Louisiana State University
LSU Digital Commons

LSU Master's Theses | Graduate School

2004

The fidelity of red snapper (Lutjanus campechanus) to petroleum platforms and artificial reefs in the northern Gulf of Mexico

Megan Blythe Peabody
Louisiana State University and Agricultural and Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_theses

Part of the Oceanography and Atmospheric Sciences and Meteorology Commons

Recommended Citation

Peabody, Megan Blythe, "The fidelity of red snapper (Lutjanus campechanus) to petroleum platforms and artificial reefs in the northern Gulf of Mexico" (2004). *LSU Master's Theses*. 3922.
https://digitalcommons.lsu.edu/gradschool_theses/3922

This Thesis is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Master's Theses by an authorized graduate school editor of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.

THE FIDELITY OF RED SNAPPER (*LUTJANUS CAMPECHANUS*) TO PETROLEUM PLATFORMS AND ARTIFICIAL REEFS IN THE NORTHERN GULF OF MEXICO

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Oceanography and Coastal Sciences

by
Megan Blythe Peabody
B.S., University of South Carolina, 2001
May 2004

To Dave Nieland, my mentor and friend

ACKNOWLEDGEMENTS

I sincerely thank Dr. Charles A. "Chuck" Wilson, my major professor for entrusting me with this exciting and challenging project. His continuous faith in my abilities pushed me farther than I believed possible. Next I am indebted to Dave Nieland for his unending support in every stage of this project; I truly could not have made it this far without his help. I also sincerely appreciate the advice and insightful comments of my thesis committee members Dr. James Cowan and Dr. James Geaghan. I must also extend my thanks to several Research Associates and graduate students in the LSU Coastal Fisheries Institute: Yvonne Allen, for the numerous maps she produced and reproduced many times for this project and Mark Miller, Andy Fischer, Scott Baker, Sean Keenan, Kevin Boswell, and Lauren Mione, for assisting in so much of the field work. A big thanks is also due to all of the people who volunteered for the tagging trips; without their hard work, we could not have tagged so many fish in only four days. In addition, to Dr. Ed Chesney of the Louisiana Universities Marine Consortium and to Dr. Mark Benfield and Dr. Larry Rouse of the LSU Department of Oceanography and Coastal Sciences who each went out of their ways to help me with either project planning or data analysis: thank you. I also owe a great deal of thanks to ChevronTexaco Corporation, especially to the pilots, crews, and staffs of South Timbalier 151 and the Leeville heliport. More thanks is due to the owner, captains and crews of Steve Tomeny Charters (Steve, Ed, Darryl, TC, Gabe, Travis, Roman, Matt, and Chad.) All of these people made my fieldwork easier and more enjoyable through their cooperation and friendship. This research was supported by the Minerals Management Service, U.S. Department of the Interior through the Coastal Marine Institute of Louisiana State University under a cooperative agreement with Louisiana State University. Finally, I cannot forget the support and love unendingly given to me by my parents, Diane Yale- and Gerald Peabody, and my wonderful fiancé Jason Westmeyer. I love you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The habitat value of petroleum platforms for red snapper, *Lutjanus campechanus*, is poorly understood. However, it is widely recognized by both scientists and fishermen that the presence of platforms in the northern Gulf of Mexico (GOM) has affected the distribution of red snapper by the addition of hard substrate habitat. I evaluated the habitat value of standing and toppled platforms by monitoring the fidelity of red snapper to these structures with acoustic telemetry. In May 2003, 125 red snapper were captured with hook and line at several platforms in a 35-km^2 portion of the South Timbalier oil and gas lease blocks, 50 km south of Port Fourchon, LA. Following anaesthetization with MS-222, an individually coded acoustic pinger was surgically implanted into the peritoneal cavity of each fish. After a short recovery period the red snapper were released at five platforms in the study area. Presences of individual snapper were recorded with omnidirectional acoustic receivers attached to seven platforms, and to one artificial reef, a toppled platform. Red snapper exhibited little movement between platforms in the study area. However, logistic regression showed a high initial fidelity to release location which subsequently decreased over time, thus site fidelity was found to be high in the short-term, but much lower in the long-term. This result differs from previous studies on red snapper fidelity that reported high fidelity over longer time spans. Red snapper recaptured outside of the study area showed little uniform directional movement. Estimates of instantaneous fishing mortality on this population were higher than those predicted by the most recent stock assessment. A Fourier analysis revealed a diel pattern of movement away from the structures at night, most likely for offsite foraging. Knowledge of red snapper fidelity to petroleum platforms will lead to more effective management of this species by clarifying both the specific function of these structures as habitat and their importance to the red snapper population in the GOM.

INTRODUCTION

Petroleum Platforms in the Gulf of Mexico

In 1942 the first petroleum platform (platform) was installed on the Outer Continental Shelf (OCS) of the Gulf or Mexico (GOM) (Pulsipher et al., 2001). Just over 30 years later, Dugas et al. (1979) claimed that there were so many platforms offshore that it was nearly impossible to find a place on the Louisiana coast without a view of at least a few. By 1997 almost 5,600 platforms had been erected on the OCS, most off the coasts of Louisiana and Texas (Pulsipher et al., 2001). This extensive system throughout the northern GOM supplies 25% of the United States' natural gas production and 10% of US oil production (Louisiana Department of Wildlife and Fisheries, 2004).

The substrate of the northern GOM is primarily muddy and sandy with limited natural hard bottom found far offshore (Render, 1995); therefore platforms are virtually the only source of hard substrate close to shore (Stanley and Wilson, 1990). Pulsipher et al. (2001) estimated that platforms have increased the total amount of reef habitat available by as much as 10 to 25 percent, depending on the definition and estimate of natural reef habitat, though other estimates have been much more conservative (Stanley and Wilson, 1997). The support pilings and cross members of platforms provide settling habitat for algae and pelagic larvae of many species of encrusting invertebrates. In addition, the platforms provide food and shelter for many species of reef fishes that subsequently attract larger predatory pelagic fishes (Hasting et al., 1976; Gallaway et al., 1981; Bull and Kendall, 1994; Fabi et al., 2002; Stachowitsch et al., 2002). The litter and shell hash that accumulates at the bottom of the platform also provides habitat for many organisms (Hasting et al., 1976; Love et al., 1999). Platforms have provided millions of square

feet of solid substrate where little existed before (Dugas et al., 1979; Driessen, 1986). Platforms on the continental shelf west of the Mississippi River may be especially important habitat because they rise above the nepheloid layer (zone of turbid water) (Render, 1995). As a result of these various characteristics, platforms in the northern GOM essentially serve as artificial reefs (Dugas et al, 1979; Bohnsack and Sutherland, 1985; Bull and Kendall, 1994; Render, 1995). A diverse community of reef and rocky bottom marine organisms now inhabit regions that were previously bare sandy and muddy bottom.

Studies have shown that there is high diversity and biomass of fishes around platforms compared to the community that would normally inhabit sandy and muddy substrate if platforms were not present. Platforms concentrate fish populations vertically and serve as vertical mixing grounds for normally stratified populations (Continental Shelf Associates, 1982; Render and Wilson, 1994). Sonnier et al. (1976) conducted a photographic survey of fish populations around platforms and artificial reefs on the Louisiana outer continental shelf and found 49 species associated with platforms. Continental Shelf Associates (1982) utilized underwater cameras to survey 13 platforms off the coast of Louisiana and identified 25 species; in another photographic survey Putt (1982) observed 35 species at Buccaneer Oil Field off the coast of Texas. From fishery logbook data Stanley and Wilson (1990) reported capture of over 46 different species around platforms off Louisiana. Wilson et al. (2003) utilized dual beam hydroacoustics to study fish biomass around natural reefs and standing and toppled platforms. They found that biomass around platforms was higher than that around natural reefs.

Federal and international law requires the removal of all decommissioned platforms to minimize hazards to navigation. Over time this removal of platforms could result in loss of recreational and commercial fishing opportunities, leading to user conflict and loss of tourism

(Wilson et al., 1987). In 1986 the Louisiana legislature enacted the Louisiana Fishing Enhancement Act (Act 100-1986) that created the Louisiana Artificial Reef Program (LARP). This program was formed to retain at least some platforms as artificial reefs. The program also provided for coordinated siting of artificial reefs to avoid the proliferation of unmarked bottom structures that could be hazardous to net fisheries and others (Wilson et al., 1987). Since its inception LARP has utilized the well jackets of 85 decommissioned platforms to create 25 artificial reef sites off the coast of Louisiana (Louisiana Department of Wildlife and Fisheries, 2004).

Although artificial reefs are viewed as a useful fisheries management and enhancement tool, not enough is known about the life history and stock structure of fish that utilize these habitats to address specific management objectives with artificial reefs. Numerous studies have been conducted on a variety of artificial reef substrates. Stone et al. (1979) utilized automobile tires to construct an artificial patch reef mimicking nearby natural reefs in southern Florida. Within eight months of construction there were equal numbers of fish at the artificial and natural reefs, but greater species diversity on the artificial reefs during daylight hours as a result of pelagic visitors. Two years after construction, the artificial reef biomass was similar to that of the nearby natural reefs and the artificial reef had matured to a stage that supported fish cleaning stations where organisms such as French angelfish, *Pomacanthus paru*, and banded coral shrimp, *Stenopus hispidus*, were observed to clean larger fish such as jacks, Carangidae, and groupers, Serrandidae.

Buckley and Hueckel (1985) found that the density of fish on an artificial reef in Puget Sound was actually greater than the density on expansive natural rocky reefs due to what they deemed the “oasis” or “home base” effect in an otherwise bare sandy environment. In addition,

the anglers fishing over the artificial reef retained almost two and a half times as many fish per hour as anglers fishing at nearby natural reefs. Bull and Kendall (1994) determined that three toppled platforms in the north central GOM were acting as recruitment sites for a variety of fish species. Szedlmayer and Shipp (1994) found that red snapper, *Lutjanus campechanus*, actually attained greater sizes at artificial reefs off Alabama compared to other nearby locations, although Strelcheck (2001) found red snapper length was negatively correlated to increasing reef densities, possibly due to less prey and more competition in greater densities of artificial reefs. Szedlmayer and Shipp (1994) also correlated the addition of artificial reef material to a rise in catch per unit effort (CPUE).

Red Snapper at Platforms

The historical distribution of red snapper is along the continental shelf from the Campeche Banks near the Yucatan Pennisula, throughout the GOM, around the southern tip of Florida, and northward along the Atlantic coast of the southern United States to Cape Hatteras (Rivas, 1966; Nelson and Manooch, 1982; Robins and Ray, 1986). *Lutjanus campechanus* is usually found over sandy and rocky bottom, around reefs, and underwater objects at depths between 0 to 200 m (GMFMC, 2001).

Juvenile red snapper less than 200 mm fork length are found over bare, soft muddy and sandy bottoms where they are susceptible to capture in shrimp trawls. One to two years after hatch, juvenile red snapper begin to disappear from trawl samples and appear at reefs (Bradley and Bryan, 1975; Gallaway et. al, 1981; Gallaway, 1984). Bull and Kendall (1994) found no age groups other than two to three year olds at toppled platforms designated as artificial reefs. Nieland and Wilson (2002) reported very few (0.68%) age-1 red snapper at platforms; the majority of the red snapper population (53%) was age-two fish. As red snapper grow older and

larger, when predation becomes less of a threat, they are found more frequently over soft bottom and other lower relief structures such as shipwrecks, lumps, sea-bottom depressions, and natural reefs (Gallaway, 1984; Nieland and Wilson, 2002).

Late juvenile and adult red snapper are generally considered to be reef-associated instead of reef-dependent because they utilize reefs for some parts of their life history, but not for others; the dominant paradigm is that red snapper utilize the reef structure as protection from predators, but move off the reef to spawn and feed (Moseley, 1965; Bradley and Bryan, 1975; Stone, 1978; Gallaway et. al, 1981; Render, 1995). Bradley and Bryan (1975) report that hook-and-line CPUE for red snapper at reefs off the coast of Port Aransas, TX, was best in the winter and lowest in the warmer months, corresponding to spawning season. Red snapper are believed to be opportunistic feeders and consume whatever is most readily available (Beaumariage and Bullock, 1976). Juvenile red snapper feed primarily on shrimp, crabs, other crustaceans and epifaunal benthic organisms; as size increases the diet of snapper incorporates fish with increasing prevalence (Bradley and Bryan, 1975; Gallaway, 1984). Some researchers have reported that the diet of red snapper does not tend to include rock or reef dwellers or members of the biofouling community (Gallaway et. al, 1981; Gallaway, 1984) engendering the hypothesis that red snapper move off reef to feed. McCawley (2003) found that to some extent red snapper did forage on water-column organisms above an artificial reef in Alabama as well as away from the reef on sand-associated organisms.

The presence of red snapper at platforms has been widely documented. They have been listed as one of the most populous and important reef species taking shelter around these platforms (Hasting et al., 1976; Render, 1995). Continental Shelf Associates (1982) found that red snapper were within the top nine species most frequently found around platforms, while Putt

(1982) found red snapper to be within the seven most populous species around platforms in the Buccaneer Oil Field. In fact, in the Buccaneer Oil Field area red snapper dominated the benthic reef fish community to such an extent that they comprised 80% of the sample (Gallaway et. al, 1981). Commercial fishery logbooks show that red snapper are one of the most frequently caught species within the vicinity of platforms, and the same is true for the recreational fishery (Stanley and Wilson, 1989; Stanley and Wilson, 1990). Remotely operated vehicles have been used to videotape fishes around platforms, revealing that red snapper gather in large schools composed of mostly juveniles with some adults (Render, 1995). In a study classifying and enumerating fish taxa after the detonation of a platform for removal, Nieland and Wilson (2002) found that 37% of fish mortalities collected were red snapper. Rademacher and Render (2003) again documented red snapper within the ten most frequently observed taxa around platforms. Clearly, platforms in the GOM are important habitats for red snapper (Nieland and Wilson, 2002).

Many scientists and fishermen believe that the presence of platforms may have changed the distribution and abundance of many fish species. Bohnsack (1989) theorized that biological production of fish populations at artificial reefs would increase in areas where the artificial reefs are isolated from natural reefs, dependent upon the site-specific fidelity and life history of each species. In areas where artificial reefs are in close proximity to natural reefs, fishes may merely be attracted to the new habitat if benefits are to be gained. Whether northern GOM platforms form a production or attraction environment is highly disputed and depends on the specific species being discussed. As for red snapper, Render and Wilson (1994) and Render (1995) argue that, regardless of whether production or attraction is occurring, platforms have definitely affected the distribution of this commercially and recreationally important species. As early as

1984, platforms constituted as much as 11% of total red snapper habitat in the GOM and 28% of habitat in the western GOM (Gallaway, 1984).

From the fishermen's perspective, the presence of platforms has unquestionably influenced the availability of red snapper. Dugas et al. (1979) reports that before 1940, when platforms were not present, offshore sport fishing in Louisiana was almost nonexistent. They claim that the construction of platforms was the largest contributor to the growth of the now lucrative offshore sportfishing industry in coastal Louisiana, where "fishing the oil rigs" is a common expression. The majority of both the recreational and commercial fisheries center around platforms, partly due to their predominance, and partly due to the relative ease with which they may be located compared to natural reefs (Putt, 1982). There is some concern that platforms may make legal size red snapper more vulnerable to fishing mortality (by increasing catchability) and that these size and age groups may be harvested in larger proportions than the remainder of the population (Nieland and Wilson, 2002).

Red Snapper Fisheries

The red snapper fishery is one of the most economically important fisheries in the GOM (Gallaway, 1984; Wilson and Nieland, 2001). It consists of highly lucrative commercial and recreational fisheries. A 1989 survey of recreational anglers and divers revealed red snapper to be among the most sought after fish (Stanley and Wilson, 1989); little has changed in the past 15 years. The net value of the Gulf-wide 2002 commercial red snapper catch (4.8 million pounds) was $10.7 million; the recreational fishery in 2002 landed an estimated 4.7 million pounds (Fisheries Information Network, 2004). The commercial fishery utilizes a variety of gear types including rod and reel, bandit rigs, bottom long lines, and fish traps (to a very limited extent and exclusively in Florida) while the recreational fishery uses rod and reel and spear gun (Goodyear,

1995). Effort is concentrated at platforms in the northern GOM, as close to port as possible, although the commercial boats often travel farther offshore (50 km to 80 km) than do recreational fishermen (Gallaway, 1984; Nieland and Wilson, 2002). Recreational fishermen tend to have smaller boats and remain in water 30 to 45 m deep, less than 50 km offshore (Nieland and Wilson, 2002).

Red snapper also are taken incidentally in another lucrative fishery in the northern GOM. As juveniles, red snapper inhabit muddy and sandy bottoms, the same habitat utilized by shrimp; as a result, many juvenile red snapper are captured over smooth bottom by shrimp trawlers (Beaumariage and Bullock, 1976; Goodyear, 1995; Schirripa and Legault, 1999; GMFMC, 2001). Because most of these red snapper taken in shrimp trawls are very small they are of no current economic value. In 1988, shrimp trawl by-catch was first identified as a significant source of mortality in the red snapper population. In 1990, the Reef Fish Stock Assessment Panel (RFSAP) for the Gulf of Mexico Fishery Management Council (GMFMC) recommended closing the directed red snapper fishery because the by-catch in the shrimp fishery equaled the Allowable Biological Catch (ABC) for the species (GMFMC, 2001). In the most recent red snapper stock assessment Schirripa and Legault (1999) state that the recovery of the red snapper fishery is more dependent on controlling the mortality inflicted by the shrimp fishery than on controlling the mortality derived from the directed red snapper fisheries. Thus, some consider red snapper to be undergoing recruitment overfishing because their movement to reefs as adults is limited by mortality in juvenile stages. This bottleneck in population growth may restrict the ability of artificial reefs to increase biological production (Bohnsack, 1989). In recent years, much work has been done on methods to reduce the by-catch of red snapper in the shrimp fishery. By-catch Reduction Devices (BRDs) are required in nearly all shrimp nets in the GOM

and continuing research is seeking to improve these designs both to minimize loss of shrimp and to maximize finfish escapement (GMFMC, 2001).

Red Snapper Management

Goodyear (1995) detailed the history of the GOM red snapper fishery from the inception of a commercial fishery over 150 years ago, its early declines in the late 1800's, the addition of a recreational fishery in the mid 1900's, the conflict of red snapper as shrimp bycatch, to the current status of this heavily managed species. The highest commercial landings in the GOM occurred in the 1960s-1980s then began to decline; the recreational harvest declined both in number and biomass after 1983. Recruitment to the adult population subsequently declined during the mid 1980s, reached a low in 1987, but then rebounded to the highest level in ten years in 1990. Goodyear noted that a depletion of older snapper in earlier years may be inferred by the historical length frequencies which show a change in length composition towards smaller (younger) red snapper over time; this depletion of older, and more fecund, red snapper may have contributed to the decline in recruitment in the mid 1980s. Goodyear (1995) also described how the geographical concentration of landed red snapper has moved westward over the last few decades, to the extent that red snapper are now essentially commercially extinct in the eastern half of its historical range.

In 1984 the GMFMC instituted management of the red snapper population with the Reef Fish Fishery Management Plan (FMP). Through the ensuing decades the GMFMC has tried various forms of management including minimum size limits, daily bag limits for the recreational fishery, commercial and recreational quotas, licenses for commercial boats, permits for charter and headboats, commercial trip limits, limited fishing seasons for both the commercial and recreational fisheries, and mandatory BRDs in shrimp trawls. The current

regulations include a 16 inch (approximately 41 cm) total length (TL) minimum size limit for the recreational fishery and a 15 inch (approximately 38 cm) TL minimum size limit for the commercial fishery. The recreational fishery is open from 21 April through 31 October and is allocated 4.47 million pounds, or 49% of the current Total Allowable Catch (TAC). The commercial fishing season is split into spring and fall sub-seasons with 4.65 million pounds, or 51% of the TAC, split between the two. The spring sub-season, opening in February, is allocated 2/3 of the commercial quota and the remaining 1/3 may be harvested in the fall, beginning in October. The seasons are limited to the first ten days of each month until the quota for that sub-season is filled (GMFMC, 2001). And although the commercial fishery is no longer the derby fishery it was in 1992 when the season closed after only 53 days, it still resembles a derby, or mini-derby, since fishermen rush to land as many trip limits as possible during the first 10 days of each month while the fishery is open (GMFMC, 2001; Nieland and Wilson, 2002). The GMFMC is currently considering establishing an Individual Transferable Quota (ITQ) system for the commercial red snapper fishery (68 Fed. Reg. 75,202 (December 30, 2003)).

The red snapper stock assessment in 1999 showed the stock to be in the same condition as the previous assessment by Goodyear in 1995 (GMFMC, 2001). After 20 years of management red snapper is currently overfished and still undergoing overfishing (Schirripa and Legault, 1999). Although the adult population has apparently remained stable, the Fall Groundfish Survey and Summer SEAMAP Survey show recruitment to have increased through the 1990s (GMFMC, 2001). A high degree of uncertainty remains about the status and recovery of the red snapper stock. The 1998 RFSAP attributes this uncertainty to ambiguity in the shrimp trawl by-catch reduction levels, in the spawner-recruit curve, and in the constant catch vs. constant fishing mortality rate scenarios (GMFMC, 2001).

Acoustic Telemetry

From the time of its inception in the late 1950s acoustic telemetry for fisheries research has evolved into a sophisticated and diverse science (Winter, 1983). Researchers have used telemetry in many ways from assessing school fidelity and site fidelity (Klimley and Holloway, 1999) to documenting the dynamics of spawning aggregations (Zeller, 1998). The science of acoustic telemetry is relatively simple. Acoustic transmitters send out a high-frequency, ultrasonic “ping” that is then detected by a hydrophone. The ping is then either recorded by a data logger or relayed directly to a listening user.

A wide variety of acoustic telemetry equipment is now used in scientific studies. Transmitters are available as simple ‘pingers’, which emit a signal at prescribed intervals, or as ‘transponders’, which relay coded information after receiving a signal from sonar. Acoustic transmitters can be individually coded to differentiate among individual subjects by changing the frequency or the pulse repetition rate (Arnold and Dewar, 2001). Transmitters may even include additional sensors to detect light intensity, water pressure, water temperature, and internal body temperature (Sibert, 2001). Acoustic transmitters can be attached externally or implanted internally through surgery or oral insertion and have been implanted into fish as small as 40 grams (Eklund and Schull, 2001; O’Dor et al., 2001).

Hydrophones can be deployed in fixed or mobile systems, and in single or multiple arrays. Fixed hydrophone systems can be used to investigate site fidelity or small-scale movement. Mobile hydrophone systems (typically deployed from boats or ships) may be used to track animals over longer distances (Arnold and Dewar, 2001). Hydrophones can be mounted singly to detect presence or absence, or in arrays so they may triangulate and estimate a spatial location of the transmitter (Sibert, 2001). They are available as omnidirectional, detecting in

360° around, and directional, which block out noise from most directions while focusing on a specific bearing (Winter, 1983).

Sound propagates very well in saltwater, but many obstacles to the acoustic signal may be found in the marine environment. Acoustic signals, or pings, can be deflected, obscured, and absorbed by solutes, suspended matter, plankton, fish, air bubbles, thermoclines, water turbulence, raindrops, wind, wave action, boat motors, submerged structures, and even biological noise like snapping shrimp (Winter, 1983; Wolcott, 1995). The range of detection for a hydrophone/transmitter combination depends partly upon the size, strength, and frequency of the acoustic transmitter (lower frequencies propagate further) and also the level of ambient noise in the environment (Klimley et al., 1998).

Acoustic telemetry offers many benefits over direct observation and conventional tag and recapture techniques. In many situations, direct observation of subjects may not be possible or may alter the behavior of the subject (limitations of SCUBA and live diver disturbance) (Wolcott, 1995; Zeller, 1997). Acoustic telemetry allows fishery independent data collection while avoiding possible bias from a subject's reaction to the presence of a research vessel (Arnold and Dewar, 2001). Continuous tracking technology (as opposed to discrete tracking) affords the users the ability to investigate diel movements, habitat utilization, and site residence times (Eklund and Schull, 2001). Traditional mark and recapture studies, where fish are usually harvested permanently after recapture, are limited to collection of two data points: release location and capture location (Klimley et al., 1998). Most such studies are also dependent upon the cooperation and accuracy of fishermen for data collection. In some cases, the researchers perform recapture and subjects are released and recaptured multiple times (Watterson et al.,

1998; Patterson et al., 2001). Even this type of mark and recapture study usually provides only vague descriptions of movement of a mobile subject (Hart and Summerfelt, 1975).

Acoustic tracking does have some drawbacks. The equipment is substantially more expensive compared with simple external tags used in traditional mark and recapture studies; acoustics transmitters cost hundreds of dollars apiece, and hydrophones cost thousands. Manual tracking studies, where the subject is followed by boat with the assistance of a directional hydrophone, are very demanding of manpower and funding, generally limiting studies to less than a week and risking disruption by rough weather (Klimley et al., 1998).

In addition, most transmitter attachment methods are extremely invasive, requiring surgical implantation or gastric insertion. External attachment is possible, but may cause more complications for which the fish must compensate (Winter, 1983). Externally attached tags may cause increased drag and affect swimming speed and energy expenditure. They may also cause abrasions or snag on objects and dorsally attached tags can disrupt balance. Internal implantation avoids many of the problems associated with external attachment (Winter, 1983). Tags are generally placed below the center of gravity negating the previously mentioned balance problems. The best option for internal implantation is surgical, but these procedures are very invasive, take longer to perform, require more handling, require anesthesia and longer recovery periods, and bring the risk of infection especially in warm water (Winter, 1983; Klimley et al., 1998; Thorsteinsson, 2002). Gastric implantation, by force-feeding, is another option, although tags are not permanently retained. Gastric implantation may affect the feeding frequency of the subject and tags can be regurgitated (Hart and Summerfelt, 1975).

Objectives

Red snapper are one of the predominant species at platforms in the northern GOM. This species is the target of lucrative and heavily managed fisheries and the petroleum industry in the GOM is economically-important to many of the Gulf States and the U.S. as whole. Effective management regulations for the red snapper fisheries and the petroleum industry must include information about the habitat preferences of red snapper as they relate to platforms. It is evident that platforms and artificial reefs (often toppled platforms) act as some sort of habitat for red snapper in the northern GOM, but the importance of these artificial habitats to the red snapper population is unknown. In order to successfully manage this species we must consider its use of platforms as habitat and determine the level of importance of these platforms to the ecology of red snapper. Advances in acoustic telemetry have resulted in a valuable technology that permits continuous tracking of specimens and can yield more detailed and accurate information on red snapper usage of platforms. Therefore the overall objective of this study was to determine what could be learned about red snapper at platforms through acoustic telemetry. The null hypothesis was that red snapper do not show any movement away from or between platforms, residing at one platform on a continuous and long-term basis. The alternate hypothesis was that red snapper do exhibit movement between various platforms. More specific objectives were examined to determine how acoustic telemetry could be utilized to detect movement of red snapper and if any movement was found, to describe it.

These specific objectives were as follows:

1. To develop a protocol for at sea surgical implantation of acoustic transmitters into red snapper.

2. To utilize acoustic telemetry to investigate the short- and long-term site fidelity of red snapper to petroleum platforms and artificial reefs on the OCS of the GOM off the coast of Louisiana, thereby evaluating the habitat value of these platforms.
3. To determine if uniform directional movement is undertaken by red snapper departing from the study area.
4. To estimate fishing mortality on the red snapper population.
5. To determine if any diel movement patterns are exhibited by red snapper around petroleum platforms and artificial reefs.

MATERIALS AND METHODS

Study Site Description

Approximately 50 kilometers south of Port Fourchon, Louisiana, is a cluster of platforms often referred to locally as “The Circle”, due to the circular placement of 12 platforms around a salt dome (Figure 1). The area is part of the South Timbalier 128, 134, 135, 151, and 152 Mineral Management Service oil and gas lease blocks primarily held by ChevronTexaco Corporation, who first erected platforms there in the 1960’s then again in the 1980’s. The area was chosen due to its unique configuration, the close proximity of 12 standing platforms and numerous artificial reefs within the 35 km^2 area, and the high frequency with which commercial and recreational fishermen visit the area. The closest platforms to this area are approximately eight km to the east in the South Timbalier 130 lease block.

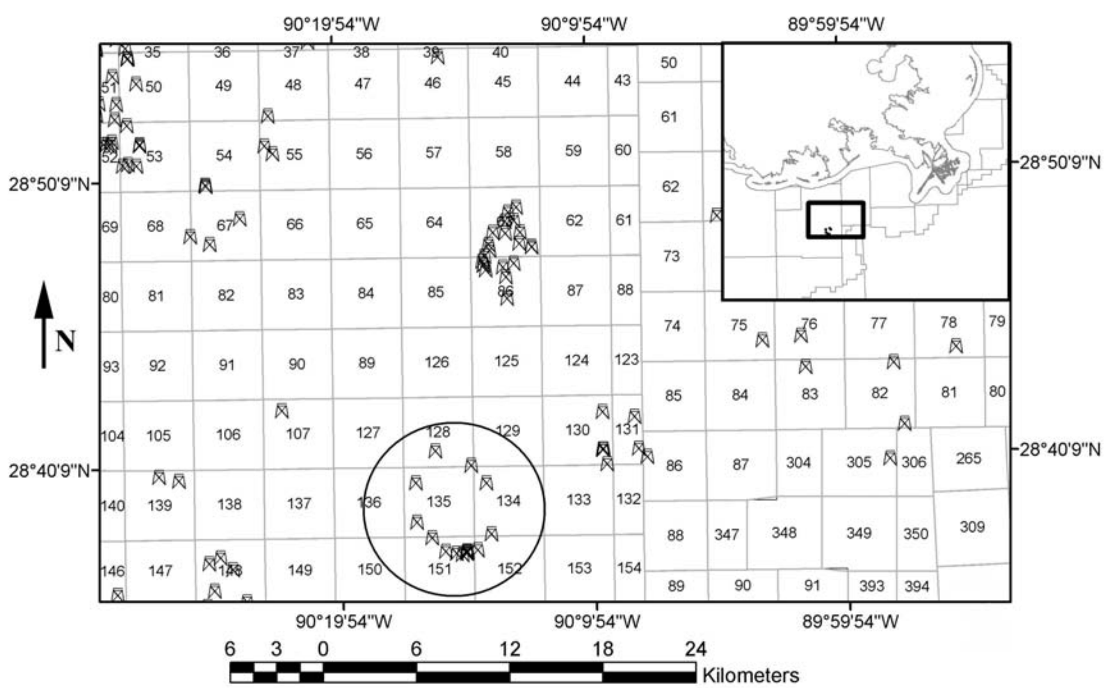


Figure 1: Map of the study area in the South Timbalier 128, 134, 135, 151, and 152 Mineral Management Service oil and gas lease blocks. The inset in the upper right corner shows the location of the study area with respect to the coast of Louisiana.

The majority of the platforms in The Circle are 6- and 8-pile structures with the exception of the ST151-Y complex that consists of four individual platforms connected by catwalks and provides living quarters for the field crew. The water depth in this area ranges from 30-42 meters and the large-scale current direction in this region is westerly (personal communication, Larry Rouse, Louisiana State University, 11 March, 2004). The study area is farther offshore than the normal extent of the hypoxic zone formed during the summer months by nutrient and freshwater input from the Mississippi River (Rabalais et al., 2002). The substrate in this region is muddy with the exception of the litter and shell hash that has accumulated within the immediate vicinity of platforms.

Equipment

The telemetry system consists of transmitters and hydrophones manufactured by VEMCO LTD.[1]. The transmitters were model V8SC-2H 4K pingers with a random pulse train delay of 150 to 300 seconds and predicted battery life of over 400 days (Figure 2). All pingers

Figure 2: The V8SC-2H acoustic pinger and Floy® internal anchor tag that were implanted into each tagged red snapper.

[1] 100 Osprey Drive, Shad Bay, Nova Scotia, Canada, B3T 2C1

operated at 69 kHz, were 9 mm in diameter by 30 mm in length, weighed 5 grams in air, and each had a unique signal determined by the timing between the seven pulses in the train.

The hydrophones were a component of a multipart system called a receiver, the VR2 model, which is a combination of an omnidirectional hydrophone, a receiver, an ID detector, a data logging memory, and a battery all housed in a submersible case 34 cm in length and 6 cm in diameter, weighing approximately 1.2 kg (Figure 3). The receiver memory is capable of storing 300,000 detections and the replaceable batteries have a life of six to eight months. Data is downloaded to a laptop computer via a magnetic probe, allowing easy download in the field.

Figure 3: The VR2 acoustic receiver.

In addition to the internal pinger, all red snapper were fitted with a Floy® internal anchor tag (FM-95W) (Figure 2). Printed on the internal and external sections of each tag were the tag number, an offer of a reward, and a 1-800 telephone number. Fishermen who returned the tags were given both $10 and an LSU Red Snapper Research fishing cap. Fliers publicizing our research efforts were posted in businesses near the coast; charter boat businesses known to frequent the study area were also notified of the project. In addition, newspapers in Baton

Rouge, New Orleans, Lafayette, and Lake Charles, LA published articles about the project in their outdoors sections.

Pinger Implantation

On 21, 22, 28, and 29 May 2003, acoustic pingers were surgically implanted in the peritoneal cavities of red snapper captured at platforms in the study area. All specimens were caught with hook and line and slowly brought to the surface to minimize depth-related decompression complications such as over-inflated air bladders and distended stomachs. Only red snapper between 28 and 47 cm TL were retained for tagging. Any fish with either its stomach protruding from the mouth or its intestines protruding from its anus was returned to the water. A 16-gauge hypodermic syringe needle sterilized in a dilute povidone iodine solution was used to puncture and deflate each fish's air bladder through the sidewall of the body a few scales below and behind the tip of the opercular flap (personal communication, Edward Chesney, Louisiana Universities Marine Consortium, 20 March, 2003). All specimens were held in an aerated, flow through tank and monitored for any ill effects of handling; those red snapper not recovered and swimming normally in the tank were not retained for tagging.

Red snapper showing no major trauma were moved to a tank with a solution of MS-222 (3-aminobenzoic acid ethyl ester or tricaine methanesulfonate) at a concentration of 80 mg/l. (Anaesthetic concentrations and surgical procedures were tested and selected in the laboratory prior to the field operations.) During sedation, rough measurements of total length were recorded. These lengths were later converted to weight with formulas found in Wilson and Nieland (2001), for the purposes of comparison to pinger weight. After approximately five minutes, or when the specimens showed signs of adequate sedation, the fish were moved to a foam-lined plastic box for surgical implantation of the pinger (Figure 4). During surgery the

gills were irrigated with a 50 mg/l solution of MS-222 pumped through tubes by a small submersible bilge pump. This water was caught within the box and flowed back through the system (Figure 4). The anaesthetic solutions were remade with fresh seawater twice daily or as needed.

Figure 4: The foam-lined boxes and gill irrigation system used for the surgical procedure.

Scales were removed from an area three scale rows wide by six to eight scales long posterior to and midway between the pectoral and pelvic fins; the area was swabbed with diluted povidone iodine and a 2-3 cm incision was made with a disposable scalpel (Figure 5). The incision was made first through the integument, then through muscle layers, and finally through the lining of the peritoneal cavity. The acoustic pinger was inserted into the cavity and pushed slightly forward, away from the internal organs. The anchor end of the Floy tag was inserted at the posterior end of the incision and the wound was sutured with Ethicon 3-0 absorbable chromic gut thread (Figure 6). The area was patted dry and the wound was sealed with Nexaband S/C

Figure 5: Scales were removed and an incision was made posterior to and midway between the pectoral and pelvic fins.

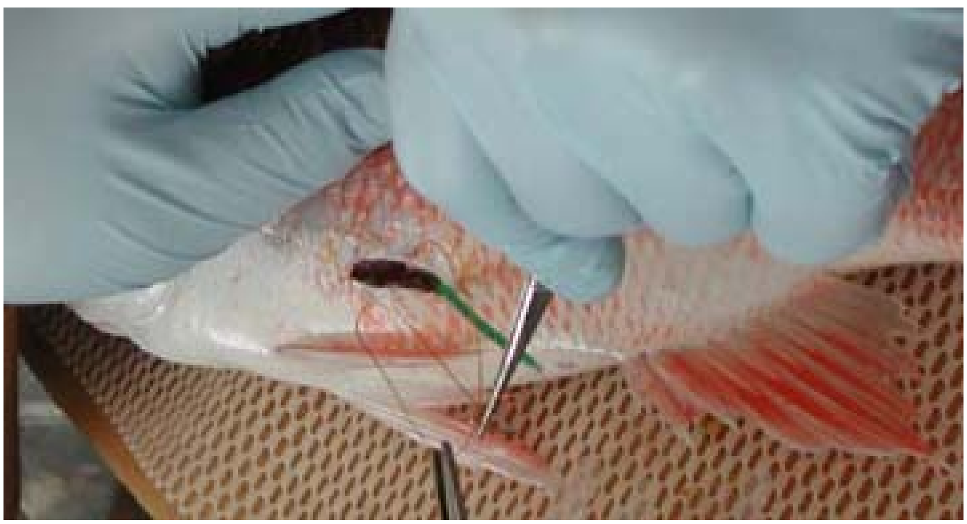


Figure 6: Placement of the Floy tag and suturing of the wound.

Topical Skin Closure, a veterinary glue. The glue was allowed to dry for one minute and then the red snapper was moved to an oxygenated recovery tank. Upon recovery, usually 15-30 minutes, the red snapper were released into a 29 foot open-ended hoop net, the bottom of which was angled towards the platform. The hoop net was intended to protect the snapper from predation as they returned both to depth and to the protection of the platform. A remotely operated vehicle (ROV) was used to monitor the release of the first few tagged fish and confirm

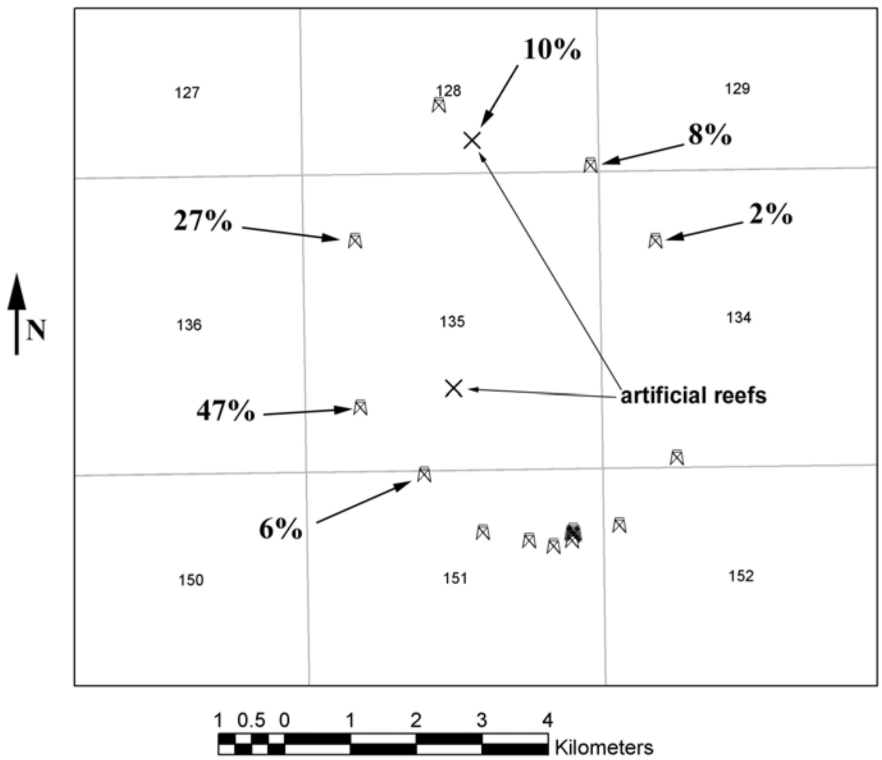
that they were able to exit the hoop net and orient towards the platform. Over the course of the surgical procedures 3% of the specimens did not recover from the surgery; the tags from these were removed and reinserted into new red snapper. Condition class upon release was recorded for all red snapper following the criteria 1) swam down immediately, 2) hesitated then swam down, and 3) floated at surface momentarily before swimming down.

The capture locations were distributed throughout the study area as much as possible, dependent upon the availability of red snapper and time constraints. Most red snapper, however, were caught in the western part of the circle (Figure 7a). Seventy-two percent of the snapper were caught and released at the same location (hereafter referred to as native snapper), whereas 28% were caught and released at different locations (relocated snapper) in order to determine whether snapper would home back to the area from which they were removed and whether the relocated snapper were more likely to leave the release location than were native snapper (similar to Watterson et al., 1998; Patterson et al., 2001). As a result, the final release locations of red snapper were slightly more geographically balanced (Figure 7b).

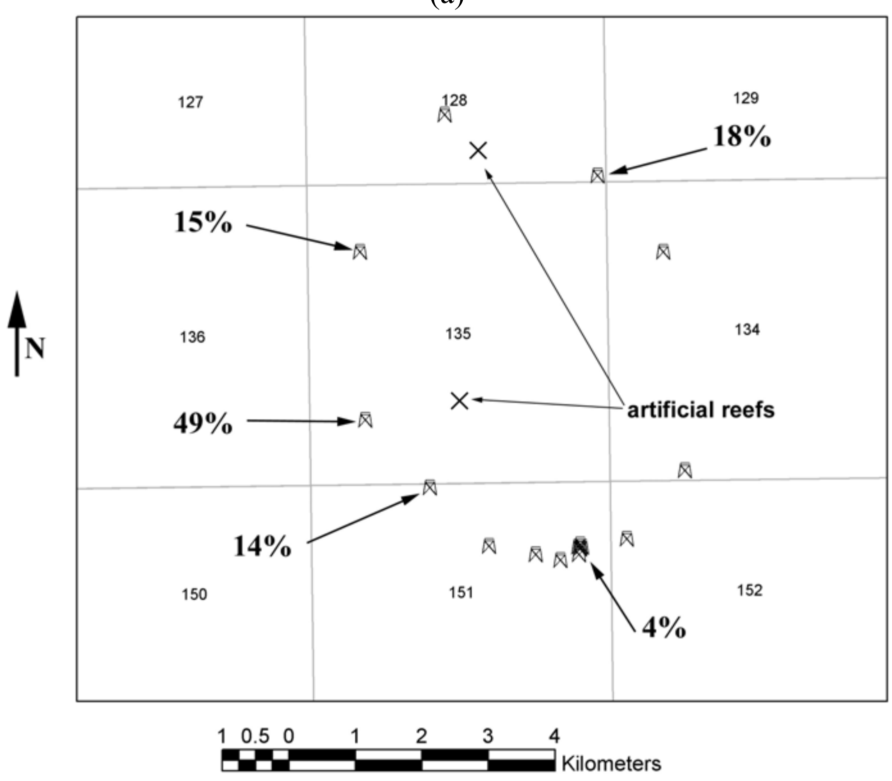
Receiver Deployment

Acoustic receivers were deployed at seven platforms in the study area on 21 and 22 May. Additional receivers were deployed at an artificial reef and another platform later in the study. The receiver deployment locations and dates are listed in Table 1 and the final receiver locations are shown in Figure 8.

The deployment system at platforms was such that the receiver would reside 10 to 20 meters below the water's surface, but was retrievable from the lower deck of the platform. Two steel cables were attached to the lower deck of the platform at one end and to a cross-member 10 to 20 meters below the surface at the other end. A weighted sled was attached to these cables



(a)



(b)

Figure 7: Capture (a) and release (b) locations for tagged red snapper are shown with the corresponding percent of total fish captured and released at each location.

Table1: Receiver deployment locations and dates.

Platform name	Latitude	Longitude	Date of deployment
ST135-M	28º 38.102’	90º 16.914’	05/21/2003
ST151-I	28º 37.540’	90º 16.334’	05/21/2003
ST128-R	28º 40.041’	90º 14.724’	05/22/2003
ST134-S	28º 39.409’	90º 14.132’	05/22/2003
ST151-Y	28º 36.970’	90º 14.974’	05/22/2003
ST134-W	28º 37.630’	90º 13.979’	05/22/2003
ST151-O	28º 36.926’	90º 15.146’	05/22/2003
Artificial Reef	28º 38.215’	90º 16.020’	06/16/2003
ST135-Q	28º 39.466’	90º 16.929’	07/29/2003

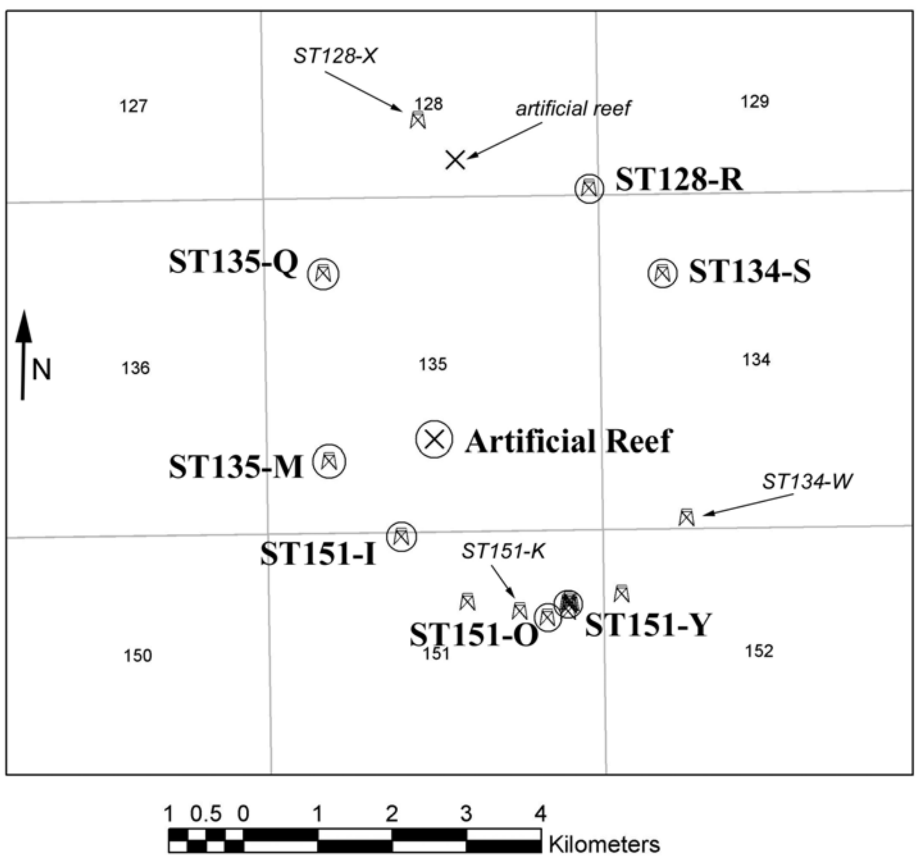


Figure 8: Map of the final locations of acoustic receivers at seven platforms and one artificial reef in the study area. Receiver locations are circled and labeled; other structures of interest are also labeled.

with U-bolts and was able to freely move up and down the cables. Bolted to the sled was an antenna mount to which a one-meter long section of PVC pipe was attached (Figure 9). The receiver was bolted to the PVC pipe and the antenna mount was locked to hold the PVC pipe in a vertical position. A safety cable also attached the receiver directly to the sled. The hydrophone end of the receiver pointed down, and the PVC bent such that the pipe angled approximately 30 degrees from vertical, exposing more of the hydrophone to the sea floor. A third cable was attached to the sled and this was used to raise and lower the sled to and from the surface. Receiver data were downloaded monthly from June through December of 2003. ChevronTexaco

Figure 9: The receiver deployment system including a weighted sled that moved along two guide cables and PVC pipe to which the receiver was bolted, hydrophone end down.

Corporation's crew transport helicopters provided transportation to and from the platforms to download data and maintain equipment.

The receiver on the artificial reef was deployed and retrieved by a SCUBA diver. This receiver was attached to a bracket chained directly to a beam of the toppled platform approximately 22 meters below the surface and was checked every two to three months. The orientation of this receiver was in the horizontal plane, but it did not show less adequate detection than did the vertically oriented receivers.

Acoustic Range Test

An acoustic range test was performed at ST151-I on 11 March, 2004 to measure the detection range of the VR2 receiver and the V8SC pinger; the sea state and weather were calm and clear (respectively.) A pinger with a pulse train delay of 3-5 seconds was suspended from a boat at a depth of approximately 20 m below the sea surface. A VR2 receiver was also suspended from the boat to confirm that the V8SC was pinging as expected throughout the range test. The boat engine and all electronic equipment were powered off and the boat was allowed to drift with the current at approximately 1 knot. Multiple drifts were made toward and away from the platform, as the current allowed, to a maximum distance of 1200 meters. The path of the boat was tracked with a handheld GPS with the time synchronized to that on the receiver. The path was subsequently compared with the data file downloaded from the receiver to determine the maximum distance between the pinger and receiver for all the detections recorded by the receiver.

Methods for Data Analyses

Data analyses were performed on both fish recapture data and acoustic data. Fish recapture locations that differed from release locations were displayed on a map to determine if

the red snapper undertook uniform directional movement. Fish recapture data was used to estimate a presumed fishing mortality with the following equations as described by Pine et al. (2003):

$$f = \lambda u \tag{1}$$

where f is the tag return rate, or the number of tags returned out of the sample population, λ is the probability that a tag on a harvested fish is reported, or reporting rate, and u is the exploitation rate, and

$$u = \mathrm{F}(1 - \exp^{(-\mathrm{F}-\mathrm{M})})/\mathrm{Z} \tag{2}$$

where F is the instantaneous fishing mortality rate, M is the instantaneous natural mortality rate, and Z is the instantaneous total mortality rate (F+M). The actual reporting rate for this study was unknown; therefore, calculations were made with a range of reporting rates between 30% and 100%. Calculations were also made with two values for instantaneous natural mortality: 0.1 and 0.2. The former value is the natural mortality rate used for age 2-15+ snapper in the 1999 red snapper stock assessment (Schirripa and Legault, 1999). There remains some degree of uncertainty in the scientific community as to the actual value of M (see Schirripa and Legault, 1999), therefore the latter value was used as a more conservative estimate of natural mortality.

Acoustic data were used in analyses of site fidelity and diel movement. Short-term site fidelity (on a scale of weeks) was examined with plots of the daily location of each tagged red snapper to determine if specimens had moved among receiver locations. Fish recapture data

(location and date) were included in these plots. Longer-term site fidelity (on a scale of months) was examined with a logistic regression performed by PROC LOGISTIC in SAS (SAS Institute Inc., 2003). All red snapper removed from the population by fishermen were left out of this dataset because this removal was a forced absence. The same regression was run on two other data sets, one including a portion of the recaptured fish (those for which exact recapture location and date were known) and the other including all of the recaptured fish to determine if addition of these specimens would change the results of the regressions. An *a priori* decision was made to use the data set excluding all recaptured fish if there was little variation in the results; if the data sets did yield differing results, all would be reported. Red snapper from ST151-I and ST135-Q were removed from the regression dataset because of missing data due to receiver malfunction and late deployment. Time was divided into ten-day increments, called periods, beginning with the day of release for each fish. If a snapper was present within a given period, it was coded as category one; if a snapper was not present during the given period, it was coded category zero. Native and relocated snapper were treated as two different populations within the logistic regression. Location of release and potential for thermocline interference also were were were tested as variables of interest. A thermocline developed below the depth of the receivers in late July, 2003 and is suspected of deflecting a substantial number of pings, causing a decrease in the ping detection rate (further explained in the results.) Periods falling within the estimated range of dates where a thermocline may have interfered with ping detection (periods 7-13) were coded category one and the remaining periods (0-6 and 14-20) were coded category 0.

The null hypothesis of the logistic regression was that the probability of presence did not change over the duration of the study. The alternate hypothesis was that some or all of the variables (Period, Population, Location, and Thermocline) could be used to predict the

probability of presence. Three models were formulated to assess different combinations of the variables. Period and Population and the interaction between the two were included in the Base Model as they were the two variables deemed most likely to affect the probability of presence. Location was not included in this model because it was confounding with population. All of the snappers released at platform ST151-Y were relocated specimens, approximately half the snapper released at platform ST128-R were relocated specimens and half were native, whereas nearly all the snapper released at platform ST135-M were native individuals. Any difference shown among locations was likely to also be affected by population; therefore, Location was left out of the Base Model to avoid multicollinearity. A second model, the Thermocline Model, added the variable Thermocline to the Base Model. This model was intended to determine if the interference of the thermocline could be used to predict a decrease in the probability of presence, regardless of whether this was an actual decrease in presence or a result of the acoustic pings being deflected and not detected by the receiver. A third model, the Location Model, added the variable Location to the Base Model to determine if this variable, in combination with Population, improved the model.

Acoustic data was also subjected to Fourier analysis in Matlab (Student Version Release 13) to determine if there was a diel periodicity in red snapper movement. Platforms ST135-M and ST128-R were included in this analysis because they were the most highly populated platforms. This analysis was limited to data collected before the decrease in ping detection rate in late July, 2003 (at hour 1669.) Hours 0-263 of the data set were removed to allow a recovery period of two days for the last set of post-surgery red snapper released. The average number of pings per fish was calculated for each hour from hour 264 to hour 1668 at both ST135-M and ST128-R. This calculation was performed to normalize the total number of pings to the actual

number of tagged red snapper present, accounting for the decrease in number of tagged snapper at each location through time. The average number of pings per fish was used as a proxy for distance from the platform, under the assumption that more detections would be received from fish closer to the platform than for fish farther from the platform because the strength of the acoustic signal decreases with distance transmitted. It is probable that some acoustic pings from red snapper in very close proximity to the platform were deflected by a cross member or support piling, which could also cause a decrease in the average pings per fish, but because red snapper tend to constantly swim around and through platforms it is unlikely that a great number of consecutive pings were missed. These time series were filtered by removing any data point more than two standard deviations from the mean. This filter was applied three times. The time series were then smoothed with a sliding box filter with a three-hour window, meaning that each data point was replaced with the average of itself and the points on either side of it (personal communication, Mark Benfield, Louisiana State University, 17 October, 2003). These time series were then subjected to a Fourier transform to decompose the times series into individual sinusoidal components, which when added together would yield the original signal.

A second time series was calculated with the average number of pings per fish for every hour (0:00-23:00) of each day during the same time period used in the Fourier analysis. Data from platforms ST135-M and ST128-R were combined in this time series. These data were fitted with a local regression using the LOESS procedure in SAS (SAS Institute Inc., 2003), a nonparametric method for estimating regression surfaces where the regression surface is fitted to data points within a chosen neighborhood of each value of the independent variable, to determine if local regression could describe a pattern of diel movement away from the platform.

RESULTS

During this study 125 red snapper were tagged and implanted with acoustic pingers. The limiting factor in the number of red snapper tagged was the number captured by volunteer anglers, not the length of time necessary to implant the pingers as was expected. The surgical tagging procedure lasted no more than ten minutes per fish including anaesthetization time. Tagged red snapper ranged in TL from 28 to 47 cm, with a mean length of 36 cm (Figure 10). The majority of tagged red snapper were smaller than legal size. Ages estimated from these lengths (using Wilson and Nieland, 2001) indicate these fish were predominately in the 2 to 4 year old age classes, with the possibility of some 5 year old fish. Weight was also estimated

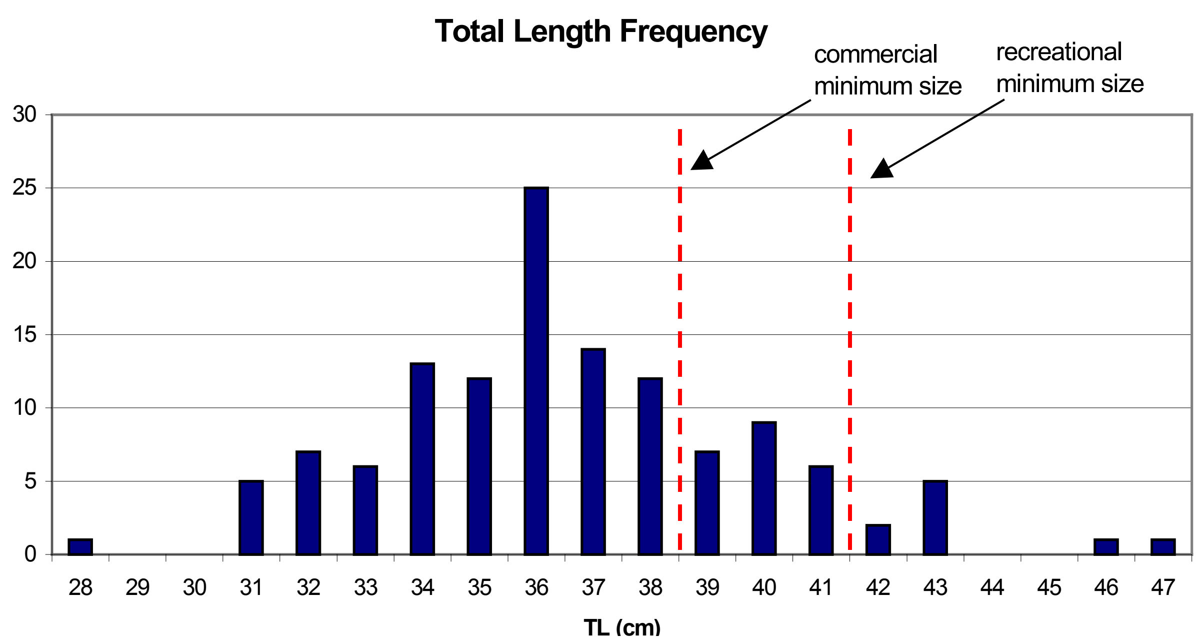


Figure 10: Histogram of the total length frequency of tagged red snapper.

from these lengths (using Wilson and Nieland, 2001) and compared to the pinger weight, revealing that the 5 gram pingers ranged from 0.3-1.6% of the body weight of tagged red snapper. This range is well below the limits given by Winter (1983) who recommended that pingers weigh less than 2% of the fish weight and by Wolcott (1995) who recommended a range

of no more than 2-5%. ROV footage revealed that upon release red snapper had no difficulties navigating out of the hoop net and orienting towards the platform. Seventy-nine percent of the fish were assigned a release condition class of 1, fish that swam down immediately after being release, 19% were assigned a release condition class of 2, fish that hesitated then swam towards the bottom, and 2% were assigned a condition class of 3, fish that floated at the surface momentarily before swimming towards the bottom. Fish movement was examined in light of these data. There were no apparent differences in the behavior of condition class 1 and condition class 2 fish, although the fish assigned to condition class 3 were either never detected or disappeared within a few days of release.

Storm Damage

In late June 2003, Tropical Storm Bill moved through the study area, affecting some of the receiver deployment equipment. When the equipment was checked on 11 July, it was evident that the brass crimps used to form loops at the ends of cables had been eroded and weakened by electrolysis allowing the storm to break the crimps and pull some cables loose. The receiver and mounting apparatus was completely lost from ST134-W; the receiver at ST134-S had been torn loose, was damaged, and flooded. No red snapper had been released at either location, and when the data file from the latter location was downloaded, it contained no detections. The receivers and mounting apparati at ST128-R, ST151-Y, and ST151-O were unharmed. Some of the cables at ST151-I and ST135-M became detached during the storm, so the receivers were temporarily suspended from the cross beam until the cabling system could be repaired. The receiver from ST151-I was also flooded, but examination of the data file revealed that the receiver had actually ceased to collect data six hours after it was originally deployed on 21 May; the manufacturer accepted responsibility for this malfunction, damage, and data loss

(personal communication, Glenn Coady, VEMCO Ltd., 23 July, 2003). The receiver deployment system was slightly modified to eliminate the brass crimps and avoid further issues with electrolysis. On 29 July the cabling systems at all platforms were repaired. On this date a receiver was also deployed at ST135-Q, replacing the receiver at ST134-W, because 19 red snapper had been released at ST135-Q and no specimens had been released at ST134-W; therefore, red snapper released at ST135-Q were only detected if they were still present at that site after 29 July.

Thermocline

While repairing the cabling at ST135-M on 29 July, 2003 a diver sensed the presence of a temperature gradient (thermocline) at approximately the same depth as the cross member used to deploy the receiver. When the receiver was positioned below the cross member, before repairs on the cabling system, it was in relatively colder water. After the cabling system was repaired and the receiver was remounted as in the original design, it was moved upward into warmer water. At the exact time and date the receiver was moved above the thermocline a severe decrease in ping detection rate is evident in the data. Around the same date other receivers also experienced decreases in ping detection rate. A detection is recorded by the receiver after all seven pulses in the pulse train are intercepted. If less than seven pulses are intercepted the receiver counts these pulses, but does not record a detection. From these data it is possible to estimate the minimum number of detections that should have been recorded if all seven pulses of each train had been intercepted, in other words, a theoretical number of detections. The ratio of actual detections to theoretical detections gives an estimate of the ping detection rate. The ping detection rate at ST135-M during the three weeks before the receiver was moved, when the receiver was below the thermocline, was 21.8%, whereas during the three weeks after the

receiver was moved above the thermocline the ping detection rate fell to 5.5%. Over these same time intervals, the ping detection rate at the receiver on ST151-Y decreased from 22.2% to 9.3%, and the detection rate at the receiver on ST138-R decreased from 31.7% to 18.1%. On 28 July, the day before the receiver at ST135-M was moved above the thermocline, it received 324 detections from 16 fish. On 30 July, the day after the receiver was moved above the thermocline, it received only 4 detections from 4 fish.

VEMCO reported that a thermocline could dampen and deflect the acoustic signals (personal communication, Glenn Coady, VEMCO Ltd., 16 December, 2003). I conducted a test at a platform by concurrently hanging one receiver above the thermocline and one below the thermocline for half an hour; the receiver below the thermocline detected 20 times as many pings as the receiver above the thermocline. The ping detection rate of the receiver below the thermocline was 38.9% whereas the ping detection rate above the thermocline was 9.6%. These facts, along with the anecdotal information provided by the diver has led me to attribute this decrease in ping detection to the putative development of a thermocline between the receivers and the lower half of the water column where red snapper are predominantly found (Continental Shelf Associates, 1982; Rademacher and Render, 2003). Unfortunately, environmental data were not collected continuously throughout the study because of low frequency of visits to the study site and constraints on equipment transport to the oil field during data download trips. Historic cruise data (1994-2003) collected within 15 miles of the study area in the month of July shows evidence that thermoclines are common in this region at depths between 15 and 25 meters with temperature changes of up to eight degrees Celsius (data supplied by Nancy Rabalais, Louisiana Universities Marine Consortium, 11 February, 2004). Subsequent CTD casts from

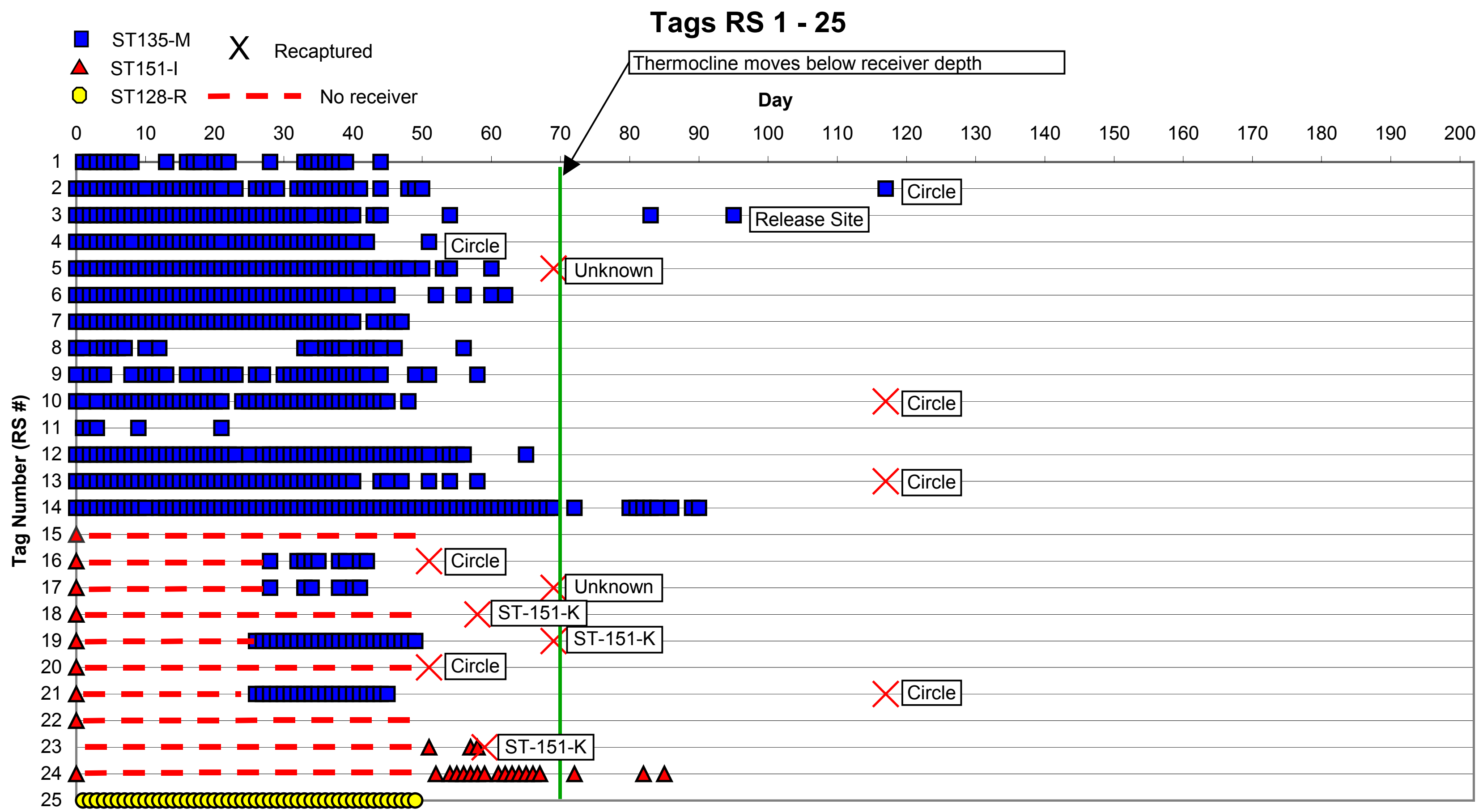
charter vessels during this study revealed that the water column in the study area was moderately mixed with no severe thermoclines by mid October, 2003.

Acoustic Range Test

The maximum distance between the V8SC pinger and VR2 receiver for successful detection was between 30 and 180 m, dependent upon geographical position of the pinger relative to the platform. Therefore, tagged red snapper at distances greater than 180 m from the receiver were unlikely to be detected during the study; tagged snapper within 180 m of the receiver were likely to be detected unless the acoustic signal was deflected by a thermocline or blocked by cross-members or support pilings of the platform. This range of detection could vary with changes in the ambient noise caused by wind and wave action, water turbulence, and anthropogenic noise such as boat motors and drilling operations on the platforms. Therefore, a realistic estimate of the actual range of detection on any given day may be closer to 50-75 m.

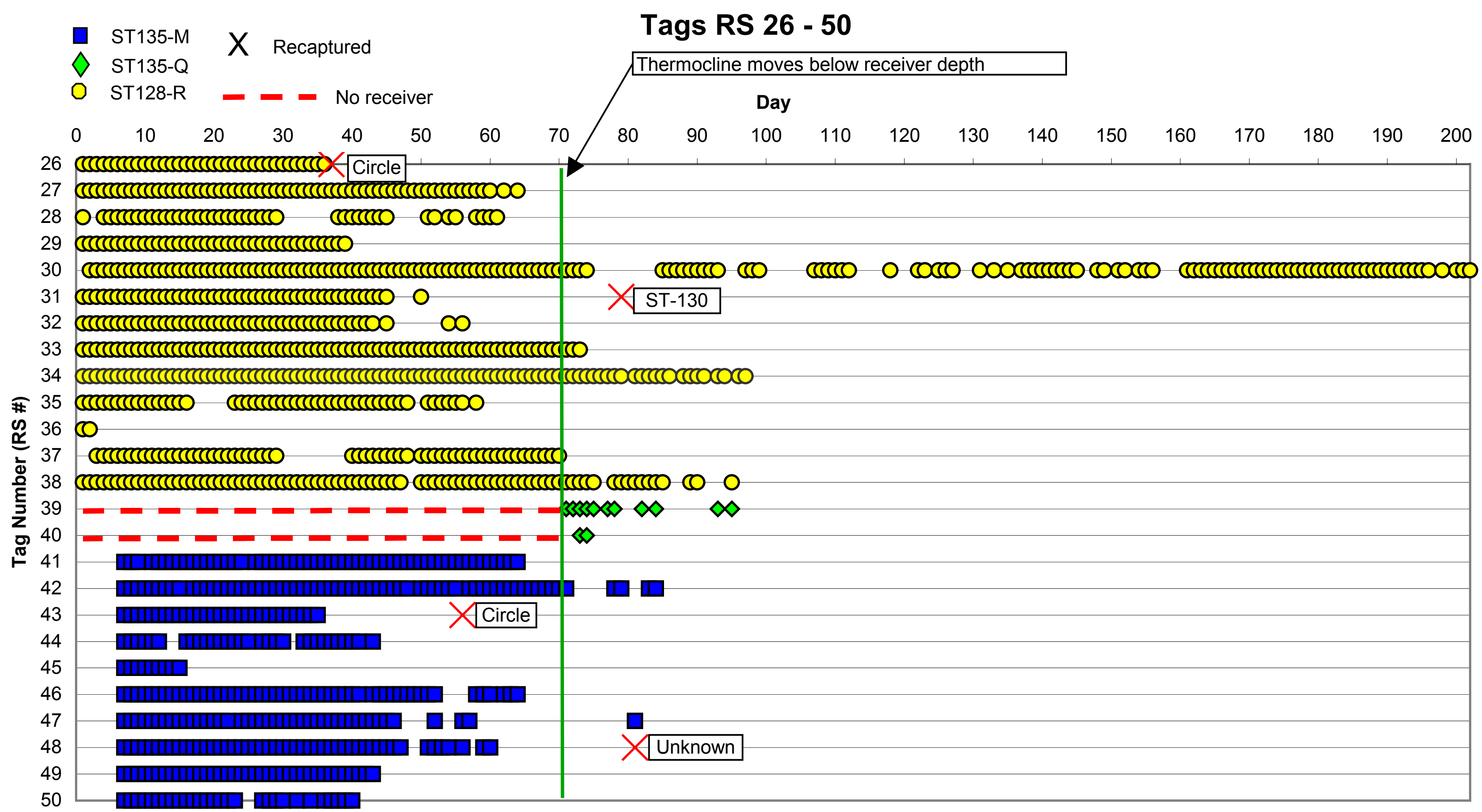
Daily Location of Individual Red Snapper

The acoustic data was best illustrated by depicting the daily presence and location of each tagged red snapper (Figure 11). In general, presence vs. absence was highly variable with individual fish, receiver location, and time. Each horizontal line in Figure 11 is a different red snapper and the different shaded symbols represented different locations; therefore, a change in symbol within a line represents a change in location for that fish. The large X's are located at the approximate date of recapture for any red snapper reported by fishermen and the X's are labeled with most specific recapture location known. The fishermen did not always provide a specific date of capture or location, therefore the placement of the X is an estimation of the date of capture and the location is as specified by the fishermen. The vertical line at day 70 denotes the



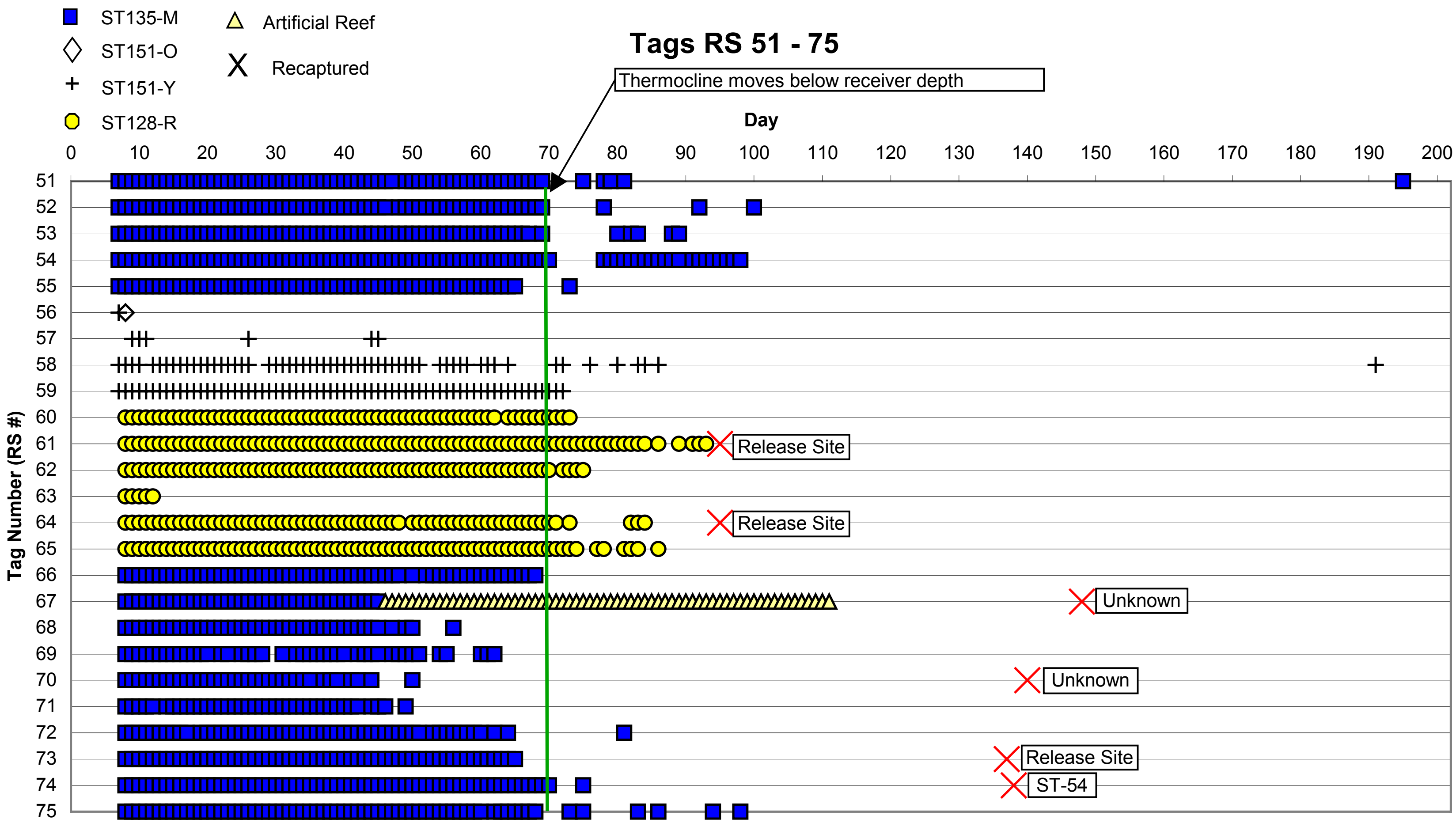
(a)

Figure 11: Daily locations of tagged red snapper a) RS 1 - 25, b) RS 26 - 50 c) RS 51- 75 and d) RS 76 - 97. Different symbols represent different locations, dashed lines denote a period not covered by a receiver, X's and labels denote when and where a red snapper was recaptured, and the vertical line at day 70 denotes the suspected interference of the thermocline with ping detection.



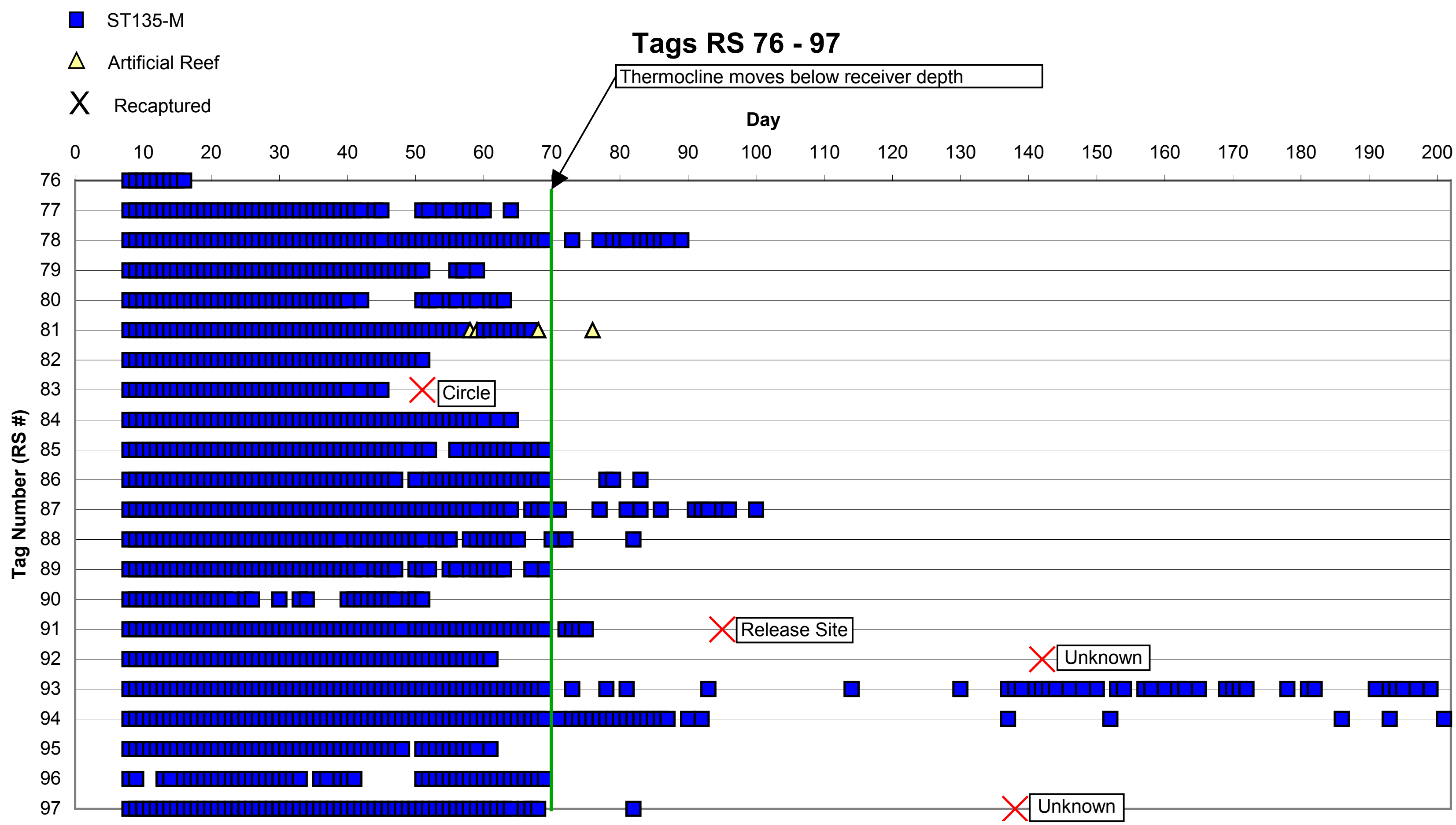
(b)

Figure 11 cont'd



(c)

Figure 11 cont'd



(d)

Figure 11 cont'd

approximate date that I suspect the putative thermocline began to interfere with ping detection rate. The time period during which a receiver malfunctioned or was missing is denoted by dashed lines for all red snapper released at those sites (ST151-I and ST135-Q.)

Ninety-seven of the 125 tagged red snapper were detected during the study. Seventeen of the 19 snapper released at ST135-Q were no longer present when the receiver was deployed there in late July. Seven of the 17 red snapper released at ST151-I were not detected before the initial receiver failed or after another was deployed there in mid-July. The other four fish tagged but not detected could have had possible pinger malfunctions. As the receiver at any given platform was deployed in advance of the release of any tagged snapper at that location, it is unlikely that a functioning pinger was not detected at least once even if the snapper immediately swam away from the platform or was preyed upon.

Red snapper movement between receivers appeared to be sparse and erratic. Seven of the 97 detected fish moved to another receiver during the study with little evidence of homing behavior or uniform directional movement. A map displaying the geographical movement of these fish is displayed in Figure 12. Approximately three weeks after release, four red snapper from ST151-I moved to ST135-M, the next platform to the north, stayed at that platform for two to three weeks, then were not detected again (tag numbers RS 16, 17, 19, and 21; Figures 11a and 12). One of these fish (RS 19) was eventually caught at ST151-K (28° 36.977' N, 90° 15.374' W), a platform 2 km to the south of ST151-I. Another red snapper (RS 56; Figures 11c and 12) was released at ST151-Y, was detected at ST151-O (only 300 meters to the west) the next day, then was not detected again. RS 67 (Figures 11c and 12) was released at ST135-M, stayed there for approximately 45 days, and then moved to the artificial reef 1.5 km to the east. RS 67 stayed at the artificial reef for the next two months then was not detected again. RS 81

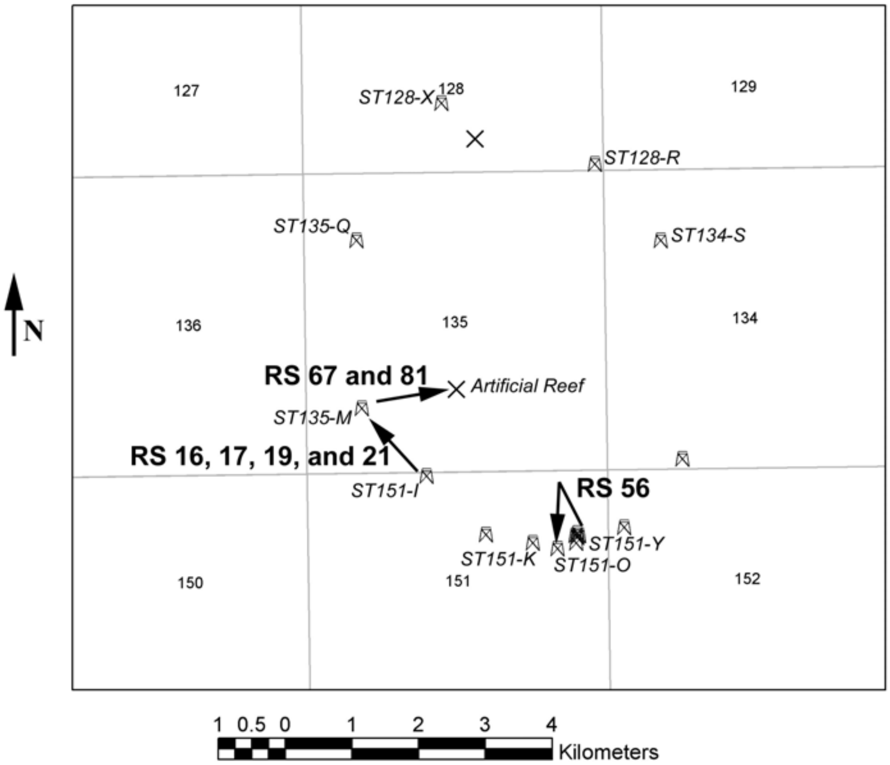


Figure 12: Map showing the starting and ending points for the seven red snapper that displayed movement between receivers.

(Figures 11d and 12) was released at platform ST135-M where it remained for over two months. Just before that snapper left the area, it was periodically detected at the artificial reef over a few days.

None of the relocated snapper showed any definitive homing behavior. Of the seven snapper that showed movement between receivers, six were relocated fish (RS 16, 17, 19, 21, 56, and 67). Four were caught at ST135-Q and relocated to ST151-I (RS 16, 17, 19, and 21). The northward movement shown by these four fish to ST135-M and then subsequent disappearance could have been homing behavior to ST135-Q, which was north of ST135-M. However, RS 19 was caught at ST151-K, farther to the south, and RS 21, which was the only one of these four snapper remaining in the population when the receiver was deployed at ST135-Q, was never detected there. RS 56 was captured at ST151-I and relocated to ST151-Y; there is no evidence that it homed toward ST151-I. RS 67 was also a relocated fish, originally captured at ST134-S

and released at ST135-M. Although this snapper did move east to the artificial reef receiver, it was never detected at ST134-S. The only location from where red snapper were relocated that was not covered by a receiver was an artificial reef located between platforms ST128-X (28° 40.564’ N, 90° 16.121’ W) and ST128-R (Figure 8). Some snapper were also relocated from ST135-Q, which was not covered by a receiver until late July.

Fish Recaptures

Tags returned from recaptured fish provided information about red snapper movement within The Circle but beyond the limited acoustic confines of the receivers, and about large-scale movement of fish that left The Circle. Of the 125 tagged red snapper, at least 36 were recaptured by fishermen. Fourteen recapture reports came with platform specific information, 14 came with area specific information (for instance a lease block or general region such as The Circle), and eight came with no location information. Seven snapper were definitely recaptured at a site other than their release location. The release and recapture locations, approximate length at tagging, time at liberty, time since last detection, and distance and direction traveled for these seven red snapper are shown in Table 2; the release and recapture locations are geographically displayed on a map (Figure 13). The range in days at liberty was great, from 5 to 130 days, as was the distance traveled, from 2 to 25 km. Many of these red snapper displayed movement with an eastward component, though southward, northward, and westward components were also shown. In addition, one to two other snapper may have been recaptured and released by fishermen 32 km to the east of the study area. These reports were heard as rumors and were never confirmed.

Of the 36 red snapper recaptured by fishermen, two were recaptured before Tropical Storm Bill in late June, 2003. One was recaptured at the artificial reef between ST128-X and ST128-R and the other was recaptured at an unknown location. This second snapper was

detected at the site of release up until the approximate date of recapture, so it is likely that it was recaptured at this site. Of the 34 red snapper that were recaptured after the tropical storm, six had definitely moved away from their release sites.

Table 2: Red snapper recaptured at locations other than their release sites.

Fish Number	Release Location	Recapture Location	Length at Tagging (TL cm)	Days at Liberty	Days since last detection	Distance Traveled (km)	Direction
RS 98	ST151-I	APCs	40	5	5*	5	NE
RS 99	ST151-I	ST151-K	38	59	58*	2	SE
RS 18	ST151-I	ST151-K	36	59	58	2	SE
RS 23	ST151-I	ST151-K	35	59	0	2	SE
RS 19	ST151-I	ST151-K	37	70	20	2	SE
RS 31	ST128-R	ST130	38	79	29	9	E
RS 74	ST135-M	ST54	36	130	44**	25	NW

*Since no detections were made, the date of last detection was assumed to be the release date.
**The last detection was considered to be when the fish was captured and released by a charterboat.

Fishing Mortality

Estimates of fishing mortality ranged from 0.36 to 6.7 depending on the combination of natural mortality and reporting rate (Table 3). Reporting rates lower than 30% were impossible without forcing total annual mortality to exceed 100%.

Table 3: Estimates of instantaneous fishing mortality rates from various combinations of tag reporting rate and instantaneous natural mortality rate (M).

Tag -reporting rate:	100%	80%	60%	40%	30%
M=0.1	0.36	0.47	0.7	1.42	4.65
M=0.2	0.38	0.5	0.74	1.54	6.7

Logistic Regression

The acoustic data was edited in three different ways for use in the logistic regression. The first data set included fish not recaptured by fishermen, the second contained the same fish as the first dataset but also included recaptured fish for which recapture location and date were known, and the third dataset included all fish. These data sets yielded little variation in results; therefore I am reporting only the results of the regression on the first data set, containing fish that were not recaptured by fishermen. The results of the three logistic regressions models, Base

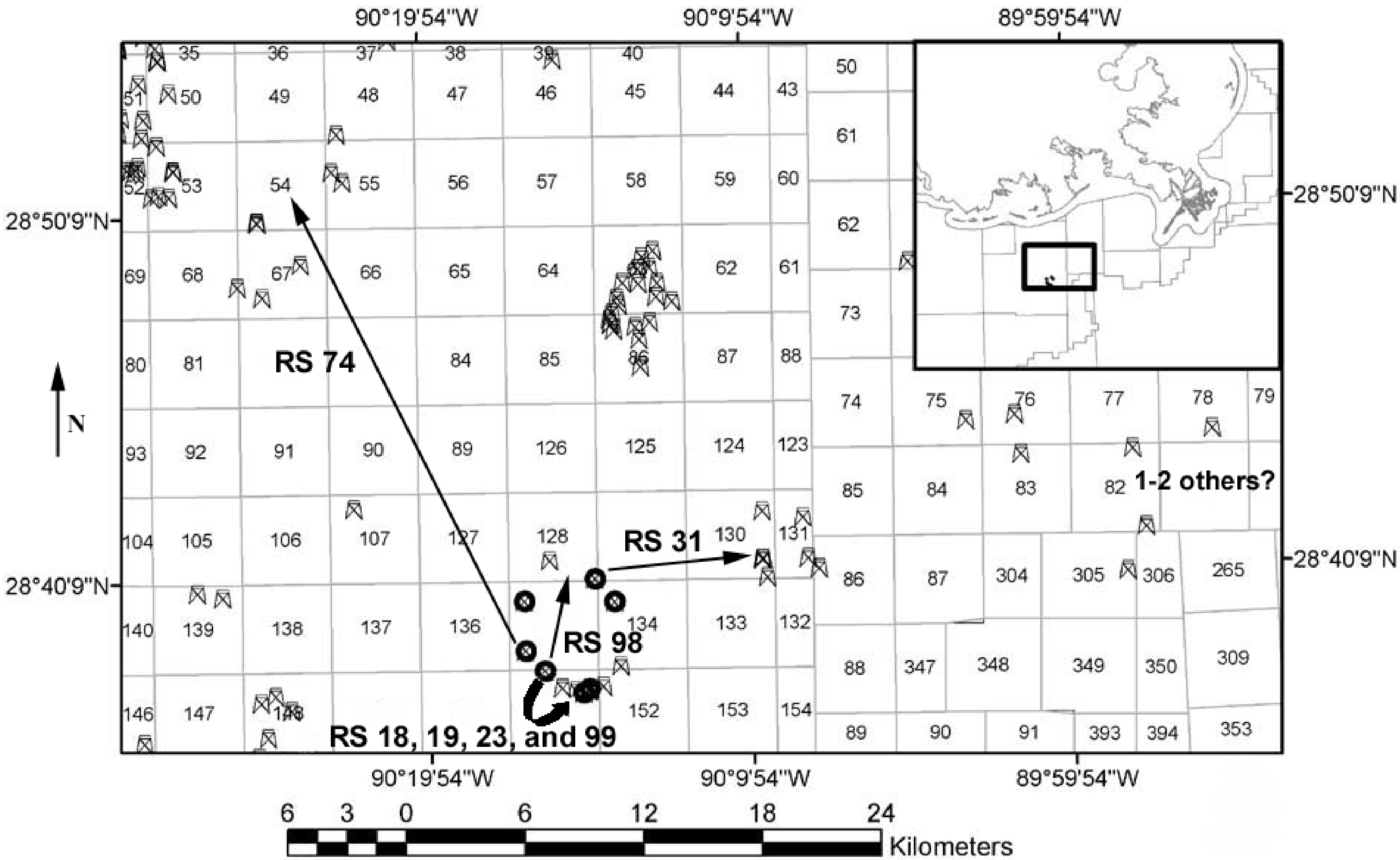


Figure 13: Map showing the starting and ending points for the seven red snapper that were recaptured at locations other than their release sites. The unconfirmed location where one or two other red snapper may have been recaptured and released east of the study area is also shown.

(including the variables Period and Population), Thermocline (Period, Population, and Thermocline), and Location (Period, Population, and Location; see Materials and Methods, page 29, for model descriptions), are displayed in Table 4. All of the models were significant at alpha=0.05. The results of the three logistic regression models, including p-values and odds ratio estimates (ratio of the probability of an event occurring, or presence of a red snapper, and the probability of the event not occurring, or absence of a red snapper) are shown in Table 4.

Table 4: Results of the three logistic regression models: Base, Thermocline, and Location.

	chi-square	d.f.	p-value	odds ratio estimate
Base Model	876.41	3	<0.0001	
Period	295.99	1	<0.0001	0.71
Population (native vs. relocated)	11.08	1	0.0009	3.62
Period*Population	12.40	1	0.0004	
Thermocline Model	926.43	4	<0.0001	
Period	259.33	1	<0.0001	0.75
Population	8.21	1	0.0042	2.92
Thermocline (1 vs. 0)	50.12	1	<0.0001	0.24
Period*Population	9.14	1	0.0025	
Location Model	882.36	5	<0.0001	
Period	292.55	1	<0.0001	0.70
Population (native vs. relocated)	6.27	1	0.0123	3.06
Location	5.69	2	0.0581	
ST135-M vs. ST151-Y				2.12
ST128-R vs. ST151-Y				2.46
Period*Population	10.94	1	0.0009	

The Base Model was used to predict the probability of presence at release location for an individual fish. These predicted probabilities were graphed and are shown in Figure 14. Both populations (native and relocated) have been plotted with their 95% confidence intervals. The probability of presence decreases with time (Period), approaching zero at period 20. In the earlier periods, the relocated population has a lower probability of presence and the 95%

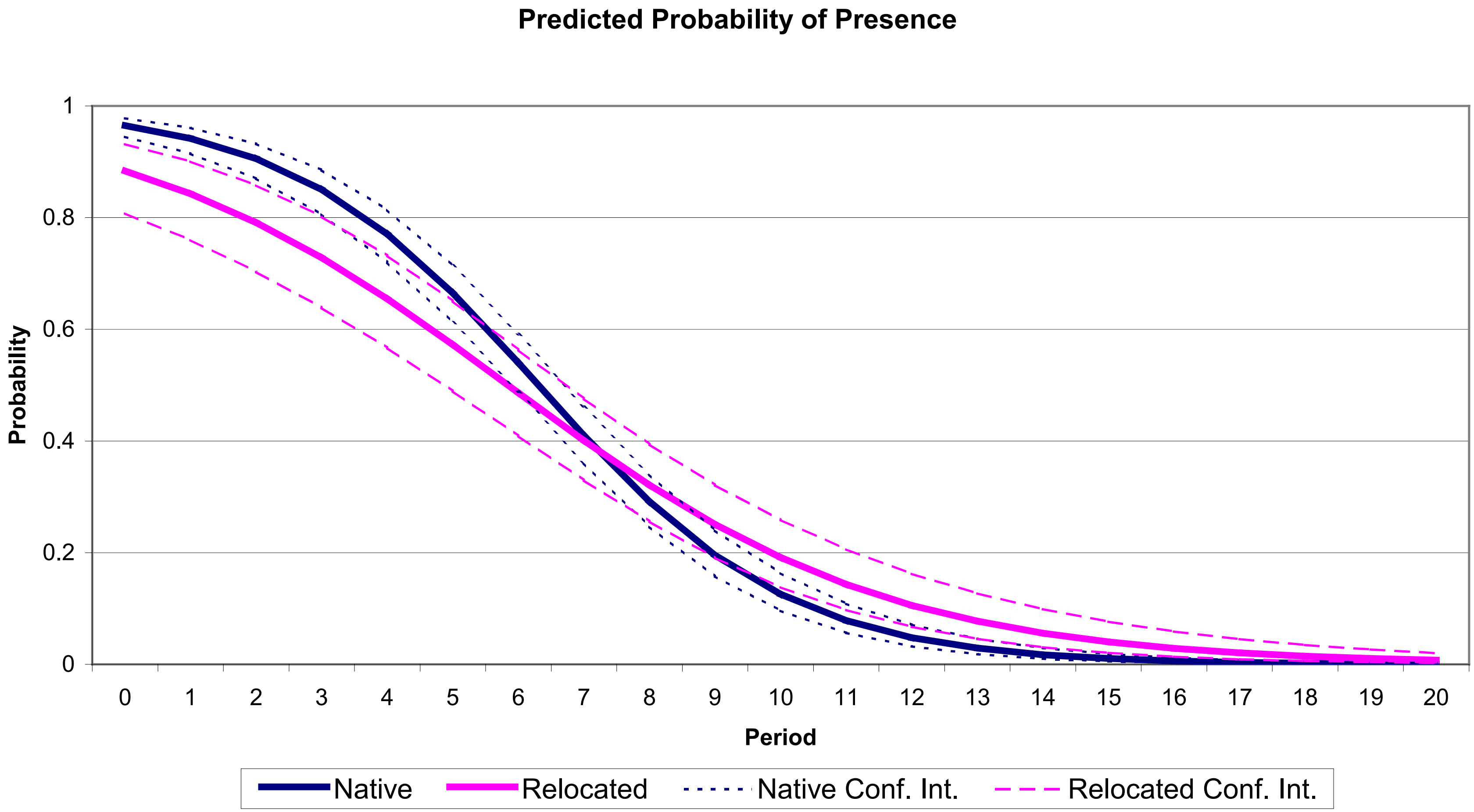


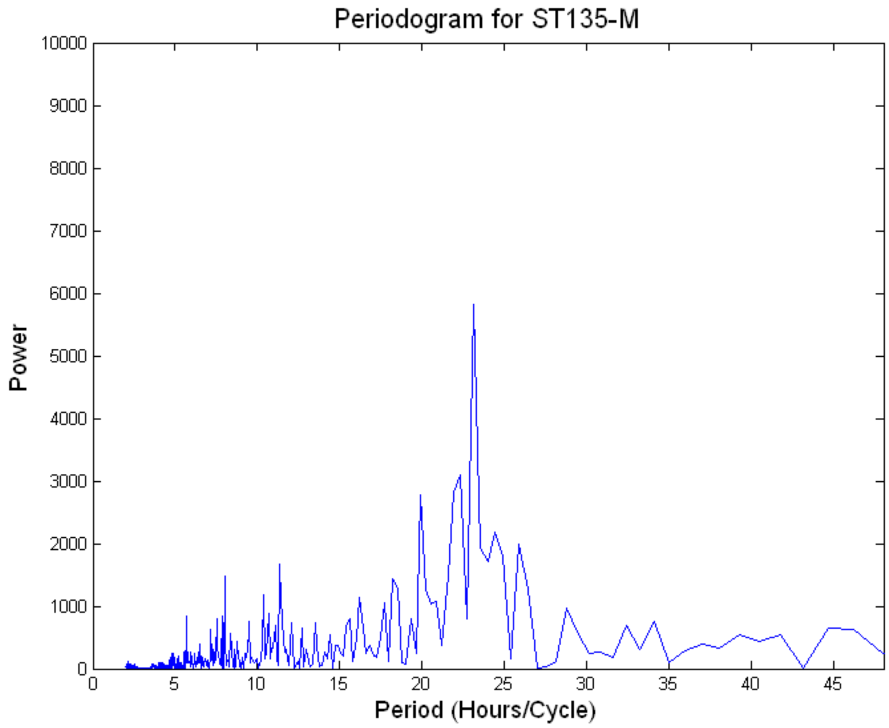
Figure 14: Predicted probability of presence at release location for both native and relocated snapper. Dashed lines are 95% confidence intervals.

confidence intervals do not overlap. During the later periods the relocated population has a higher probability of presence, but the 95% confidence intervals overlap during these periods.

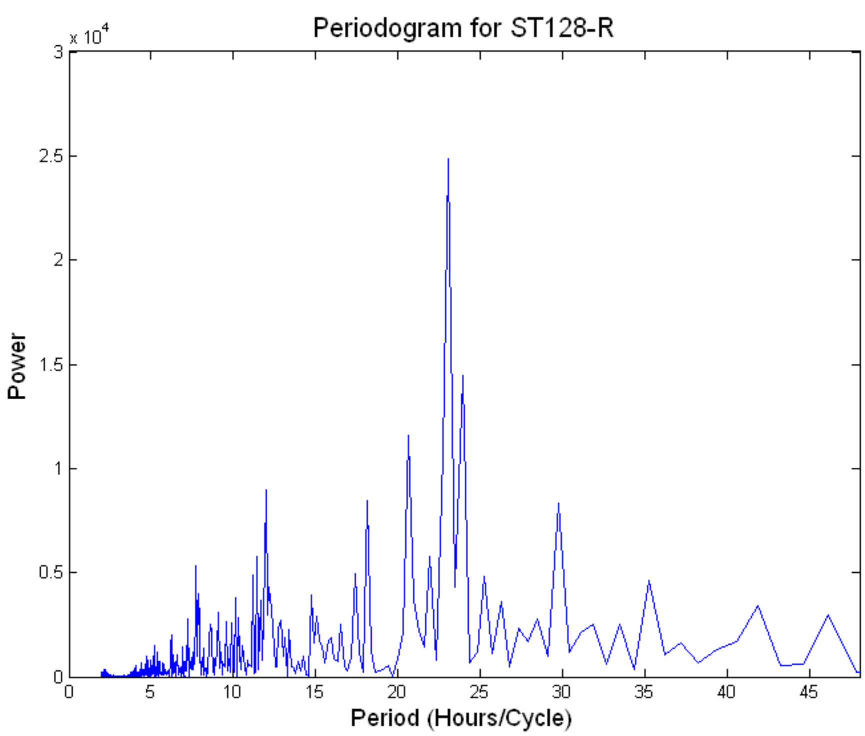
Fourier Analysis

The Fourier analysis was conducted to determine if red snapper exhibit diel movement away from platforms. Fourier analysis decomposes a signal into many individual sine functions. Periodograms show the period (hours/cycle) and power, or magnitude, of each sine function. The resulting periodograms for ST135-M and ST128-R (the locations where the majority of tagged red snapper were released) are shown in Figure 15. The red snapper populations at ST135-M (Figure 15a) and ST128-R (Figure 15b) had very similar patterns of periodicity with the most powerful sine functions centered on a period of 24 hours/cycle. These 24-hour cycles represent a pattern of diel movement away from the receivers.

The LOESS procedure revealed that red snapper are closest to the platform (the greatest number of pings, or detections, per fish) during the daylight hours, and farther from the platform at night (lower number of pings per fish.) The LOESS procedure also shows that the greatest movement away from platforms during the night occurs around sunset and just before sunrise. The actual distribution of pings per fish as a scatter plot with the predicted pings per fish overlaid as a local regression line is presented in Figure 16.



(a)



(b)

Figure 15: Periodograms for ST135-M (a) and ST128-R (b) showing the period and power of the sine functions describing red snapper movement away from the platforms.

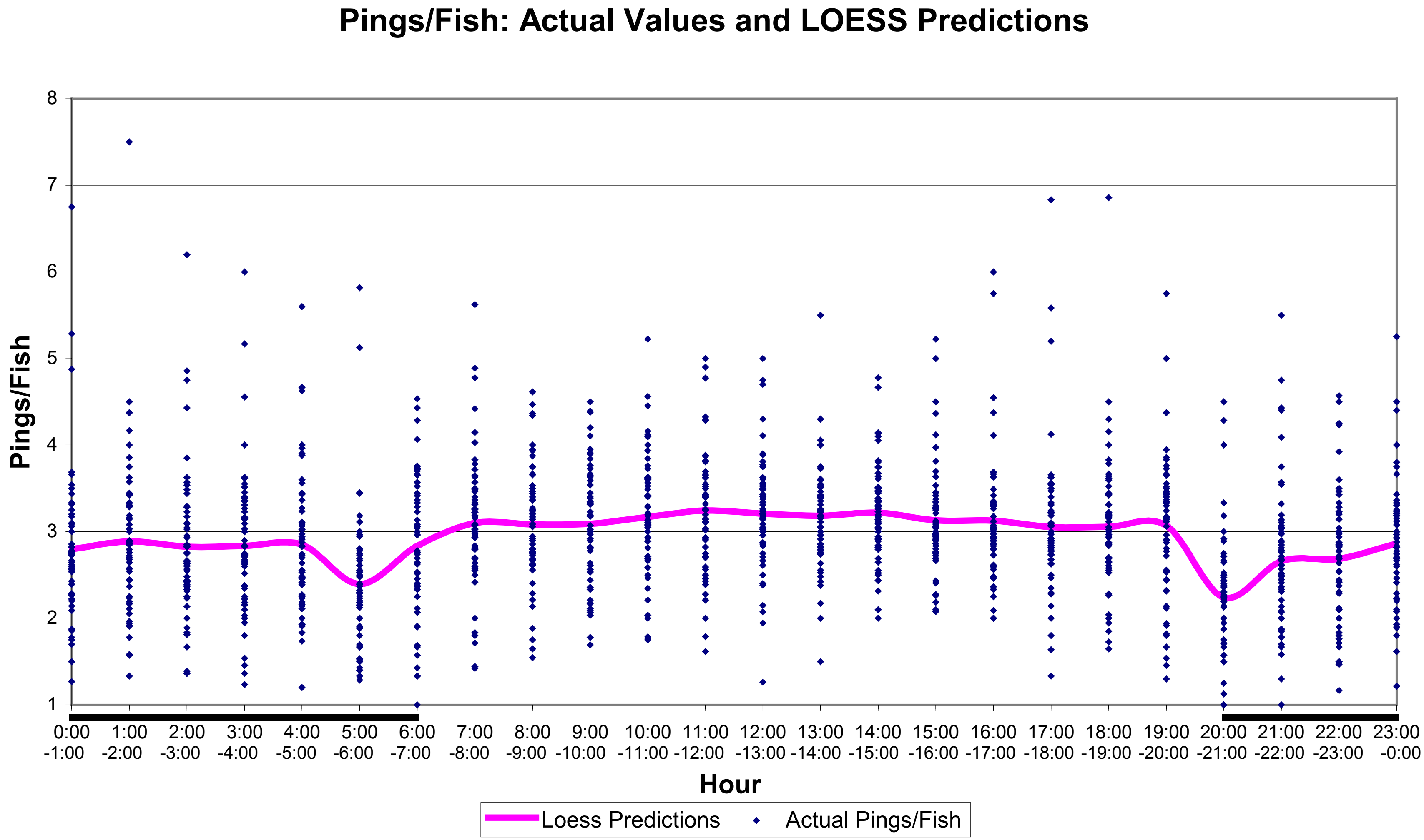


Figure 16: The actual values of pings/fish and LOESS predicted values of pings/fish for each hour of the day. The black bar below the x-axis denotes nighttime hours.

Pinger Malfunction

After pingers were returned by fishermen each were tested in the lab and the majority were pinging as expected. Initially any malfunction was attributed to the pingers being frozen inside the fish before being returned to my possession. In January of 2004, while using these tags to test acoustic receivers in the laboratory, I discovered that a great number of pingers that had been functioning properly when returned by fishermen were no longer functioning after storage in the lab for a few months. These pingers had been activated for a total of eight months (the original specification for these pingers predicted a battery life of over 400 days (personal communication, Dale Webber, VEMCO Ltd., February, 2003).) Thirty of the 32 pingers that I had received from fishermen were not functioning properly or at all, so a portion of the tags were returned to VEMCO for testing. VEMCO found that the battery power was expended and informed me that the batteries may have come from a "bad" batch (personal communication, Glenn Coady, VEMCO Ltd., 25 February, 2003). Further testing revealed that some tags were still transmitting an acoustic signal, though the output was very low, indicating that the battery capacity had dropped off fairly recently (personal communication, Glenn Coady, VEMCO Ltd., 26 February, 2003). It was impossible to differentiate between a red snapper leaving the study area and a pinger battery failing. Because most pingers returned by fishermen during the first few months of the study were operating correctly I made the assumption that most pingers still in the field were operating correctly during the first few months of the study, when the majority of the acoustic data were collected. Thus, I completed the analyses as planned keeping in mind that the acoustic data used to examine site fidelity may have been incorrect.

DISCUSSION

Analysis of fish recapture and acoustic data revealed lower site fidelity and less uniform directional movement than shown by previous research on red snapper. The estimates of instantaneous fishing mortality were generally greater than the current value predicted by red snapper stock assessment. Red snapper at platforms exhibit diel movements away from the platforms during the night that may be explained by offsite foraging behavior.

Site Fidelity

The apparent site fidelity of red snapper is dependent upon the time scale being examined, whether days, weeks, months, or years. The daily locations of each fish were used to examine site fidelity on a scale of weeks and suggest low short-term site fidelity. The logistic regression was used to examine site fidelity on a longer-term scale, months, and predicts much lower site fidelity. Watterson et al. (1998) define site fidelity in terms of the percentage of fish recaptured at the site of release. For this study I modified their definition to the percentage of red snapper acoustically detected at the site of release.

Red snapper in this study displayed high short-term fidelity and relocated fish showed no evidence of homing behavior to original capture locations. The majority of tagged snapper did not exhibit movement between receiver locations on a daily or weekly, or in most cases, even a monthly basis (Figure 11). Although six of the seven red snapper that did move between receiver locations were relocated snapper, none showed evidence of homing back to their original capture location. Watterson et al. (1998) and Patterson et al. (2001) also relocated red snapper; Watterson et al. (1998) did not report any homing behavior and Patterson et al. (2001)

reported only one out of 111 transported red snapper recaptured at its original capture site. None of the 35 relocated snapper in this study were detected or recaptured at the original capture site.

The logistic regression used the acoustic data to predict the probability of an individual fish's presence at the location of release. The Base Model was the simplest, testing whether or not Period (time) and Population (native vs. relocated) influenced site fidelity. The Thermocline Model tested the influence of the thermocline on the probability of presence of individual fish and the Location Model tested whether or not red snapper exhibited different site fidelity at different receiver locations. The results of the logistic regression suggest that the longer-term site fidelity of red snapper is very low, perhaps approaching zero, and much less than short-term site fidelity.

The Base Model predicts that both Period (time) and Population (whether a fish was native or relocated) affect the site fidelity of red snapper. Odds ratios are used in logistic regression to describe the ratio of the probability of an event occurring and the probability of the event not occurring (i.e. the opposite event). For instance, the logistic regression Base Model gives an odds ratio estimate of 0.71 for the variable Period. This is interpreted as the odds of presence (or likelihood of presence compared to the likelihood of absence) decreasing by 29% for each unit of Period, or every ten days. This suggests that site fidelity decreases with time. The odds ratio estimate of 3.62 for Population is interpreted as the likelihood of presence for a native snapper being 3.62 times the likelihood of presence for a relocated snapper. In terms of site fidelity, native red snapper exhibit higher site fidelity than relocated red snapper. These results concur with the results of Watterson et al. (1998) who reported that 77% of recaptures of transported red snapper had moved from the release site whereas only 39% of recaptures of non-transported red snapper had moved from the release site. Patterson et al. (2001) also reported

that non-capture release site (transportation of red snapper) increased probability of fish movement. Explanation for this phenomenon is elusive, though it may be related to environmental carrying capacity or red snapper behavior. Any given platform may only be able to support a given number of red snapper, and some locations may be more suitable than others. Charter fishermen who frequent The Circle quickly become knowledgeable of which platforms tend to yield the most red snapper (personal communication, Steve Tomeny Charters, 2003). Some platforms may provide better habitat than others because of quantity and/or quality of food, competition with other species for resources, and the risk of predation. Another possibility is if the environment at a platform is already ecologically balanced or saturated with red snapper, the habitat may not be able to support additional red snapper, forcing the exodus of a certain number of red snapper to regain the ecological balance. Red snapper could exhibit this sort of social structure or interspecific and intraspecific competition for shared resources; studies have shown these type of interactions and competition by other species of reef fish, including other lutjanids (Mueller et al., 1994; Overholtzer and Motta, 1999; Munday et al., 2001). But the question remains, why are the new snapper, the relocated fish, those that leave the habitat? Are they driven away because they are not already established in the population at the platform? Do red snapper occupy such specific and limited niches at oil platforms and exhibit such rigorous social structure? The answers to these questions may lie in red snapper behavior and relationships and are not within the scope of this study, though they would make a very interesting study for an animal behaviorist.

The Thermocline Model predicts a significant relationship between the existence of the thermocline and a lower probability of presence. The changes in the odds ratio estimates for Period and Population are minor, and do not change the qualitative interpretation of these

variables. I do not believe that the presence of thermocline actually decreases the probability of presence of red snapper, but only decreases the probability that a receiver will successfully detect a tagged snapper. The odds ratio estimate (0.24) tells us that the likelihood of a detection decreases to 24%, approximately one quarter, of the original level while the putative thermocline is interfering with detection rate; this amount of decrease is proportionally similar to the decreases in ping detection rate described on pages 33 and 34. Care must be taken when interpreting these results for two reasons. First of all, the timing of the movement of the thermocline below the receiver depth in mid summer and subsequent dissipation in autumn are estimates because environmental data were not collected on a regular or continuous basis. Secondly, the estimated date for the movement of the thermocline below the receiver depth is shortly after a number of fish apparently left their sites of release. Therefore, Period and Thermocline may be somewhat confounding, or both attempting to explain the same variation.

The Location Model did not vary much from the Base Model. The variable Location was not significant, though it was close, with a p-value just above alpha=0.05. The odds ratio estimates for Period and Population were again not very different from those predicted by the Base Model.

The estimates of red snapper site fidelity resulting from this study differ from other studies conducted on the site fidelity of red snapper in the GOM. I found that red snapper exhibit high short-term site fidelity. They do not move from platform to platform on a daily or even weekly basis; following tagging red snapper remain at a platform for a few weeks to even a month or two. Longer-term, over a period of a few or more months, red snapper have low site fidelity; it is unlikely that a red snapper will remain at one location for more than a few consecutive months.

Though my short-term site fidelity estimates are not anomalous, every other study, whether traditional mark and recapture or acoustic telemetry, has found much higher site fidelity in the long-term. Beaumariage (1969) tagged and release 312 red snapper off the coast of Florida. Fishermen returned approximately 26% of those fish, and all but eight (>90%) had been recaptured at their site of release after being at liberty for an average of 113 days. Beaumariage and Bullock (1976) reported that red snapper show definite specific reef residency in shallow water and that the only extensive movement occurred at reefs in water deeper than 15 fathoms, which may have been forage-motivated or in response to reproductive stimuli. Fable (1980) tagged 299 red snapper at natural reefs off the coast of Texas. Although the tag return rate for red snapper was very low (5.6%), only one red snapper moved from its release location (<6% of the tag returns.) This fish was at liberty for 162 days and moved only 5 km. In another study off the coast of Texas, this time at the Buccaneer Oil Field, Gallaway et al. (1981) found very high site fidelity for red snapper: none of the tags returned or noted during a visual SCUBA census were found at a location other than where the snappers had been tagged. A red snapper study at artificial reefs off the coast of Alabama again reported high site fidelity (Szedlmayer and Shipp, 1994). Of 1,155 tagged red snapper, 146 were recaptured by fishermen, although only 37 of those were accompanied by known recapture location. Fifty-seven percent of these fish were taken at the site of release and 76% of recaptures were within 2 km. Watterson et al. (1998) conducted a study over a period of two years, tagging 1,604 red snapper at artificial reefs off the coast of Alabama, and concluded that red snapper generally display high site fidelity. The researchers and fishermen recaptured 167 fish. Almost 80% of recaptures that were not at liberty during a major hurricane were recaptured at their site of release, although red snapper at liberty during a major hurricane had a much higher likelihood of movement. Strelcheck (2001)

conducted a similar study in the same area, tagging 2,608 red snapper, and reported annual site fidelity to range from 49% and 72% dependent upon type of artificial reef. Patterson and Cowan (2003) continued the study by Watterson et al. (1998) and after tagging an additional 1,328 red snapper and collecting two more years of data, these authors estimated annual site fidelity to range from 24.8 to 26.5%. These results departed greatly from the results all of the previous work, though my current study departs to an even greater extent.

The studies reviewed thus far have all been traditional mark and recapture techniques. Only one other study has utilized acoustic telemetry, and yet still concluded that red snapper display limited movements and exhibit high site fidelity (Szedlmayer, 1997). This research was conducted at artificial reefs in the northeastern GOM off the coast of Alabama. Twenty-three red snapper were tagged with ultrasonic transmitters and release sites were acoustically scanned on a monthly basis for a period of nearly 20 months. Twelve red snapper remained at the site of release, seven moved distances less than one km, and four were not located after release. The authors concluded that the repeated locations of the tagged red snapper at the same artificial reef suggested high site fidelity.

It is important to note that none of the previously mentioned studies have taken place at platforms off the coast of Louisiana. Although Gallaway et al. (1981) also conducted their research at platforms, it is important to remember that since 1981 the number of platforms in the OCS region of the GOM has risen by almost 145% (Pulsipher et al., 2001). It is conceivable that red snapper in the north central GOM, off the coast of Louisiana, exhibit much lower site fidelity than in other regions of the GOM because of the proximity and plethora of available habitat in the form of platforms. Frazer and Lindberg (1994) showed that stone crabs (genus *Menippe*) showed lower residency, or site fidelity, at more closely spaced artificial reefs. This relates to

the ‘resource mosaic hypothesis’ proposed by Lindberg et al. (1990) which states that as reef spacing decreases, so does access to prey on the soft-bottom around each reef. The foraging haloes, or areas of depleted prey, at closely spaced reefs may overlap and cause a disproportional depletion of resources. At closely spaced reefs, foraging fish may be forced to travel greater distances to locate a suitable amount of prey, possibly encountering new habitat. Platforms are sometimes closely spaced, within a few hundred meters of each other; therefore red snapper may encounter numerous other suitable habitats on foraging forays. Because platforms offer such high relief, vertical habitat, they may support higher densities of fish than natural reefs (e.g. Wilson et al., 2003); therefore the foraging haloes at platforms may be even larger than would be found at natural reefs, forcing platform red snapper to forage at greater distances where they may lose sensory orientation to the platform, thus losing the ability to find their way back to that same platform.

Fish Recaptures

The fish recapture data, although not always as precise and complete as was desired, lends itself to the conclusion that red snapper movement does not appear to have a uniform direction. Red snapper that were at liberty longer moved greater distances, as though they gradually dispersed from their area of origin over time. There does not appear to be a pattern associating TL at time of tagging with distance moved; the largest of the seven snapper that showed movement traveled one of the shorter distances and the snapper that moved the greatest distance was one of the smallest of the seven. Contrary to these results, other studies have found evidence of uniform directional movement. Beaumariage (1969) found a general pattern of eastward movement of red snapper tagged off the Florida Panhandle. Watterson et al. (1998) and Patterson et al. (2001) found overall eastward movement of red snapper tagged off the coast

of Alabama. The area to the east where many of these fish were captured is also one that supports the highest recreational landings in the northern GOM; therefore this apparent eastward directional movement could simply have been a result of higher fishing pressure (Watterson et al., 1998). All three of these studies were conducted over much longer periods of time, had much larger sample sizes than the current study, and were conducted in the GOM east of the Mississippi River.

Watterson et al. (1998) and Patterson et al. (2001) found that hurricane events increased the probability and distance of red snapper movement. Tropical Storm Bill potentially affected fish movement in this study and passed through my site one month into the study. No departures of tagged fish coincided with the storm and since the majority of tags were returned after this storm (94.4%) it is difficult to determine if the storm increased the probability of fish movement in this study.

These estimates of red snapper movement must of course be taken as conservative. It is probable that not every recaptured red snapper was reported by fishermen and also possible that some snapper lost their external tags and were not reported when recaptured.

Fishing Mortality

The various combinations of natural mortality and tag reporting rates yielded a wide range of estimated instantaneous fishing mortality (F) values, ranging from 0.36 to 6.7. The most recent red snapper stock assessment panel report (GMFMC, 1999) predicted a current F ranging between 0.292 and 0.474 (dependent upon the value of the steepness parameter of the stock recruitment curve.) The smaller value is less the any of my estimates, though the larger value, 0.474, almost precisely matches the value resulting from the combination of a 0.1 natural mortality and a tag reporting rate of 80%. The stock assessment panel report also predicts that F

at Maximum Sustainable Yield (MSY) ranges from 0.097 to 0.118, values much lower than any of the F estimates in this study.

Although many tagging studies have discussed the potential bias due to tag reporting rates, few have attempted to directly predict these rates. Green et al. (1983) surreptitiously implanted tags during creel surveys in Texas; only 29% of the tags were returned. A study conducted in the western tropical Pacific Ocean found that the overall average reporting rate was 59% (Hampton, 1997). Heifetz and Maloney (2001) estimated tag reporting rates for sablefish in the northern Pacific Ocean to be 28%, although the rate varied greatly by region and year, with more recent years having higher reporting rates. Another study was undertaken to estimate a tag reporting rate for recreational red drum fishermen in South Carolina and Georgia (Smith and Woodward, 1999 in Latour et al., 2001); estimates ranged from 60% to 80%. Most of these tag reporting rates are lower than the 80% reporting rate that in combination with natural mortality of 0.1 yielded a value close to the stock assessment value.

As in many tagging studies, I did not directly estimate the tag return rate, but instead utilized a range of tag return rates to calculate fishing mortality. It is likely that the reporting rate for this study varied temporally and spatially. For the first four months of my study only the recreational red snapper fishery was open, the participants in which may be more likely to take note of a tag and report it. In October 2004 the commercial red snapper fishery opened and the recreational fishery closed. The pace on a commercial boat is generally much more intense and tags are more likely to be overlooked. Only two tagged fish (5% of the total returns) were reported from the commercial catch, and neither report was from the actual fishermen. A fish market and a restaurant reported tags after the snapper had been sold and shipped to Nashville, TN. In addition, I believe the tag reporting rate for red snapper recaptured in the study area may

have been higher than for red snapper recaptured outside of the study area. A large proportion, approximately 75% (Steve Tomeny Charters, personal communication, 6 April 2004), of the fishing pressure in The Circle is exerted by Steve Tomeny Charters, a charter boat business with which I worked very closely; it was responsible for 53% of my tag returns and I expect that their reporting rate approached 100%. As the tagged red snapper dispersed from the area with time they may have been more likely to be caught by non-charter fishermen who may have been less likely to report the tag. In fact, only non-charter recreational fishermen reported tagged fish that were recaptured outside of the study area.

In light of these results, I believe that a tag reporting rate of 40-60% is appropriate for this study. Regardless of the level of natural mortality used to calculate F, 40% and 60% reporting rates yield rather high fishing mortality estimates (0.7-1.54) in comparison to the 1999 stock assessment predictions. We must remember that the red snapper population sampled in this study is certainly not representative of the entire population of the GOM. These red snapper were of a limited size range and were tagged and recaptured primarily at platforms off the coast of Louisiana. Also, it may be possible that this area, because of its popularity with charter and private fishermen, may have a higher fishing mortality than the general red snapper population in the GOM.

Although the estimated values of instantaneous fishing mortality may be higher than expected, F may yet have been underestimated for a variety of reasons. The data used in this analysis are from a six-month period; collection of a full year's data likely would have resulted in more tag returns. In addition, as stated before, tagged fish recaptured by commercial fishermen were likely to go unnoticed and unreported. Tag shedding may also have resulted in an underestimation of recaptures. Patterson et al. (1999) used similar tags in red snapper and

found tag retention for red snapper at liberty 200 days (the approximate length of this study) was 87-96%. Any such increase in the tag return rate (*f*, Equation 1) would increase the exploitation rate (*u*, Equations 1 and 2), resulting in larger instantaneous fishing mortality rates (F, Equation 2).

Diel Movement

The results of the Fourier analysis and the LOESS procedure show that red snapper undergo a diel movement away from the receivers and platforms at night. The most likely explanation for the nocturnal movement away from the platform is feeding behavior. As stated previously, red snapper feed on benthic organisms, most likely moving off reef, or platform as the case may be, to feed. Other studies have reported that red snapper exhibit nocturnal feeding behavior. Moseley (1965) found that the diet of red snapper includes a high percentage of mantis shrimp, which is known to burrow into the sediment during the day and emerge at night and become vulnerable to predation. Beaumariage and Bullock (1976) also found a predominance of squid and mud-burrowing shrimp in the gut contents of red snapper and believed that to be evidence of nocturnal feeding behavior. Moseley (1965) and Bradley and Bryan (1975) both reported that night fishing for red snapper was much more productive than during the day, potentially signifying nocturnal feeding behavior. Recent research conducted at artificial reefs off of Alabama suggests that red snapper actually feed continuously during the 24-h cycle but exhibit a diel shift in prey categories; during the day red snapper foraged above the reef on water-column organisms and at night snapper foraged away from the reef on sand-associated organisms (McCawley, 2003). Combining the theories that red snapper feed off platform and feed nocturnally may explain why red snapper appear to move away from platforms at night: to feed on benthic organisms in the surrounding area.

Although the overall trend in my study shows a diel pattern with less presence at platforms during the night compared to the day, two troughs are depicted by the LOESS procedure, just before sunrise and at sunset, suggesting that red snapper may exhibit some sort of crepuscular movement. Crepuscular movement and nocturnal feeding behavior are not mutually exclusive. Fish exhibit crepuscular feeding behavior to take advantage of the overlap of diurnal and nocturnal organisms during the twilight periods as diurnal organisms settle into nighttime inactivity and nocturnal organisms initiate activity; during these times, predators are maximally active and successful (Helfman, 1986). Red snapper may take advantage of this overlap in potential prey by venturing on intense feeding forays at dusk and dawn, with intermittent feeding forays throughout the night. This behavior would explain the pattern shown by the LOESS procedure.

Pinger Malfunction

The premature loss of battery power in the pingers causes some lack of confidence in the acoustic data used to examine site fidelity. It is impossible to determine whether a fish was truly absent from an area or if the pinger lost power. The majority of pingers I retrieved from fishermen functioned through the end of the summer. Most of the apparent movement of red snapper away from the study area occurred during the early-mid summer and I believe that the pingers in those red snapper functioned beyond the summer months due to VEMCO's conclusion in February 2004 that the battery capacity appeared to have decreased recently. Some pingers functioned for much longer and may still exhibit the expected battery life. The site fidelity portions of this study have been compromised by the thermocline and pinger malfunction, but the data were analyzed as planned because the extent of these complications is not certain. The

analysis of diel movement, estimates of fishing mortality, and fish recapture data were all unaffected by the pinger malfunction.

CONCLUSIONS

Based on analysis of fish movement shown by acoustic data I conclude that on a short-term time scale (a few weeks) red snapper appear to exhibit high site fidelity but as the time scale increases (over a period of months) red snapper appear to exhibit lower site fidelity. Site fidelity on longer time scales, for instance on an annual basis, would likely appear even lower. In other words the probability of a red snapper remaining at one location decreases with time. Tagged red snapper showed little movement between receiver locations while in the study area, but as time increased the probability of a tagged fish remaining at its release locations decreased. Some of this decrease could be due to recaptures not reported by fishermen or by pinger battery failure. Relocated red snapper exhibited lower site fidelity than did native snapper, but these relocated fish did not display any homing behavior. The acoustic data also revealed diel movement away from the platforms at night, most likely for offsite feeding.

Based on the fish recapture data I conclude that red snapper in this region of GOM do not appear to display uniform directional movement. The tropical storm that passed through the study area did not appear to affect the probability or magnitude of red snapper movement. The estimates of instantaneous fishing mortality derived from the fish recapture data were higher than current red snapper stock assessment prediction, but are not unreasonable.

Even if the acoustic data used for the site fidelity analyses is incorrect due to pinger malfunction, rough estimates of site fidelity can be derived from the movement of red snapper between receivers and from fish recapture data. Thirteen of the 125 tagged red snapper moved away from their original release location over a period of six months. Therefore a maximum estimate of site fidelity for six months is 90%. Assuming that red snapper would continue to

disperse from the study area during the next six months, a maximum estimate of annual site fidelity would be 80%. It is highly unlikely that all red snapper movements were documented by acoustic data or fish recaptures, especially if pinger batteries failed, therefore actual site fidelity is likely to be much less than these maximum estimates.

Management Implications

One of the most controversial topics in artificial reef theory, and also very important to fishery managers if artificial reefs are utilized as a management tool, is the question of attraction vs. production. James Bohnsack first introduced this idea in 1989. He hypothesized that artificial reefs could either "provide additional critical habitat that increases the environmental carrying capacity and eventually the abundance and biomass of reef fishes" (production) or "attract fishes as the result of behavioral preferences but do not significantly increase total fish biomass" (attraction). Increased production is one of the underlying rationales behind establishment of artificial reefs, but if attraction is actually the case, reef fishes could be subjected to increased catchability, thus increased fishing mortality (Bohnsack, 1989).

Attraction and production are not necessarily mutually exclusive; Bohnsack (1989) describes them as opposite extremes along a gradient. Numerous factors contribute to the placement of an artificial reef or fish population along this gradient such as local habitat availability, the level of fishery exploitation, the various life history and behavioral characteristics of each species, and whether a population is limited by habitat or recruitment (Bohnsack, 1989). Application of these criteria to red snapper in the GOM may lead one to believe that red snapper lie more toward the attraction end of the gradient. The only criterion that points toward production is the sparse availability of local reef habitat, at least in the western GOM (Gallaway, 1984). The red snapper population is heavily exploited and overfished and,

according to Bohnsack, such a population is less likely to experience increased production. It is also likely that the population is recruitment limited due to bycatch mortality in the shrimp fishery rather than habitat limited, again pointing towards attraction. Production is more likely for species that are highly faithful to and dependent upon reefs. Red snapper are reef-associated, not reef-dependent, and as this study has shown, do not exhibit high long-term site fidelity. As mentioned previously, Goodyear (1995) describes a shift in the red snapper population center from the eastern GOM in the mid-1900s to the western GOM in the late-1900s. It is conceivable that this shift could have been a result of attraction to new habitats provided by platforms. But is it feasible that absolutely no additional production resulted from the presence of platforms? This answer is likely no, placing red snapper somewhere in middle of the gradient Bohnsack describes. Of course, any increase in production could be balanced or negated by an increase in fishing mortality if the catchability of red snapper has increased because platforms make them easier to locate. But, if the bottleneck in population growth caused by the shrimp fishery were eliminated and if fishing pressure were reduced, platforms might function more as sites of production. As I have shown, there are many uncertainties and questions left to be answered in the attraction vs. production debate. Unfortunately, due to the complexity of the issue, the question of attraction vs. production may never be definitively answered for red snapper in the GOM. Consequently, managers should not assume that the GOM red snapper population is growing due to the additional habitat created by platforms.

The concept of marine reserves, or no-take marine protected areas, arose in the 1960's, developing into a popular tool for fisheries managers in the 1970's and 1980's (Alder, 1996; Bohnsack, 1996; Shipp, 2003). Many authors have detailed the immense and varied benefits of marine reserves (Bohnsack, 1990 in Roberts and Polunin, 1991; Ticco, 1995; Amos, 1998;

Coleman et al., 2004). Reserves protect the spawning stock biomass within the area, therefore providing a recruitment source for surrounding areas and supplemental restocking of fished areas through emigration. These protected populations are insurance against management failures in fished areas and protection against fishery stock collapse. It is important to remember that all vulnerable life stages must be protected as must all habitats and prey species (Carr and Reed, 1993). Reserves can also be utilized to reduce user conflicts and protect habitat (Coleman et al., 2004).

Some groups have suggested the use of marine reserves for red snapper in the GOM. In light of the results of this study, I do not believe reserves would be an effective management tool in this case. A NOAA Technical Memorandum (Plan Development Team, 1990) used red snapper as an example of a reef fish in a model to show the effect of fishing on a population: reduction in average age and total fecundity per individual. They subsequently recommended placing 20% of available reef habitat in marine reserves while utilizing traditional management in the remaining 80% of habitat. The authors believed the system would preserve the genetic composition of the reef fish stocks and protect older fish that are more valuable as egg producers. Unfortunately they conducted the study under the assumption that reef fish are sedentary and display high site fidelity, stating that marine fishery reserves "are ideally suited for reef fishes" for these reasons. I have shown this to not be the case for 2-4 year old red snapper, at least those using the habitat provided by platforms.

Yet again in 1996, GOM red snapper were used in a simulation model to demonstrate how a combination of effort reduction and establishment of 15-19% of the available habitat as marine reserves could be utilized to protect a fishery (Holland and Brazee, 1996). One of the key assumptions for the use of red snapper was limited movement of adults. Bohnsack (2000)

also uses GOM red snapper to show how protection of 30% of the all age and size classes with marine reserves is a better tool than minimum size limits. He does explain that the more mobile the species the more habitat area must be protected to achieve the requisite 30%. His graphs show that for a moderate mobility species, almost 40% of fishing grounds should be closed and for a higher mobility species, almost 60% of fishing grounds should be closed. I believe red snapper fall into the moderate or higher mobility group.

The GMFMC has established three marine protected areas intended to reduce the fishing pressure on red snapper in the GOM. None were designated for the purpose of increased production and none were "no take" reserves; only one seems to have been effective in meeting its objectives. Coleman et al. (2004) offer a review and evaluation of these marine reserves; a summary follows here. The first reserve was the Reef Fish Stressed Area, designated in 1981. This reserve was created to reduce the intense recreational fishing pressure in the near shore reef-fish populations, especially red snapper (GMFMC, 1981) but the implemented gear restrictions were aimed at the commercial sector and rarely used gear types (Coleman et al., 2004). Overall, the objective was not addressed by the regulations and recreational fishing effort does not appear to have been reduced. The second reserve was the Alabama Special Management Zone (ASMZ), designated in 1993, that was intended to decrease recreational vs. commercial user conflicts on artificial reefs off the coast of Alabama by limiting commercial access to these areas (GMFMC, 1993). Although formal evaluations of the effectiveness of the ASMZ have not been conducted, it appears to be meeting the objective (Coleman et al., 2004). The third reserve is the seasonal closure of the recreational and commercial fisheries as was described in the Introduction. The objective was to reduce overfishing of red snapper, but the result has merely been a temporal shift of effort into the open seasons (Coleman et al., 2004).

Some scientists believe that dense networks of reserves should be established as protection against management failure without assessing whether or not the reserves are likely to function as desired (Roberts, 1998). If reserves do not produce the predicted results they could actually promote management failure by instilling a false sense of security. Coleman et al. (2004) give examples of marine protected areas in the GOM that have both failed and succeeded, often due to the level and depth of planning before establishment of the reserve. Reserves that do not contribute to fishery welfare are a waste of time, effort, and money and restrict fisheries unnecessarily (Carr and Reed, 1993). Red snapper are not good candidates for marine reserves, as some have previously believed. They are highly mobile and exhibit little long-term site fidelity; therefore management efforts should be focused on other methods. Shipp (2003) arrives at this same conclusion, citing Watterson et al. (1998) and Patterson et al. (2001) as evidence that red snapper do exhibit movement away from tagging sites, especially under the influence of tropical cyclones.

One fisheries enhancement tool with which some of the Gulf States have experimented is the use of decommissioned platforms as artificial reefs (Louisiana Department of Wildlife and Fisheries, 2004; Texas Parks and Wildlife Department, 2004). The intent of these artificial reef programs is not necessarily to rebuild fish populations, but rather to maintain local habitat and fishing opportunities. By 1997, 1,645 platforms had been removed from the GOM; the number of platforms on the OCS is predicted to decline 29% from 1999-2023 as yearly removals exceed installations by an average of 44 per year (Pulsipher, 2001). This decrease in easily available fishing opportunities may cause economic stress in the commercial and recreational fishing industries. Although red snapper do not display high site fidelity to one specific platform they do move from one platform to another. Red snapper are attracted to platforms for some reason,

and therefore probably derive some sort of benefits from them. The removal of a large portion of these platforms may have potential to hinder the recovery and rebuilding of this heavily exploited population and must be taken into consideration and thoroughly researched in the future.

In addition, many of the new installations are expected to be located in deeper water, whereas most of the removals will be platforms with closer proximity to shore and at lesser depths (Pulsipher, 2001). Many of these near shore removals will be platforms that were easier and safer for fishermen to access. Commercial fishermen, who must fish for their livelihood, will likely follow the habitat farther and farther from shore, spending more of their time and income and taking greater risks. Recreational fishermen and recreational divers may choose to change their habits rather than spend more time and income and take these same risks. According to Hiett and Milon (2002) over 20% of all recreational fishing trips and almost 94% of dive trips in Texas, Louisiana, Mississippi and Alabama are to platforms. The economic impact to coastal counties in these regions from fishing and diving at platforms is $324.6 million, $164.1 million of that in personal income, and these industries support 5560 full time jobs (Hiett and Milon, 2002). The same study interviewed for-hire operators (charter and headboat) and dive shop owners and found that 85% of for hire operators and 100% of dive shop owners feel their industry would be damaged if platforms are removed after decommissioning. For these reasons, I believe the Gulf States should expand their artificial reef programs and allow more of the decommissioned platforms to remain as valuable habitat for red snapper in the northern GOM.

The red snapper fishery in the GOM is clearly important to the economy of the Gulf States, as is the oil and gas industry. Although red snapper do not show high site fidelity to

platforms, they do utilize them as important habitat. The question of whether artificial reefs are sources of production for red snapper or sites of attraction is yet unanswered, and is likely to remain so. It is important to remember that the catchability of red snapper at platforms may be higher than at natural hard bottom because of the ease with which fishermen may locate platforms; an increase in catchability would likely lead to an undesirable increase in fishing mortality, therefore this subject must be investigated. Neither red snapper nor platforms appear to be good candidates for marine reserves, but the artificial reef programs in the Gulf States are beneficial to the red snapper fisheries.

Recommendations for Future Research

The mass tagging procedures developed in this study were extremely successful. It was possible to tag as many fish as could be captured by 10-12 people fishing at all times. Onboard anaesthetization and post-surgery recovery eliminated the costly and time-consuming need to transport fish back to shore for surgery. MS-222 is appropriate for rapid anaesthetization of red snapper. The combination of sutures and veterinary glue adequately closed and sealed the wound; examination of fish recaptured and returned whole revealed that the wounds healed well enough that the scars on most fish were barely visible and scales were beginning to regenerate. Half an hour of post-surgery recovery time in an oxygenated tank was sufficient for fish to return to a conscious and alert state. The hoop-net protected the fish from immediate predation and guided them to depth and to the platform.

The GOM offshore environment is often severe and it is difficult to maintain research equipment in this setting. Storms are often harsh and prolonged, especially during hurricane season and the winter. Equipment must be designed to withstand the wind, waves, and currents generated by these storms. Research undertaken at platforms may face additional difficulties

such as metal degradation by electrolysis. Oil and gas companies deal with this problem by deploying large anodes on the underwater portion of the platforms, but these are eroded through time and must be periodically replaced. When deploying gear underwater on platforms great care should be taken to preemptively combat electrolysis by deploying additional large anodes or using only stainless steel of the same series so as to avoid loss of and damage to equipment.

Another way to eliminate the risk of electrolysis is to deploy equipment independently of platforms. Although deploying the receivers on the platforms allowed for easy retrieval of equipment, a receiver moored on a buoy a short distance away from the platform would have not only eliminated the risk of electrolysis, but would also have reduced the acoustic shadow caused by the support pilings and cross-members of the platform which may have shielded some pings from detection. An array of receivers moored around the platform would reduce the potential for acoustic shadowing to an even greater extent.

The effect of a temperature gradient on an acoustic signal can be considerable, depending upon the strength of the signal, distance traveled, and degree of temperature change. A thermocline is a likely culprit for the decrease in ping detection rate the receivers experienced two months into the study. Deeper deployment would likely have avoided or lessened this decrease in the rate of ping detection. Future studies should deploy receivers deeper to lessen the probability of a thermocline developing between the tagged red snapper and the receivers and should collect environmental data on a regular basis; ideally, temperature data loggers would be attached to the receiver to constantly collect data. Future studies should also attempt to continuously or regularly measure the ambient noise in the environment that could interfere with the reception of an acoustic signal.

Due to the malfunction of the pinger batteries, the acoustic data may not have represented true presence and absence of red snapper in the study area. Re-examination of the site fidelity objectives and hypotheses is warranted and these portions of the study should be conducted again if time and finances allow.

The next step in assessing the habitat value of platforms for red snapper is to determine if platforms increase the catchability of red snapper. This information is crucial to the successful management of the red snapper population in the northern GOM. If the catchability is increased, platforms may not be as beneficial to the red snapper population as is currently thought by many.

REFERENCES

Alder, J. 1996. Have tropical marine protected areas worked? An initial analysis of their success. *Coastal Management* 24:97-114.

Amos, A. M. 1998. Marine protected areas and reserves are vital conservation tools. *Gulf of Mexico Science* 1998(2):233-234.

Arnold, G. and H. Dewar. 2001. Electronic tags in marine fisheries research: a 30-year perspective. In *Electronic Tagging and Tracking in Marine Fisheries*, ed. J. R. Sibert and J. L. Nielsen, 7-64. Netherlands: Kluwer Academic Publishers.

Beaumariage, D. S. 1969. Returns from the 1965 Schlitz tagging program including a cumulative analysis of previous results. *Florida Department of Natural Resources Technical Series* 59:1-38.

Beaumariage, D. S., and L. H. Bullock. 1976. Biological research on snappers and groupers as related to fishery management requirements. In *Colloquium on Snapper-Grouper Fishery Resources of the Western Central Atlantic Ocean*, ed. H. R. Bullis, Jr. and A. C. Jones, 86-94. Texas A&M University Sea Grant College and Mississippi-Alabama Sea Grant Consortium.

Bohnsack, J. A. and D. L. Sutherland. 1985. Artificial reef research: a review with recommendations for future priorities. *Bulletin of Marine Science* 37(1):11-39.

Bohnsack, J. A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? *Bulletin of Marine Science* 44(2):631-645.

_____. 1996. Marine reserves, zoning, and the future of fishery management. *Fisheries* 21(9):14-16.

_____. 2000. A comparison of the short-term impacts of no-take marine reserves and minimum size limits. *Bulletin of Marine Science* 66(3):635-650.

Bradley, E. and C. E. Bryan. 1975. Life history and fishery of the red snapper (*Lutjanus campechanus*) in the Northwestern Gulf of Mexico. *Gulf and Caribbean Fisheries Institute* 27: 77-106.

Buckley, R. and G. Hueckel. 1985. Biological processes and ecological development on an artificial reef in Puget Sound, Washington. *Bulletin of Marine Science* 37(1):50-69.

Bull, A. S. and J. J. Kendall, Jr. 1994. An indication of the process: offshore platforms as artificial reefs in the Gulf of Mexico. *Bulletin of Marine Science* 55(2-3):1086-1098.

Carr, M. H. and D. C. Reed. 1993. Conceptual issues relevant to marine harvest refuges: examples from temperate reef fishes. *Canadian Journal of Fisheries and Aquatic Sciences* 50:2019-2028.

Coleman, F.C., P.B. Baker, and C.C. Koenig. 2004. A review of Gulf of Mexico marine protected areas: successes, failures, and lessons learned. *Fisheries* 29(2):10-21.

Continental Shelf Associates. 1982. Study of the effect of oil and gas activities on reef fish populations in the Gulf of Mexico OCS area. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region, MMS 82-10, New Orleans, LA.

Driessen, P. 1986. Offshore oil platforms: An invaluable ecological resource. In *Oceans '86 Conference Record: Science-Engineering-Adventure. Data Management, Instrumentation and Economics held in Washington, DC, USA 23-25 September 1986*, 2: 516-521. Washington, DC, New York

Dugas, R., V. Guillory, and M. Fischer. 1979. Oil rigs and offshore sport fishing in Louisiana. *Fisheries* 4(6):2-10.

Eklund, A.-M. and J. Schull. 2001. A stepwise approach to investigating the movement patterns and habitat utilization of goliath grouper, *Epinephelus itajara*, using conventional tagging, acoustic telemetry and satellite tracking. In *Electronic Tagging and Tracking in Marine Fisheries*, ed. J. R. Sibert and J. L. Nielsen, 189-216. Netherlands: Kluwer Academic Publishers.

Fabi, G., F. Grati, A. Lucchetti, and L. Trovarelli. 2002. Evolution of the fish assemblage around a gas platform in the northern Adriatic Sea. *ICES Journal of Marine Science* 59(Supplement S):S309-S315.

Fable Jr., W. A. 1980. Tagging studies of red snapper (*Lutjanus campechanus*) and vermilion snapper (*Rhomboplites aurorubens*) off the South Texas coast. *Contributions in Marine Science* 23:115-121.

Fisheries Information Network. Internet database maintained by the Gulf States Marine Fisheries Commission available at http://www.gsmfc.org/fin.html; accessed on 7 February 2004.

Frazer, T.K. and W. J. Lindberg. 1994. Refuge spacing similarly affects reef-associated species from three phyla. *Bulletin of Marine Science* 55(2-3):388-400.

Gallaway, B. J., L. R. Martin, R. L. Howard, G. S. Boland, and G. D. Dennis. 1981. Effects on artificial reef and demersal fish and macrocrustacean communities. In *Environmental Effects of Offshore Oil Production: The Buccaneer Gas and Oil Field Study*, ed. B. S. Middleditch, 237-299. Houston, Texas: Plenum Press, New York.

Gallaway, B. J. 1984. Assessment of platform effects on snapper populations and fisheries. In *Fifth Annual Gulf of Mexico Information Transfer Meeting held in New Orleans, LA 27-29 November 1984*. OCS Study MMS 85-0008:130-137

Goodyear, C. P. 1995. Red snapper in the U.S. waters of the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami MIA-95/96-05.

Green, A. W., G. C. Matlock, and J. E. Weaver. 1983. A method for directly estimating the tag-reporting rate of anglers. *Transactions of the American Fisheries Society* 112:412-415.

GMFMC (Gulf of Mexico Fishery Management Council). 1981. Fishery management plan for reef fish fishery of the Gulf of Mexico. Gulf of Mexico Fishery Management Council, Tampa, Florida.

_____. 1993. Supplemental environmental impact statement for the reef fish fishery of the Gulf of Mexico and amendment 5 to the fishery management plan for the reef fish resources of the Gulf of Mexico. Gulf of Mexico Fishery Management Council, Tampa, Florida.

_____. 1999. September 1999 report of the reef fish stock assessment panel. Gulf of Mexico Fishery Management Council, Tampa, Florida.

_____. 2001. Regulatory amendment to the reef fish fishery management plan to set a red snapper rebuilding plan through 2032. Gulf of Mexico Fishery Management Council, Tampa, Florida.

Hampton, J. 1997. Estimates of tag-reporting and tag-shedding rates in a large-scale tuna tagging experiment in the western tropical Pacific Ocean. *Fishery Bulletin* 95:68-79.

Hart, L. G. and R. C. Summerfelt. 1975. Surgical procedures for implanting ultrasonic transmitters into flathead catfish (*Pylodictis olivaris*). *Transactions of the American Fisheries Society* 104(1):56-59.

Heifetz, J. and N. E. Maloney. 2001. Estimation of tag-reporting rates for sablefish in the northeastern Pacific Ocean. *Alaska Fishery Research Bulletin* 8(1):1-11.

Helfman, G.S. 1986. Fish behavior by day, night and twilight. In *The Behavior of Teleost Fishes*, ed. T.J. Pitcher, 366-387. Baltimore, Maryland: The Johns Hopkins University Press.

Hiett, R. L. and J. W. Milon. 2002. Economic impact of recreational fishing and diving associated with offshore oil and gas structures in the Gulf of Mexico. Final Report. OCS Study MMS 2002-010. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 98 p.

Holland, D. S. and R. J. Brazee. 1996. Marine reserves for fisheries management. *Marine Resource Economics* 11:157-171.

Klimley, A. P., F. Voegeli, S. C. Beavers, and B. J. Le Boeuf. 1998. Automated listening stations for tagged marine fishes. *MTS Journal* 32(1):94-101.

Klimley, A. P. and C. F. Holloway. 1999. School fidelity and homing synchronicity of yellowfin tuna, *Thunnus albacares*. *Marine Biology* 133:307-317.

Latour, R. J., K. H. Pollock, C. A. Wenner, and J. M. Hoenig. 2001. Estimates of fishing and natural mortality for subadult red drum in South Carolina waters. *North American Journal of Fisheries Management* 21:733-744.

Lindberg, W.J., T.K. Frazer, and G.R. Stanton. 1990. Populations effects of refuge dispersion for adult stone crabs (Xanthidae, *Menippe*). *Marine Ecology Progress Series* 66:239-249.

Louisiana Department of Wildlife and Fisheries. “Louisiana Artificial Reef Program” website available at http://www.wlf.state.la.us/apps/netgear/index.asp?cn=lawlf&pid=133; accessed on 27 February 2004.

Love, M. S., J. Caselle, and L. Snook. 1999. Fish assemblages on mussel mounds surrounding seven oil platforms in the Santa Barbara Channel and Santa Maria Basin. *Bulletin of Marine Science* 65(2):497-513.

McCawley, J.R. 2003. Diet and prey demand of red snapper, *Lutjanus campechanus*, on Alabama artificial reefs. Master’s Thesis, University of South Alabama, Mobile, AL.

Moseley, F. N. 1965. Biology of the red snapper, *Lutjanus aya* Bloch, of the Northwestern Gulf of Mexico. Master’s Thesis, University of Texas, Austin, TX.

Mueller, K.W., G.D. Dennis, D.B. Eggleston, and R.I. Wicklund. 1994. Size-specific social interactions and foraging styles in a shallow water population of mutton snapper, *Lutjanus analis* (Pisces: Lutjanidae), in the central Bahamas. *Environmental Biology of Fishes* 40:175-188.

Munday, P.L., G. P. Jones, and M.J. Caley. 2001. Interspecific competition and coexistence in a guild of coral-dwelling fishes. *Ecology* 82(8):2177-2189

Nelson, R. S. and C. S. Manooch III. 1982. Growth and mortality of red snappers in the West-Central Atlantic Ocean and Northern Gulf Mexico. *Transactions of the American Fisheries Society* 111:465-475.

Nieland, D. L. and C. A. Wilson. 2002. Red snapper recruitment to and disappearance from oil and gas platforms in the northern Gulf of Mexico. In *Gulf of Mexico fish and fisheries: bringing together new and recent research*, ed. J. McKay, J. Nides, and D. Vigil, 270-279. U.S. Dept. of the Interior, Minerals Managment Service, Gulf of Mexico OCS Region, New Orleans, LA.

O'Dor, R. K., J.P. Aitken, R.C. Babcock, S. K. Bolden, S. Seino, D.C. Zeller, and G.D. Jackson. 2001. Using radio-acoustic positioning and telemetry (RAPT) to define and assess marine protected areas (MPAs). In *Electronic Tagging and Tracking in Marine Fisheries*, ed. J. R. Sibert and J. L. Nielsen, 147-166. Netherlands: Kluwer Academic Publishers.

Overholtzer, K.L. and P.J. Motta. 1999. Comparative resource use by juvenile parrotfishes in the Florida Keys. *Marine Ecology Progress Series* 177:177-187.

Patterson III, W. F., J. C. Watterson, R. L. Shipp, and J. H. Cowan Jr. 2001. Movement of tagged red snapper in the Northern Gulf of Mexico. *Transactions of the American Fisheries Society* 130:533-545.

Patterson III, W. F., and J. H. Cowan Jr. 2003. Site fidelity and dispersion of red snapper associated with artificial reefs in the northern Gulf of Mexico. In *Fisheries, Reefs, and Offshore Development. American Fisheries Society Symposium, v. 36*, ed. D. R. Stanley and A. S. Bull, 181-193. Bethesda, Maryland: American Fisheries Society.

Pine, W. E., K. H. Pollock, J. E. Hightower, T. J. Kwak, and J. A. Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. *Fisheries* 28(10):10-23.

Plan Development Team. 1990. The potential of marine fishery reserves for reef fish management in the U.S. Southern Atlantic. NOAA Technical Memorandum NMFS-SEFSC-261, 40 p.

Pulsipher, A. G., O. O. Iledare, D. V. Mesyanzhinov, A. Dupont, and Q. L. Zhu. 2001. Forecasting the number of offshore platforms in the Gulf of Mexico OCS to the year 2023. Prepared by the Center for Energy Studies, Louisiana State University, Baton Rouge, La. OCS Study MMS 2001-013. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. 52 p.

Putt, R. E. J. 1982. A quantitative study of fish populations associated with a platform within Buccaneer Oil Field, Northwestern Gulf of Mexico. Master's Thesis, Texas A&M University, Galveston, Texas.

Rabalais, N.N., R.E. Turner, and W.J. Wiseman, Jr. 2002. Gulf of Mexico Hypoxia, A.K.A. "The Dead Zone". *Annual Reviews in Ecology and Systematics* 33:235-263

Rademacher, K. R. and J. H. Render. 2003. Fish assemblages around oil and gas platforms in the northeastern Gulf of Mexico: developing a survey design. In *Fisheries, Reefs, and Offshore Development. American Fisheries Society Symposium, v. 36*, ed. D. R. Stanley and A. S. Bull, 101-122. Bethesda, Maryland: American Fisheries Society.

Render, J. H. and C. A. Wilson. 1994. Hook-and-line mortality of caught and released red snapper around oil and gas platform structural habitat. *Bulletin of Marine Science* 55(2-3):1106-111.

Render, J. H. 1995. The life history (age, growth and reproduction) of red snapper (*Lutjanus campechanus*) and its affinity for oil and gas platforms. Ph.D. Dissertation, Louisiana State University, Baton Rouge, LA.

Rivas, L. R. 1966. Review of the *Lutjanus campechanus* complex of red snappers. *Quarterly Journal of the Florida Academy of Science* 29(2):117-136.

Roberts, C. M. and N. V. C. Polunin. 1991. Are marine reserves effective in management of reef fisheries? *Reviews in Fish Biology and Fisheries* 1:65-91.

Roberts, C. M. 1998. Sources, sinks, and the design of marine reserve networks. *Fisheries* 23(7):16-19.

Robins, C. R. and G. C. Ray. 1986. A Field Guide to Atlantic Coast Fishes of North America. Boston: Houghton Mifflin Company, 324 p.

SAS Institute Inc. 2003. Statistics Version 9.0. SAS Institute Inc. Cary , North Carolina.

Schirripa, M. J. and C. M. Legault. 1999. Status of the red snapper in U.S. waters of the Gulf of Mexico: updated through 1998. National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Sustainable Fisheries Division, Miami. SFD-99/00-75.

Shipp, R.L. 2003. A perspective on marine reserves as a fishery management tool. *Fisheries* 28(12):10-21.

Sibert, J. R. 2001. Electronic tagging and tracking in marine fisheries: introduction to the proceedings. In *Electronic Tagging and Tracking in Marine Fisheries*, ed. J. R. Sibert and J. L. Nielsen, 1-6. Netherlands: Kluwer Academic Publishers.

Sonnier, F., J. Teerling, and H. D. Hoese. 1976. Observations on the offshore reef and platform fish fauna of Louisiana. *Copeia* 1976(1):105-111.

Stachowitsch, M., R. Kikinger, J. Herler, P. Zolda, and E. Geutebruck. 2002. Offshore oil platforms and fouling communities in the southern Arabian Gulf (Abu Dhabi). *Marine Pollution Bulletin* 44(9):853-860.

Stanley, D. R. and C. A. Wilson. 1989. Utilization of offshore platforms by recreational fishermen and SCUBA divers off the Louisiana coast. *Bulletin of Marine Science* 44(2):767-775.

_____. 1990. A fishery-dependent based study of fish species composition and associated catch rates around oil and gas structures off Louisiana. *Fishery Bulletin* 88:719-730.

_____. 1997. Seasonal and spatial variation in the abundance and size distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico. *Canadian Journal of Fisheries and Aquatic Sciences* 54:1166-1176

Stone, R. B. 1978. Artificial reefs and fishery management. *Fisheries* 3(1):2-4.

Stone, R. B., H. L. Pratt, R. O. Parker Jr., and G. E. Davis. 1979. A comparison of fish populations on an artificial and natural reef in the Florida Keys. *Marine Fisheries Review* 41(9):1-11.

Strelcheck, A.J. 2001. The influence of reef design and nearest-neighbor dynamics on artificial-reef fish assemblages. Master's Thesis, University of South Alabama, Mobile, AL.

Szedlmayer, S. T. and R. L. Shipp. 1994. Movement and growth of red snapper, *Lutjanus campechanus*, from an artificial reef area in the Northeastern Gulf of Mexico. *Bulletin of Marine Science* 55(2-3):887-896.

Szedlmayer, S. T. 1997. Ultrasonic telemetry of red snapper, *Lutjanus campechanus*, at artificial reef sites in the northeast Gulf of Mexico. *Copeia* 1997(4):846-850.

Texas Parks and Wildlife Department. "Artificial Reefs" website available at http://www.tpwd.state.tx.us/fish/reef/artreef.htm; accessed on 27 February 2004.

Thorsteinsson, V. 2002. Tagging Methods for Stock Assessment and Research in Fisheries. Report of Concerted Action FAIR CT.96.1394 (CATAG). Reykjavik. Marine Research Institute Technical Report (79), 179 p.

Ticco, P. C. 1995. The use of marine protected areas to preserve and enhance marine biological diversity: a case study approach. *Coastal Management* 23:309-314.

Watterson, J. C., W. F. Patterson III, R. L. Shipp, and J. H. Cowan Jr. 1998. Movement of red snapper, *Lutjanus campechanus*, in the north central Gulf of Mexico: potential effects of hurricanes. *Gulf of Mexico Science* 1998(1):92-104.

Wilson, C. A., V. R. Van Sickle, and D. L. Pope. 1987. Louisiana Artificial Reef Plan. Louisiana Department of Wildlife and Fisheries, Technical Bulletin No. 41. Baton Rouge, LA: Louisiana Sea Grant College Program, 143 p.

Wilson, C.A. and D.L. Nieland. 2001. Age and growth of red snapper, *Lutjanus campechanus*, from the northern Gulf of Mexico off Louisiana. *Fishery Bulletin* 99(4):653-664.

Wilson, C. A., A. Pierce, and M. W. Miller. 2003. Rigs and reefs: a comparison of the fish communities at two artificial reefs, a production platform, and a natural reef in the northern Gulf of Mexico. Prepared by the Coastal Fisheries Institute, School of the Coast and Environment. Louisiana State University. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-009. 95 p.

Winter, J. D. 1983. Underwater biotelemetry. In *Fisheries Techniques*, ed. L. A. Nielsen and D. L. Johnson, 371-395. Bethesda, Maryland: American Fisheries Society.

Wolcott, T. G. 1995. New options in physiological and behavioural ecology through multichannel telemetry. *Journal of Experimental Marine Biology and Ecology* 193:257-275.

Zeller, D. C. 1997. Home range and activity patterns of the coral trout *Plectropomus leopardus* (Serranidae). *Marine Ecology Press Series* 154:65-77.

_____. 1998. Spawning aggregations: patterns of movement of the coral trout *Plectropomus leopardus* (Serranidae) as determined by ultrasonic telemetry. *Marine Ecology Press Series* 162:253-263.

VITA

Megan Blythe Peabody, born 16 April, 1979, to Diane Yale- and Gerald Peabody, was raised in Amherst, Ohio. She became interested in science, especially oceanography, at a young age and pursued her goals at the University of South Carolina as a major in marine science with a minor in environmental studies. During her initial year at the University of South Carolina she became involved in geologic research project investigating the climate record as preserved in the sediments of Lake Baikal, Russia. After processing core samples in the lab during the semester she traveled to Siberia during the following summer to lead the American student team at the laboratory in Russia. During her sophomore year Megan began work in a benthic eco-toxicology lab. The following summer, as a break from lab work, she monitored loggerhead sea turtle nesting at Cape Lookout National Seashore, North Carolina. Returning to the University, she continued her work in the toxicology lab for the next two years, conducting research on the endocrine-disrupting effects of pesticides on estuarine amphipods, which became the topic of her Honors College Senior Thesis. After graduation, Megan took a year off from school before pursuing her Master of Science. During this year she traveled around the country, worked aboard a commercial shrimp vessel as a bycatch observer, and interned at the South Atlantic Fishery Management Council. In the fall of 2002 Megan moved to Baton Rouge and enrolled in Louisiana State University to pursue her master’s degree in Oceanography and Coastal Sciences. After graduate school Megan plans to pursue a career in fisheries management.