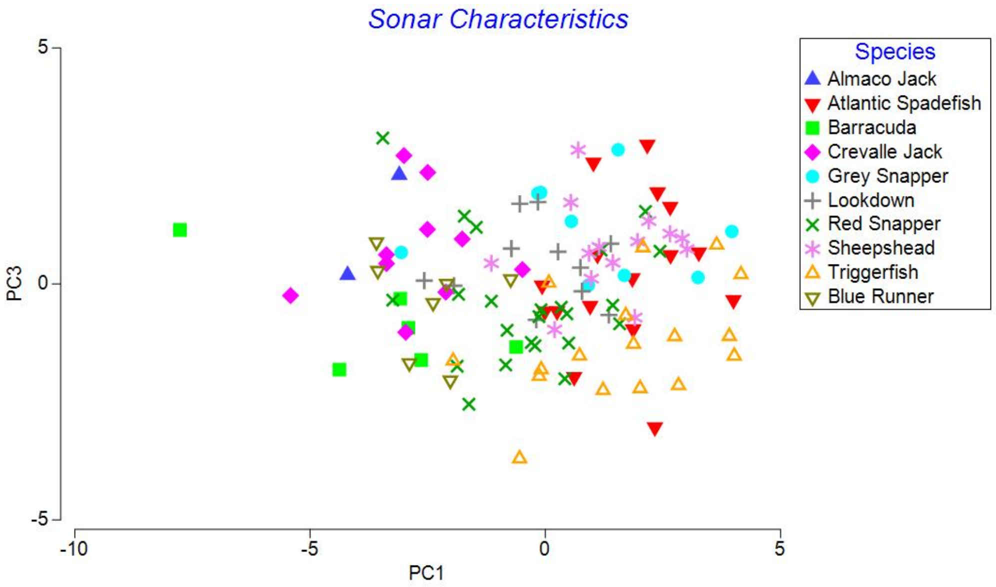


Figure 8. 2D Comparison of PC1 to PC3. Variables were measured in ImageJ software.

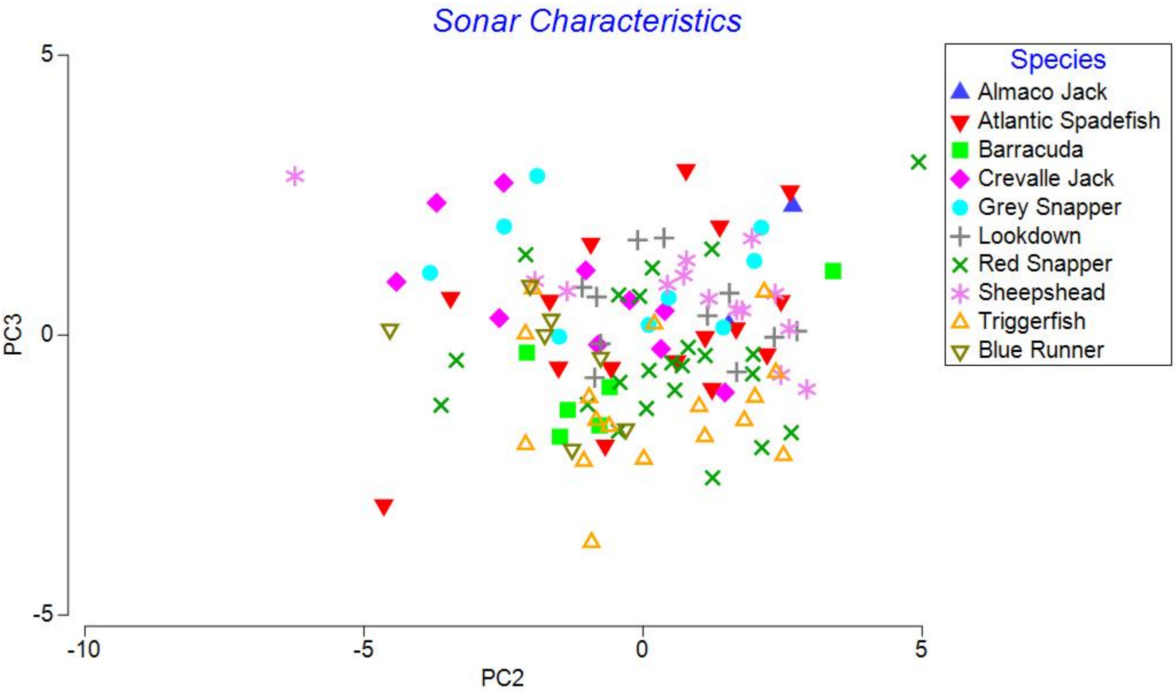


Figure 9. 2D Comparison of PC2 to PC3. Variables were measured in ImageJ software.

CHAPTER IV

DISCUSION

Comparison of Abundance Estimates from ROV versus Diver Surveys

The purpose of part of this study was to compare fish communities via roving diver and ROV surveys. Of the three transformations applied to the data, diver surveys yielded higher average occurrences (presence/absence transformation) and relative abundances (categories transformations) for the major discriminating species (Table 1; Table 3). Furthermore, certain species were absent from ROV surveys all together within the species that contributed at least 70% of the variation presence/absence transformation (Table 1). Top contributors to dissimilarity within presence-absence analysis were species tightly associated with the reef structure such as Gag (*Mycteroperca microlepsis*), Rock Hind (*Epinephelus adscensionis*), Tomtate (*Haemulon aurolineatum*), and Blue Angelfish (*Holacanthus bermudensis*). The presence/absence analysis reinforces the findings and conclusions of Andalaro et al. 2013, who observed that the differences between ROV and UVC surveys on standing oil and gas platforms were largely due to cryptic species. These distinctions based on the observation of smaller, demersal species suggest that ROVs are less apt at capturing these individuals. In order to understand this discrepancy, we must take into account the bias associated with each survey method.

Compared to the ROV, divers demonstrated a greater capacity to peer under and within artificial reef structure where demersal species reside. The ROV likely had an impact on the level of avoidance exhibited by cryptic species. However, divers also witness certain levels of avoidance behavior (Schmdit et al. 2006), yet research indicates that ROVs may experience relatively more (Stoner et. al. 2008). The highest numbers of species observed in ROV footage occurred when the ROV was slowed or stopped along a reef structure, suggesting avoidance could be caused by the operation of the ROV. Patterson et. al. (2008) was able to precisely characterize artificial reef communities using a similar ROV, though reef complexity was much lower than in our study. The method used in their study involved performing stationary 360-degree rotations of the ROV at specific points on and around the reef structure. Our study, in contrast, involved "flying" the ROV over and within the structure, with little to no stationary periods. Thus, it seems likely that the "noise" associated with attempting to maneuver an ROV around and within the reef structure causes some avoidance by the species that reside there.

While species diversity was significantly higher for diver surveys, certain larger species were seen in comparable numbers across both ROV and diver surveys. Of the species observed in higher abundance by ROVs within the untransformed relative abundance analysis, seven were classified as larger, more conspicuous species (i.e. Red Snapper, Sheepshead, Atlantic Spadefish, Gray Snapper, Lookdown, Gray Triggerfish, and Common Jack). These species, with the exception of Sheepshead, represent water-column schooling species, making them easier to observe via ROV video footage.

Actual Length vs. Lengths Measured via Sonar Images

Our comparative analysis of fish lengths measured via sonar images and actual standard lengths validates the Blueview P900-90 as an effective and accurate tool for measuring fish lengths, and therefore biomass. There was high predictive power between single measurements of each individual's length from sonar and actual standard lengths. Red Snapper dominated our dataset, yet similarly strong predictive power was seen for other species (Figure 6). Much of the research on imaging echosounders has focused on DIDSON units (Lin et al. 2016; Hightower et al. 2013; Burwen et al. 2010) with the resounding conclusion that high frequency sonars are able to measure the lengths of fish directly, effectively eliminating the need for target strength-length equations. This study confirms that the Blueview P900-90, operating at slightly lower frequencies than the upper range of DIDSON units, is just as capable in terms of estimating fish sizes. This study relied on ROV video footage to establish optimal lateral aspects for single measurements of fish length. In monitoring practices, multiple measurements of each individual are expected, as the roving nature of the sonar-ROV assemblage will produce variable length measurements dependent on the orientation of the individual versus the sonar transducer. Similar studies performed on DIDSON units demonstrate that the incorporation of algorithms for averaging lengths and isolating maximum length maintains measurement integrity (Hightower et al. 2013). As such, the application of the Blueview P900-90 sonar unit to fisheries monitoring would necessitate the use of similar algorithms to establish this sonar unit as an efficient means for monitoring artificial reef communities.

Acoustic Imaging Characteristics

The hypothetical identification of fish species via acoustics alone has many obstacles to overcome before it becomes a reality. One of the largest obstacles is the fact that frequency and number of beams are critical to the nature of the data provided, therein negating the application of other sonar methods across sonar types. Within each sonar technology, though, a certain set of parameters seems to be the most impactful in terms of differentiating fish. This study represents a baseline dataset on the Blueview P900-90, in which we highlight certain trends in sonar characteristics that help to better understand the role of sonar in fisheries research.

The PCA of sonar characteristics highlights the role of fish morphology and relative position of the target in obtaining differentiating factors between species. Morphology has been identified as one of the most important aspects of identification via acoustic imaging (Horne 2000). The results of this study seem to agree, while adding the importance of swim bladder morphology in addition to body morphology.

Within the first principle component, which accounted for 30.8% of the overall variation (Table 4), aspects of the swim bladder echo dominated the sources of variation between species. These factors include Log (perimeter of the area of highest reflectivity) (-0.386), Log (x-coordinate of the center of mass of the area of highest reflectivity) (-0.379), mean reflectivity of the area of highest reflectivity divided by the area of highest reflectivity (0.345) and Log (area of highest reflectivity) (0.344)(Table 5).

Of these four dominate factors, Log (area), Log (perimeter), and mean/area were all associated with the morphology of the swim bladder. The perimeter of the swim bladder echo, the area, and the mean/area are most impacted by changes in the shape and size of the swim bladder. Thus, shape and size of the target's swim bladder were important in differentiating fish based on swim bladder echoes. The species-specific morphology of swim bladders in physoclistous fish has long been established (Jones and Marshall 1953; Alexander 1970). More recently, researchers have begun to characterize the target strengths of a variety of species, in pursuit of fish identification (Benoit-Bird 2003; Yudhana et. al. 2012). Our study did not involve target strength measurements, yet the differentiating potential of the echo produced by the swim bladder remains. Additionally, we utilized higher frequencies (relative to other studies) and yet the impact of swim bladder morphology seems to be maintained.

The second most impactful variable, Log (XM), within the first principle component, was associated with the orientation of the target versus the sonar transducer. The orientation of the swim bladder versus the transducer when measuring echo intensity has been identified as an important factor affecting the intensity of the return echo (Horne 2000). The XM value represents the x-coordinate for the center of mass of the area of highest reflectivity. Thus, the position of the target along the x-axis versus the transducer had a significant impact, second only to the Log (perimeter of the area of highest reflectivity). The fact that the perimeter of the swim bladder echo superseded the orientation indicates that swim bladder shape and size is of particular importance in the differentiation of species, especially with regards to high frequency sonars such as the one utilized in this study.

The second principle component, which accounted for 23.1% of the overall variation (Table 4), was dominated by a number of derived variables linking the size of the swim bladder to the length of the individual and the relative position of the target versus the sonar transducer. These factors were Log (area of highest reflectivity/length of the individual plus the distance from the transducer) (0.449), the area of highest reflectivity divided by the length of the individual (0.394) and the mean reflectivity of the area of highest reflectivity divided by the distance from the transducer (0.317) (Table 5).

The two most impactful variables, Log (area/length+distance) and area/length introduce the importance of the ratio of the size of the swim bladder versus the length of the individual. As previously mentioned, the area of highest reflectivity is most impacted by the size and shape of the swim bladder. The inclusion of the distance of the target from the transducer in the most impactful variable (Log(area/length + distance)) serves to standardize the reflected intensity, as energy is lost via attenuation as you move further from the transducer, especially in high frequency sonar units (Urick 1987). This reinforces the importance of technology-specific standardizations for fish identifications.

Within the third principle component, which accounted for 11.1% of the overall variation (Table 4), the top contributors to variation were distance to nearest neighbor (-0.435), distance from the transducer (-0.375), and the left-most point of the target (0.353) (Table 5).

Distance to nearest neighbor represents our schooling behavior measurement. The use of schooling behavior to identify fish has been explored in numerous other studies (Robotham et al. 2010; Hannachi et al. 2005; LeFeuvre et al. 2000; Korneliussen et al. 2009), though our study is one of the first with this specific technology. Thus, the fact that distance to nearest neighbor dominated this principle component is unsurprising. The present study does serve to reinforce this importance, with regards to fish species inhabiting artificial reefs.

Distance from the transducer and the left most point of the target are associated with the relative position of the target in the sonar field of view. Distance from the transducer was involved in the second principle component, and its reappearance here reinforces the importance of the attenuation of sound as it moves through the water column. This suggests that the use of high frequencies to identify fish necessitates standardization based on the target's distance from the transducer.

In summary, aspects of the swim bladder echo, its orientation, and its relationship to the body length of the first dominated our dataset in terms of variation between samples. Schooling characteristics and standardizations based on distance from the transducer were only slightly less impactful.

Conclusions

The purpose of this study was to investigate the extent to which ROVs and multibeam, imaging sonars can be applied to fisheries research and management. Our study involved a multi-layered analysis of ROV surveys, sonar fish length measurements, and sonar image characteristics of a variety of reef dwelling fish. In lieu of our results, we conclude the following:

Primarily, ROV surveys performed according to the Roving Diver Technique fail to capture similar levels of species diversity, as those seen in diver surveys. Thus, the development of a survey method specific to the ROV's advantages and disadvantages is necessary. Specifically, we suggest that further ROV surveys be performed in a manner that reduces the amount of noise produced by the unit (i.e. the implementation of stops or slows) and more time allocated to the investigation of crevices of the reef structure. The intent here is to allow the ROV to more consistently capture smaller, cryptic species. However, if the intent is to focus surveys on adult phase commercial species, which generally school and large-bodied, then the ROV performs equally well.

Secondly, length measurements performed in Blueview Proviewer 4.6 software had high predictive power to actual standard lengths, indicating that the Blueview P900-90 sonar unit can accurately measure individual fish standard lengths. The development of an algorithm and automation of averaging fish length measurements would expedite the monitoring process, to a point were it becomes a viable method for estimating the biomass of fish communities.

Lastly, the analysis of acoustic imaging characteristics revealed the importance of swim bladder morphology and relative positioning of the target fish in the search for differentiating characteristics based on species. While the importance of relative position has been well established, the incorporation of swim bladder morphology may open new pathways to fish identification, both for the sonar used in our study and other sonar types.

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BIOGRAPHICAL SKETCH

Robert Figueroa-Downing was born in Albuquerque, New Mexico and graduated from Ransom Everglades High School with an interest in marine science and physics. He attended Colgate University where he earned a B.A. in Marine and Freshwater Science in May 2014. He completed his Masters Thesis Project at The University of Texas Rio Grande Valley with a M.S. in Biology in May 2017.

Robert Figueroa-Downing has worked on “resacas” and the Arroyo Collorado freshwater systems in Brownsville, Texas, with Dr. Jude Benavides. His graduate career involved working with Dr. David Hicks in the monitoring of artificial reefs in the Northwestern Gulf of Mexico. During this time, he performed fish and invertebrate surveys, operated and maintained two remotely operated vehicles, aided in the deployment and retrieval of data loggers, and aided in the use of vertical long lines to capture fisheries data.

He has performed multiple outreach events including Rio Grande Science and Arts Festival (RiSA) (2014-15), Subsea Robotics (2016), and Oceanarium (2015). He has presented his masters thesis work at the Texas Parks and Wildlife Artificial Reef Consortium (2014 and 2017), National Oceanic and Atmospheric Administration EPP/MSI Biannual Forum (2016), and the Gulf of Mexico Foundation Government Cruise (2015).

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