2017

Reproductive Dynamics of Gulf Black Sea Bass in the Northeastern Gulf of Mexico

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REPRODUCTIVE DYNAMICS OF GULF BLACK SEA BASS IN THE NORTHEASTERN GULF OF MEXICO

By

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A Thesis submitted to the
Department of Biological Science
in partial fulfillment of the
requirements for the degree of
Master of Science

2017

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ACKNOWLEDGMENTS

To be a scientist means a lifetime of failed experiments, equipment malfunctions, and sleepless nights. To succeed in this endeavor, you must have a solid foundation of people that support you when you fail, and celebrate when you succeed. Luckily for me, I have been blessed to be supported by a community of amazing individuals throughout my master's that I would like to thank for their support and inspiration.

First, and foremost, I would like to thank my major advisor Dr. Felicia Coleman. Her enthusiasm and mentorship throughout this experience has taught me a lot about what it means to be a great scientist, and a wonderful human being. I would also like to thank Dr. Emily DuVal and Dr. Joe Travis for serving on my committee, and overall making me a better scientist. I also thank Dr. Chris Koenig, for his endless support and inspiration. I also thank the FSU Biological department staff, for expanding my knowledge and curiosity of the natural world.

For fieldwork and data collection, I would like to thank all the volunteers who braved the freezing cold, high seas, and broken boat motors with me; without these individuals, my thesis research would not be possible and I am incredibly grateful. So, thanks to: Alejandra Mickle, Micaiah Ward, Johanna Imhoff, Alex Cory, Christian Gredzens, Maggie Vogel, Kevin Olsen, Lindsay Hooper, Natassjia Ragbeer, Chrissy McCrimmon, Austin Heil, Anthony Sogluizzo, Abigail Engelmann, Johanna Imhoff, Cheston Peterson, Brendan Talwar, Mackellar Violich, Bryan Keller, Renee Richardson, Logan Turner, Christopher Matechik, Jessica Cusick, and Lance Burch. I would also like to thank the Flying Mongooses dive team and the FSU Academic diving program for their support.

For logistic support and general well-being, I would like to give a special thanks to my second family at the FSU Coastal and Marine Laboratory, who offered an endless supply of enthusiasm, expertise, and friendship. I also thank my fellow graduate students in the biology department and my lab mate Chris Malinowski. I especially thank Micaiah “Sepa” Ward and Austin Heil, for their incredible friendship and motivation during the past three years, without these two, my experience would have been incomplete.

I would also like to thank the people who have guided me to this point in my career. I thank the Late Dr. Eugenie Clark, for first introducing me to the wonderful world of ichthyology. I thank Ms. Vanessa Santos, for motivating me to pursue my graduate studies. I also thank Dr. Philip Motta for exposing me to the scientific process and being a great research mentor. I also thank my family, for there constant love and support throughout the years.

Lastly, for funding my research, I would like to thank the Florida State University Coastal and Marine Laboratory, the PADI Foundation, and the Southern Association of Marine Laboratories. All research in this thesis was conducted under the approved FSU ACUC Protocols #1411 and #1525.

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ABSTRACT

Our knowledge of the reproductive dynamics of many economically important marine fish species is remarkably poor. This limits our ability to assess and manage the effects of exploitation on their reproductive potential. The Gulf Black Sea Bass *Centropristis striata melana* is a temperate serranid that contributes to both recreational and commercial fisheries in the state of Florida, however, the reproductive dynamics of this species are not well understood. To fill this gap, I conducted a fisheries-independent survey to explore the spatial and demographic scales of spawning populations in the northeastern Gulf of Mexico.

To ensure effective and non-biased sampling, I assessed gear type and fish behavior sampling biases for the Gulf Black Sea Bass. Baited fish traps and hook-and-line were equally selective for fish size, however, hook-and-line had a higher catch efficiency. Body size was strongly correlated to social dominance in the Gulf Black Sea Bass, however, larger individuals in the population were not more susceptible to hook-and-line gears. These results indicated that hook-and-line was the optimal sampling method with relatively high efficiency and low sampling bias.

Using hook-and-line fishery-independent surveys, I assessed the spatial and temporal dynamics of the Gulf Black Sea Bass spawning populations to test whether spawning populations were consistent across spawning habitats and describe demographic trends in spawning. Spawning populations were not consistent across available spawning habitat and displayed a high degree of spatial variability over scales of no more than 10 kilometers. These patterns were likely influenced in part by differences in juvenile recruitment rates. Demography was a clear factor in the timing of reproduction as the proportion and average size of females and males significantly changed over the course of the spawning season. Larger females began spawning earlier in the spawning season and larger males were present on spawning habitats for longer periods. Overall, the findings of this study highlighted the important roles of spatial and demographic variation in the reproduction of the Gulf Black Sea Bass, and warrant future investigation due to their implications into the conservation and management of this economically important fishery.

CHAPTER 1

ASSESSING SAMPLING BIASES FOR THE GULF BLACK SEA BASS

1.1 Introduction

A key assumption of ecological monitoring programs that allow us to infer population and community level dynamics is that samples are representative of the entire study population (Hansen et al. 1953). To meet this assumption, samples must be collected randomly and without bias. However, sampling biases are common in many ecological studies due to the logistical constraints associated with when, where, and how samples are collected. Understanding these inherent sampling biases are essential to ecological monitoring programs as unaccounted sampling bias can lead to erroneous conclusions about the dynamics of natural systems resulting in ineffective conservation and management practices (Pierce 1997; Rudstam et al. 1984).

In fish monitoring programs, sampling biases are often caused by gear selectivity (Graham et al. 2007; McClanahan and Mangi 2004; Rudstam et al. 1984; reviewed in Stewart 2001). Fishing gears are often selective because they possess mechanical properties that exclude specific individuals from being captured. Gill nets for example, select for body sizes that closely match the mesh size being used (Rudstam et al. 1984). In these cases, individuals that are smaller than mesh sizes freely pass through nets and individuals larger than mesh sizes are obstructed from entering nets and become entangled at lower rates (Rudstam et al. 1984). Hook-and-line gears can also be selective, given the sizes of hooks and baits used during fishing. In these cases, the susceptibility of individuals to capture is determined by the size of their gape. For example, hook-and-line sampling can be biased for larger individuals when hook and bait sizes are sufficiently large to exclude smaller individuals from capture due to their smaller mouth size

(Løkkeborg and Bjordal 1992; Vainikka et al. 2012). To reduce sampling biases, multiple gear types can be deployed simultaneously to increase the size range of individuals captured. However, the gear types available are often limited by logistic constraints associated with the study system (habitat types, time periods available for sampling, study species, etc.). To ensure the efficiency and accuracy of fish monitoring programs, sampling biases of gear types logistically feasible to the system should be assessed.

As our knowledge of fishing selectivity has increased, it has become clear that fishing can also select for certain behavioral traits expressed by individuals in the population. For example, the spatial range and activity level of individuals are often positively correlated to their capture susceptibility (Biro and Post 2008; Rhodes et al. 2012; Rudstam et al. 1984). In this case, individuals with larger spatial ranges and higher activity levels are more likely to encounter passive fishing gears such as gill nets, fish traps, and baited hooks over a given space. Once fishing gears are encountered, the behavioral traits can also influence the willingness of individuals to attack fishing tackle (Suski and Philipp 2004). For example, in the Largemouth Bass, aggression levels are positively correlated to angling susceptibility (Suski and Philipp 2004). Social dominance has also been commonly cited as a possible mechanism of sampling bias (Gilmore and Jones 1992; Løkkeborg and Bjordal 1992; Robinson et al. 2015). Social dominance hierarchies are common in many species as individuals compete for access to food, territory, and mating opportunities (Warner 1984). The social rank and the competitive ability of individuals to acquire these resources are often correlated with phenotypic traits such as body size and sex. In several fish species, sampling biases for body size due to fish behavior have been observed (Gilmore and Jones 1992; Løkkeborg and Bjordal 1992; Myers et al. 2014; Vainikka et al. 2012). In these cases, it has been hypothesized that larger individuals may be more dominant and outcompete smaller subordinate individuals for fishing gear, thereby increasing their risk to capture. However, the relationship between body size, social dominance, and fishing susceptibility are not well understood.

The purpose of this study was to assess gear type and fish behavior sampling biases for the Gulf Black Sea Bass, *Centropristis striata melana*, in the northeastern Gulf of Mexico. I compared the efficiency and size-selectivity of hook-and-line gear and baited traps. I also tested whether size-related behaviors (e.g., social dominance) influenced the susceptibility of individuals to hook-and-line fishing gear.

1.2 Methods

1.2.1 Study Species

Gulf Black Sea Bass are a protogynous fish species found in the northeastern Gulf of Mexico from Charlotte Harbor, FL to Pensacola, FL. They are economically important contributing to both recreational and commercial fisheries along the west Florida shelf and reach a maximum age of 7 years and maximum standard length of 330 mm (Addis et al. 2011). Adults primarily inhabit shallow water (< 30 m) reefs that limit the gear types used in monitoring programs, the most common being hook-and-line and baited traps (Addis et al. 2011; Godcharles 1970).

1.2.2 Gear-Selectivity Surveys

Baited fish trap and hook-and-line surveys were conducted on shallow water (< 30 m) reefs in Apalachee Bay from December 2015 to September 2016. Trap gear consisted of chevron-style fish traps (frame size: 91 cm length x 81 cm width x 33 cm height; throat size: 33 cm height x 20 cm width) made of coated wire mesh baited with a 16-oz. permeable cloth bag filled with frozen shrimp heads as bait. For each trap, a 25 m line with a surface-marker buoy was attached and used for deployment and retrieval. Hook-and-line fishing gear consisted of two rod and reel outfits fitted with 30-lb monofilament line and a standardized "reef drop rig" (two 2/0 non-stainless steel circle hooks, wire leader, and 6 oz. lead sinker) baited with cut squid. For each round of sampling, fish traps were first deployed at survey stations (one per station) and fished for 90 minutes. During this time, each station was also sampled for 10 minutes with hook-and-line gear. For all captured Gulf Black Sea Bass, standard length (SL; measured from tip of snout to last vertebrae) and gear type were recorded. Following sampling, individuals were immediately released at original capture locations.

1.2.3 Behavioral Trials

Replicated behavioral trials were conducted at the Florida State University Coastal and Marine Laboratory (FSUCML), St. Teresa, FL over the course of two reproductive seasons (December- May) from 2015 to 2017. Gulf Black Sea Bass used in behavioral trials were collected from shallow water reefs in Apalachee Bay with hook-and-line and trap fishing gear. At the time of collection, individuals were measured for SL and sexed.

Sex was only assessed during reproductive months (December through April) when it could be determined non-lethally with an abdominal massage of the ventral-exterior surface of the abdominal cavity, beginning posterior of the pelvic fin and progressing to the anal pore. Successful abdominal massages resulted in the release of gametes through the gonaduct and allowed sex to be determined through gross visual inspection (Fig. 1.1a). Release of free-flowing milt indicated a male whereas release of vitellogenic and/or hydrated oocytes indicated a female. For each trial, two male and three female Gulf Black Sea Bass that differed in size by a minimum of 10 mm SL were transported back to the FSUCML (sex ratio based on field data reported by Hood et al 1994). At the lab, individuals were assigned a size rank (1-5, 1 = largest) based on their SL relative to other individuals in their trial group, and tagged with a uniquely colored tag for individual identification (1.5 mm T-Bar anchor tag, Floy Tag & Mfg. Inc.). Tag colors were randomized to avoid possible systemic biases caused by behavioral responses to specific tag colors. After tagging, individuals were acclimated in circular tanks (3.6 m diameter x 1.4 m height) that were supplied with a constant exchange of filtered seawater from Apalachee Bay and outfitted with three rock pile/ polyvinyl chloride (PVC) pipe structures that provided refuge and opportunities for resource disputes (Fig. 1.1b). Gulf Black Sea Bass were acclimated to tanks for five days before behavioral observations began.

1.2.4 Behavioral Observations

To record behavior, I placed underwater remote cameras (GoPro 3, GoPro Inc.) in front of each PVC structure and recorded a 30-minute observation. Observations were made once a day, every other day, for two-weeks. Filming began five minutes after cameras were placed into tanks to allow individuals to acclimate. All observations were conducted between the hours of 9:00 am and 5:00 pm.

To quantify social dominance, the outcomes of all recorded social interactions between individuals were scored as a “win”, “loss”, or “tie”, along with the relative sizes of individuals involved. A win was scored for individuals that displayed an act of aggression (bite, gill flare, rushing) directed at one or multiple conspecifics within the vicinity of the PVC structure immediately followed by displacement (curling of the body, listing to one side, full retreat) of the receiver/s of the aggressive act. Losses were scored for individuals that were displaced following an aggressive act by a conspecific. Ties were scored for individuals that displayed or received aggressive acts with no immediate displacement behavior and were excluded from analysis.

1.2.5 Behavioral-Selectivity Surveys

Behavioral-selectivity surveys were conducted during the spawning period (December through April) at shallow water reef areas in Apalachee Bay from January 2016- January 2017. At each site, 20 Gulf Black Sea Bass were captured by two fishers using standardized "reef drop rigs" (see above). For all captured Gulf Black Sea Bass, capture order (1-20) and SL were recorded. After sampling, individuals were immediately released at their original capture location. When two individuals were caught at the same time on one rig, the individual on the bottom hook was recorded first followed by the individual on the top hook.

1.2.6 Data Analysis

All individuals captured in gear-selectivity surveys were pooled by gear type. Overall size distributions were compared with a two-sample Kolmogorov–Smirnov (K.S.) test conducted using the ks.test function in the stats package (version 3.3.2) of R statistical software (R core team; www.r-project.org/). To compare the efficiency of gear types, an average catch-per-unit-effort (CPUE) for each gear type was calculated by dividing the total number of individuals captured by fishing effort. For trap gear, fishing effort was calculated by multiplying the number of traps deployed at all stations per day by trap fishing time per station (90 min). For hook-and-line gear, fishing effort was calculated by multiplying the number of reef drop rigs deployed at all stations per day by the hook-and-line fishing time per station (10 min).

To measure the relationship between size and social dominance, size and social ranks of individuals in each replicated behavioral trial (N=10) were compared using a series of Spearman's rank correlation coefficient tests (*alpha* level $\alpha = .05$) conducted using the cor. test function in R. Size ranks (1-5, 1 = largest) were based on the relative sizes of individuals in each behavioral trial. Social ranks (1-5, 1= most dominant) were based on their relative average dominance index (ADI) score. Average dominance indices were calculated for individuals within each behavioral trial using the methods of Hemelrijk et al. (2005). For each pair of individuals, a dominance index (DI) was calculated by taking the total number of wins of the focal individual (i) over a specific opponent (j) divided by the total number of contests with that opponent, thus

$$\mathrm{DI_{ij}} = \frac{\mathrm{Wins_{(i)}}}{\mathrm{Total\ Contests_{(ij)}}}$$

The average dominance index (ADI) was then calculated for each individual by dividing the sum of all its dominance indices by the total number of interaction partners (N), thus

$$\mathrm{ADI} = \frac{\sum \mathrm{DI_{ij}}}{\mathrm{N}}.$$

Average dominance index scores therefore represent the average dominance relationship of an individual with other members of its social group it interacted with. Values of ADI range from 1, indicating that an individual was completely dominate to all interaction partners, to 0 indicating that an individual was completely submissive to all interaction partners. Pairs that did not interact were excluded from the calculation of average dominance index. Due to protogynous life history of Gulf Black Sea Bass, there was a high degree of collinearity between the size and sex of individuals used captive experiments; males were on average larger than females (males: N-20, $\overline{SL}$ = 215.7 ± 4.7 SE; females: N-30, $\overline{SL}$ = 173.4 ± 6.4 SE). Due to this relationship, body size was used as the only predictor of social dominance.

To test whether body-size related behaviors influenced the susceptibility of individuals to hook-and-line fishing gear, a linear-mixed effects model (LME) was conducted using the lme function in the nlme package of R. The response variable was the SL of individuals captured in behavioral selectivity surveys and the predictor variable was capture order (1-20). Standard length was nested within surveys (N=15) to account for any spatial variation in sizes of individuals between sampling sites. The LME model was validated using visual inspection of residual plots and evaluated using maximum likelihood and effect significance was determined using type II likelihood ratio tests. Analyzing the data in this way provided information on whether the average length of individuals captured significantly changed over the catch period. If size-related behaviors influenced capture speed (our measure of fishing susceptibility), then we assumed significant size trends over the catch would be observed. For example, if larger individuals were more susceptible to fishing and were captured faster, this would result in a general decrease in average length over the catch period as the largest/most susceptible individuals are removed first followed by smaller/less susceptible individuals. In contrast, if smaller individuals were captured faster (i.e., more susceptible to fishing), this would result in an increase in average length over the catch period. A non-significant result ($P > 0.05$) would indicate that no changes in average length occurred, suggesting that all size ranges were captured at similar speeds and that size-related behaviors did not influence fishing susceptibility.

1.3 Results

1.3.1 Gear Size-Selectivity and Efficiency

From December 2015 to September 2016, a total of 115 sampling stations were surveyed with both hook-and-line and baited trap fishing gears resulting in the capture of 512 Gulf Black Sea Bass (Fig. 1.2). Catch data are summarized in Table 1.1. Results from the size distribution analysis indicated that baited traps and hook-and-line did not differ in size-selectivity (K.S. Test, D = 0.105, $P = 0.26$). However, hook-and-line gear was significantly more efficient (CPUE= 0.21 ± 0.03 SE) on average than baited trap fishing gear (CPUE= 0.01 ± 0.002 SE).

1.3.2 Behavioral Trends and Fishing Selectivity

Results from replicated behavioral trials are summarized in Table 1.2. Overall, the relative size and dominance of individuals in behavioral trials were strongly correlated (Fig. 1.3). Eight out of the ten behavioral trials resulted in a perfect Spearman correlation value of 1, indicating that the relative size rank of individuals were identical to their dominance rank. The positive correlation indicated that the largest individuals (Size rank = 1) were the most dominant individuals (Dominance rank = 1) in the tank and vice versa. In Trials 4 and 5, size rank was not significantly correlated to dominance rank. However, both trials still possessed moderate Spearman correlation values of 0.8 and 0.7, suggesting a strong relationship between size and dominance ranks. In addition, out of the 50 experimental individuals used, only one individual differed by more than one rank between relative size and dominance rank.

No significant changes in average SL were detected over the capture period in behavioral-selectivity surveys (LME, $\chi^2 = 1.55$, d.f.=1, $P = 0.21$). Because the overall slope of model was not significantly different from zero, this indicated that hook-and-line fishing was random in respect to body size and suggested that size-related behaviors did not significantly influence capture susceptibility (Fig. 1.4). Average time to capture 20 Gulf Black Sea Bass during surveys was 46.14 minutes (± 5.18 minutes SE).

1.4 Discussion

1.4.1 Gear Sampling Biases

The similarities between length distributions of Gulf Black Sea Bass sampled by both baited fish traps and hook-and-line fishing gears indicated no relative bias or skew towards any specific size class between the two gear types. The size ranges of Gulf Black Sea Bass captured in this study were also similar to those described by Hood et al. (1994), who used a variety gear types to sample Gulf Black Sea Bass over multiple years. These results suggest that both baited trap and hook-and-line gears can sample the entire size range of the adult population. Therefore, both gear types are viable sampling methods that could be implemented in Gulf Black Sea Bass population monitoring programs and life history parameters derived from them should produce similar biological reference points for stock assessment and management.

In general, it is desirable to maximize the efficiency of sampling gear to save time and reduce costs in fish monitoring programs. In this study, I found that catch per unit effort (CPUE) of Gulf Black Sea Bass was much higher using hook-and-line than chevron traps. The difference could be due to a variety of factors, including bait type, fishing duration, fisher experience, and fish behavior. The type of bait used, for instance, can significantly affect catch rates. The greater the palatability and the stronger the odor (which enhances the duration and distance traveled in the environment), the greater the total number of individuals attracted and retained (Alos et al. 2009; Broadhurst and Hazin 2001). Bait quality also degrades over time, so soak time and bait replacement can also influence CPUE (Langlois et al. 2015). Therefore, differences in the chemical properties of each bait type combined with the soak time of each gear type could have contributed to the differences in CPUE. Another factor to consider is the maximum number of individuals each gear type can retain over a defined sampling period. In the case of hook-and-line fishing gears, the maximum number of individuals retained is primarily driven by fisher experience. Once an individual fish is caught and reeled in, the fisher removes the fish from the hook, rebaits the hook, and redeploys the line. While fish continue to bite, the faster the fisher, the greater the number of fish that could be captured during a defined sampling period. In the case of baited traps, the maximum number of individuals retained is primarily driven by the number of individuals that can occupy a given trap, which can be affected by the size and behavioral interactions of individuals in the trap (Arlinghaus et al. 2016; Diaz Pauli et al. 2015). These factors should be considered in future sampling programs to maximize efficiency.

1.4.2 Fish Behavior Sampling Biases

Many fishes live in size-associated dominance hierarchies that can determine their access to territory, mates, and food resources (Warner 1984). In this study, I addressed the question of whether size-related behaviors influenced the susceptibility of individuals to fishing; resulting in size-based sampling biases. Relative size was strongly correlated to social dominance in the Gulf Black Sea Bass, however, I found no evidence that size-related behaviors influenced the susceptibility of individuals to fishing. The disconnect between size-related behaviors and capture speed may be related to the random nature of food resources used in hook-and-line gears. As McCarthy et al. (1999) demonstrates, feeding rank is correlated to social dominance under conditions where resources are predictable and contest competition occurs. In these cases, more dominant individuals feed first and possess higher consumption rates. When resources are unpredictable, scramble competition occurs and there is no significant correlation between feeding rank and social dominance. In this study, food resources used with hook-and-line gear could have represented an unpredictable resource, thereby eliminating any correlation between feeding rank and size-related social dominance. It is also possible that I did not remove enough of the larger/more dominant individuals in the population to allow smaller/subordinate individuals to access baited hook-and-line gear. However, the relatively long time period needed to capture 20 Gulf Black Sea Bass, the declines in capture rates over sampling periods, and the overall size ranges of catches all suggest that a large proportion of the population was captured during surveys.

A major limitation to this study was the scale at which fishing susceptibility was measured. In this study, I examined the relationship between size-based behaviors and fishing susceptibility based on the capture speed (i.e. capture order) of individuals. This measure provides insights into the immediate susceptibility of individuals in a population to fishing, however, it does not provide information on fishing susceptibility over time. In many fishes, larger and more dominant individuals are territorial and may differ from smaller subordinates in spatial use (Hoffman 1985; Rhodes et al. 2012). In our study, Gulf Black Sea Bass social dominance was derived from social contests over territory, so it is probable that larger and more dominant individuals are territorial and may differ in space use than smaller subordinates. These differences in spatial use patterns can result in larger and more dominant individuals being more susceptible to fishing over time (Coleman et al. 1996; Rhodes et al. 2012). Therefore, although size-based behaviors may not influence short-term fishing susceptibility, it may play an important role in long-term fishing susceptibility and future investigations are warranted.

1.4.3 Conclusions

In summary, this study indicated that baited trap and hook-and-line fishing gear were both viable sampling gears that can be used in Gulf Black Sea Bass monitoring programs. It also demonstrated that hook-and-line fishing gears were more efficient and do not immediately select for size-related fish behaviors, however, these behaviors warrant further investigation due to their implications for long-term fishing susceptibility, sampling biases, and conservation.

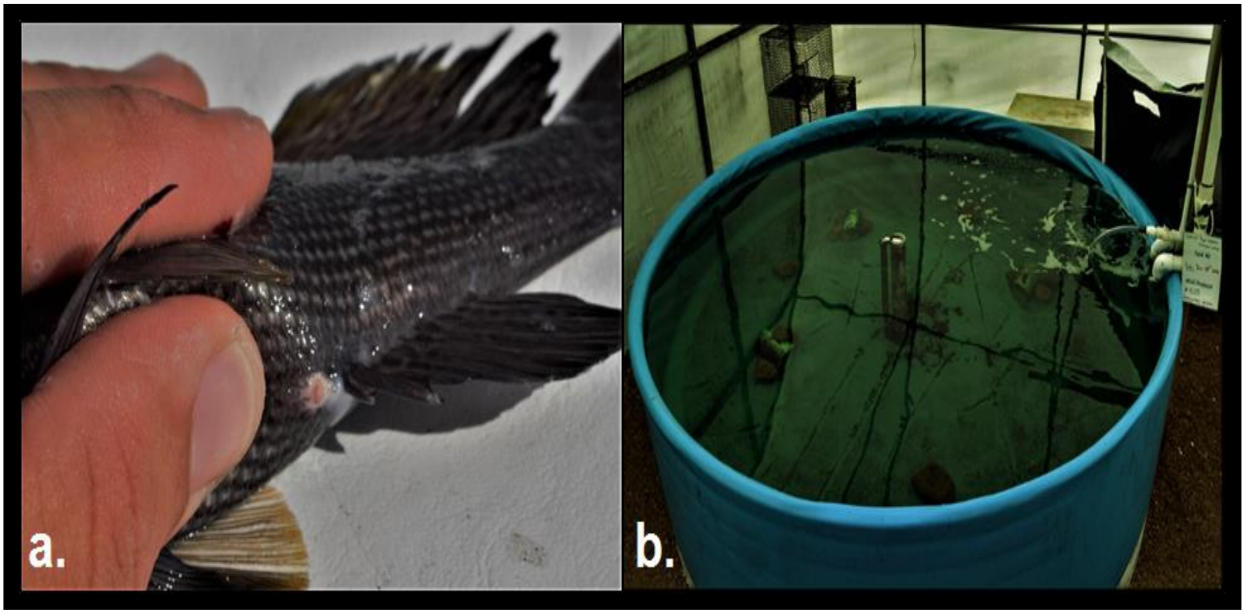


Figure 1.1: Experimental methods: (a.) Example of abdominal massage technique used for sex determination in Gulf Black Sea Bass, *Centropristis striata melana*. Male with free-flowing milt is displayed. (b.) Aquaria with rock/PVC structures used in captive behavioral trials

Table 1.1: Summary of Gulf Black Sea Bass *Centropristis striata melana* catch data from gear-selectivity surveys conducted December 2015 to September 2016 in the northeastern Gulf of Mexico.

Gear Type	Total # of Black Sea Bass	Mean CPUE (± 95% CI)	Min. SL	Max. SL	Mean SL (± 95% CI)
Baited Traps	117	0.01 ± 0.004	105	242	164.91 ± 3.15
Hook-and-line	447	0.21 ± 0.06	100	278	170.40 ± 5.08

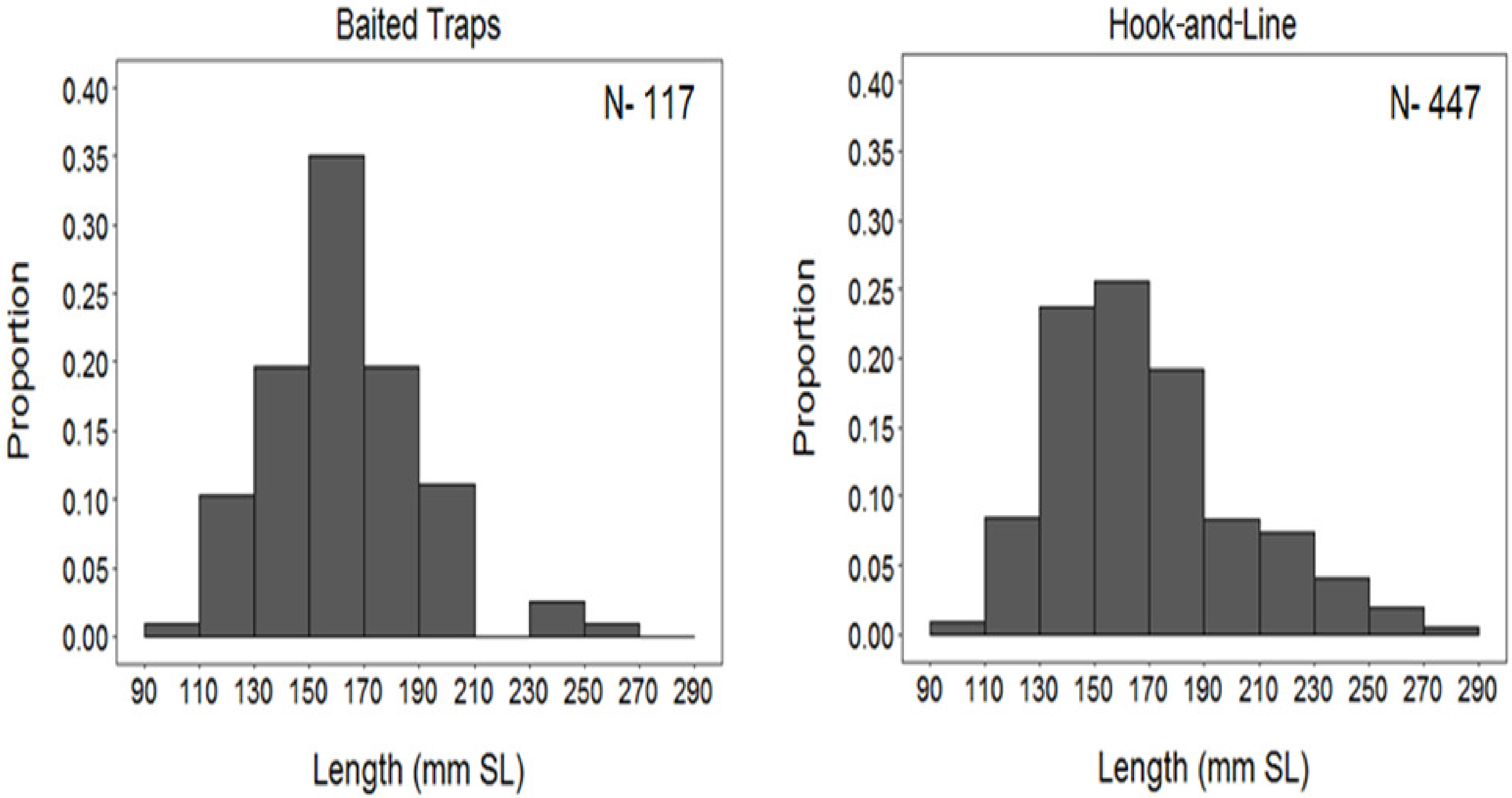


Figure 1.2: Size-frequency distributions of Gulf Black Sea Bass *Centropristis striata melana* captured with baited trap and hook-and-line fishing gears on shallow water reefs in Apalachee Bay, northeastern Gulf of Mexico. No significant differences in size-selectivity were observed between gear types (K.S. Test, D = 0.105, *P* = 0.26).

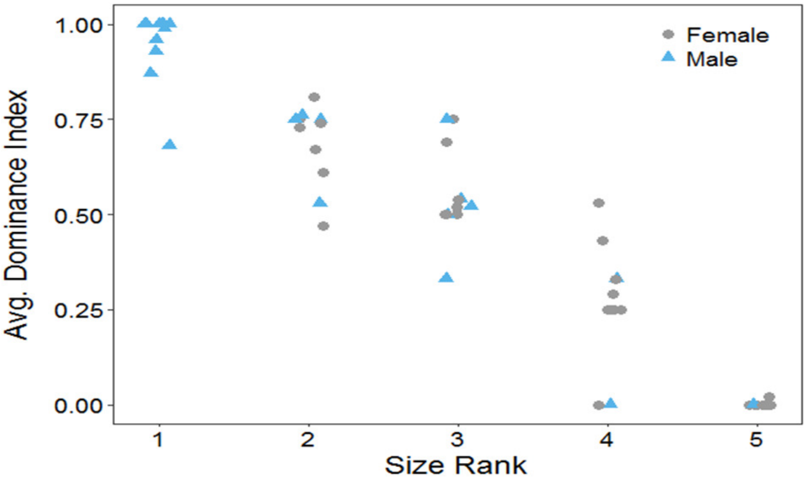


Figure 1.3: Relation between size and average dominance index of Gulf Black Sea Bass *Centropristis striata melana* combined across 10 replicated behavioral trials. Significant correlations were found between 8 out of 10 behavioral trials indicating a strong connection between relative size and dominance rank (Table 1.2).

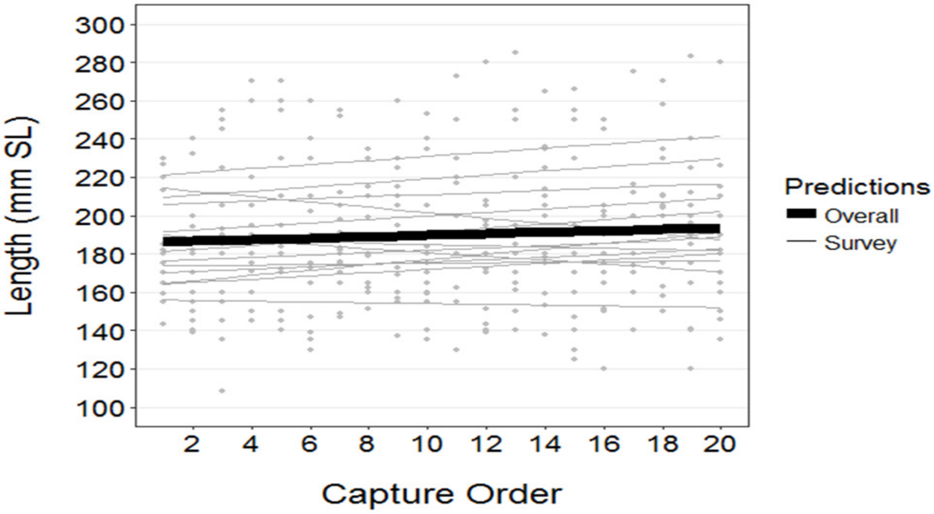


Figure 1.4: Results from behavioral analysis testing if size-related behaviors influence the capture speed of Gulf Black Sea Bass *Centropristis striata melana* in Apalachee Bay, northeastern Gulf of Mexico. Individuals captured during surveys (grey dots), predicted model values for 15 individual surveys (grey lines), and overall predicted model values (black line) are displayed. No significant changes in average length were observed over capture period, indicating that size-related behaviors did not significantly influence capture speed (LME, χ^2= 1.55, d.f.=1, $P = 0.21$).

Table 1.2: Results from Spearman's rank correlation tests between relative size and dominance ranks (based on average dominance index) of Gulf Black Sea Bass *Centropristis striata melana* in replicated behavioral trials. Average number of social contests per individual in each trial, Spearman's rank correlation coefficient (*r*) and probability values (*P*) are indicated.

	Average # Contests	d.f.	*r*	*P*
Trial 1	54.6	3	1	< 0.001
Trial 2	37.4	3	1	< 0.001
Trial 3	30	3	1	< 0.001
Trial 4	48.4	3	0.8	0.10
Trial 5	26.8	3	0.7	0.19
Trial 6	34.4	3	1	< 0.001
Trial 7	24	3	1	< 0.001
Trial 8	20.4	3	1	< 0.001
Trial 9	34.4	3	1	< 0.001
Trial 10	34	3	1	< 0.001

CHAPTER 2

REPRODUCTIVE DYNAMICS OF GULF BLACK SEA BASS IN THE NORTHEASTERN GULF OF MEXICO

2.1 Introduction

Assessing and managing the reproductive potential of fish populations has been fundamental to their management and long-term sustainability (Lowerre-Barbieri 2009; Marshall et al. 2003). Traditionally, fishery managers have relied on measures of spawning stock biomass (SSB) and egg production to assess reproductive potential and set management regulations (Goodyear 1993). For example, in many recreational fisheries, minimum length regulations are adopted to conserve SSB (Gwinn et al. 2015). In these situations, it is assumed that removal of individuals above minimum length limits will increase the growth rate of the unharvested population; thereby maintaining SSB and reproductive potential (Gwinn et al. 2015). However, as our understanding of fish reproductive ecology has increased, and many fisheries have suffered population declines, it has been recognized that SSB and egg production measures alone are often poor indicators of reproductive potential and do not effectively protect spawning populations from overfishing (Hesselgrave and Sheeran 2012; Lowerre-Barbieri et al. 2009; Marshall et al. 2006; Worm et al. 2009).

The spatial, temporal, and demographic scales of spawning populations play important roles in assessing and managing the effects of exploitation on reproductive potential (Berkeley et al. 2004a; Hixon et al. 2014). In many marine species, limited adult movement combined with variable levels of recruitment, growth, and mortality result in a high degree of spatial variability in spawning population structure and reproductive potential (Kritzer and Sale 2004). In these cases, if traditional egg production measures are used, which ignore spatial variation and treat spawning populations as one panmictic regional stock, then local depletion of sub-stock reproductive populations may occur and eventually lead to increases in recruitment variability and possibly recruitment failure (Berkeley et al. 2004; Hsieh et al. 2010; Ying et al. 2011).

The timing and duration of spawning are also critical to reproductive potential and are often linked to demographic traits such as sex, age, and body size (Wright and Trippel 2009). For example, in many batch-spawning species, older and larger females spawn earlier and for longer durations during the spawning season (Lowerre-Barbieri et al. 2011). These larger females often possess higher rates of reproductive success and contribute more to recruitment classes over time (Field et al. 2008; Wright and Trippel 2009). In fisheries regulated by minimum length limits, selective harvest of older and larger females could result in the truncation of spawning windows and increase yearly fluctuations of recruitment strength (Wright and Trippel 2009). In addition, males and females often differ in their arrival and residency times at spawning grounds (Rhodes et al. 2012; Robichaud and Rose 2003; Solmundsson et al. 2003). In these cases, exploitation during specific times can result in heavy exploitation rates for a specific sex, causing shifts in the spawning sex ratio that may disrupt reproductive output (Coleman et al. 1996; Rhodes et al. 2012; Solmundsson et al. 2003).

Currently, spawning populations of many marine fisheries are poorly defined and data on the spatial, temporal, and demographic scales of their spawning populations are needed to design effective management and conservation strategies. In this study, I conducted a fisheries-independent survey to examine the reproductive dynamics of Gulf Black Sea Bass *Centropristis striata melana* on natural reefs in the northeastern Gulf of Mexico. Specifically, I assessed the spatial and temporal variation of their spawning population structure to (1) determine if spawning populations were consistent across spawning habitats, and (2) describe demographic trends (i.e. sex and body size) in the timing of spawning. This study is the first to examine the spatial and demographic patterns of Gulf Black Sea Bass reproduction in the northeastern Gulf of Mexico and provides important insights into their conservation and management.

2.2 Methods

2.2.1 Study Species

The Gulf Black Sea Bass *Centropristis striata melana* is a temperate serranid that contributes to both recreational and commercial fisheries in the state of Florida, USA (annual catch in Florida averaging ~ 260,000 pounds since 2006, Addis et al. 2011). Juvenile Gulf Black Sea Bass are primarily found in nearshore seagrass and oyster reefs during the early spring and summer and are believed to migrate offshore to shallow-water (water depth < 30 m) reefs when waters cool in the late fall and winter (Godcharles 1970; Moe 1963). Once established on reefs, adults are believed to be highly residential based on limited tagging data (Beaumariage 1969; Moe 1966; Topp 1963). Spawning occurs from December to April (Hood et al. 1994). Currently, the Gulf Black Sea Bass stock is considered a data poor fishery relative to its life history and reproductive dynamics (Addis et al. 2011).

2.2.2 Study Area

In this study, spawning populations were monitored at three 1-km^2 shallow water (< 30 m water depth) study plots located on natural reefs off the eastern end of Dog Island, a barrier island in Apalachee Bay, FL, in the northeastern Gulf of Mexico (Fig. 2.1). These natural reefs, like others in the northeastern Gulf of Mexico, are composed of patchy networks of sand and live bottom habitat, consisting of exposed limestone substrate colonized by coral, sponge, and algae species (Kingon 2013). They serve as the primary spawning habitat for the Gulf Black Sea Bass (Fig. 2.2; Hood et al. 1994). Within each study plot, five fixed-survey stations were established on live-bottom habitat patches and were repeatedly sampled during the winter (December through February) and spring (March and April) spawning periods from 2015 to 2017.

2.2.3 Sampling Design

Gulf Black Sea Bass were sampled with hook-and-line fishing gear consisting of a rod and reel outfit with 30-lb test monofilament and a standardized "reef drop rig" (two 2/0 non-stainless steel circle hooks, orange marking beads, wire leader, 6 oz. lead sinker) baited with cut squid. Within each study plot, each fixed-survey station was fished by two fishers for 10 minutes; for a total of 100 minutes of sampling effort per study plot, per sampling event (5 stations x 2 fishers x 10 minutes). Repeat sampling surveys conducted a minimum of three weeks apart. Due to poor weather conditions in the 2015-2016 spawning season, study plots were sampled twice during the winter spawning period and only once during the spring spawning period. During the 2016-2017 spawning season, study plots were sampled once a month.

For each captured individual, I measured standard length (SL, tip of lower jaw to the posterior end of the last vertebrae) to the nearest mm and assessed reproductive condition. Reproductive condition was first assessed with an abdominal massage applied to the ventral-exterior surface of the abdominal cavity, beginning posterior of the pelvic fin and progressing to the anal pore. Individuals that expressed free-flowing milt following abdominal massage were classified as reproductive males (Fig. 2.2c). If no milt was released, I conducted gonad biopsies using a small polypropylene catheter (2.54 cm length x 0.25 mm inner diameter) inserted into the gonad through the gonaduct. After biopsy collection, samples were immediately stored in labeled vials containing 10% buffered formalin and transported to the lab for staging. To monitor whether I ever recaptured the same individual within the same spawning period, individuals were marked by clipping the fifth and sixth dorsal fin spine at the base of the dorsal musculature. Based on a limited number of uniquely marked individuals, fin spine markings were still present for 4 months after initial marking, so this method provided an estimate of within-season but not across season recaptures. After fin spines were removed, individuals were immediately released back to their original capture location. Total time from capture to release for individuals was less than five minutes.

2.2.4 Reproductive Staging

Gonad biopsy samples were staged using a dissecting scope (Zeiss Dissecting Scope, 50x total magnification, transmitted light) and were classified as either reproductive females or non-reproductive individuals based on the most advanced stage of their oocyte development (Smith et al. 2014). Reproductive females were classified as individuals that possessed vitellogenic and/or hydrated oocytes (Fig. 2.3b). Non-reproductive individuals were classified as individuals that possessed either primary stage or cortical alveolar stage oocytes (Fig. 2.3a). Fish that yielded no viable gonad tissue during sampling were classified as unknown.

2.2.5 Data Analysis

To assess the spatial and temporal variation of Gulf Black Sea Bass spawning population structure, I compared the spawning sex ratio (SSR) and size structure between study plots and spawning periods. To test for differences in SSR, the total number of reproductive females and males were first counted for each study plot and each spawning period. To test for significant differences in counts, I used a series of pair-wise chi-square tests between the three study plots and both spawning periods (alpha = 0.05).

To test for differences in the size structure of the spawning populations, SL distributions of reproductive females and males were compared between study plots and spawning periods with a series of two-sample Kolmogorov-Smirnov (KS) tests in R. In addition, I calculated the percentage of females below 147 mm SL in spawning populations for each study plot and spawning period by dividing the number of reproductive females below 147 mm SL by the total number of reproductive females captured during surveys. Based on the age and length data reported in Hood et al. (1994), Gulf Black Sea Bass below 147 mm SL represent 0 and 1-year-old age classes. In this study, I used the percentage of reproductive females in this size range as a measure of juvenile recruitment.

In addition, a series of linear-mixed effects models (LME) were conducted for reproductive males and females to test for differences in average length between study plots and spawning periods using the lme function in the nlme package of R. The response variable was SL and the predictors were study plot, spawning period and a study plot by spawning period interaction term. Sampling year was included as a random effect to account for any annual variation in SL over the study period. If significant differences were detected among study plots or interaction term ($P< 0.05$), Tukey's tests were conducted in the multcomp package of R to evaluate which levels of these factors were different from one another. The LME models were validated using visual inspection of residual plots and were evaluated using maximum likelihood and effect significance was determined using type II likelihood ratio tests.

2.3 Results

Overall, a total of 493 Gulf Black Sea Bass were captured and sampled over the course of the 2015-2016 and 2016-2017 spawning seasons. Of the 493 individuals, 42 individuals (8.5%)

were recaptured within the same spawning period and were excluded from demographic analyses. Of the 42 recaptured individuals, 67% were reproductive males, 26% were reproductive females, 5% were unknown, and 2% were non-reproductive. The large proportion of male recaptures suggests that males may be more residential during the spawning season.

2.3.1 Spatial Variation in Population Structure

The results from the chi-square analysis indicated that female to male SSR was significantly different between study plots (Table 2.1). Study plot 1 was significantly male biased compared to study plots 2 and 3 which were slightly female biased (Fig. 2.4). The average SSR over the entire study area was 1.02, indicating that female to male sex ratio was close to a 1:1.

Reproductive female size structure was not homogenous across study plots (Fig. 2.4). KS pairwise tests indicated that the length distribution of study plot 1 was significantly different from study plot 3 (D= 0.28, P = 0.02). No significant changes were observed in reproductive female length distributions between study plot 1 and study plot 2 (D=0.13, P = 0.83) and study plot 2 and study plot 3 (D=0.24, P = 0.10). The percentages of newly recruited females (< 147mm SL) were highly variable between study plots (Plot 1= 23%, Plot 2= 28%, Plot 3= 39%); suggesting that female recruitment was not consistent across spawning habitats. Results from the LME model indicated that the average length of reproductive females was significantly different among study plots (Study Plot: LME, χ^2=9.31, d.f.=2, P = 0.01, Table 2.2). Tukey's tests indicated that the average length of reproductive females at study plot 1 was significantly higher than study plot 3 (P = 0.03, Fig. 2.5). No significant differences in the average length of reproductive females were observed between study plots 1 and 2 (Tukey, P = 0.98) and between study plots 2 and 3 (P = 0.06; Fig. 2.5).

Reproductive male population structure was also not homogenous across study plots (Fig. 2.4). KS pairwise tests indicated that the length distribution of study plot 1 was significantly different from study plot 3 (D= 0.24, $P = 0.05$). No significant changes were observed in reproductive male length distributions between study plot 1 and study plot 2 (D=0.16, $P = 0.58$) and study plot 2 and study plot 3 (D=0.25, $P = 0.13$). Results from the LME model indicated that the average length of reproductive males was consistent among study plots (Study Plot: LME, χ^2=5.53, d.f.=2, $P = 0.06$, Table 2.2; Fig. 2.5).

2.3.2 Temporal Variation in Population Structure

The results from the chi-square analysis indicated that female to male SSR was significantly different between winter and spring spawning periods (χ^2= 92.6, d.f.= 1, $P < 0.001$). Spawning sex ratio was male biased during the winter spawning period (SSR= 0.65) and shifted to a female bias during the spring spawning period (SSR= 2.33, Fig. 2.6).

Reproductive female size structure was not consistent across spawning periods (Fig. 2.6). KS pairwise tests indicated that the winter spawning and spring spawning length distributions were significantly different (D= 0.38, $P < 0.001$). The percentages of newly recruited females between spawning seasons (winter= 17%, spring= 47%), indicated a large number of females recruited in the spring. Results from the LME model indicated that the average length of reproductive females was significantly different across spawning periods (Spawning period: LME, χ^2=9.60, d.f.=1, $P = 0.002$, Table 2.2). Females on average were significantly larger during winter than spring (Fig. 2.7).

Reproductive male size structure was not consistent across spawning periods (Fig. 2.6). KS pairwise tests indicated that the winter spawning and spring spawning length distributions were significantly different (D=0.32, $P = 0.01$); primarily driven by the loss of males < 180 mm

SL during spring. Results from the LME model indicated that the average length of reproductive males was significantly different across reproductive periods (Spawning period: LME, χ^2=5.64, d.f.=1, *P* = 0.02, Table 2.2). Males on average were significantly smaller during winter than spring (Fig. 2.7).

2.4 Discussion

The spawning populations of Gulf Black Sea Bass are poorly defined and data on the spatial, temporal, and demographic scales of their reproduction are needed to design effective management and conservation strategies. To address this data gap, I assessed the spatial and temporal variation of Gulf Black Sea Bass spawning population structure in the northeastern Gulf of Mexico to (1) test if spawning population structure was consistent across spawning habitats, and (2) describe demographic trends (i.e. sex and size) in the timing of spawning.

2.4.1 Spatial Variability in Spawning Demography

Significant variation in population structure across reef habitats seems to be a relatively common trait of reef fishes and has been documented in a growing number of Gulf of Mexico species (Allman 2007; Collins and McBride 2015; DeVries 2005; Ingram 2014). In Gulf Black Sea Bass spawning populations, I found significant spatial variation in spawning sex ratio and reproductive female and male size structure; indicating that spawning population structure was not consistent across available spawning habitats. The spatial variation in spawning population structure was likely due differences in juvenile recruitment, growth, and/or mortality rates between study plots. The large variation of spawning females < 145 mm SL, representing the average length attained during the first year of life (Hood et al 1994) suggested that juvenile recruitment was highly variable among study plots. Recruitment dynamics of reef fishes are very complex and many ecological factors can affect the number of individuals that decide to settle on a given reef patch. In the northeastern Gulf of Mexico, many studies have investigated the dynamics of reef fish larval recruitment in nursery seagrass and oyster reef habitats (Allman and Grimes 2002; Fitzhugh et al. 2005; Switzer et al. 2012). However, in species such as Gag and Gulf Black Sea Bass, very little is known about the spatial and temporal dynamics of juveniles leaving nursery areas and settling on offshore reefs; representing a critical data gap in their life history. In addition, once established on reefs, very little is known about the spatial and temporal variations in the density of predators and food resources that are likely to influence mortality and growth rates of Gulf Black Sea Bass (Jaap et al. 2014). To understand the full spatial dynamics of Gulf Black Sea Bass spawning population structure, more information will be needed on the spatial and temporal patterns of juvenile recruitment, growth, and mortality rates.

The significant variation in spawning population structure across study plots on the scale of less than 10 km clearly indicates that Gulf Black Sea Bas spawning populations are not panmictic and show a high degree of spatial variability. Because spawning population structure is an important factor in reproductive potential, these results clearly highlight the importance of incorporating spatial variation in reproductive potential assessments and management. However, incorporating small-scale spatial variability into assessment models may or may not lead to better assessment results and small-scale spatial management would likely be logistically challenging. To improve our ability to assess and manage reproductive potential, data will also be needed at larger spatial levels (e.g. medium range: 50 to 100 km, large range: 100 to 300 km, nearshore vs offshore, etc.) to determine the optimal level of spatial variation in population structure to include in assessment models and management.

2.4.2 Demographic Trends in Reproduction

Demographic traits such as the size, sex, and age of individuals have been observed to influence the onset and duration of reproduction of many fishery species (see reviews by Lowerre-Barbieri et al. 2011; Wright and Trippel, 2009). In Gulf Black Sea Bass, demography was a clear factor in the timing of reproduction as the proportion and average size of females and males significantly changed over the course of the spawning season. For females, spawning populations consisted mostly of larger females in the winter and became inundated with smaller females in the spring. Similar patterns have been observed in a number of species as larger, repeat spawners often spawn before smaller, first-time spawners (Wright and Trippel 2009). A number of factors can contribute to the onset of female spawning, including differences in body condition (Ridgway et al. 1991), environmentally driven maturation rates (Lowerre-Barbieri et al. 2011), and differences in arrival times to spawning grounds (Trippel et al. 1997). In this study, the seasonal changes in female size structure were likely due to size based differences in arrival times at spawning grounds. Based upon the age at length of Gulf Black Sea Bass (Hood et al. 1994), the majority of smaller females observed during the spring were likely juveniles (ages 0-1) that had recently egressed from nursery habitats to offshore reefs. Gulf Black Sea Bass are capable of spawning in their first year of life, so as these individuals arrived onto reef sites they were able to participate in spawning.

Significant demographic patterns were also observed in males. During the winter, spawning populations consisted of a high proportion of reproductive males across a large size range. During the spring the frequency of males decreased and the average size of males increased, largely due to the loss of smaller males in the spawning population. Similar patterns of male spawning have also been observed in the Brook trout *Salvelinus frontinalis* (Blanchfield and Ridgway 1997) and the three-spine stickleback *Gasterosteus aculeatus* (Candolin and Voigt 2003). In these species, mate competition and the energy costs of reproduction were proposed as factors contributing to the absences of smaller spawning males late in the reproductive periods. These factors could have also contributed to the patterns observed in this study. In many protogynous reef species similar to the Gulf Black Sea Bass, mating systems often include large territorial males that exclude smaller males from occupying spawning reef patches (Kline et al. 2011). Although the mating system of the Gulf Black Sea Bass has not been investigated, my captive experiments indicate that social dominance is strongly correlated to body size and larger males are more likely to win in territorial contests (see Chp. 2). If this pattern was present in the wild, then smaller, subordinate males may have been displaced by larger, dominant males as the spawning season progressed, lowering their catch rates in the spring. In addition, males in spawning populations can accrue a large metabolic debt during the spawning season as they compete for territory and mating opportunities. In these cases, larger individuals in better body condition are often capable of spawning for longer periods (Hutchings 1994; Ridgway et al.1991). If mate competition is high in the Gulf Black Sea Bass, then smaller lower condition males in the spawning population may deplete their energy reserves faster than larger higher condition males; resulting in a shorter spawning period.

Understanding the demographic roles of spawning populations provide important insights into how spawning populations may be affected by fishing. Currently, the Gulf Black Sea Bass is managed by a 10-inch minimum length limit (~190 mm SL) and a 100 lb. per person quota. Based on my findings, these regulations would directly protect the majority of females in spawning populations, including larger females spawning earlier in the season. However, the minimum length limit and quota allow for a large proportion of spawning males to be harvested, which may be exacerbated early in the spawning season when males make up the majority of the reproductive population. Male selective harvesting is a common trait in many protogynous fisheries with unknown consequences. In the Gulf Black Sea Bass, male selective harvesting could have a number of effects. One hypothesis is that as males are removed, the remaining males in the spawning population, including those below the minimum length limit, can compensate for the loss by mating with more females in the population. In this case, the effect of male removals would likely not have a large impact on reproductive potential. Another hypothesis is that as males are removed from the spawning population, the remaining males cannot compensate for this loss and female to male sexual transition rates increase. In this case, the effect of male removals could impact reproductive potential by affecting the timing and volume of egg production and by reducing the number of reproductive females. The last hypothesis is that as males are removed from the spawning population, the remaining males and transitioning females are not able to functionally replace the loss of males. In this case, the effect of male removals could result in a reduction of fertilization rates due to sperm limitation. Currently, our knowledge of the effects of male selective harvesting is relatively poor and studies are needed to test these hypotheses to better our understanding and ensure that reproductive potential is conserved in protogynous species.

2.4.3 Conclusions

In summary, this was the first study to explore the spatial and demographic scales of Gulf Black Sea Bass reproduction in the northeastern Gulf of Mexico. Spawning populations were not consistent across available spawning habitat and displayed a high degree of spatial variability over scales of no more than 10 kilometers, that was likely influenced by juvenile recruitment rates. Demography was a clear factor in the timing of reproduction as the proportion and average size of females and males significantly changed over the course of the spawning season. Larger females began spawning earlier in the spawning season and larger males were present on spawning habitats for longer periods. The spatial and demographic patterns of reproduction described in this study provide new insights into the reproductive ecology of the Gulf Black Sea Bass and warrant future investigation due to their implications into the conservation and management of this economically important fishery.

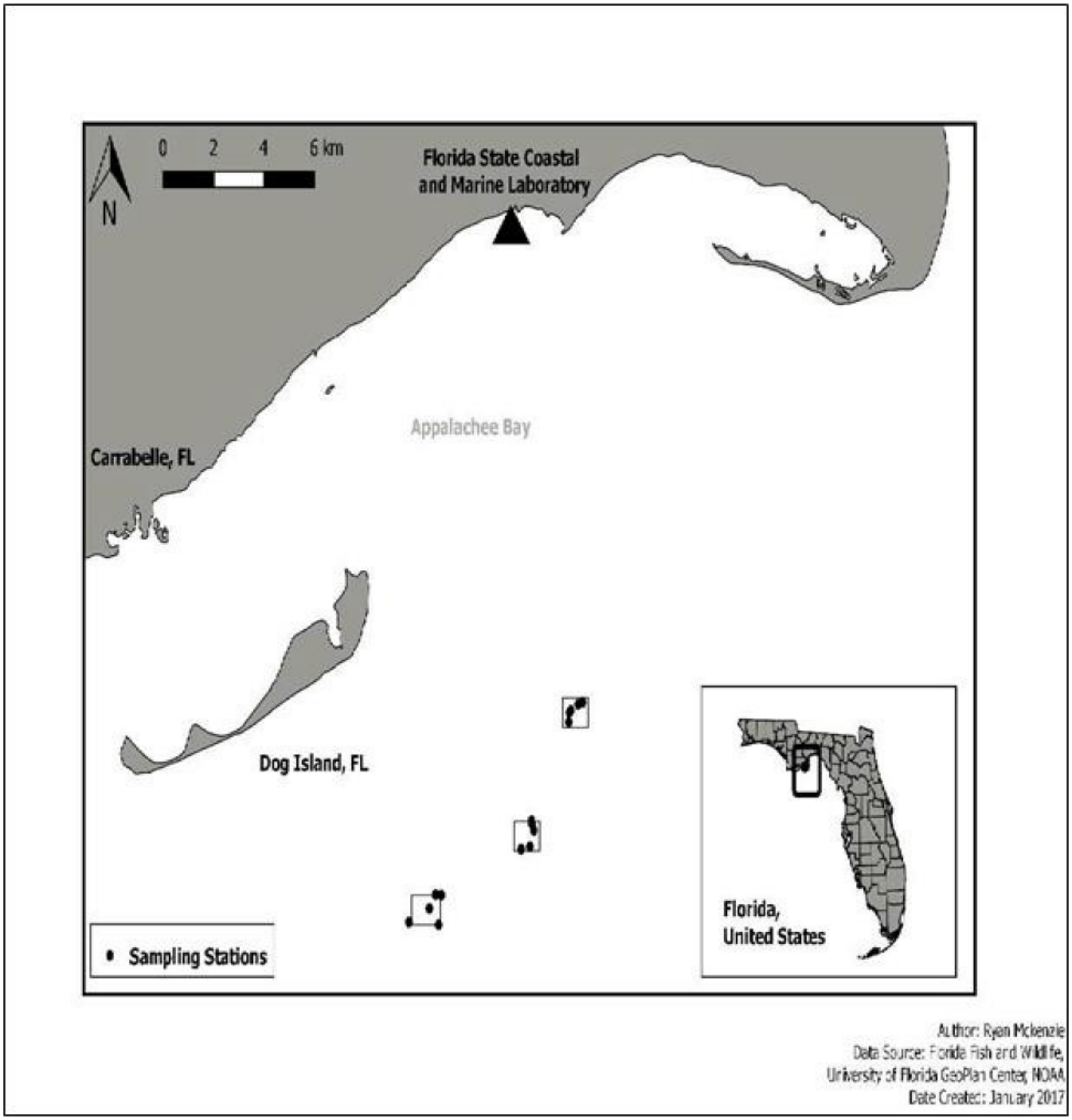


Figure 2.1: Map of study plots located on natural reefs off Dog Island, a barrier island in Apalachee Bay in the northeastern Gulf of Mexico. Within each 1 km^2 study plot (black squares), five fixed survey stations (black dots) were repeatedly sampled for Gulf Black Sea Bass Centropristis striata melana during winter (Dec-Feb) and spring spawning periods (Mar-Apr) from 2015 to 2017.

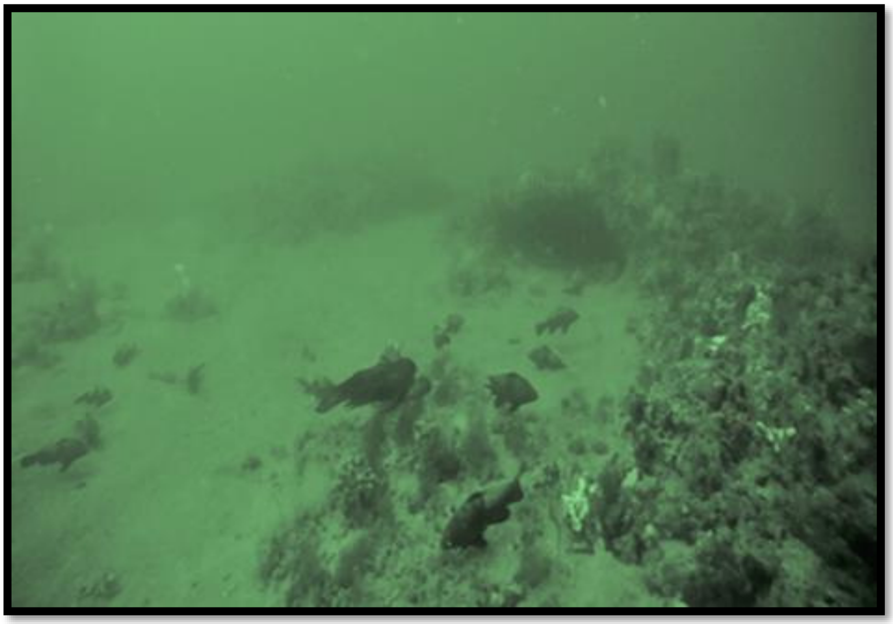


Figure 2.2: Gulf Black Sea Bass *Centropristis striata melana* on natural reef habitat in the northeastern Gulf of Mexico.

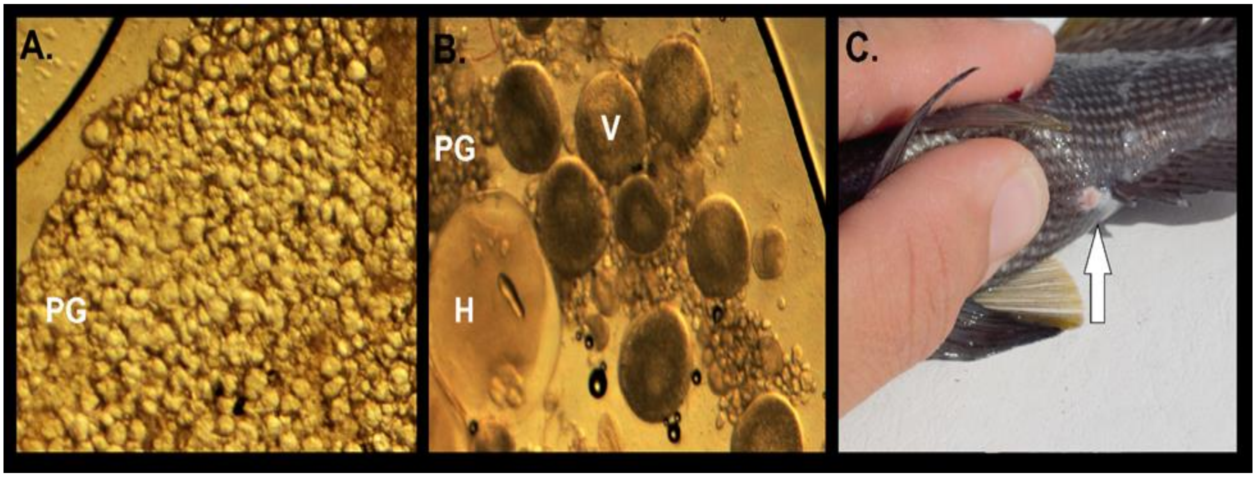


Figure 2.3: Examples of gonad stages used for sex determination in the Gulf Black Sea Bass *Centropristis striata melana*: A.) Gonad biopsy from a non-reproductive individual indicated by the presence of primary growth oocytes (PG). B.) Gonad biopsy from a reproductive female indicated by the presence of vitellogenic (V) and hydrated (H) oocytes. Note the size differences between primary growth oocytes (PG). C.) Reproductive male indicated by free-flowing milt (arrow) following abdominal massage.

Table 2.1: Statistical results from pairwise chi-square tests comparing the female to male spawning sex ratios of Gulf Black Sea Bass *Centropristis striata melana* among study plots.

Study Plots	d.f.	χ^2	*P*
1 vs. 2	1	4.13	**0.04**
2 vs. 3	1	0.0001	0.99
1 vs. 3	1	4.21	**0.04**

Table 2.2: Statistical results from linear mixed effects models that examined the effects of study plot and spawning period on the average standard lengths of reproductive female and male Gulf Black Sea Bass *Centropristis striata melana*.

		Average length of reproductive females		Average length of reproductive males	
Effect	d.f.	χ^2	*P*	χ^2	*P*
Study plot	2	9.31	**0.01**	5.53	0.06
Spawning period	1	9.60	**0.002**	5.64	**0.02**
Study plot x spawning period	2	2.38	0.30	0.13	0.94

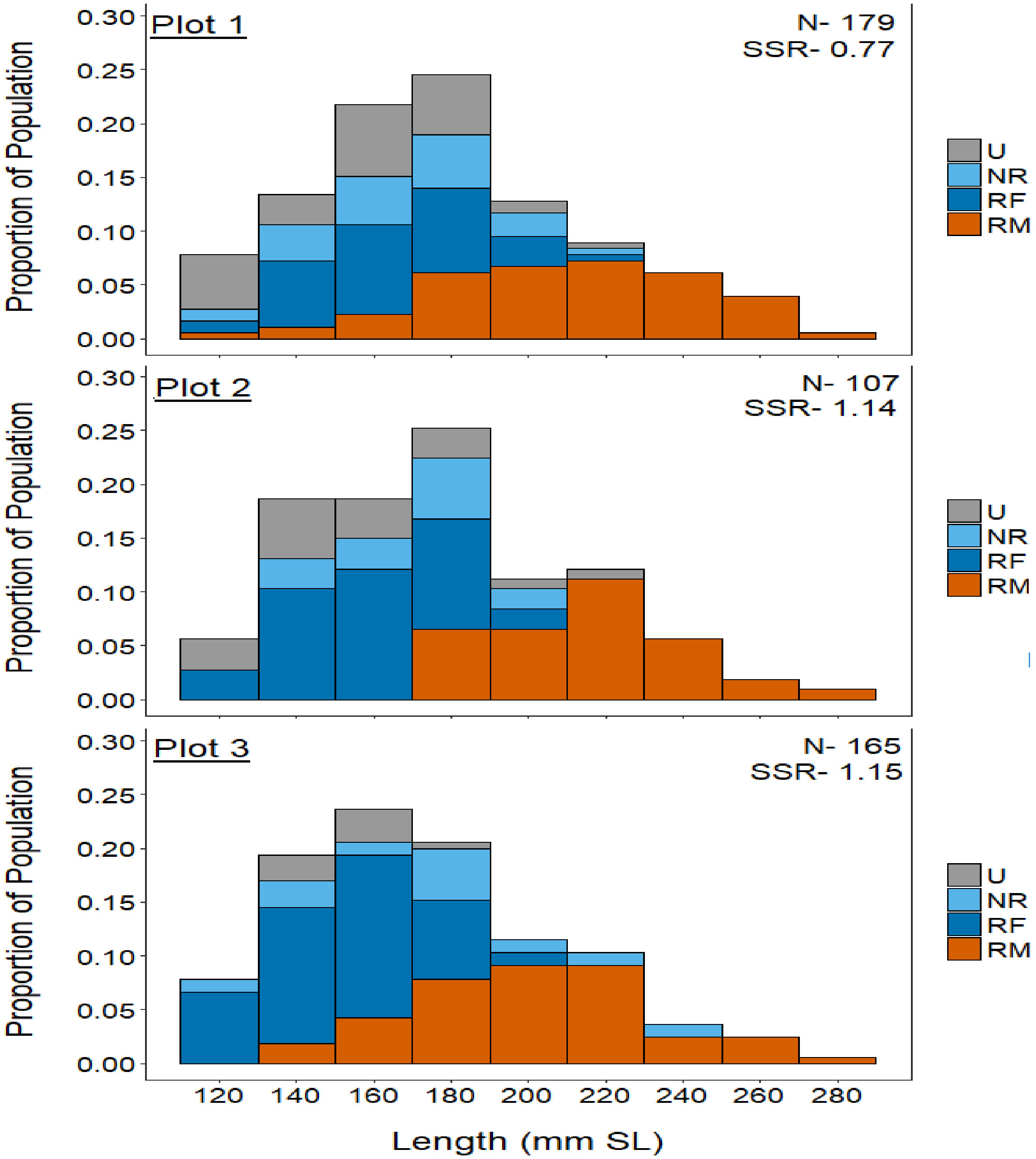


Figure 2.4: Demographic composition of Gulf Black Sea Bass *Centropristis striata melana* spawning populations surveyed at three shallow-water reef study plots in the NE Gulf of Mexico from 2015-2017. Significant changes in female to male spawning sex ratio (SSR) were observed at study plot 1. Reproductive female (RF) and reproductive male (RM) length distributions were also significantly different between study plot 1 and study plot 3 (RM: KS Test, $P = 0.05$; RF: KS Test, $P = 0.02$). Unknown (U) and non-reproductive (NR) individuals are displayed.

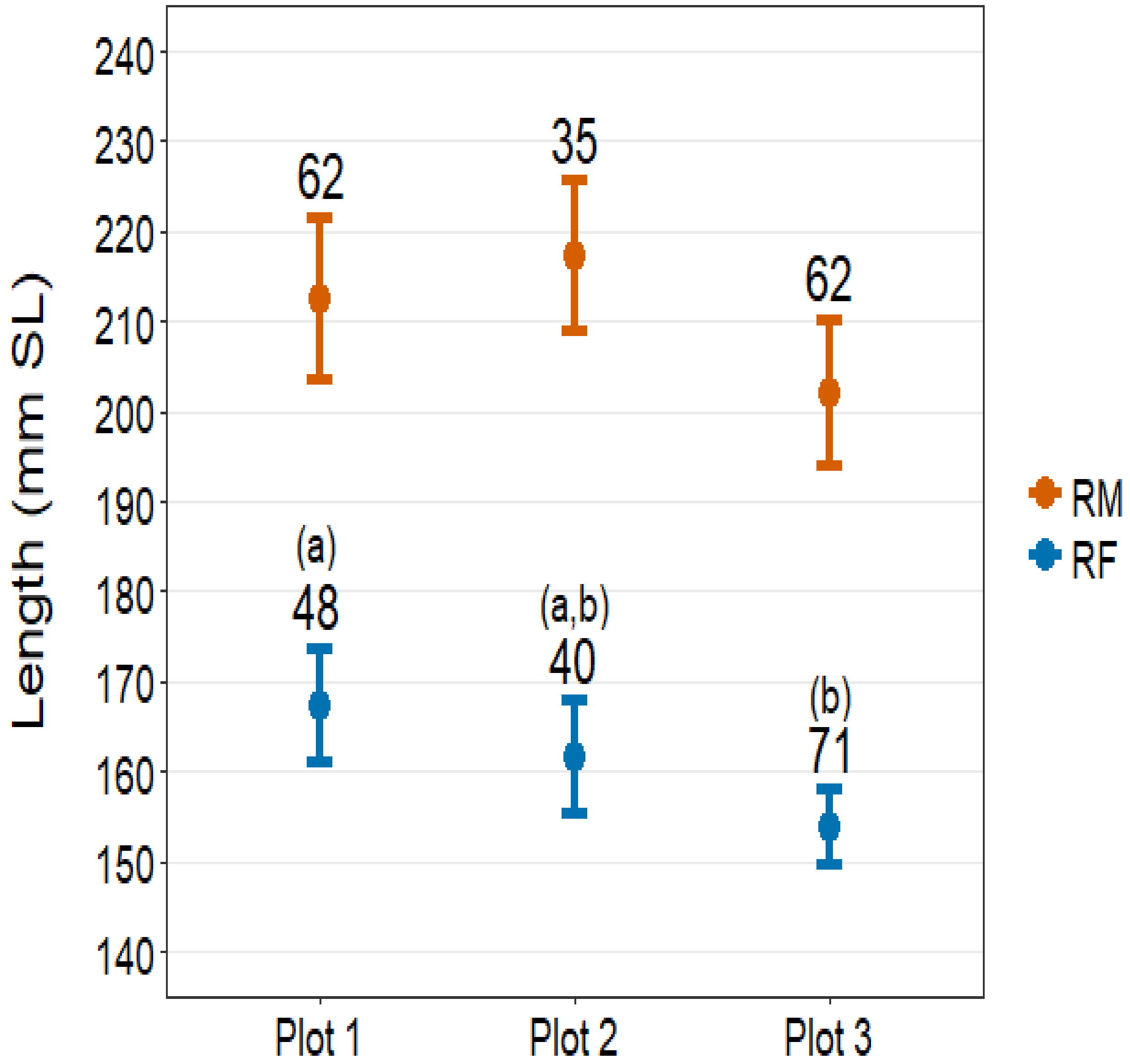


Figure 2.5: Gulf Black Sea Bass *Centropristis striata melana* mean and 95% confidence intervals of reproductive male (RM) and reproductive female (RF) standard lengths across study plots on shallow reefs in the northeastern Gulf of Mexico. Sample sizes are indicated with counts above confidence interval bars. Significant differences in average RF length were observed among plots (LME, P = 0.01) and results from Tukey's tests are indicated by lower case letters. No significant differences were observed in average RM length among plots (LME, P = 0.06).

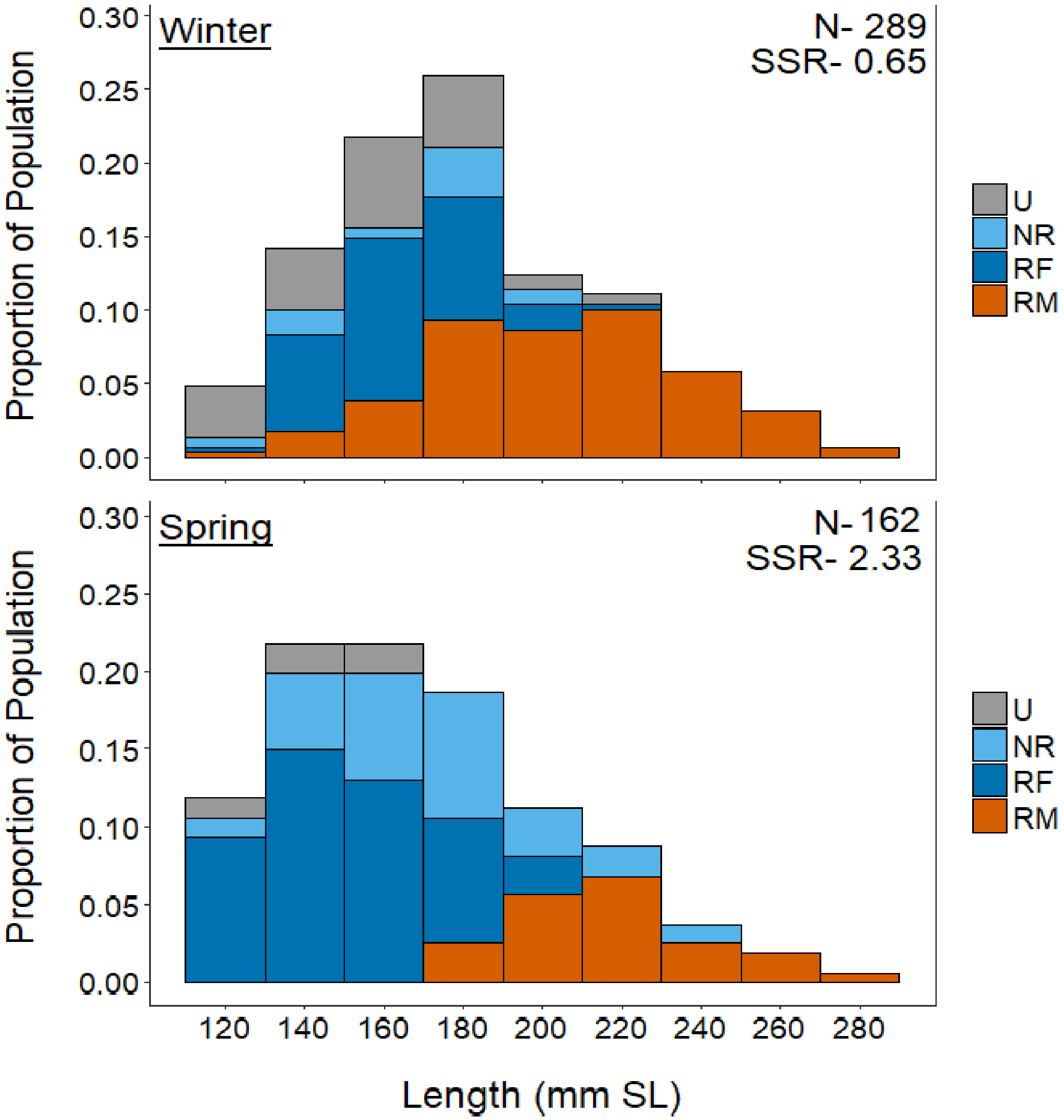


Figure 2.6: Demographic composition of Gulf Black Sea Bass *Centropristis striata melana* spawning populations during winter and spring spawning periods on shallow reefs in the NE Gulf of Mexico from 2015-2017. Significant changes in female to male spawning sex ratio (SSR) occurred between reproductive periods (Chi-square test, $P < 0.001$). Significant shifts in both reproductive female (RF) and reproductive male (RM) length distributions were also observed (RF: KS Test, $P < 0.001$; RM: KS Test, $P = 0.01$). Unknown (U) and non-reproductive (NR) individuals are displayed.

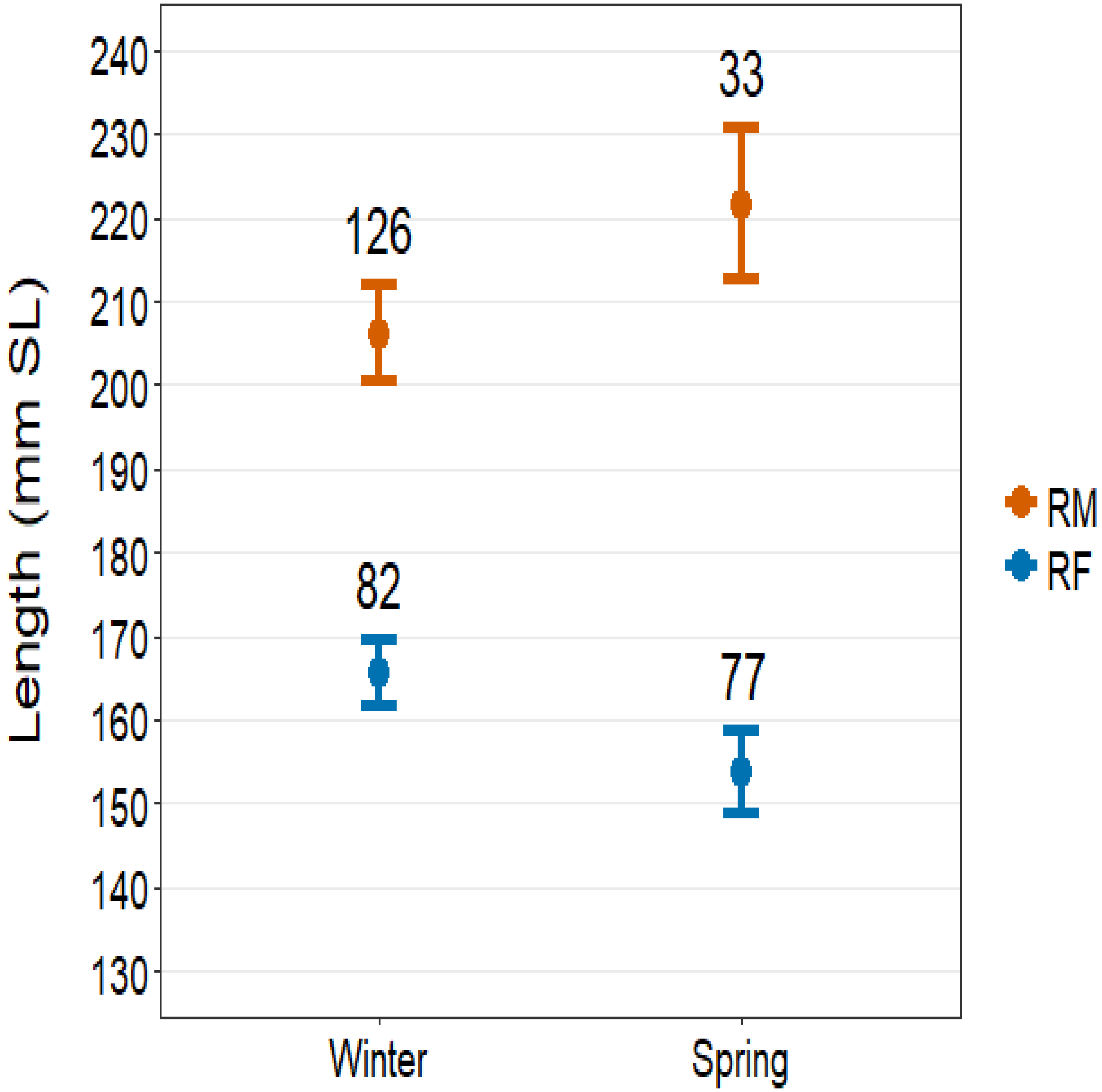
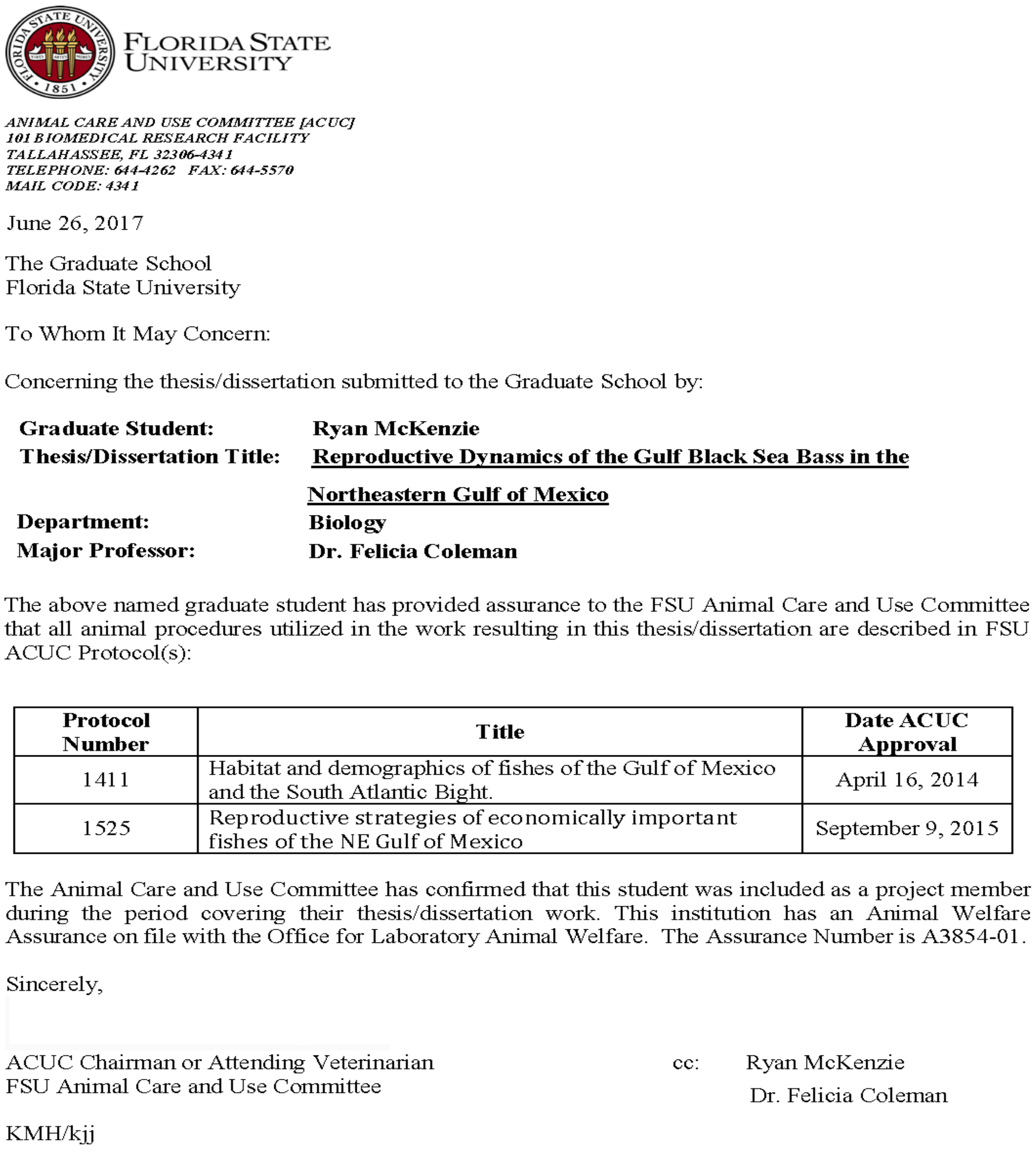


Figure 2.7: Gulf Black Sea Bass *Centropristis striata melana* mean and 95% confidence intervals of reproductive male (RM) and reproductive female (RF) standard lengths across spawning periods. Sample sizes are indicated with counts above confidence interval bars. Significant differences in average RM and RF lengths were observed between spawning periods (RM: LME, $P = 0.02$; RF: LME, $P = 0.002$).

APPENDIX A

IACUC APPROVAL



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June 26, 2017

The Graduate School
Florida State University

To Whom It May Concern:

Concerning the thesis/dissertation submitted to the Graduate School by:

Graduate Student: **Ryan McKenzie**
Thesis/Dissertation Title: **Reproductive Dynamics of the Gulf Black Sea Bass in the Northeastern Gulf of Mexico**
Department: **Biology**
Major Professor: **Dr. Felicia Coleman**

The above named graduate student has provided assurance to the FSU Animal Care and Use Committee that all animal procedures utilized in the work resulting in this thesis/dissertation are described in FSU ACUC Protocol(s):

Protocol Number	Title	Date ACUC Approval
1411	Habitat and demographics of fishes of the Gulf of Mexico and the South Atlantic Bight.	April 16, 2014
1525	Reproductive strategies of economically important fishes of the NE Gulf of Mexico	September 9, 2015

The Animal Care and Use Committee has confirmed that this student was included as a project member during the period covering their thesis/dissertation work. This institution has an Animal Welfare Assurance on file with the Office for Laboratory Animal Welfare. The Assurance Number is A3854-01.

Sincerely,

ACUC Chairman or Attending Veterinarian
FSU Animal Care and Use Committee

cc: Ryan McKenzie
Dr. Felicia Coleman

KMH/kjj

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BIOGRAPHICAL SKETCH

Education

Master of Science Degree, Biology GPA: 3.95 **August 2017**
Florida State University
Tallahassee, FL

Bachelor of Science Degree, Biology GPA: 3.44 **December 2011**
University of South Florida
Tampa, FL

Research Experience

Principal Investigator, Florida State University, 8/14-8/17. Developed and managed seasonal reef fish surveys. Constructed and maintained experimental aquaria used in reef fish behavioral studies. Developed public-outreach materials and participated in events promoting environmental awareness through the FSU Coastal and Marine Laboratory.
Skills Obtained: Small Boat Operations; Scientific Diving; Statistical Analysis using R Software: GLMM's.

Collection Manager, Florida State University Coastal and Marine Laboratory, 6/14-8/17. Digitized and managed the FSUCML zoological collection used in undergraduate biological courses and public outreach activities. Established a collaboration with Integrated Digitized Biocollections, increasing public access through an online web portal in order to promote research networking and public education.
Skills Obtained: Database development and management; Animal specimen identification and preservation.

Fisheries Biologist II, Florida Fish and Wildlife Commission, 12/13-5/14. Supervised research team tasked with conducting snorkeling nesting and simulated fishing surveys during a study investigating the effects of fishing on nesting Large Mouth Bass in the state of Florida. Assisted project leaders with data analysis, public outreach projects, and presentations to state fisheries research and management personnel.
Skills Obtained: Snorkeling surveys; Electro-fishing; Fish transportation and stocking; Pit tagging and anesthetization; Data management using Excel.

Principal Investigator, University of South Florida, 8/11-7/13. Led research development and investigation on the influence of placoid scales on the sensory perception in two species of sharks. Presented research findings at scientific conferences and completed project with a published article in the Journal of Fish Biology.
Skills Obtained: SEM Microscopy; Data Analysis using R software; Photo Analysis using Sigma Pro Plot Software.

Intern, Bimini Biological Field Station, 2/12-3/12. Assisted principal investigators with a variety of ongoing research projects on the physiology and behavioral ecology of Lemon sharks inhabiting Bimini, Bahamas.
Skills Obtained: Small Boat Operation; Active acoustic telemetry; Bathymetry mapping; Long-lining; Gill netting; Juvenile shark handling and tagging.

Professional Experience

*Lake Biologist***,** Lake Doctors Inc., 5/12-7/13. Conducted aquatic vegetation surveys. Developed and implemented nuisance and invasive aquatic vegetation management plans. Managed over $200,000 in annual treatment budgets for both private and public accounts.
Skills Obtained: Water testing and monitoring; Fish stocking; Aquatic vegetation identification and treatment; Hazardous chemical handling; Small boat operation.

Seasonal Biologist, The Florida Aquarium, 5/10-8/10. Managed feeding schedules, food preparation, and medical needs of exhibit animals. Conducted routine maintenance and improvements on aquatic life support systems. Supervised volunteers' activities and led public outreach educational activities.
Skills Obtained: Spectrometer water testing; Aquatic animal husbandry; Public speaking.

Teaching Experience

Biology Lab Instructor, Florida State University, 8/14- 8/17. Lead class discussion, supervised biological experiments, and facilitated learning to over 190 undergraduate students. Courses included lectures on a large array of topics including molecular biology, animal ecology, and evolution.

Camp Councilor, Saturday at the Sea Program, Florida State University, 2015. Led classroom discussions and activities during summer camp for middle school students. Curriculum was primarily based on marine science and conservation topics.

Publications

McKenzie, R. W., Motta, P. J. and Rohr, J. R. (2014) Comparative squamation of the lateral line canal pores in sharks. Journal of Fish Biology, 84: 1300–1311. doi: 10.1111/jfb.12353

Presentations

McKenzie, R.W. (2017) Thesis Defense. Reproductive Dynamics of the Gulf Black Sea Bass in the northeastern Gulf of Mexico. Florida State University. Tallahassee, FL.

McKenzie, R.W. (2017) Oral Lecture. Reproductive Dynamics of the Gulf Black Sea Bass. Florida State University Ecology and Evolution Seminar. Tallahassee, FL.

McKenzie, R.W. (2016) Poster session. The effects of relative body size and sex on the behavior and fishing susceptibility of the Gulf Black Sea Bass. Joint meeting of the American Society of Ichthyologists and Herpetologists and American Elasmobranch Society. New Orleans, LA.

McKenzie, R.W. and Coleman, F.C. **(**2016) Oral Lecture. Social dominance and fishing susceptibility of the Gulf Black Sea Bass. Ecological and Evolutionary Ethology of Fishes. Florida State University, Tallahassee, FL.

McKenzie, R.W., Coleman, F.C. and Koenig, C. C. **(**2016) Poster session. Seasonal population dynamics of the Gulf Black Sea Bass in the northeastern Gulf of Mexico. Ecological and Evolutionary Ethology of Fishes. Florida State University, Tallahassee, FL.

McKenzie, R.W. (2014) Poster session. A marriage of form and function, an investigation of morphological features which may play a role in shark sensory perception. Natural Sciences Graduate Symposium. Florida State University, Tallahassee, FL.

McKenzie, R.W. and Evans, T. (2014) Oral Lecture. Assessment of the impacts angling for nesting largemouth bass has on annual recruitment. Monthly Research Seminar. Florida Fish and Wildlife Research Institute, Eustis, Fl.

McKenzie, R.W. (2011) Oral Lecture. External Morphology of the Lateral line system in the shortfin mako, *Isurus oxyrinchus.* 2011 F.I.S.H. annual meetings. Florida Atlantic University, West Palm Beach, Fl.

Accomplishments and Awards

Southern Association of Marine Laboratories Travel Grant, 2017. Travel grand awarded to attend and present at the 2017 National AFS meeting in Tampa, FL.

Student Employee of the Year Nominee, 2016. Nominated for the student employee of the year award at the Florida State University.

PADI Foundation Grant, 2016. Grant awarded to fund thesis research on the behavioral ecology and fishing susceptibility of the Gulf Black Sea Bass.

Florida State University Coastal and Marine Lab Graduate Scholarship Recipient, 2015-2017. Scholarship given to Florida State University graduate students pursuing research at the marine laboratory.

Bright Futures Scholarship Recipient, 2006-2011. Scholarship given to Florida high-school students who achieve a 3.0 GPA, 1175 SAT Score, and over 75 hours of community service.

Service

Volunteer, Camp STEMTastic, Thomas University, 2015. Camp STEMTastic is a public-school program geared toward educating selected 7th grade students in the areas of science, technology, engineering and math. Assisted with field activities and presented a short video on deep water sharks followed by an interactive talk with museum specimens.

Volunteer, Levy County GEAR UP Program, FSUCML 2015. The Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP) is designed to provide extra training to low income middle and high school students to prepare them college. Assisted in field activities and taught students about fish identification and seagrass fish communities.

*Species Collection Volunteer***,** Florida Fish and Wildlife Research Institute, 2013-2014. Assist staff in museum tasks such as specimen fixation, preservation and maintenance per established protocols, data entry and report production, and taxonomic identification.

Volunteer, Tampa Bay Watch, 2013. Participated in public conservation projects such as oyster restoration and annual scallop surveys. Worked with other volunteers to coordinate efforts to restore Tampa Bay ecosystems.

*Volunteer***,** The Florida Aquarium, 2010. Assisted staff with feeding schedules, food preparation, and medical needs of exhibit animals.

Volunteer, Southeast Florida Archaeological Society. 2008. Mt. Elizabeth excavation project.

Professional Memberships

The American Fisheries Society
The American Society of Ichthyologists and Herpetologists

Meetings

2017	American Fisheries Society National Meeting. Tampa, FL.
2016	The American Society of Ichthyologist and Herpetologists. New Orleans, LA.
2016	Ecological and Evolutionary Ethology of Fishes. Tallahassee, FL
2015	“Fish at Night” Conference. Miami, FL
2015	Mote Symposium in Fisheries Ecology. Sarasota, FL.
2014	FSU Natural Sciences Graduate Symposium. Tallahassee, FL.
2014	Florida Chapter of the American Fisheries Society. Ocala, FL.
2014	Florida Fish and Wildlife Research Institute. St. Petersburg, FL.
2011	Florida Ichthyology Student Hominy. Florida Atlantic University. Jupiter, FL.