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Utilizing Accelerometer Telemetry Tags to Compare Red Snapper (Lutjanus campechanus) Behavior on Artificial and Natural Reefs

Ethan T. Getz
The University of Texas Rio Grande Valley

UTILIZING ACCELEROMETER TELEMETRY TAGS TO COMPARE RED SNAPPER

(*LUTJANUS CAMPECHANUS*) BEHAVIOR ON ARTIFICIAL

AND NATURAL REEFS

A Thesis

by

ETHAN T. GETZ

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ETHAN T. GETZ

COMMITTEE MEMBERS

Dr. Richard Kline
Chair of Committee

Dr. David Hicks
Committee Member

Dr. MD Saydur Rahman
Committee Member

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ABSTRACT

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Artificial reefs have been shown to support important reef fishes such as red snapper (*Lutjanus campechanus*), however, few studies have compared fish behavior on artificial and natural habitats. We examined activity levels and behavioral patterns of red snapper over natural reefs, oil platforms and submerged ships. Telemetry tags (Sonotronics model MTT) with tri-axial acceleration range, average depth, and average temperature were used to monitor fish. Fifty-five wild snapper were surgically implanted at depth and monitored for one year. Overall dynamic body acceleration (ODBA) as the sum of x, y and z acceleration range was used to estimate activity levels of red snapper at each reef. Acceleration and depth data indicated that time of day, depth, lunar cycle, and season influence red snapper behavior. Average ODBA was significantly higher over artificial than natural reefs ($p=0.03$) during May 2016 suggesting that red snapper behave differently on artificial habitats at specific times. This is likely due to the increased vertical relief provided by these structures.

DEDICATION

To my family and loved ones for supporting me and to my mentors for inspiring me.

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CHAPTER I

INTRODUCTION

Artificial Reefs

Artificial reef deployment is a common management tool to enhance marine habitats and fish stocks worldwide (Carr & Hixon 1997, Rilov & Benayahu 2000). The main goals of artificial reef deployment are: (1) enhance the production of reef-associated species, and (2) increase the efficacy of harvesting reef-associated species (Carr & Hixon 1997, Baine 2001). In the Western Gulf of Mexico (GOM), artificial reef deployment is increasing since the bottom substrate consists mainly of mud, silt and sand with sparse and diminishing natural reef patches (Campbell et al. 2011, Froehlich & Kline 2015). The first artificial habitats in the GOM were installed unintentionally when petroleum platforms were constructed after oil reserves were discovered offshore of Texas in 1947. Throughout the following decades, over 4,000 oil platforms were deployed in coastal waters of the GOM. In the past decade, the number of standing platforms has decreased and will likely continue to decrease as removals exceed new installations. This trend is noteworthy since platforms support fish densities 10-1,000 times greater than the surrounding mud-bottom habitats (Shipp & Bortone 2009).

In response to the increased abundance of marine life on artificial habitats, fisheries managers have now deployed artificial reefs in every gulf coast state for the purpose of fisheries enhancement. While Alabama boasts the most robust artificial reef program, with over 20,000 artificial structures deployed (Shipp & Bortone 2009, Topping & Szedlmayer 2011), Texas has also developed an extensive artificial reef program. The Texas Parks and Wildlife Department (TPWD) Artificial Reef Program (TARP) was established when the Texas legislature enacted the Artificial Reef Act of 1989. TARP currently monitors 66 permitted reef sites along the Texas coast covering an area of 3,440 acres. These sites are designated through the rigs-to-reef, ships-to-reef and near-shore reefing programs. Common materials used in these programs include decommissioned petroleum platforms, marine vessels and concrete culverts respectively (TPWD online, 2017). These structures are strategically placed in areas supporting limited marine life to provide hard substrate and vertical relief for encrusting organisms and reef fishes. Despite the popularity of artificial reef programs, their affect on marine fisheries overall, is still largely unknown (Streich et al. 2017).

Red Snapper

Red snapper (*Lutjanus campechanus)* are especially abundant on artificial reefs (Galloway et al. 2009). Red snapper have been observed over artificial reefs ever since they were introduced to the GOM and are often the most common species present (Topping & Szedlmayer 2011). This species is of particular interest to humans because they support one of the most valuable fisheries in the GOM (McCrawley & Cowan 2007, Hood et al. 2007).

Red snapper are generally found in coastal waters from Cape Hatteras, North Carolina to the Yucatan Peninsula of Mexico. They are large predatory reef fish commonly found along the continental shelf of the northern GOM (Patterson et al. 2001). Traditionally, red snapper throughout the GOM were considered members of a single stock, with low genetic diversity between populations. Recent studies have confirmed a considerable amount of genetic exchange between red snapper of different regions, but also suggest that distinct subpopulations may exist in areas with unique population demographics (Patterson 2007). Red snapper achieve a high degree of genetic exchange between populations because their planktonic larvae can be transported large distances before recruiting to an area (Patterson 2007).

Red snapper utilize different habitat types throughout their lives. Strong evidence has been reported suggesting that juvenile red snapper undergo ontogenic shifts from low to high-relief reefs as they age (Szedlmayer & Lee 2004, Wells 2007, Galloway et al. 2009). After settlement, juvenile red snapper seek low-relief hard bottom substrate such as relic oyster shell habitat. Once an area of suitable complexity and relief is found, juveniles show high site fidelity since these habitats provide the interstitial spaces small enough for them to escape predators (Workman et al. 2002, Gallaway et al. 2009). At two years of age (200-375 mm total length), red snapper are too large to find protection on low-relief reefs. Instead, they generally move to find reefs with higher relief (on the order of meters). These reefs include rock ledges, reef pinnacles, shelf-edge banks and artificial reefs such as shipwrecks (Gallaway et al. 2009). Red snapper associate with these structures from ages 2-7 for protection and food. However, site fidelity to a specific reef varies widely depending on the individual. While some adults have been shown to stay on a certain reef for months, others have been recorded moving hundreds of kilometers between habitats (Diamond et al. 2007, Patterson 2007, Gallaway et al. 2009).

Red Snapper Fishery

Although red snapper support significant recreational and commercial fisheries, the National Marine Fisheries Service did not develop a fisheries management plan for this species until 1981. The initial assessment determined that both commercial and recreational fisheries were in decline due to overfishing (Hood et al. 2007, Patterson 2007, Strelcheck & Hood 2007). Red snapper have since been intensively managed with mixed success. Fisheries managers are currently attempting to rebuild populations of red snapper by controlling the recreational and commercial fisheries, limiting bycatch in the shrimp trawl fishery and implementing programs to enhance the GOM stock. The current plan, created in 2004, seeks to rebuild the stock to maximum sustainable yield by 2032 (Hood et al. 2007, Strelcheck & Hood 2007).

To achieve this goal, federal managers have introduced targets for total allowable catch to curb fishing pressure in federal waters in both the recreational and commercial fisheries. Most states have implemented the federal regulations in their state waters with the only exceptions being Texas and Florida, who manage state water fisheries differently (Strelcheck & Hood 2007). Marine protected areas (MPAs) and stock enhancement strategies have also been suggested to strengthen the red snapper fishery (Ogle & Lotz 2006). The development of artificial reef programs around the GOM has prompted extensive research efforts to determine how significant these reefs are to fishes, and how valuable species like red snapper utilize the structures (Szedlmayer & Schroepfer 2005, Gallaway et al. 2009, Shipp & Bortone 2009).

Artificial Reef Use by Red Snapper

Much of the research on artificial reefs in the Gulf of Mexico has focused on red snapper since understanding their movements around and among artificial structures is crucial to the management of the species (Szedlmayer & Shipp 1994, McDonough & Cowan, 2007). In addition, these studies provide confirmation that red snapper are benefitting from the deployment of new artificial reefs (Piraino & Szedlmayer 2014). Due to the red snapper's affinity for these structures, artificial reefs have become significant fishing locations with the current red snapper fishery being heavily dependent on catches from artificial reefs (Gallaway et al. 2009). Shipp and Bortone (2009) have gone as far as to suggest that the red snapper fishery is not overfished, but that the main problem is habitat limitation. It may be the case that "unrealized harvest potential" can be corrected by constructing more artificial reefs that will increase snapper production and expand the snapper fishery (Shipp & Bortone 2009). To determine whether artificial reefs enhance red snapper production, efforts have been made to describe red snapper demographics, residency times, growth rates, and movement patterns on artificial reefs (Szedlmayer & Shipp 1994, Szedlmayer & Schroepfer 2005, Streich et al. 2017).

A large portion of the research directed at red snapper production on artificial reefs has focused on determining residency times of individual fish. These studies are essential because they determine whether or not red snapper use particular artificial reefs as a "home base" or an area that provides everything they need to survive (Szedlmayer & Schroepfer 2005, Piraino & Szedlmayer 2014). The majority of these studies have recorded wide varieties in residency time, but overall, mounting evidence suggests that many individuals will use a reef for long periods of time. For example, several studies have reported median residence times of over a year, with some fish inhabiting specific reefs for 595-958 d (Szedlmayer & Shipp 1994, Szedlmayer & Schroepfer 2005, Schroepfer & Szedlmayer 2006, Topping & Szedlmayer 2011). These results have prompted researchers to conclude that red snapper are either “stayers” or “movers” depending on the individual (Diamond et al. 2007).

Water temperature, time of day, and storm events have all been shown to affect red snapper movements on artificial reefs (Patterson et al. 2001, Szedlmayer & Schroepfer 2005, Topping & Szedlmayer 2011, Piraino & Szedlmayer 2014). Intense weather events such as hurricanes are thought to have a significant influence on red snapper by increasing the likelihood of movement between reefs (Patterson et al. 2001). Home range size has also been determined to change with the seasons. Red snapper exhibit significantly smaller home ranges during the winter when water temperatures cool (Piraino & Szedlmayer 2014). Diel movement patterns are less clear. Most researchers have reported greater movements at night, but some have recorded more activity during the day (Szedlmayer & Schroepfer 2005, Topping & Szedlmayer 2011, Piraino & Szedlmayer 2014).

Many have reasoned that red snapper living on artificial reefs must be able to find the required food and protection needed to survive if they are staying on the reefs for such long periods of time (Szedlmayer & Schroepfer 2005, Topping & Szedlmayer 2011). These ideas are reinforced by reports that have estimated faster growth rates, older age, and larger size in red snapper on artificial habitats (Nelson & Manooch 1982, Szedlmayer & Shipp 1994). Today, many experts acknowledge that artificial reef function varies between levels of attraction, to enhanced production (Carr & Hixon 1997, Love et al. 2006, Broughton, 2012). As a result, the main focus has become understanding the ecological performance of artificial reefs and comparing their functional role to natural reefs in order to incorporate any differences in management decisions (Streich 2016, Schwartzkopf et al. 2017).

Acoustic Telemetry and Accelerometers

Acoustic telemetry techniques, developed over the past 20 years, have been used to record continuous data from electronic tags attached to fish. These data have revealed information on fish behavior, migration, and habitat use in a variety of ecosystems (Thorstad et al. 2013). Acoustic transmitters function by continuously emitting high frequency acoustic pulses that can be recorded by a receiver up to a few kilometers away (Pincock & Johnston 2012). These tags can be equipped with a variety of different sensors to record pressure, depth, temperature, salinity and acceleration (Thorstad et al. 2013). New telemetry methods such as those that incorporate tri-axial accelerometers, promise novel ways to determine fish movements and energy budgets (Whitney et al. 2007, Wright et al. 2014).

Accelerometer tags are a useful technique for studying swimming speed, metabolic rate and energy expenditure of free-swimming fishes (Thorstad et al. 2013). Accelerometers can be attached to fish either externally or surgically implanted internally. They function by recording and logging body acceleration in units of gravity, g (9.8 m/ s^2) along one, two or three spatial axes (Thorstad et al. 2013). Tri-axial acceleration values can be summed across x, y, and z planes to provide an Overall Dynamic Body Acceleration (ODBA) estimate for the tagged fish given a specific time period (Gleiss et al. 2011, Silva et al. 2007, Wright et al. 2014).

Since tri-axial accelerometers are a relatively new technology, many studies to date have been restricted to laboratory trials of captive fish (Almeida et al. 2013). However, the most recent studies have overcome data transmission limitations to outline the utility of accelerometers for field observations of fish behavior patterns (Brown et al.

2013, Brownscombe et al. 2014, Murchie et al. 2015). Differences in ODBA can be coupled with behavioral observations to categorize specific behaviors such as bursting, prey capture and routine swimming (Whitney et al. 2007, Almeida et al. 2013, Murchie et al. 2015). Accelerometers can also be fitted with temperature and depth sensors, which can further describe movement patterns and habitat preference. In addition, temperature data can be coupled with ODBA to determine oxygen consumption (Wright et al. 2014). ODBA can also be scaled linearly with oxygen consumption in respirometry studies as a function of ambient temperature (Wright et al. 2014). From ODBA calculations, overall metabolic rates and energy budgets can be calculated to generate bioenergetics models for a certain fish species (Murchie et al. 2015). These methods are some of the only techniques for determining the cost of short-lived behaviors in fishes (Gleiss et al. 2011).

Study Objectives

Artificial reefs have the potential to enhance fish stocks and create complex marine habitat. However, the successful management of important species like red snapper depends on our ability to compare the ecological performance of fish on artificial reefs with those on natural reefs (Carr & Hixon 1997, Love 2006, Streich 2016, Schwartzkopf et al. 2017). The objective of this study was to determine red snapper behavioral and activity patterns on natural reefs and compare these observations to fish residing on artificial reefs in an effort to describe how natural and artificial habitat type influences red snapper behavior. To meet this goal, telemetry tags with tri-axial accelerometers, depth, and temperature sensors were developed and ground-truthed with observations on captive fish. Red snapper were then implanted with these tags in the field on three replicates each of the following habitat types: petroleum platform jackets (artificial), submerged ships (artificial) and reef patches (natural) in the GOM. The following hypotheses were tested to determine differences in red snapper activity based on reef type, depth use and body temperature:

1) Red snapper movement between reef sites will result in significant differences in habitat preference among reef types.
2) The average activity levels and frequency of high activity events of red snapper as recorded by Overall Dynamic Body Acceleration (ODBA) will be significantly different on each reef type.
3) Monthly depth use and body temperature of red snapper will have a significant impact on ODBA.

CHAPTER II

METHODS

Calibration and Captive Behavioral Experiments

Sonotronics tri-axial accelerometer tags (MTT-D-2 and MTT-T-2, Sonotronics Ltd., Tuscon, AZ.) were selected as the transmitters for this study and were specifically customized for red snapper based on results of captive and field-based trials. As a result of prior tag optimization experiments, data was recorded continuously and a 'ping' was transmitted every three minutes with the range of acceleration calculated on chip. Preliminary field trials on two red snapper were conducted to determine the scale of acceleration recorded by each tag. Results showed that the acceleration range was 0.003 *g* to 0.206 *g* over a three-month period along any one axis. Accelerometer detection range was therefore set to 8-bit or 0-0.398 *g* for any future fish. Data was transmitted in a 30 second string which relayed x, y and z-axis acceleration range telemetry values (8-bit or 0-0.398 *g*) to the receiver at 75 kHz. Telemetry values were converted to acceleration in *g* by multiplying the x, y, and z telemetry values by 0.00156, according to manufacturer specifications. In addition to acceleration range, half the accelerometer tags calculated average depth and the other half calculated average temperature during the three-minute recording interval. Each tag possessed a unique tag ID to identify fish and had a lifespan of three years after deployment.

Behavioral experiments on captive red snapper (n=3, 491 mm ± 22.4 [TL]) were conducted to determine distinct behaviors in wild fish based on ODBA. Using acceleration data and observations of captive fish, other studies such as Broell et al. (2013) and Brownscombe et al. (2014) have defined unique behaviors including resting, coasting, bursting and foraging in captive fishes. In order to define behavioral categories in red snapper, three individuals were captured from the wild and observed in large aquaria. After a two-week period of recovery, snapper were implanted with accelerometers in a similar manner to the wild fish outlined above. Another two-week period of recovery followed before data was collected. To decipher individual behaviors, fish were filmed using a GoPro camera during times of rest, normal activity and feeding. ODBA values calculated during observational periods were grouped into categories as patterns in swimming behavior emerged. The average ODBA range was calculated for each behavioral category and then compared using a one-way ANOVA with Scheffe post hoc testing to determine which behaviors reflected a significant difference ($p<0.05$) in acceleration from one another.

Study Area

Fifty-five red snapper were tagged at two reef area locations, 40 km northeast of South Padre Island, TX in the Gulf of Mexico (Figure 1). The Port Mansfield Liberty Ship Reef was chosen because it contained both oil platform jackets and ships adjacent to Big Seabree a large natural reef area with numerous patches and outcroppings at a similar depth (~33 m). A total of nine reef sites (three ships, three oil platform jackets, and three natural reef patches) were used in this study.

The Port Mansfield Liberty Ship Reef (PS-1070. 26° 25' 35.785" N 97° 01' 27.607" W) was created in 1975-1976 and is now managed by the Texas Parks and Wildlife Department. The reefing area contains two types of artificial structures including nine submerged oil platform jacket pieces as well as the hulls of three WWII liberty ships. Oil platform jackets had up to 15 m of vertical relief while ships did not exceed 8 m of vertical relief. Three oil platform jacket replicates and three ship replicates were chosen as tagging sites (Figure 2) based on size, vertical relief and proximity to other structures (minimum 130 m apart) so that telemetry data transmitted to receivers was only from tagged fish living on the intended structure.

The Big Seabree Natural Reef (26° 26' 59.8812" N 97° 0' 34.02" N) was comprised of natural reef patches with up to 4 m of vertical relief. Three replicate patches > 0.2 km apart were selected as tagging and receiver placement locations (Figure 3).

Fish Tagging

Adult red snapper, 432-660 mm total length (TL) (532 mm TL ± 57), were tagged between March 2016 and July 2016 at each of the nine reef sites (three ships, three oil platform jackets, and three natural reef patches). Initially, six red snapper were tagged at each site for a total of 54 fish implanted. However, one additional individual was tagged after an angler returned a transmitter early into the study. A sample size of six fish per reef site was chosen to provide a sufficient sample size for comparison of reef types and to limit the amount of data lost through tag collisions. Tags were implanted internally using surgical procedures similar to Starr et al. (2000). Surgeries were performed at a depth of 20 m using SCUBA in order to minimize the stress on fish due to barotrauma, thermal shock and mortality due to predation. A vertical long line outfitted with ten 11/0 circle hooks was used to catch snapper on each structure. Divers then descended down the long line, removed captured fish, and strapped them to a “v-shaped” surgery table suspended in the water column (Figure 4). The table was anchored to the bottom and suspended at 20 m with buoys to not only ensure the survival of the fish, but also allow divers ample time to complete multiple surgeries.

To implant the tag, a small (~15 mm) incision was made between the pelvic girdle and anus of the fish. The transmitter was then inserted into the peritoneal cavity and the incision closed with three Ethicon 2-0 absorbable monofilament sutures. As the fish completed a recovery period (~1 min), its total length was measured before it was released back to the reef. Typical implantation time was roughly 5 min per fish. The Institutional Animal Care and Use Committee at the University of Texas Rio Grande Valley approved the tagging procedure used for all snapper in captive and field portions of this study (2013-004-IACUC).

Long-Term Remote Monitoring

Underwater acoustic receivers were placed at each of the nine tagging sites (three ships, three oil platform jackets, and three natural reef patches) to record red snapper presence and telemetry. Sonotronics Submersible Ultrasonic Receivers (SURs, Sonotronics Ltd., Tuscon, AZ) were programmed to record data being transmitted from the fish at 75kHz. Before deployment, SURs were wrapped in duct tape and placed in a stocking to prevent decreased detections due to biofouling (Heupel et al. 2008). At each of the nine tagging sites, at least one SUR was deployed at ~25 m for 4-5 months before being retrieved to provide routine maintenance, replace batteries and offload telemetry data. SURs were deployed and recorded data from March 2016 to July 2017.

Range Tests

Previous studies using SURs in the GOM have determined the maximum detection range of these receivers to be 600 m. However, due to unpredictable acoustic conditions in the marine environment, a more conservative 300 m range has been assumed (Topping & Szedlmayer 2011). Range tests conducted similar to Topping & Szedlmayer (2011) at Big Seabree and the Port Mansfield Liberty Ship reef determined the maximum detection range in this area to be 142 m ± 35.4 in suboptimal acoustic conditions during the winter. Since the usefulness of range tests can be limited to due environmental variability (Binder et al. 2016), a more conservative detection range of 200 m at each of the nine study sites was assumed. No individual pings were recorded by more than one SUR at the same time throughout the study.

Data Analyses

Tag Returns

To estimate the number of red snapper caught by anglers throughout the study, a contact phone number with a reward was provided on each transmitter. Anglers that caught tagged snapper provided the tag ID number and an estimate of fishing mortality was calculated for each reef type. The fate of the remaining red snapper was estimated using detections from SURs. Fish detected within the final two weeks of the study (June 25- July 9, 2016) were determined to be "present" while all remaining fish were determined to have "emigrated."

Residency Time

The residency time of each fish was calculated for each reef type (oil platform jacket, ship and natural reef) as the average number of days an individual was detected on one of the nine tagging sites. By calculating residency this way, individuals with a strong preference for a particular reef type (>100 days resident) were apparent. While others have recorded residency as the number of days a fish is detected in an array (Schroepfer & Szedlmayer 2006, Topping & Szedlmayer 2011), here it was necessary to take the average residency on each reef type since not all sites had coverage from SURs for the length of the study. The relationship between total length and number of reef sites visited was tested by plotting the length of every snapper (N=55) against the number of reef sites it visited and tested for significance using Pearson's correlation test.

Overall Dynamic Body Acceleration

Acceleration telemetry values recorded from each fish were converted to acceleration (*g*) and used to calculate Overall Dynamic Body Acceleration (ODBA) by modifying the equation outlined by Wright et al. (2014). Since transmitters calculated the acceleration range, the following equation was used to calculate an ODBA range:

$$\text{ODBA} = R_x + R_y + R_z$$

where R_x, R_y, and R_z are the ranges of acceleration along each axis calculated during the three-minute recording interval.

Seasonal Trends

Seasonal changes in activity were analyzed by calculating the average ODBA for each fish during a given season (spring, summer, fall, winter). Only fish with > 20 ODBA samples were used ($N \geq 6$) for each season pooled across all reef types. The average ODBA for each season was calculated from all fish present during that time on all reef sites and then compared against other seasons for significance ($p<0.05$) using a one-way

ANOVA and post-hoc testing. Average ODBA, depth and temperature were also calculated for each month of the study using the average of fish with >20 detections per month. These data were used to reveal long-term trends in each variable throughout the study.

Artificial vs Natural Reefs

To compare red snapper activity by reef type, all fish with > 20 ODBA samples ($N \geq 3$ for each reef type) were sorted into ship, platform and natural reef groups before average ODBA was calculated for each month. Since significant differences between ships and platforms were not found, they were combined into an artificial reef group. In all further analyses, comparisons of reef type were therefore conducted with artificial and natural reefs as the two reef types. Average ODBA was calculated for all fish on a given reef type and compared across artificial and natural reefs each month for significance using a paired t-test. The same method was used to compare the percentage of behavioral categories across reef type, but only fish with > 50 detections ($N \geq 3$) were used to provide sufficient samples of each behavioral type.

Short-term Trends

Further investigation was warranted for fine-scale analyses in May and June since the largest differences in activity between natural and artificial reefs were found during this time. At least five fish from each reef type with > 20 ODBA samples were used to investigate the relationship between lunar cycle and depth, depth and activity, and time of day and activity.

Lunar Phase

Depth data were compared across lunar phase and tested for correlation with ODBA. To compare depth by lunar phase, the average depth use per day was calculated for fish on all reef types. Red snapper (N=7) with > 5 depth samples were pooled from all reef types and average depth was calculated for the three days surrounding each lunar phase (new moon, first quarter moon, full moon, last quarter moon, determined by United States Naval Observatory) These phases were then compared using a one-way ANOVA and Scheffe post-hoc testing for significance.

Depth/Activity Relationship

The relationship between red snapper depth use and activity was investigated separately for fish on natural reefs and artificial reefs (fish from ships and platforms combined). Average depth use of all fish per day on a given reef type was plotted against the percentage of high activity pings per day and tested for significance using Pearson's correlation test. This test was repeated for fish residing on artificial reefs and natural reefs.

Night vs Day

Differences in ODBA between night and day (defined using NOAA sunrise and sunset times for the area) were investigated by calculating the average ODBA for each fish with > 20 detections during May and June 2016. Fish were sorted into natural or artificial reef (ships and platforms combined) groups with at least seven fish in each group. Average ODBA was compared using paired t-tests by night and day across both reef types.

CHAPTER III

RESULTS

Calibration and Captive Behavioral Experiments

As a result of the captive behavioral activity trials, observations from captive red snapper were binned into three significantly different behavioral categories: routine swimming, active swimming, and burst swimming ($p<0.01$, Figure 8). Burst swimming (0.878 g ± 0.053) was observed eight times, each time when a snapper had detected food and quickly accelerated to consume it. Active swimming (0.341 g ± 0.011) was observed 41 times and was the result of a snapper searching for food. This behavior occurred at lower accelerations and was differentiated from burst swimming by a lack of clear direction towards a target. Routine swimming (0.176 g ± 0.003) was the most common behavior with 630 observations. This behavioral category occurred when snapper were hovering and was differentiated from active swimming by a lack of directed movement. Once defined, these three categories were then used to compare behaviors of snapper on artificial and natural reefs. Bins for each behavioral category were created using the average ODBA value for each behavior. The percentage of each behavior was calculated per month across artificial and natural reefs.

Tagging and Monitoring

All 55 red snapper tagged at depth were returned to the reef alive and were detected for at least three days afterward. The first SUR was deployed in March 16, 2016 and the last was retrieved on July 9, 2017. Due to inclement weather and poor visibility during the winter, not all SURs were recovered in time to replace their batteries every five months. In addition, two SURs were never relocated and one was stripped from its mooring line and lost. Heavy fishing activity from illegal long-line fishing is a probable cause of the missing SURs as long-lines were found wrapped around many of the SURs that were retrieved. Despite not having continuous datasets from all nine tagging sites, ample overlap in coverage allowed for comparisons between reef types (ships, oil platform jackets, natural reefs) from March 2016-August 2016 (Figure 5).

Tagged red snapper ranged in size from 432-660 mm TL (mean= 532 mm TL, SD= 57) making them susceptible to capture by recreational and commercial anglers. The fate of every snapper was determined after the last SUR was retrieved in July 2017 (Table 1). Throughout the study, high fishing pressure was observed on all reef types with 14 tags (25%) being returned by anglers. Only 7 individuals (13%) were detected and deemed to be present during the final week of the study. The fate of the remaining 34 fish (62%) was unknown. While it is likely that many of these fish simply emigrated from the area, it is likely that anglers did not return the tags from all captured fish.

Long-term monitoring data showed that red snapper displayed a high degree of movement between reef sites throughout the study. The mean number of reefs visited by and individual was 2.9 ± 0.2 with one individual visiting seven of the nine reef sites. While most fish moved freely between reef sites and types, seven individuals (13%) showed a strong preference for certain reefs by each spending over 100 days on one of the three reef types (Table 2). Size was a significant predictor of movement as total length was positively correlated with the number of reef sites visited by an individual (Pearson correlation test, r=0.32, p=0.02)

Long-term Activity and Behavior Trends

Analysis of long-term activity patterns in red snapper on all reef types determined that average ODBA (Mean ± SE) was significantly higher during the summer (N=24, 0.211 *g* ± 0.003, $p<0.05$) than all other seasons (Figure 6). ODBA was lowest during the winter (N= 11, 0.174 *g* ± 0.003), but not significantly different from fall (N=12) or spring (N=6) ($p>0.05$). Several long-term trends also emerged when examining depth, temperature and ODBA data by month throughout the study. In both 2016 and 2017, ODBA peaked in the spring with the highest average values being recorded in May 2016 (0.217 *g* ± 0.003) and April 2017 (0.222 *g* ± 0.003). When comparing the timing of these activity peaks to body temperature data, they coincided with temperatures warming to ~23.3°C in both May 2016 (23.3°C ± 0.5) and April 2017 (23.6 °C ± 0.1). Average depth use also decreased during the same months both years (21.1 m ± 0.9 May 2016, 18.3 m ± 1.7 April 2017). However, average depth use and temperature both peaked during September 2016 (depth: 26.7 m ± 0.3, temperature: 29.3 °C ± 0.5, Figure 7).

Artificial and Natural Reef Comparisons

Since several SURs were lost or were not recovered for more than 5 months, resulting in gaps in telemetry data collected, comparisons of ODBA between ships and platforms were only made from March – June 2016. During this time, no significant differences in average ODBA were found between fish on ships ($N \geq 4$) and platforms ($N \geq 4$) for any month ($p > 0.25$). Since significant differences between ships and platforms were not found, they were combined into an artificial reef group. All comparisons of reef type were made between artificial and natural reefs between March 2016 and August 2016. During this 6-month period, at least three and up to ten red snapper per month were routinely detected from each reef type.

No significant differences in average ODBA were detected between fish on natural and artificial reefs for five of the six months, but fish on artificial reefs had a higher average ODBA for every month except March 2016. May 2016 was the only month where red snapper displayed a significantly higher average ODBA on artificial reefs than natural reefs (Artificial (N=8): 0.232 *g* ± 0.007, Natural (N=7): 0.200 *g* ± 0.010, p=0.03, Figure 9). A similar result was observed in June 2016, but the difference in average ODBA between natural and artificial was narrowly insignificant (Artificial (N=10): 0.217 *g* ± 0.007, Natural (N=6): 0.186 *g* ± 0.014, p=0.08). Comparisons of behavioral categories were made every month from March- July 2016. Similar to average ODBA, fish residing on artificial reefs exhibited more high activity events (>0.341 *g*) than those on natural reefs during four of the five months (excluding April 2016). The only month where the percentage of high activity events was significantly higher on artificial reefs than natural reefs was during May 2016 (Artificial (N=6): 7.59 % ± 1.07, Natural (N=6): 3.98 % ± 1.03, p=0.02, Figure 10).

Short-term Activity and Behavior Trends

May and June 2016 were used for short-term analyses since the largest differences in activity between natural and artificial reefs were found during this time. Analyses of short-term behavioral patterns revealed that depth, time of day and lunar cycle had an impact on red snapper. A significant negative correlation (Pearson correlation test, r=-

0.22 $p=0.02$) between average depth per day and percentage of high activity detections per day was observed on artificial reefs (both ships and platforms) with fish becoming increasingly active as they went shallower (Figure 11). However, this trend was not observed in red snapper inhabiting natural reefs during the same time period ($r=0.21$, $p=0.11$, Figure 12). Time of day also influenced activity, with average ODBA being significantly higher at night than during the day on both artificial and natural reefs during May and June 2016 (artificial ($N=9$): $p<0.01$, natural ($N=7$): $p=0.04$, Figure 13). While average ODBA was higher in fish on artificial reefs than natural reefs during both night and day, these differences were only significant at night (day: $p=0.36$, night: $p<0.01$).

Lunar phase significantly influenced red snapper depth use on all reef types during June 2016. During the new moon phase, fish ($N=7$) were significantly shallower than during any other moon phase ($p<0.01$, Figure 14). In addition, fish were significantly deeper during the full moon phase then at any other time ($p<0.01$). While this trend was strongly observed during June 2016, the influence of moon phase on depth use was not significant during April, May and July 2016 ($p > 0.05$).

CHAPTER IV

DISCUSSION

To our knowledge, this study was the first to use overall dynamic body acceleration (ODBA), calculated with accelerometers, to compare red snapper activities on both artificial and natural reefs. Telemetry methods developed with captive fish were used to determine that red snapper residing on artificial reefs behaved similarly to those living on natural reefs with several exceptions. ODBA data from fish on natural and artificial reefs provided insight into how fish behaved on each reef type. Spawning activity or increased feeding could explain why late spring/early summer appeared to be a significant time for snapper residing on artificial reefs with higher activity rates observed in May and, to a lesser extent, June 2016 (Adams et al. 1982, Galloway et al. 2009, Schwartzkopf et al. 2017). Moreover, results of the behavioral category analysis showed that there was a greater percentage of high activity behavior on artificial reefs during this time.

Collectively, these results suggest that red snapper on artificial reefs exhibit increased average activity and more frequent high activity behaviors than fish on Big Sea Bree Reef, an adjacent natural reef. In addition, no differences in activity were detected between fish living on ships and oil platform jackets. While oil platform jackets are more complex than the stripped hulls of ships, both are very large structures with greater vertical relief than typical natural reefs in the GOM (Patterson et al. 2001, Cowan et al. 2011). Vertical relief may be an important aspect of preferred habitat for red snapper since other *Lutjanid* species have been known to aggregate on reef promontories to spawn (Carter & Perrine 1994, Heyman et al. 2005).

Further insights into the high activity late spring/early summer period were provided by depth, temperature, and short-term ODBA analyses. Average depth was negatively correlated with frequency of high activity events during May and June 2016 for red snapper on artificial reefs. These results suggest that red snapper moved shallower when taking part in high activity behaviors and are consistent with reports that red snapper on artificial reefs feed up in the water column (Schwartzkopf et al. 2017). When comparing activity by night and day, a more precise estimate of the timing of high activity events on artificial reefs was discerned. Fish on both natural and artificial reefs were more active at night but, the activity of fish on artificial reefs was significantly higher than those on natural reefs only during the night. These results indicate that the specific high activity behaviors of interest on artificial reefs occurred at night in relatively shallow water. These results are consistent with Hamner et al. (1988) who stated that reef fish feeding in the water column form a "wall of mouths" above the reef. Long-term body temperature data provided some insight into the timing of this event. The increased activity observed in May 2016 corresponded with an increase in average body temperature to ~23.3 °C A similar trend was observed in 2017, with peak activity occurring in April when body temperature warmed to ~23.3°C. Based on these results, several hypotheses could explain the high activity event that occurred on artificial reefs during May/June 2016 such as spawning, feeding, or physical competition.

Spawning activity, increased competition or increased pre-spawn feeding could explain higher activity rates on artificial reefs during late spring/early summer (Lindberg et al. 2006, Topping & Szedlmayer 2011). Red snapper spawn in the northern Gulf of Mexico between April and September with peak spawning occurring in June-August (Galloway et al. 2009). It may be the case that the increased activity on artificial reefs was due to the first major pulse of spawning activity. Spawning induced movement has been previously recorded in other fishes (Lucas 1992, Zeller 1998, Bolden 1998). While spawning activity could be a possibility, the diel timing of high activity behaviors presented here contradicts the timing of spawning in other studies. Here, we report higher activity at night, while Jackson et al. (2006) report peak spawning near 1600 hours. However, Jackson et al. (2006) conducted their study further north in coastal Louisiana and only collected samples later in the season during July and August.

If not spawning, the increased activity could have been due to increased feeding prior to spawning. Other fish species have been shown to increase feeding prior to spawning when water temperatures warm in spring and early summer (Adams et al. 1982). Increased feeding before peak-spawning season in July and August could be the cause of high activity rates in late spring/early summer. Red snapper may be taking advantage of a more abundant food source found over artificial reefs, but not natural reefs. Schwartzkopf et al. (2017) found that red snapper on natural reefs fed on and above the reef whereas, snapper on artificial reefs fed on the surrounding seafloor and up in the water column. Moreover, they reported little overlap in diet between snapper on natural and artificial reefs (Schwartzkopf et al. 2017). Ouzts & Szedlmayer (2003) found that the diet of red snapper on artificial reefs shifts between day and night. If red snapper predated heavily on a pelagic prey species at night, it would explain the increased activity at night and the negative correlation between depth and activity.

While increased feeding activity is most likely, increased intra- or interspecific competition could also cause the increased activity observed in red snapper on artificial reefs. Some research suggests that the configuration of certain artificial reefs creates competition in gregarious species like red snapper (Lindberg et al. 2006, Cowan et al. 2011). Red snapper may have been competing with one another or other species for a possible food source only concentrated on artificial reefs during this time.

Red snapper were more active on artificial reefs than natural reefs for a short time but, activity levels were similar on both reef types most of the time from March-August 2016. Habitat selection of red snapper throughout the study reinforces the idea that red snapper behave similarly on artificial and natural reefs for most of the year. Habitat preferences were not evident as most red snapper commonly moved between reef sites throughout the year. Only seven individuals (13%) showed a strong preference for certain reefs by spending over 100 days at a particular site. These individuals were found on all reef types; natural reefs, ships, and oil platform jackets. Most of the remaining individuals visited multiple reef sites throughout the study. Combined, these results align closely with those who have concluded that individual red snapper are either “movers” or “stayers” (Szedlmayer & Shipp 1994, Szedlmayer & Schroepfer 2005, Schroepfer & Szedlmayer 2006, Diamond et al. 2007, Topping & Szedlmayer 2011). In this case, red snapper showed a wide variety of residency times (1-178 days) regardless of which habitat type they were living on. In addition, they were not drawn to particular reef types or even specific sites.

One of the main concerns about artificial reef deployment is that mortality rates can be higher due to increased fishing pressure (Galloway et al. 2009). Fishing mortality was relatively high in this study with 14 tags (25%) returned by anglers in just 14 months. However, fish were caught from all reef types; six from natural reefs, three from oil jacket platforms, and five from submerged ships. These results suggest that red snapper are being targeted just as heavily on natural reefs as they are on artificial reefs. In this case, it is likely that the artificial reefs are actually diluting fishing pressure that would otherwise be directed solely on natural reefs (Streich 2016). Size was positively correlated with the number of reef sites visited suggesting, as others have found, that larger red snapper make more wide-ranging movements (Galloway et al. 2009). These fish are therefore likely to experience fishing pressure regardless of where they move. It is also interesting to note that much of the fishing pressure during this study came from recreational anglers harvesting snapper out of season and from illegal long-line fishing.

Activity patterns observed here coupled with tag returns from anglers add to the mounting evidence that artificial reefs aid red snapper production rather than simply attracting them to areas where they are easily caught (Galloway et al. 2009). Since activity and movement patterns were similar on artificial reefs and natural reefs most of the time, red snapper were most likely deriving the same benefits living on artificial reefs as they would on natural reefs. In late spring/early summer, red snapper were more active on artificial reefs, but this is more likely due to increased feeding or spawning than competition. While the large difference in area between Big Seabree and the smaller artificial structures makes this comparison difficult, if spawning or increased foraging activity is the case, red snapper production may actually be greater on artificial reefs in this case.

While the primary goal of this study was to compare red snapper behavior on natural and artificial reefs, some patterns can be generalized for all reef types. For instance, the activity of red snapper on all reef types peaked in summer. This was expected since metabolism increases with temperature in poikilotherms. While others have also found that temperature influences movement on a seasonal scale (Piraino & Szedlmayer 2014), temperature did not predict activity on a monthly scale in this study. The highest body temperatures throughout the study were recorded in September and October 2016 (September: 29.3 °C ± 0.5, October: 28.7 °C ± 0.4) at a time when activity was steadily decreasing (September: 0.193 *g* ± 0.019, October: 0.174 *g* ± 0.016). In addition, activity peaked in late spring/early summer when temperature was increasing. Instead of a direct correlation between temperature and activity, monthly peaks in activity corresponded with temperatures of roughly 23.3 °C. While further investigation is required, these results suggest that ~23.3 °F may be the thermal optimum for red snapper in the northern GOM.

Evidence presented here also suggests that the lunar cycle may have an influence on red snapper behavior. During the month of June 2016, depth data revealed that red snapper moved significantly shallower during the new moon phase and significantly deeper during the full moon phase. While Jackson et al. (2006) found no evidence of the lunar cycle influencing red snapper spawning, differences in depth based on lunar cycle could have been attributed to foraging behavior. Lowry et al. (2007) found that lunar phase influenced the feeding behavior of several marine gamefish with many species feeding heavily during the new moon. Unfortunately, insufficient ODBA detections were recorded during the June 2016 lunar phases to compare the activity rates of red snapper during each phase. However, foraging behavior driven by the lunar cycle could explain the changes in depth reported here and should be the focus of future efforts on the topic.

Developing tri-axial accelerometers to record data more efficiently could enhance our ability to compare red snapper behaviors. Low visibility, currents, and significant environmental sound make the northern GOM a difficult location to design a telemetry study. In addition, tradeoffs between sample size and tag collisions needed to be considered. Accelerometers used here transmitted a ping every three minutes to lower the probability of tag collisions with other fish. However, six red snapper were tagged at each site to provide a large enough sample size for comparison. Each tag had a transmission time of 30 seconds resulting in common tag collisions. Despite these obstacles, important comparisons of red snapper on artificial reefs and natural reefs were made. Although the sample size was small for some comparisons (N = 3), tagged red snapper likely exhibited behaviors representative of other fish present on each reef. Red snapper are a highly gregarious species and typically shoals of fish display similar behavioral patterns (Cowan et al. 2011). While a larger sample size could have benefitted some comparisons reported here, it is likely that the tagged fish accurately represented the behaviors of all fish present on the reef.

While tri-axial accelerometers proved to be a useful tool, improvements can still made to increase recording efficiency. Tags used in this study transmitted acceleration range along the x, y, and z-axes. In preliminary studies, measuring the acceleration range proved to be more useful than the average acceleration, since bursts of high activity were far more apparent. However, transmitting the x, y, and z-axes separately led to many interrupted data strings in the field. In many cases, ODBA calculations could not be made because one or two of the acceleration axes were not detected for a given time interval. In the present study, the tag pulse train lasted 30 seconds and transmitted ID, x, x, z acceleration range, and depth or temperature data. In the future, if ODBA were calculated on-chip the pulse train would be reduced to 15 seconds. A much larger amount of ODBA data could have been collected using the same type of tag had ODBA been calculated on chip and transmitted as a single range instead of each axis calculated separately. Future efforts should consider this option unless each individual axis is required and field applications using accelerometers should carefully consider the tradeoff between sample size and tag collisions. By using the acceleration range to calculate ODBA, several behavioral categories such as burst and active swimming were also defined for red snapper. These experiments were largely preliminary leaving sufficient room to expand in this area with red snapper and other fishes.

Conclusion

In the context of artificial reef management, this study demonstrates how new technologies such as accelerometers can be used to determine the effectiveness of artificial reefs in providing suitable habitat for marine life. Red snapper exhibited similar behavior on artificial and natural reefs throughout most of the study period. The key exception was a pulse of higher activity observed on artificial reefs in late spring/early summer, which was most likely due to increased foraging activity prior to spawning. These results, combined with low habitat preference and similar fishing pressure on all reef types, suggests that artificial reef deployment is a viable management tool to enhance the red snapper stock in the GOM.

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TABLES

Table 1. Summary of every fish that was implanted with an accelerometer throughout the study. Tagging occurred between March-August 2016 at nine reef sites.

Tag ID#	Site Tagged	Date Tagged	Fate	Length (mm)
62	Big Seabree 1	3/29/16	Emigrated	584
70	Big Seabree 1	3/29/16	Caught	660
94	Big Seabree 1	3/29/16	Emigrated	533
102	Big Seabree 1	3/29/16	Emigrated	610
126	Big Seabree 1	3/29/16	Caught	559
142	Big Seabree 1	3/29/16	Emigrated	508
54	Big Seabree 2	4/8/16	Emigrated	610
70_2	Big Seabree 2	6/22/16	Emigrated	483
90	Big Seabree 2	4/8/16	Emigrated	508
158	Big Seabree 2	6/22/16	Emigrated	533
190	Big Seabree 2	6/22/16	Present	559
238	Big Seabree 2	6/22/16	Emigrated	457
6	Big Seabree 3	7/13/16	Caught	457
182	Big Seabree 3	7/13/16	Present	483
202	Big Seabree 3	7/13/16	Present	483
206	Big Seabree 3	7/13/16	Emigrated	432
210	Big Seabree 3	7/13/16	Caught	457
250	Big Seabree 3	7/13/16	Caught	457
50	Lib Plat 1	6/22/16	Emigrated	584
58	Lib Plat 1	4/8/16	Emigrated	660
122	Lib Plat 1	4/8/16	Emigrated	610
166	Lib Plat 1	6/22/16	Present	533
170	Lib Plat 1	6/22/16	Present	533
218	Lib Plat 1	6/22/16	Emigrated	533
78	Lib Plat 2	3/16/16	Emigrated	483
106	Lib Plat 2	3/16/16	Caught	559
110	Lib Plat 2	3/16/16	Emigrated	559
114	Lib Plat 2	3/16/16	Emigrated	559
130	Lib Plat 2	3/16/16	Emigrated	610
134	Lib Plat 2	3/16/16	Emigrated	559
2	Lib Plat 3	7/29/16	Emigrated	559
14	Lib Plat 3	7/29/16	Caught	508
66	Lib Plat 3	7/29/16	Emigrated	533
154	Lib Plat 3	7/29/16	Caught	584
162	Lib Plat 3	7/29/16	Emigrated	584
174	Lib Plat 3	7/29/16	Emigrated	533
10	Lib Ship C	8/4/16	Emigrated	457
150	Lib Ship C	8/4/16	Present	457
178	Lib Ship C	8/4/16	Emigrated	483
186	Lib Ship C	8/4/16	Caught	483
226	Lib Ship C	8/4/16	Caught	533
234	Lib Ship C	8/4/16	Emigrated	432
86_2	Lib Ship E	8/4/16	Emigrated	533
194	Lib Ship E	8/4/16	Emigrated	660
198	Lib Ship E	8/4/16	Emigrated	483
214	Lib Ship E	8/4/16	Caught	508
222	Lib Ship E	8/4/16	Emigrated	483
230	Lib Ship E	8/4/16	Present	559
242	Lib Ship E	8/4/16	Emigrated	508
74	Lib Ship W	3/26/16	Emigrated	483
82	Lib Ship W	3/28/16	Emigrated	559
86	Lib Ship W	3/26/16	Caught	483
98	Lib Ship W	3/28/16	Emigrated	559
118	Lib Ship W	3/28/16	Caught	584
138	Lib Ship W	3/26/16	Emigrated	559
			Average:	532.0
			SD:	57.1

Table 2. Summary of red snapper movements between reef sites and the average number of days they stayed at each reef type (natural reef, submerged ship, oil platform jacket).

Tag ID#	Site Tagged	Number of Reefs Visited	Average Residency on Natural Reefs (days)	Average Residency on Ships (days)	Average Residency on Petroleum Platforms (days)
62	Big Seabree 1	3	58.0		
70	Big Seabree 1	1	36.0		
94	Big Seabree 1	2	49.5		
102	Big Seabree 1	3	54.0		
126	Big Seabree 1	3	67.7		
142	Big Seabree 1	1	1.0		
54	Big Seabree 2	7	23.0	6.0	36.0
70_2	Big Seabree 2	2	25.0		
90	Big Seabree 2	1	45.0		
158	Big Seabree 2	1	6.0		
190	Big Seabree 2	2	5.0		
238	Big Seabree 2	1	82.0		
6	Big Seabree 3	1	102.0		
182	Big Seabree 3	1	18.0		
202	Big Seabree 3	3	140.0	1.0	
206	Big Seabree 3	1	32.0		
210	Big Seabree 3	1	61.0		
250	Big Seabree 3	1	75.0		
50	Lib Plat 1	3		1.0	2.0
58	Lib Plat 1	3		6.0	59.0
122	Lib Plat 1	6		156.3	10.7
166	Lib Plat 1	2		2.0	14.0
170	Lib Plat 1	6	3.0	33.7	57.0
218	Lib Plat 1	2		55.0	1.0
78	Lib Plat 2	1			15.0
106	Lib Plat 2	2		2.0	65.0
110	Lib Plat 2	1			9.0
114	Lib Plat 2	2			56.0
130	Lib Plat 2	2		1.0	23.0
134	Lib Plat 2	6		8.0	102.0
2	Lib Plat 3	4		14.0	30.0
14	Lib Plat 3	4		29.5	88.0
66	Lib Plat 3	5		9.0	51.0
154	Lib Plat 3	4		43.5	64.0
162	Lib Plat 3	4		22.0	47.5
174	Lib Plat 3	4		178.5	13.0
10	Lib Ship C	2		21.0	
150	Lib Ship C	6		149.3	2.3
178	Lib Ship C	2		36.0	
186	Lib Ship C	6		139.7	7.7
226	Lib Ship C	6		40.3	13.7
234	Lib Ship C	2		41.0	
86_2	Lib Ship E	5		23.0	
194	Lib Ship E	5		56.3	19.0
198	Lib Ship E	4		39.0	26.0
214	Lib Ship E	5		44.7	13.0
222	Lib Ship E	1		5.0	
230	Lib Ship E	5		26.3	41.5
242	Lib Ship E	1		10.0	
74	Lib Ship W	1		10.0	
82	Lib Ship W	1		6.0	
86	Lib Ship W	1		72.7	9.0
98	Lib Ship W	3		26.5	
118	Lib Ship W	2		48.0	
138	Lib Ship W	5		19.3	76.5
	Average:	2.9	46.5	38.4	34.0
	SD:	1.8	36.7	46.2	28.2

FIGURES

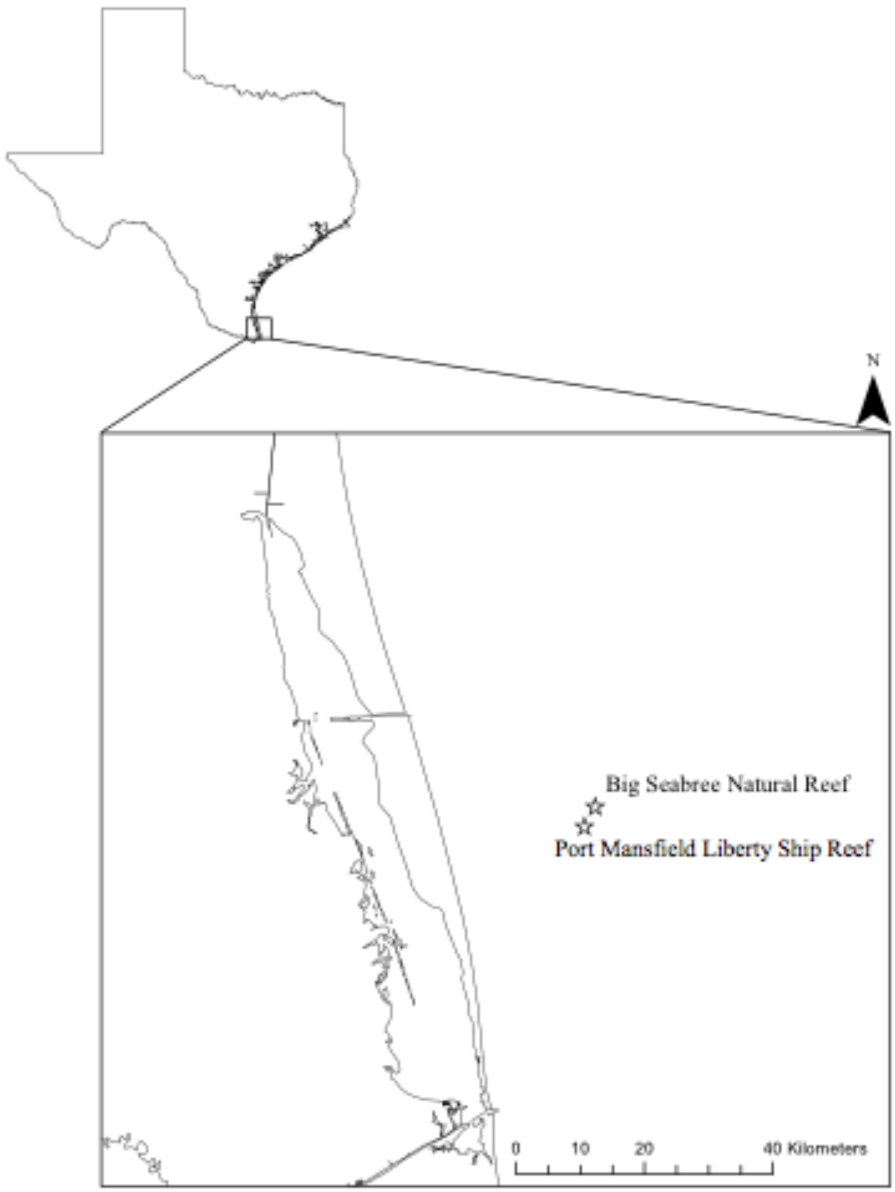
N
Big Seabree Natural Reef
Port Mansfield Liberty Ship Reef
0 10 20 40 Kilometers

Figure 1. Location of tagging sites at the Big Seabree natural reef and Port Mansfield Liberty Ship artificial reef off the coast of South Padre Island, Texas. Map adapted from the Texas Parks and Wildlife Department Artificial Reef Program interactive reef map.

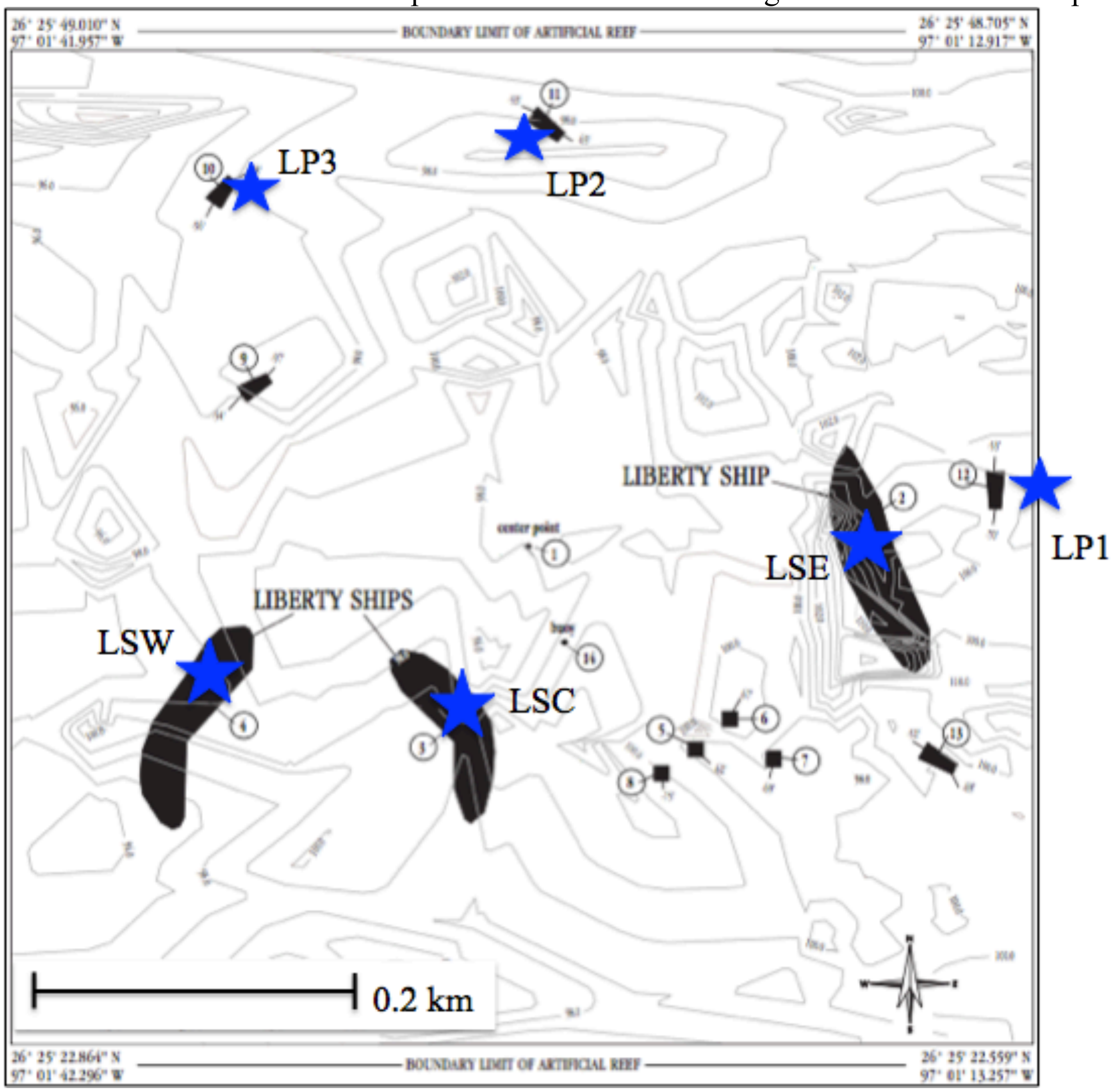

Figure 2. Map of artificial structures deployed within the Port Mansfield Liberty Ship Reef. Red snapper were tagged at three petroleum platform jackets (LP1, LP2, LP3) and three submerged liberty ships (LSW, LSC, LSE) indicated by blue stars. Map adapted from the Texas Parks and Wildlife Port Mansfield Liberty Ship map.

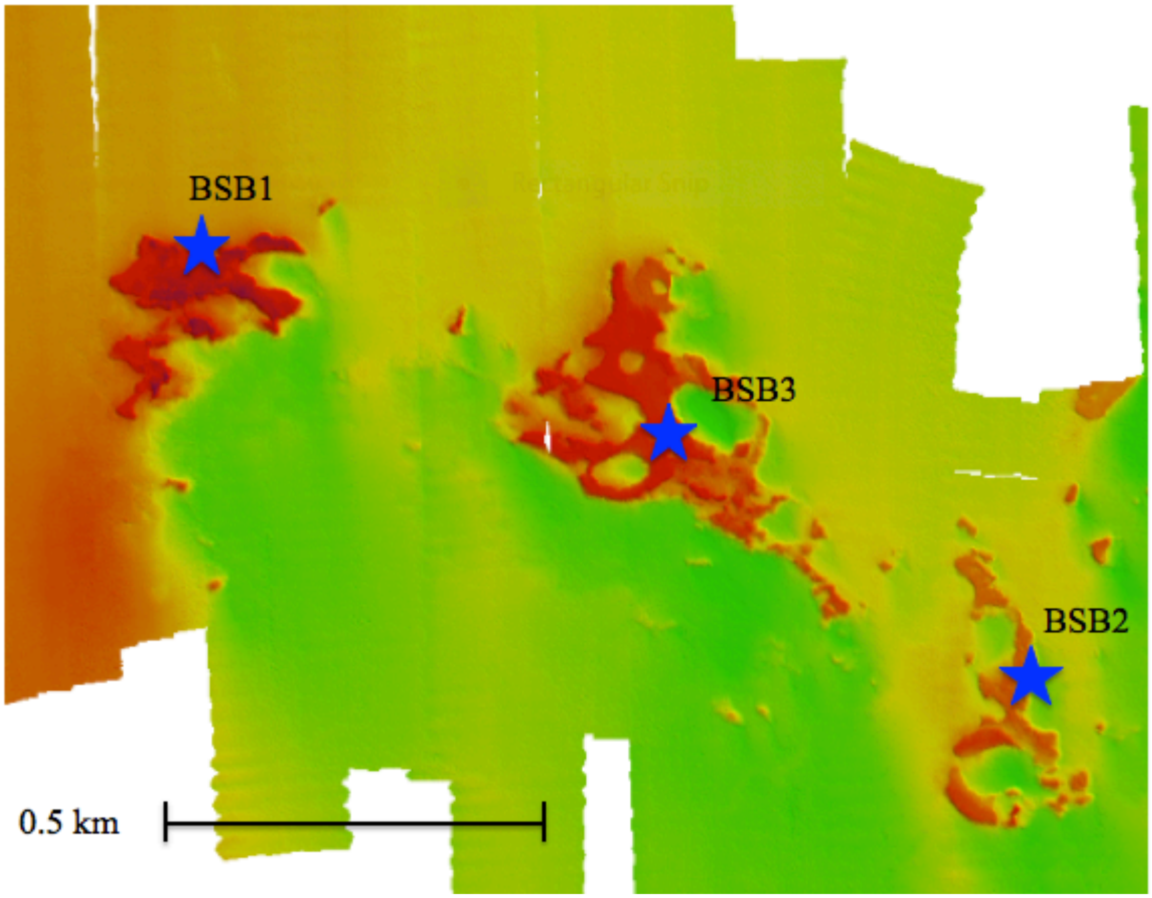

Figure 3. Multibeam sonar image of the Big Seabree natural reef bank. Red snapper were tagged at three individual reef patches (BSB1, BSB2, BSB3) indicated with blue stars. Image courtesy of Schmidt Ocean.

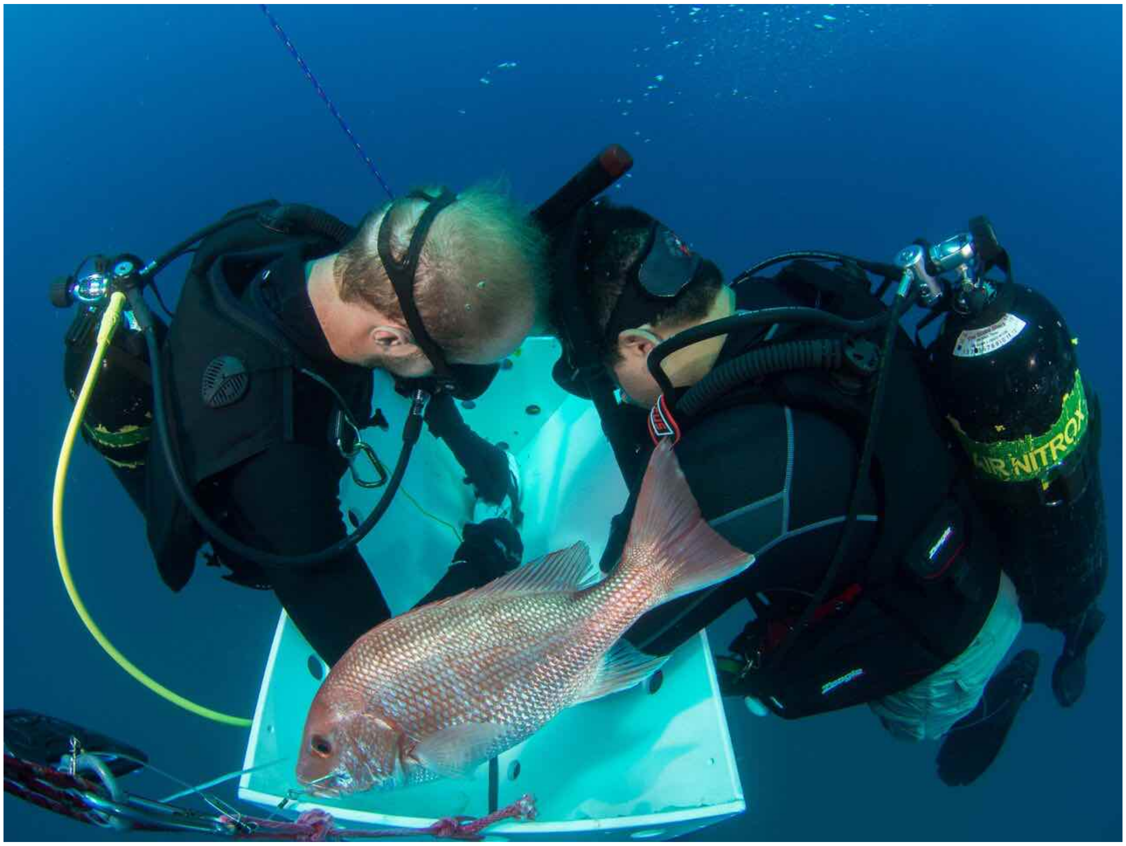

Figure 4. Red snapper tagging at depth through the use of a suspended surgery table. Red snapper were taken off a long line and strapped to the table before undergoing surgery to implant accelerometers. Photo courtesy of Gwyn Carmean.

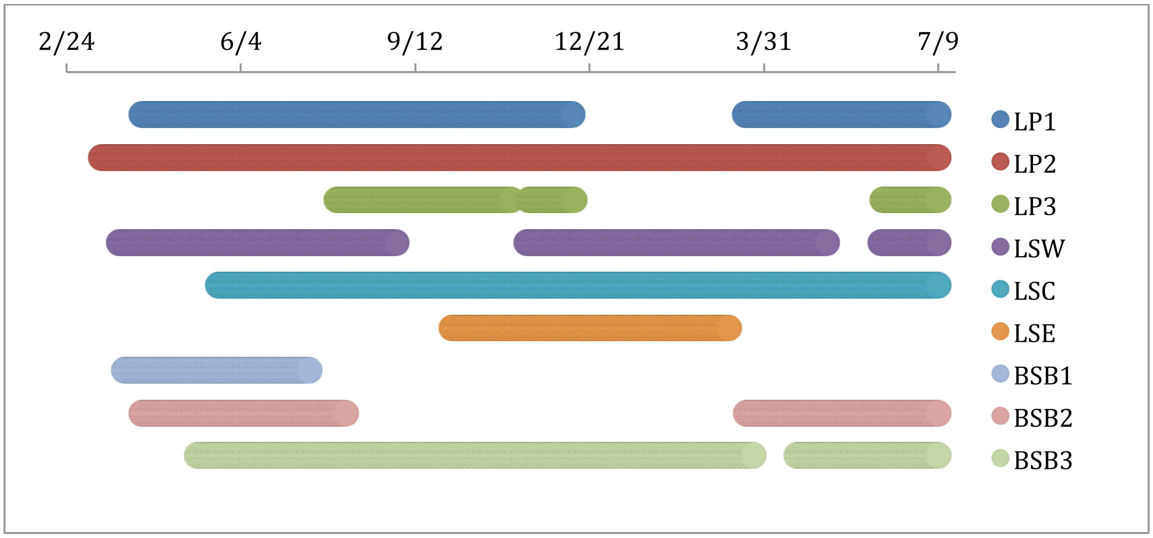

Figure 5. Coverage of SURs showing days where at least one red snapper was detected at each site. Overlap was sufficient to compare snapper on natural and artificial reefs from March 2016 to August 2016.

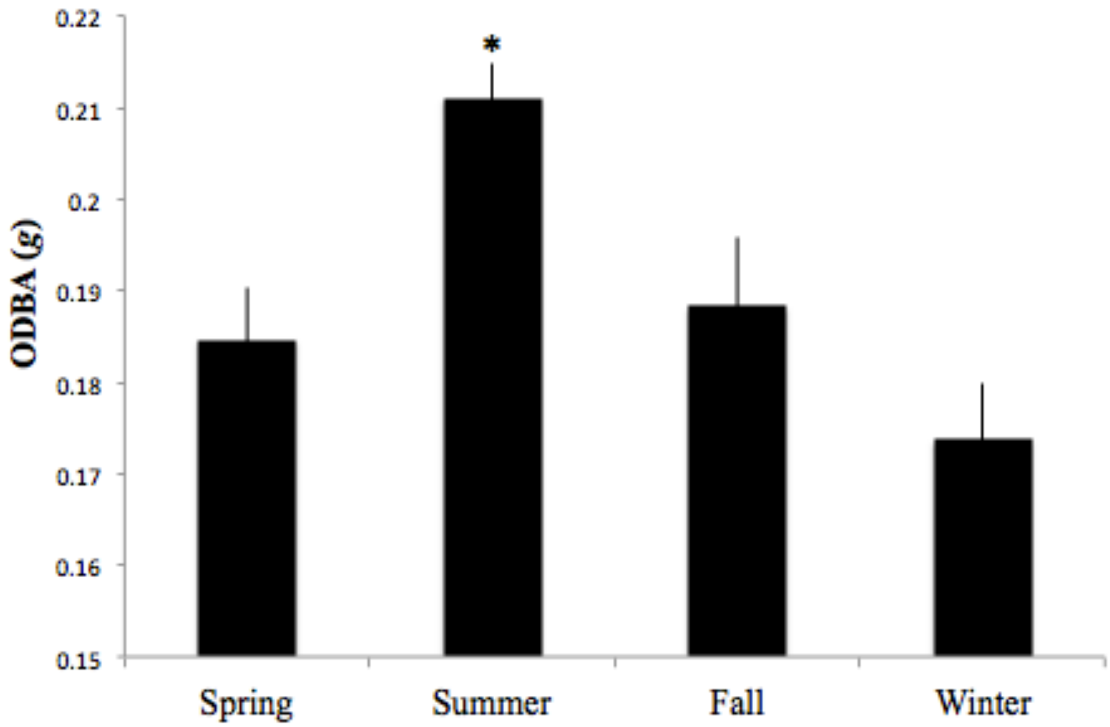

Figure 6. Seasonal changes in average ODBA recorded from red snapper on all reef types. Average ODBA was calculated for all fish present during a given season with >20 ODBA samples. Average ODBA was significantly higher in summer than all other seasons. * indicates significance between summer and fall: $p=0.02$, summer and winter: $p<0.01$, summer and spring: $p<0.01$. ANOVA with Scheffe post hoc test.

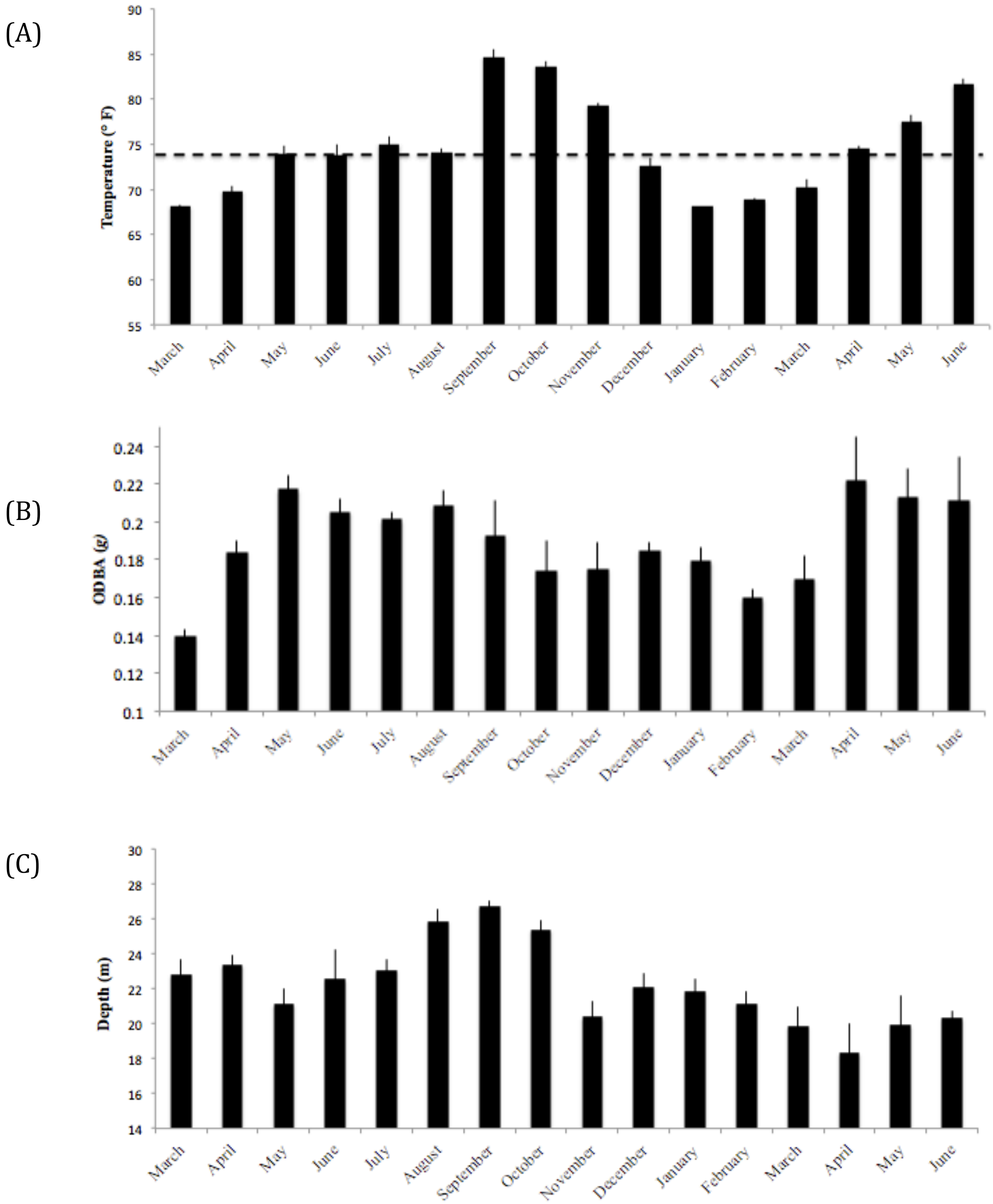

Figure 7. A) Average body temperature of red snapper per month on all reef sites throughout the study. Dashed line indicates 23.3 °C. B) Average ODBA of red snapper per month on all reef sites throughout the study. C) Average depth of red snapper per month on all reef sites throughout the study.

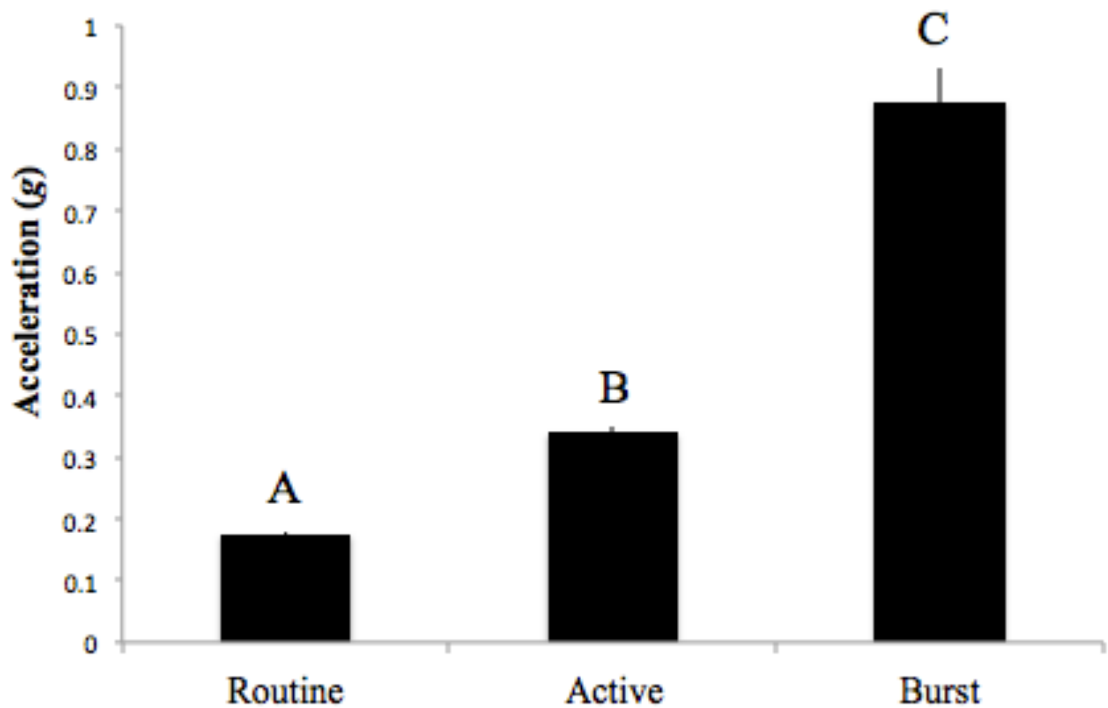

Figure 8. Average ODBA of the three behavioral categories determined by observations of captive fish (N=3). High activity detections were defined as ODBA recordings >0.341 *g*, or the average of active swimming, and used for behavioral analysis in wild fish. Each behavior, routine swimming, active swimming and burst swimming is significantly different from the others (indicated by letters) at $p < 0.01$.

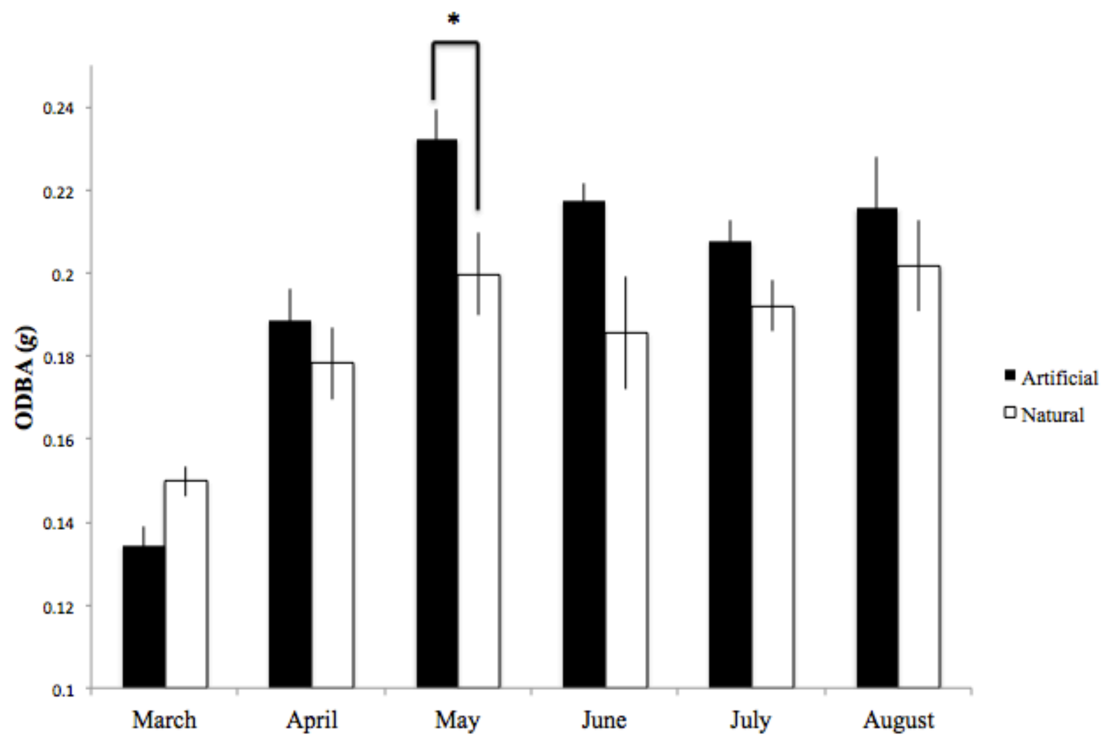

Figure 9. Average ODBA per month of red snapper living on natural and artificial reefs (fish on ships and platforms combined). After March 2016, average ODBA was consistently higher on artificial reefs, but was only significantly higher during May 2016. * indicates significance at p=0.03.

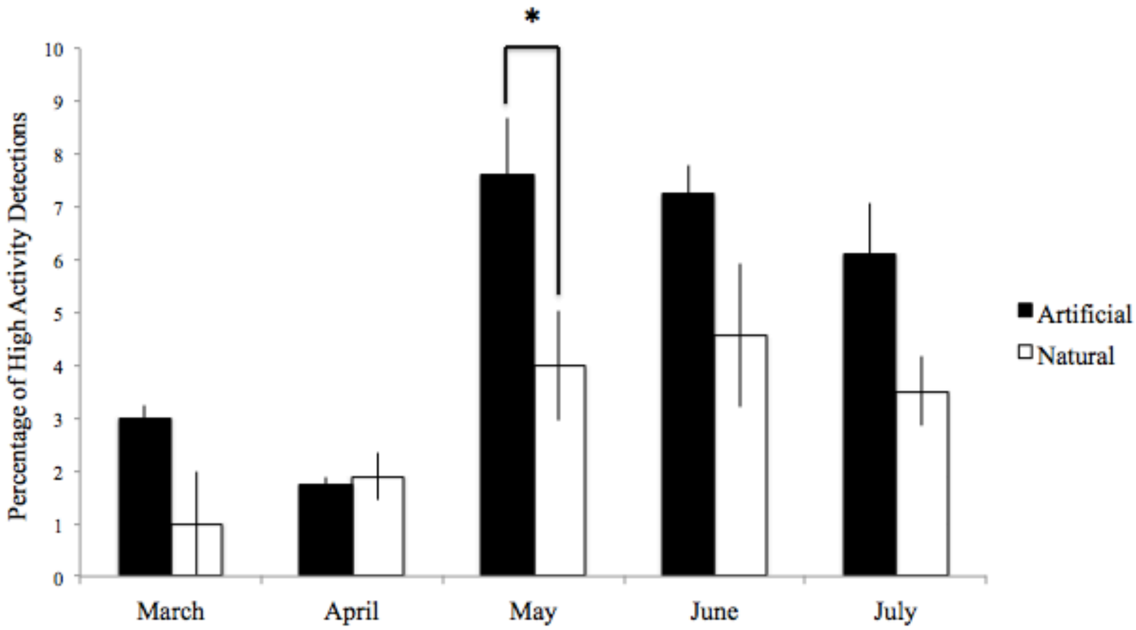

Figure 10. Average percentage of high activity detections (ODBA>0.341 *g*) per month for red snapper living on natural and artificial reefs (fish on ships and platforms combined). Higher average percentages were recorded on artificial reefs during four of five months, but the difference was only significantly higher in May 2016. * indicates significance at p=0.02.

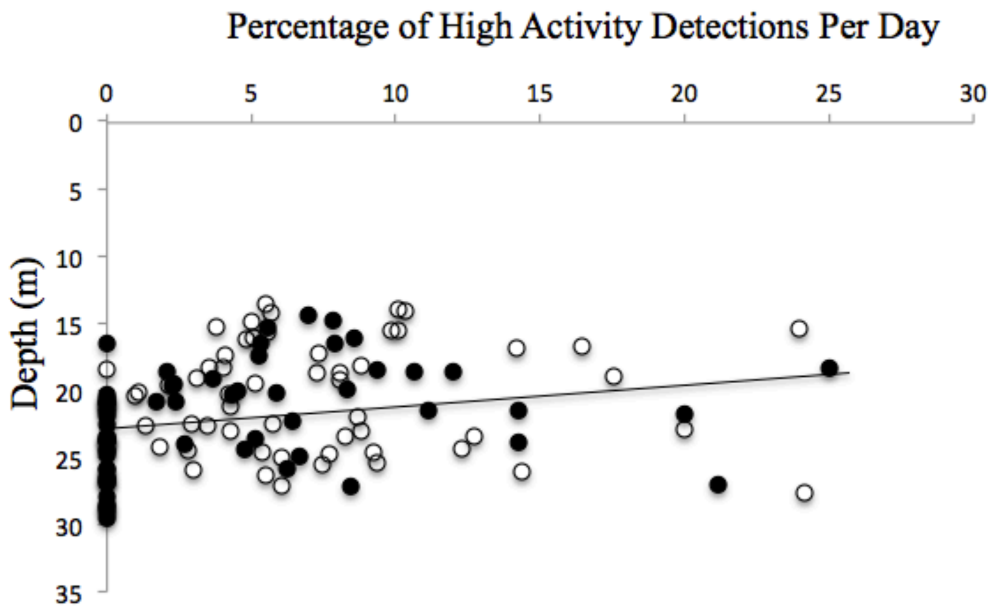

Figure 11. Relationship between average depth use and percentage of high activity detections (ODBA>0.341 *g*) per day for red snapper (N=8) on artificial reefs during May and June 2016. Symbols are the average of all fish for a given day. Open circles represent fish on platforms and filled circles represent fish on ships. A negative correlation was recorded as red snapper were more active with shallower depth use. Pearson correlation test, r=-0.22 p=0.02.

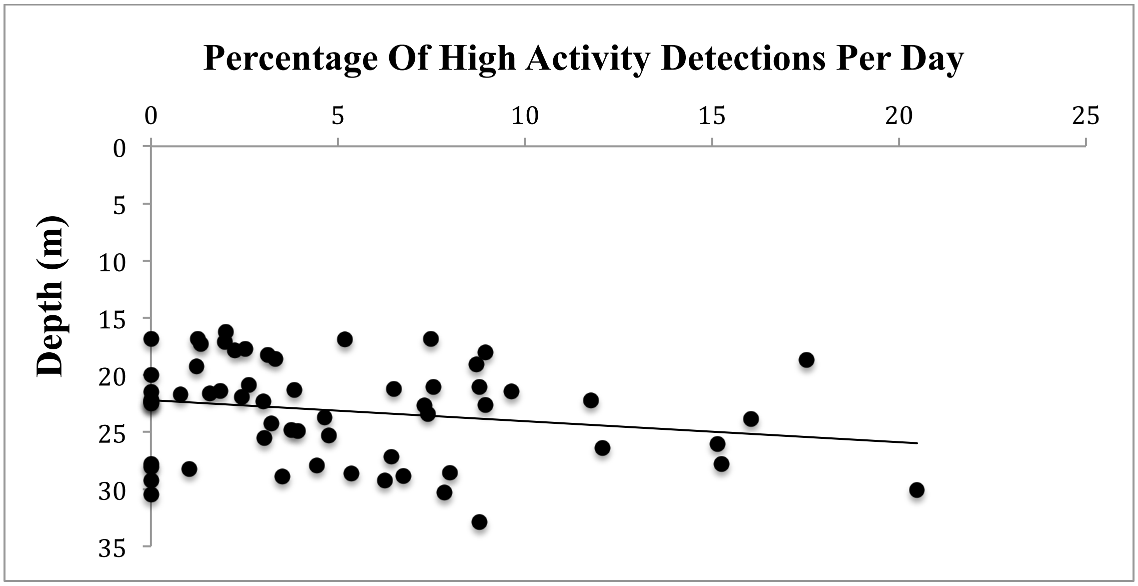

Figure 12. Relationship between average depth use and percentage of high activity detections (ODBA>0.341 *g*) per day for red snapper (N=6) on natural reefs during May and June 2016. Black dots are the average of all fish for a given day. No significant correlation was detected during this time. Pearson correlation test, r=-0.21 p=0.11.

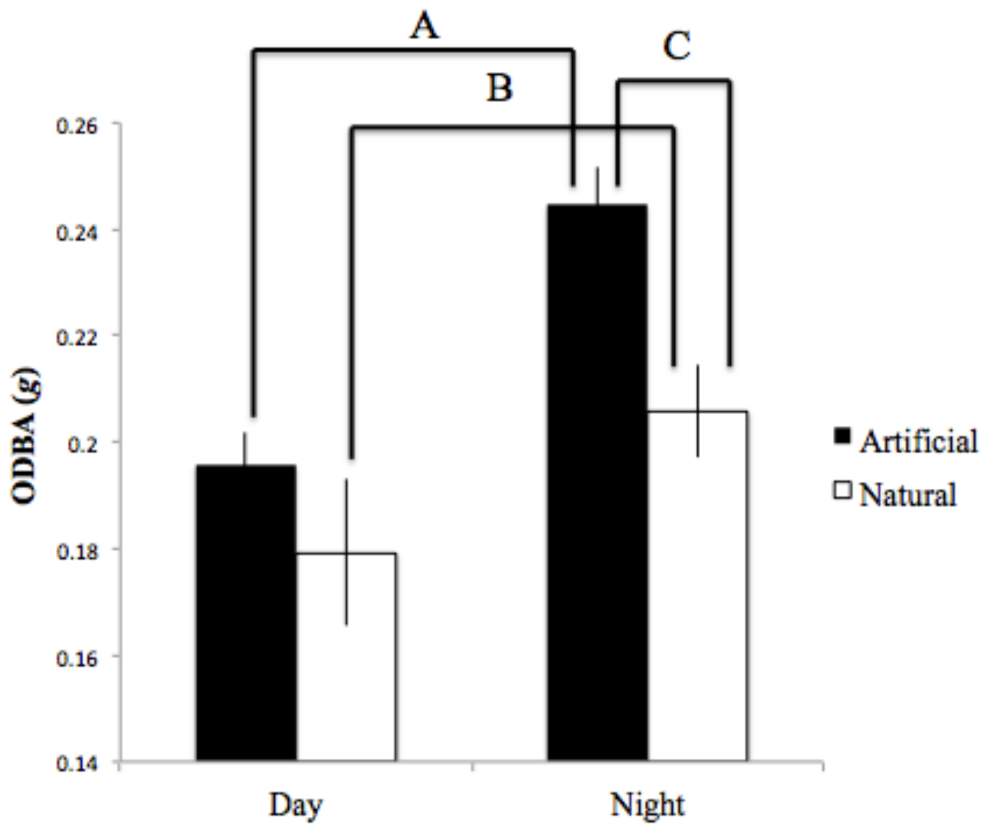

Figure 13. Average ODBA across day and night for red snapper on natural (N=6) and artificial reefs (N=9, fish on ships and platforms combined) during the months of May and June 2016. Red snapper were significantly more active at night on both reef types. However fish on artificial reefs were only significantly more active than those on natural reefs during the night. Significant differences were found (indicated by letters A-C) between night and day (artificial $p<0.01$, natural $p=0.04$) and between natural and artificial reefs at night ($p<0.01$).

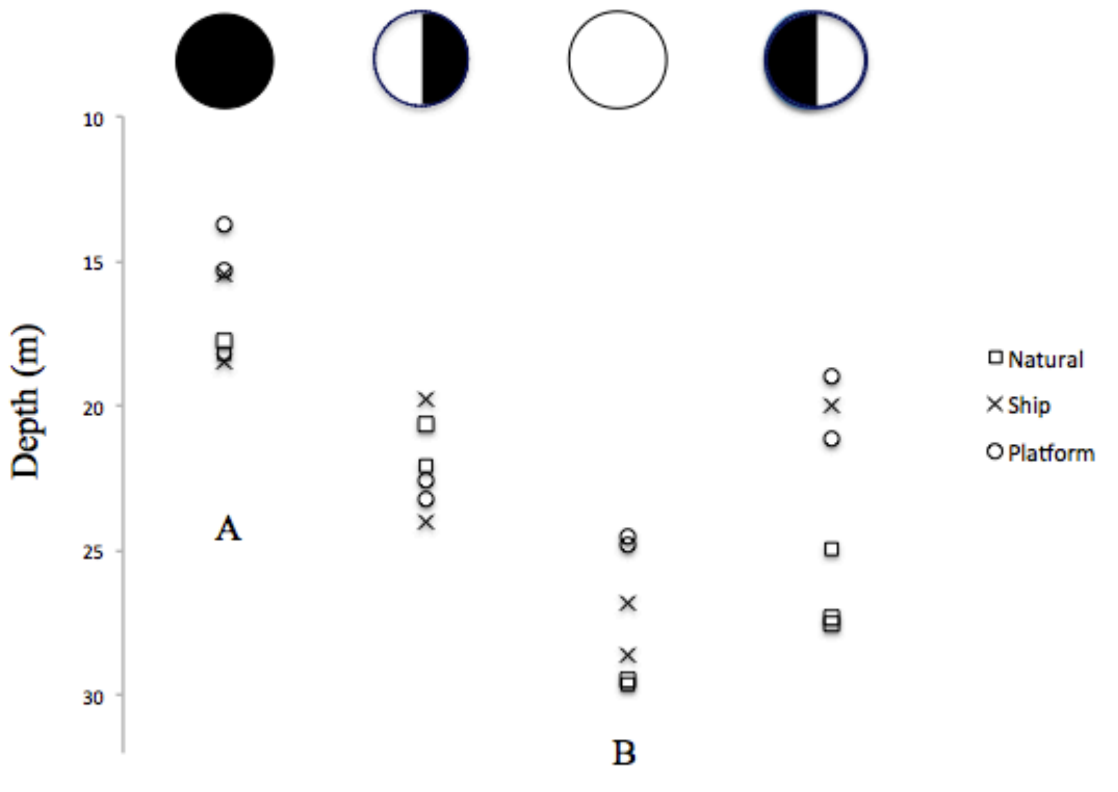

Figure 14. Average depth use of red snapper (N=7) on all reef sites throughout the lunar cycles during June 2016. Fish were significantly shallower during the new moon (A) and significantly deeper during the full moon (B) from all other moon phases at $p < 0.01$. Symbols indicate the reef type of each of the seven fish.

BIOGRAPHICAL SKETCH

Ethan T. Getz attended the University of North Carolina, Wilmington and earned a bachelor's of science in Marine Biology in December 2013. During his undergraduate career Ethan contributed to studies ranging from marine geology to surf-zone fish ecology. He was awarded the Chancellor's Achievement Award in December 2013. After graduating, Ethan worked as a fisheries technician for the Wyoming Game and Fish Department. In January 2015, Ethan began his masters thesis under Dr. Richard Kline at the University of Texas, Rio Grande Valley which he completed in September 2017. Ethan has been hired as the Marine Science Manager for the Madagascar Research and Conservation Institute. Starting in Fall 2017, he will work to monitor marine protected areas and mitigate anthropogenic stressors on coral reefs.

Permanent address:

3058 Swamp College Rd.

Trumansburg, NY. 14886

Email: egetz@twcny.rr.com