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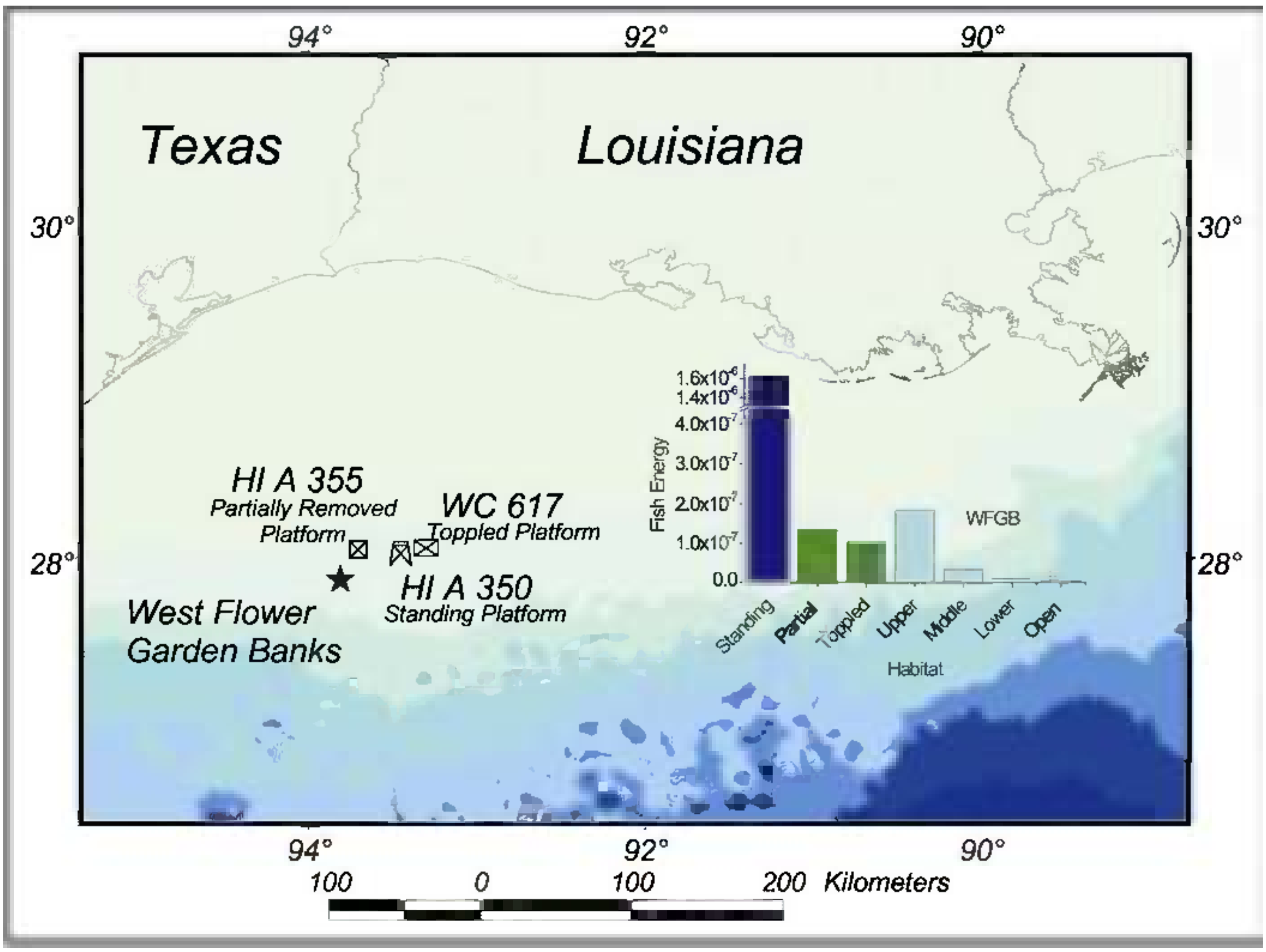
MMS 2003-009

Coastal Marine Institute

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

Final Report



U.S. Department of the Interior
Minerals Management Service
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Louisiana State University

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Final Report

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EXECUTIVE SUMMARY

The proximity of the two Rigs to Reefs projects and an operating oil and gas platform to the natural coral formations of the Flower Gardens (WFGB) afforded us the opportunity to not only compare several platform configurations, but also to compare the fish communities at "artificial reefs" to that of a neighboring natural system. It was therefore the purpose of this study to compare the fish communities associated with an operating oil and gas platform, two artificial reef configurations, and the WFGB. Reef configurations included a production platform toppled in place as a deep water artificial reef (West Cameron 617A), a nearby partially removed platform (High Island A355), and an operating production platform (High Island A350). We sought to identify species composition at each site; to estimate the fish biomass/density associated with each site; to determine the effects of side, depth, and distance from each site on fish biomass. Comparisons were then made between these sites and to other sites that had been surveyed.

Dual beam hydroacoustic surveys were used to estimate fish density and biomass at all sites. Survey design consisted of a stationary array of four transducers at the standing platform and mobile surveys at the remaining sites. The mobile survey of the two reefs sites consisted of multiple vessel passes over each structure and the mobile survey of WFGB consisted of twenty-seven transects spaced 300 meters apart running along the long axis of the WFGB, from northeast to southwest. Visual surveys were conducted with a Deep Ocean Engineering Phantom HD2 ROV with standard visual census techniques recorded onto S-VHS video tape.

Overall, we found that fish biomass and density and around the standing oil and gas platform was higher than the artificial reefs or natural reef. Comparison of the mean biomass (Sv) found at the standing platform and over and immediately around the two reef sites and the WFGB terraces clearly indicate an order of magnitude difference in fish biomass between the standing platform and other sites, suggesting that standing platforms support greater fish biomass. Our results are in support of previous findings that when a platform is converted into a artificial reef by toppling in place or by partial removal, it loses a significant portion of the fish community. Fish biomass at the artificial reef sites was similar to the upper terrace of the nearby natural reef. In each habitat, we tended to find higher fish densities in habitats with more vertical structure.

This research continues to support the working hypothesis that platforms do make useful artificial reefs since they tend to support a population of fish that can be 10 to over 1000 times greater in density than the adjacent sand and mud bottom habitats, and are equal to or even exceed that of natural coral reef habitat like the WFGB. The species associated with the artificial reefs (including standing platforms) do however, differ from those found on natural reef habitats. Future research efforts might be directed toward determining the reasons for this difference. Integration of these types of study results into a comprehensive spatial database will go far to improving management of these resources.

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LIST OF ABBREVIATIONS

ANCOVA	analysis of covariance
ANOVA	analysis of variance
GOM	Gulf of Mexico
HI	High Island
kts	knots
RBD	randomized block design
RTR	rigs to reefs
S	sigma
TOD	time of day
TS	target strength
WC	West Cameron
WFGB	West Flower Garden Bank

1.0 INTRODUCTION

Most of the natural substrate in the northern Gulf of Mexico (GOM) from Destin, Florida to Brownsville, Texas is silty with approximately 2800 km² of naturally occurring hard bottom (Parker et al. 1983). In the last 60 years, the area of hard substrate in this region has increased through the development of infrastructure for a thriving oil and gas industry. Currently, there are 4,046 oil and gas platforms operating in state and federal waters of the northern GOM (http://www.gomr.mms.gov/homepg/pubinfo/freeasci/platform/freeplat.html), creating the largest de facto artificial reef system in the world. Combined, these platforms only increase the surface area of hard substrate available in the northern GOM by 4% (Stanley and Wilson 1990, 1991, 1997), but they arguably have a substantial impact on regional fisheries. Off the coast of Louisiana in particular, the Mississippi River deposits vast amounts of clay and other fine-grained sediment and oil and gas platforms provide a large percentage of hard-bottom area for reef-dwelling fishes. In coastal waters off Louisiana, Stanley and Wilson (1996, 1997, 1998, 2000a), determined that each standing platform seasonally provides habitat for 10,000-20,000 fishes, many of which are of great recreational and commercial importance. By adding substantially to the amount of reef available, petroleum platforms have doubtless affected many regional ecosystem processes such as energy (food) availability, habitat, recruitment, competition, and predation (Menge and Sutherland 1987; Doherty and Williams 1988; Bohnsack et al. 1991; Stanley and Wilson 2000a).

In response to both the federally mandated removal of obsolete platforms, and to the popularity of petroleum platforms as fishing destinations, Louisiana, Texas, and other states along the northern GOM now convert retired oil and gas platforms into artificial reefs (NRC 1996). The Louisiana Artificial Reef Program (LARP) was established in 1986 and is currently administered by the Louisiana Department of Wildlife and Fisheries. The Texas Parks and Wildlife Department established a rigs-to-reef program in 1988. To date, these states have established over 150 artificial reefs from converted oil and gas platforms.

The concept of using oil and gas platforms as artificial reefs i.e. "Rigs to Reefs" (RTR) is strongly supported by recreational and commercial fishers and their respective organizations such as the Coastal Conservation Association. The scientific community, however, still questions the real ecological value of artificial reefs in general, and the particular effectiveness of petroleum platforms as artificial reefs. Specifically, do artificial reefs primarily increase reef fish production or do they attract reef fishes away from natural substrates. How do species composition and density of artificial reef fish communities compare to those found on natural substrates? (Seaman and Jensen 2001).

Beyond purely scientific concerns, there are also many management questions concerning the effect of water depth, geographic location, and general reef configuration on fish production at both standing platforms and artificial reefs. For example, under current RTR projects, oil and gas platforms are typically converted into reefs by laying a platform on its side either by toppling in place or by moving a toppled platform to a new location. More recently, the Louisiana Artificial Reef Program has followed the Texas Artificial Reef Program by removing the top portion of a standing platform to a depth (typically 85 feet below surface) sufficient to comply with Coast Guard regulations. This practice is referred to as partial removal. Stanley and Wilson (1997) proposed that vertical profile is important in maintaining the fish density resident at standing platforms. There is a great difference in the vertical profile of standing, toppled and partially removed platforms, and we therefore may expect fish density and species composition to be different among these three different artificial reef configurations.

1.1 Past Research

There have been several surveys of fish communities conducted around oil and gas platforms in the GOM. The extent of this work was reviewed by Stanley and Wilson (2000a) and is summarized below. Scientific investigations of fish assemblages at petroleum platforms did not start until the mid 1970's. They consisted of visual surveys performed by SCUBA divers, with remotely operated underwater vehicles (ROV), and with stationary cameras. The majority of these projects were short term, even one time studies (Sonnier et al. 1976; Gallaway et al. 1981; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982). The results of this early research described the fish density and species composition found at each platform, and how they varied amongst platforms, water depth, and time of year. The results are, however, difficult to compare due to sampling problems associated with limited visibility, gear bias, and diver avoidance by fish, including lack of standardized survey methodology. Although visual surveys are the method of choice to survey natural and artificial reefs (Bortone and Kimmel 1991), the presence of SCUBA divers affects the density and possibly species composition of fishes at the site (Sale and Douglas 1981; Brock 1982; Bohnsack and Bannerot 1986; Stanley and Wilson 1995).

In response to the difficulty in assessing these fisheries resources, several investigators evaluated and established guidelines for using acoustics to survey platform communities. Gerlotto et al. (1989) demonstrated that towed hydroacoustics could be used to measure fish densities near petroleum platforms off Cameroon. Scientists at Louisiana State University's Coastal Fisheries Institute combined visual surveys and quantitative dual beam hydroacoustics to document the assemblage of fishes associated with four petroleum platforms in the northern Gulf of Mexico (Wilson and Stanley 1991; Stanley and Wilson 1995, 1996, 1997, 2000a).

Regardless of methodologies, investigators have reported that platforms harbor a large numbers of fishes, and that abundances and species compositions vary greatly both spatially and temporally (Sonnier et al. 1976; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982; Stanley and Wilson 1996, 1997, 2000a). Gerlotto et al. (1989) reported that fish densities were 5 to 50 times higher immediately adjacent to a platform than 50 m away. Stanley and Wilson (1996, 1997) reported that fish densities were 3-25 times higher within 16m of the a standing platform on the GOM continental shelf. At 30m, they found that fish densities were comparable to open waters of the northern GOM. Long-term studies have also reported that fish populations at petroleum platforms are highly variable over time. Putt (1982) reported that density varied by a factor of two from month to month, while Stanley and Wilson (1996, 1997, 2000b) reported that spatial, monthly, and seasonal abundances varied by up to a factor of five.

The importance of standing platforms in holding significant reef fish communities has been well established. There are, however, little data to determine whether currently popular RTR configurations are as productive as standing platforms. And further, there is little research comparing fish community characteristics on artificial and natural reefs. Although Wilson and Stanley (1998) suggested that both toppled and partially removed platforms may not be as productive as either standing platforms or natural reef systems, the impact of various RTR conversions on the resulting reef community needs further investigation.

The largest natural reef in the northern GOM is the Flower Garden Banks (Flower Gardens). Although fishermen have known about the Flower Gardens since the late 1800's, it was not until 1936 that the banks were officially discovered by the U.S. Coast and Geodetic Survey during surveys in the GOM to map pinnacles. In 1961, Dr. Thomas E. Pulley documented that the Flower Gardens were viable coral communities (Elvers and Hill 1985). After nearly two decades of effort, the Flower Gardens were designated a marine sanctuary in 1992 (Gittings and Hickerson 1998). Although several fisheries surveys have been conducted around these geological features, few scientific investigations have considered a holistic account of the fish population and fish density beyond the cryptic reef fishes.

To date, the most extensive survey of fish assemblages on the Flower Gardens was conducted by LGL Ecological Research Associates during a period from 1980 to 1982. The report (Boland, et. al. 1983), funded by the Environmental Protection Agency through the National Marine Fisheries Service, was based on 357 hours of video data processed in 1 minute intervals and determined the standing stock/density estimates of 16 primary reef fish taxa. A total of 141 fish taxa were reported from 12 cruises to the East and West Flower Garden Banks. The investigators reported characteristic fish assemblages zoned primarily by depth and/or habitat types. Habitat types included: upper coral reef, algal-nodule sponge zone, shallow drowned reef, deep drowned reef, and soft bottom. The investigators also estimated species abundance. For example, they estimated that the population size for creole-fish *Paranthias furcifer* ranged from 400,000 to 993,948, red snapper *Lutjanus campechanus* from 4,000 to 20,000, and groupers *Mycteroperca spp.* from 20,000 to 47,000 at the East Flower Garden Bank.

Biotic zonation of the West Flower Garden Bank (WFGB) was described by Bright et. al. (1974). They reported on the major biotic elements of the bank and provided a quantitative baseline assessment of the reef community. They used divers, towed video systems and manned submersibles to collect seventy days of data during 17 cruises between July 1970 and December 1972. Their report included a thorough catalog of fauna. Bright and Cashman (1974) reported that 101 fish species at the WFGB.

Three distinct reef fish assemblages were reported at the WFGB (Dennis and Bright 1988) in association with three major biotic zones (coral reef, algal-sponge, and drowned reef). Species composition is similar to outer slope Carribean reefs, but the WFGB exhibits a much lower diversity (253 primary species reported at Caribbean reefs versus 84 found at the WFGB). Cluster analysis of fish assemblages yielded three depth zonations with a distinct species composition in each of the three zones. Twenty-eight species were observed in the upper zone (<45m), 45 species were observed in the middle zone (45-85m), and 20 species were observed in the lower zone (>85m). These depth ranges are consistent with the known epifaunal zones for this area

Rooker, et. al. (1997) found marked differences when they compared fish species richness at the WFGB to a nearby oil platform (High Island A389A). They reported 54 species and 39 species, respectively, at the WFGB and HI A389A. They also reported that midwater pelagics such as carangids and scombrids accounted for over 50% of all taxa enumerated at the platform while 50% of the observed total fish population at the WFGB was species from the family Pomacentridae.

1.2 Goals of This Study

The close geographic proximity of several RTR projects to a standing platform (HI A355) and the natural coral formations of the Flower Gardens afforded us the unique opportunity compare the fish communities associated with these different habitats using hydroacoustics and ROV. RTR configurations included a production platform toppled in place as a deep water Louisiana artificial reef (WC 617A), and a nearby platform (HI A355) partially removed as a Texas artificial reef.

While several qualitative studies have documented the colonization and relative abundance of organisms associated with standing production platforms, no one has attempted to compare the fish communities of these platforms to those found associated with different artificial reef configurations and natural reefs. This research project was designed to assist MMS, the National Marine Fisheries Service, and the artificial reef programs of Louisiana and Texas in decisions regarding the deployment and siting of platforms as artificial reefs, especially with respect to deep water artificial reefs.

The goals of this study were therefore to : 1) identify species composition at each artificial reef site, 2) estimate fish density and biomass associated with each site, 3) determine the effects of orientation, depth, and distance away from each site on fish biomass, and 4) determine the relative importance of reef configuration on the each of these measures. During the course of the study, we expanded our efforts to include an analysis of the abundance and distribution of fish populations at the WFGB reef system, and determine how these metrics compare to those found at artificial reefs. Comparisons were also made to results from previously published studies.

This report is presented in four sections. The following Materials and Methods (Section 2) gives detailed site descriptions, explains the equipment, site specific sampling design, and acoustic and statistical analysis. The Results section (Section 3) is separated into the results for the standing platform (HI A350) and the two artificial reef sites (HI A355, and WC 617A) and the WFGB. A common Discussion (Section 4) section is used to compare and synthesize the results.

2.0 MATERIALS AND METHODS

2.1 Site Descriptions

This research project was designed to effectively sample and compare the fish resources associated with a standing platform, two artificial reefs and natural reef system located in a similar geographic region in the northern GOM off the Texas/Louisiana border (Figure 1 and Table 1).

2.1.1 High Island A350 (standing platform)

The standing platform, HI A350, owned by Shell Corporation, is located at 28º 1.130' north latitude and 93º 27.512' west longitude. This large 8 pile structure was installed in 1976 (Table 1) in 90 m of water. The vertical profile of this standing platform goes from the bottom to the surface of the 90m in water column and occupies a footprint of 68m x 40m at its base.

2.1.2 West Cameron 617A (toppled platform)

The toppled platform, WC 617A, owned by Mobil Corporation, is located at 28º 3.664' north latitude and 93º 18.805' west longitude at a depth of 98 m. It was installed as an eight pile structure in 1976. In July 1992, the upper deck was removed then the jacket was severed below the mudline with explosives, then the remaining structure was toppled in place. This toppled platform has a vertical profile of 31m in the 98m water column and occupies a footprint of 84 m x 20 m.

2.1.3 High Island A355 (partially removed platform)

The partially removed platform, HI A355, owned by Occidental Petroleum, is located at 28º 2.491' north latitude and 93º 42.551' west longitude in 90 m water depth. It was installed as a large eight pile structure in 1978. In January 1996, it was partially removed by mechanically cutting it at -27.5 m. The upper jacket was split vertically, and a four pile portion was set to the southeast side of the main structure. The remainder was returned to shore. This partially removed platform has a vertical profile of 68m in the 90m water column and occupies a footprint of 60m x 40m. The four pile section on the south side has a vertical profile of 32 m and occupies a footprint of 24m x 18m.

2.1.4 West Flower Garden Bank (WFGB)

The WFGB is located about 172 km southeast of Galveston, Texas, on the edge of the outer continental shelf at 27˚ 52.4' north latitude and 93˚ 48.8' west longitude. The WFGB was created by the uplift of a salt dome of Jurassic, Louann origin (Rezak 1981, as in Dokken et

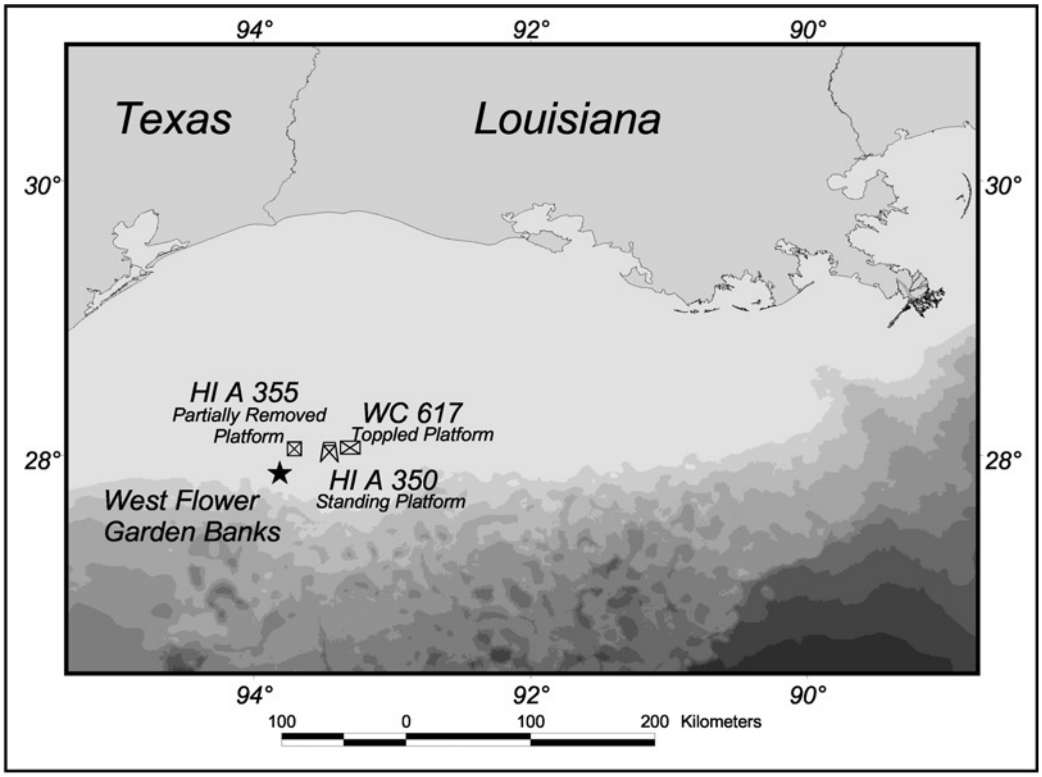


Figure 1 . Map of the sites surveyed in June 1999 and 2000

Table 1.

General information about the oil and gas structures surveyed in June 1999 and 2000 with stationary or mobile dual beam hydroacoustics.

SITE	COMPANY	LATITUDE	LONGITUDE	DEPTH	PILES	INSTALLED	REMOVED	REMOVAL METHOD
HI A350 (standing)	SHELL	28.01884N	93.4585W	89	8	1976		
HI A355 (partially removed)	OXY USA	28.04152N	93.70919W	88.4	8	1978	1/15/1996	CUTTING
WC617A (toppled)	MOBIL	28.06107N	93.31342W	97.5	8	1976	7/16/1992	EXPLOSIVE

al. 1999). It is the largest charted calcareous bank in the northwestern GOM (Bright et al. 1985 as in Dokken et al. 1999) and the northern-most coral reef on the continental shelf of North America (Bright et al. 1984 as in Dokken et al. 1999). The coral cap varies in depth from approximately 18 to 36 meters. (Rezak et al. 1985 as n Dokken et al. 1999). The major features of the 137 km² WFGB are three crests aligned along an east-west axis. The middle, most prominent crest rises from a surrounding depth of 100 –150 meters to within 18 meters of the surface and supports a coral reef community. (Rezak et al. 1985 as in Dokken et al. 1999).

2.2 Survey Designs

At the standing platform, stationary dual beam hydroacoustic surveys (Stanley and Wilson 1997) were conducted using an array of four transducers. At the remaining sites, mobile acoustic surveys were done using a single transducer mounted on a v-fin tow body (towfish). The original plan was to conduct stationary acoustic sampling at each of the two RTR sites, however, the research vessels were unable to anchor effectively due to high currents

2.2.1 High Island A350

The standing platform was surveyed in June 1999 with stationary dual beam hydroacoustic equipment and sampling design developed during previous research efforts (Wilson and Stanley 1991; Stanley and Wilson 1995, 1996, 1997,1998, 1999). The stationary transducer array (Figure 2) was designed to measure in situ target strength distribution and density of fishes immediately adjacent to each side of the platform. Three downward-oriented transducers (120 kHz) were placed approximately 3 m below the surface, one on each side of the platform. The fourth transducer on the west side could not be used due to equipment failure. Vertical acoustic sampling consisted of two hour time blocks over a 24 hour interval encompassing four periods (dawn, noon, dusk and midnight). Hydroacoustic data were collected sequentially from each transducer in five minute intervals.

2.2.2 West Cameron 617A and High Island A355

For the mobile acoustic surveys at the RTR sites, a 120 kHz downward oriented transducer was towed from the starboard hip of the research vessel R/V Pelican (June 1999) or the M/V Epic Mariner (June 2000). The towfish was flown 5 m from the side of the hull with a telescoping mast and 3 m below the surface at approximately 4 kts. Navigational data were collected with a Garmin GPS III global positioning system (GPS) with a Garmin GB 21 differential beacon receiver. The antenna for the GPS was mounted directly above the tow body. The navigation data stream, updated once per second, was incorporated into the acoustic data string and then saved onto a laptop computer. The towed transducer provided acoustic coverage from a depth of 10 m to within approximately 5 m of the bottom depending upon site.

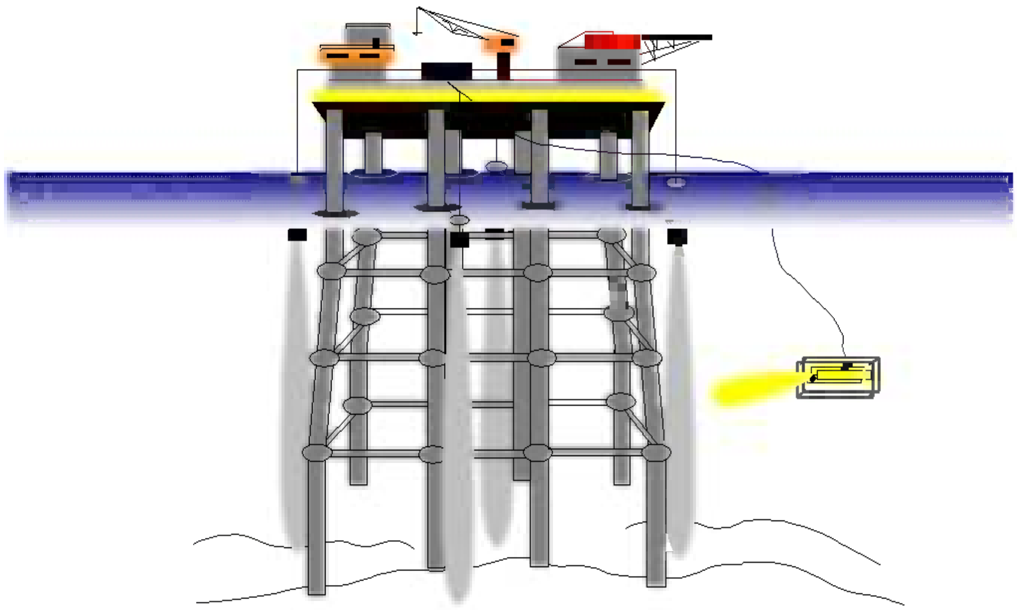


Figure 2. Configuration of downward-facing transducers at HI A350.

Survey transects over the RTR sites were alternating east-west then north-south passes over the target area (Figure 3). In June 1999 a total of 100 transects (50 east-west and 50 north-south) were run over each site. In the June 2000 survey, efforts were reduced to a total of 40 transects (20 east-west and 20 north-south) which gave the same statistical power as the 1999 survey. Transects were extended out to a distance of 100 m from each side of the target area for a total transect distance of approximately 300 m.

2.2.3 West Flower Garden Bank

The mobile survey of WFGB consisted of twenty-seven transects spaced 300 meters apart running along the long axis of the WFGB, from northeast to southwest (Figure 4). Transect lines were planned to begin and end near the outer boundaries of the Marine Sanctuary along the 100 m depth curve. This design allowed an open water control sample to be collected at the beginning and ending of every transect line. The lines varied in length from 2.5 kilometers to 13.5 kilometers. Data were collected along these transects continuously over a 29 hour period from 21-23 June 2000. For analysis purposes, the data collected at the WFGB were separated into three “terraces” based on water depth and specified as upper (20-50 meters), middle (80-100 meters), and lower (> 100 meters) (Bright and Boland 1985). A high resolution multi-beam side scan survey assisted the determination of the terraces (Gardner et al. 1998). These geological terraces have also been related to distinct biological zonations (Dennis and Bright 1998).

2.3 Acoustic Data Collection and Processing

Acoustic data were collected with a BioSonics model DT5000 scientific echosounder/multiplexer. All data were collected with 120 kHz transducers which had been factory calibrated to a - 42 dB tungsten sphere. Source levels were 223 dB / Pa at 1 m. Sampling rate was 5 pings /sec with a pulse width of 0.4 ms. Received signals were adjusted for spreading loss by applying a 40 log R time varied gain, digitized and recorded on the computer hard drive and later transferred to CD digital media. The data collection threshold was -55 dB, corresponding to a minimum detection of a 2.5 cm fish (Love 1971).

Digitized hydroacoustic data were processed with a BioSonics' Visual Analyzer 4.02. Recent advances in the software allowed simultaneous estimates of sigma (target strength) and mean volume backscatter (reflected acoustic energy) for each depth strata. These parameters are used to estimate fish density/m^3 and fish size. Data were aggregated into ten meter depth strata for each site. For the mobile surveys, data were processed through Visual Analyzer with the bottom tracking feature turned on; the bottom was then manually inspected and adjusted to insure that neither the bottom nor the platform were included in the analyzer window (Figure 5). Interactive bottom correction was not necessary for the standing platform as the transducers were fixed.

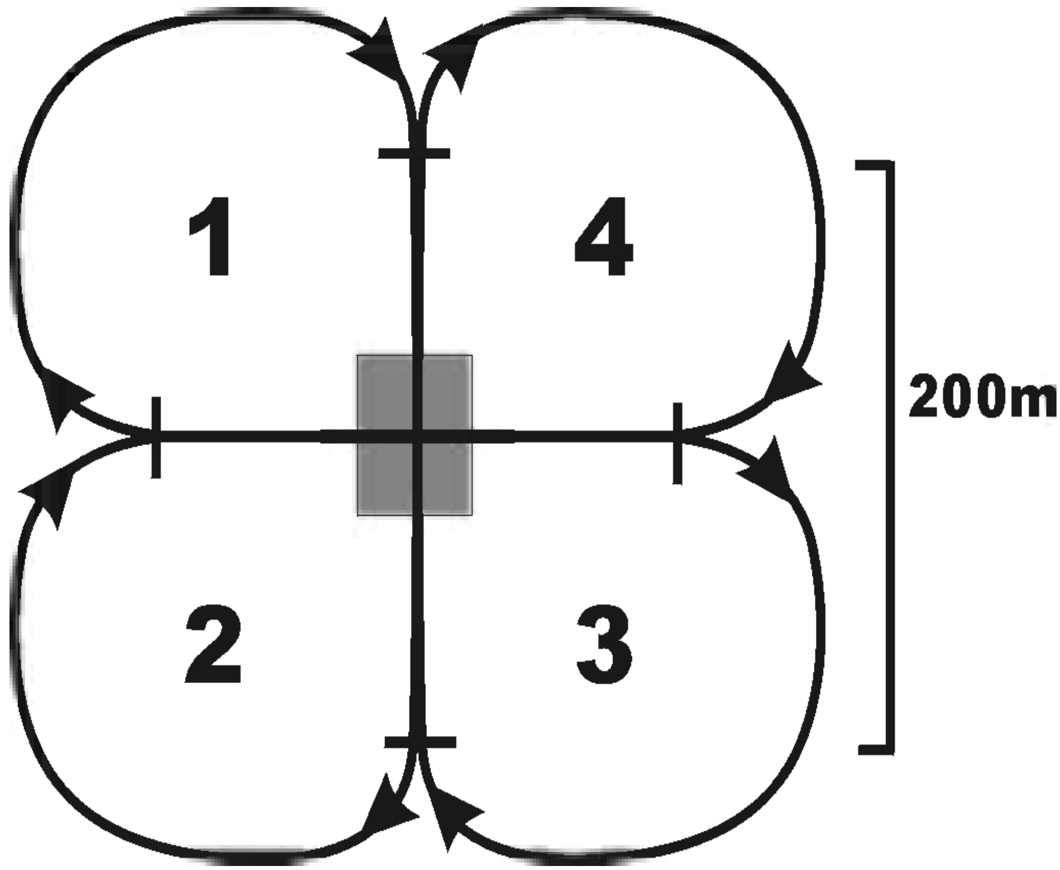


Figure 3. Survey design for the mobile surveys of the artificial sites. The arrows indicate the vessel direction.

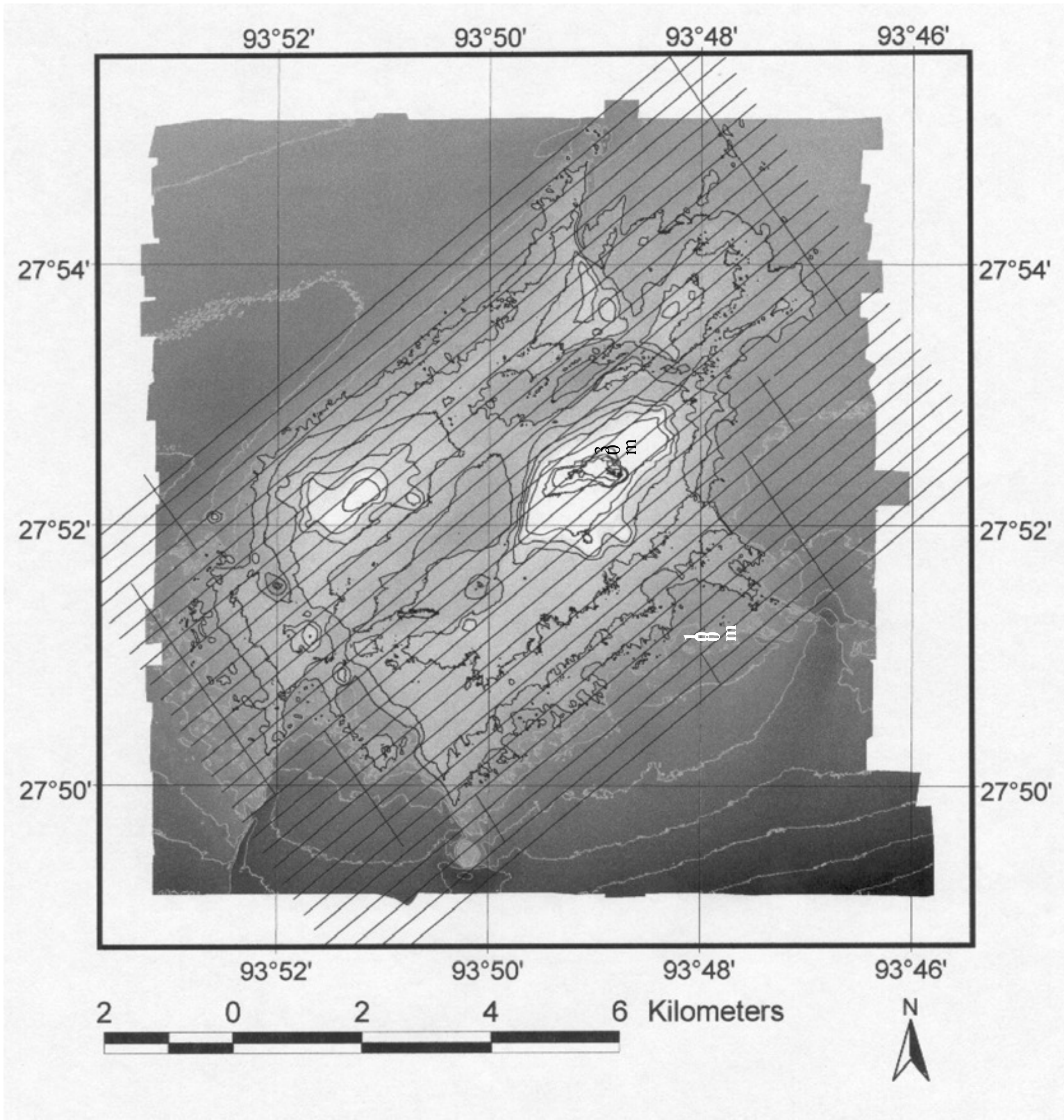


Figure 4. Intended vessel track lines of the WFGB hydroacoustic survey conducted in June 2000.

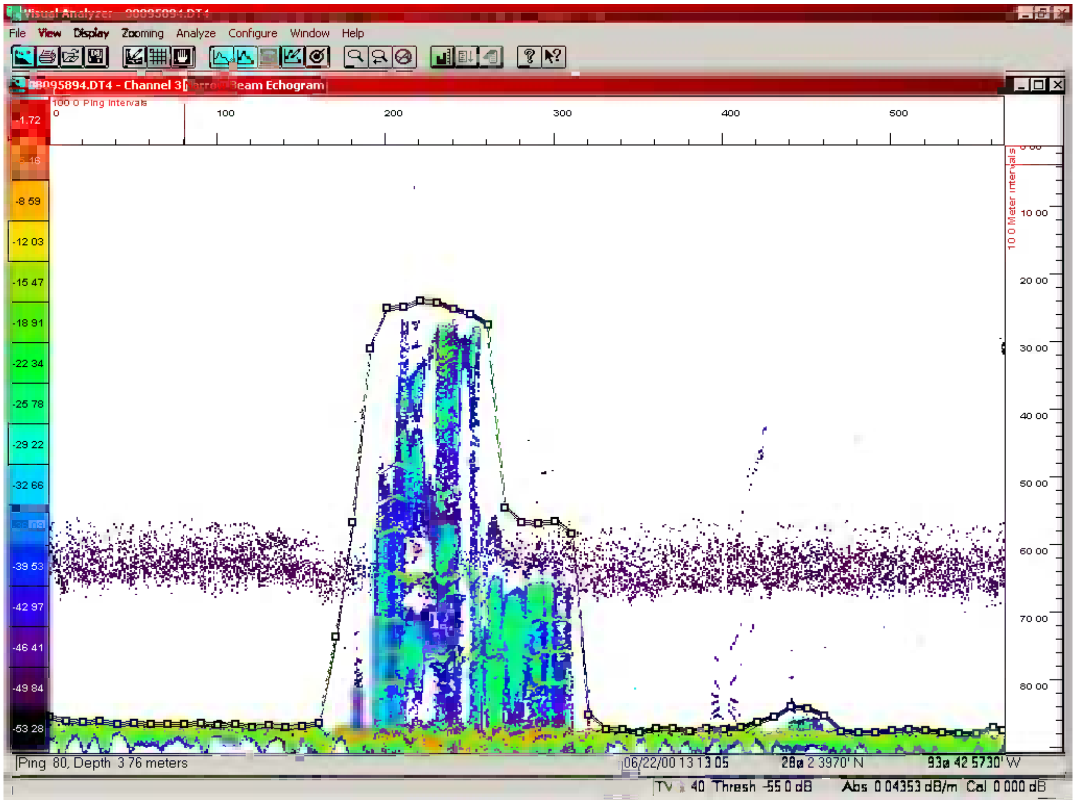


Figure 5. Sample color echogram showing structure as viewed in Visual Analyzer v 4.02. The bottom limit of the processed data was set just above the structure as shown by small boxes.

The standing platform data were analyzed in 5 minute blocks for each side as in previous studies (Stanley and Wilson 1997). Visual Analyzer outputs for the standing platform included volume backscatter/m^3, fish density/m^3, and mean target strength/m^3. A Visual Basic program was used to extract the data of interest from analysis outputs and to compile the results into a site specific database for statistical analysis.

Mobile transects were analyzed at one second resolution (2 meters linear distance) to determine the volume backscatter and target strength/m^3 within each depth stratum along the transect. Analysis of each one second block of data provided geographic position and mean volume back scatter. Individual target strength information was acquired by extracting ping specific data, which could be selectively output as a text file. A Visual Basic program was used to calculate an average target strength for each target, by strata, and location.

2.4 Data Analysis

Processing of acoustic data yields several parameters of interest. Fish density is calculated based on the volume backscatter (reflected acoustic energy) per volume of water divided by the average target strength (reported as sigma) from that same volume of water. Density is reported as number/m^3 in this study. Density estimates are dependent upon accurate estimates of the mean sigma of the targets within that same volume of water. Analysis of standing platform data with Visual Analyzer version 4.02 produced useful density estimates; however, analysis of the mobile data required refinement for more accurate density comparisons. The accuracy of sigma increases with repeated acoustic hits on the same target (Jim Dawson - pers com .Biosonics Inc. 4027 Leary Way NW Seattle Wa 98107- . Given that research operations were from a vessel moving at 4 knots and transmitting acoustic pulses (pings) at a rate of 4-5 pings per second, the chance of hitting a target multiple times was very low. In many cases, data processing resulted in a volume backscatter, but no sigma for that same volume of water. In estimating fish densities for mobile surveys, a mean sigma (proxy sigma) was calculated for a 30 m linear distance by stratum, and used as a proxy for target strength to calculate density. The assumption in this case, was that fish size was similar in the same stratum for 30 linear meters for the artificial reef sites and WFGB. If sigma was missing, but a volume backscatter volume was available, the proxy sigma was substituted to estimate density.

2.4.1 Statistical Analysis

Statistical analysis of these data included the reported reflected acoustic energy as volume backscatter (Sv), a proxy for fish biomass, as a dependent variable in our analysis. Sv is an exponential number provided by the BioSonics Visual Analyzer and is a per ping average of energy/m^3. For regression analysis and calculation of means, Sv is converted into a “arithmetic form”, called “Fish Energy”, with the relationship,

$$\text{Fish Energy} = 10^{\,sv/10}, \qquad \text{(Equation 1)}$$

where sv is volume backscatter (reflected acoustic energy) per cubic meter of water.“Fish Energy” should be considered to be an acoustic measurement of fish biomass as it is reported on the average acoustic reflectance/m^3 in decibels. The second dependent variable in our analysis was density/m^3, which was generated from Visual Analyzer for HI A350 and calculated for the mobile surveys of two reef sites at the WFGB with the equation,

$$10^{Sv/10} / 10^{S/10} = \text{fish/m}^3 \qquad \text{(Equation 2)}$$

where Sv is the volume backscatter/m^3 and S is the observed sigma (or the proxy sigma discussed above).

$$10^{s/10} \qquad \text{(Equation 3)}$$

is also the formual used to calculate Target strength (TS).

A randomized block analysis of variance was used to examine the main effects at HI A350 and TS at all sites as described by Stanley and Wilson (1997). Due to the larger number of zero values in the mobile survey, logistic regression (Trexler and Travis 2001) was used to analyze the mobile data.

2.4.2 Randomized Block Design (RBD) ANOVA's

Randomized block design ANOVA's (SAS Institute Incorporated 2000) were performed on the data from HI A350 with transformations as $\log_{10}$ (fish density + 1). Class variables included time of day (TOD; dawn, noon, dusk, midnight), platform side (north, south, east, west) ten meter depth strata (strata), and their interactions.

ANOVA's were used to analyze TS at all sites. Class variables for HI A350 include TOD, stratum, platform side, and all two-way interactions. Class variable for WC 617A and HI A355 include time of day (TOD), depth bin (stratum), reef side, horizontal 10 meter distance intervals away from the reef structure (away), and all two-way interactions. Class variables for WFGB included depth or terrace, stratum, TOD, transect number, and all two-way interactions. Tukey's standardized range tests (Ott 1982) were used to compare the means of significant variables. Statistical tests were reported as significant at the alpha < 0.01 level.

2.4.3 Logistic Regression

Traditional parametric analysis was not used for analysis of mobile acoustic data given the large number of zero values and the problem of autocorrelation that occurs in mobile acoustic data. A binomial logistic regression model was constructed for each site using the presence or absence of "fish energy" to evaluate the probability, or chance, of finding fish. This analysis was performed on the primary output of acoustic data analysis which was reported in 1 second intervals. Class variables for the artificial reef sites included orientation (over the platform, and north, south, east, and west sides), 10 m depth bin (stratum), distance away from the ref structure (away), Time of day (TOD), year (1999 or 2000), site (standing or toppled) and transect (ordinal number). Class variables for the WFGB were depth b in (stratum), terrace, and TOD.

The use of logistic regression in ecological sampling was described by Trexler and Travis (2001). It has been shown to be useful with data that have a large proportion of zero values when error is usually not normally distributed. In most cases, analysis consists of converting the dependent variable into a discrete form (e.g. presence/absent, agree/disagree, etc). The regression model then assumes a binomial distribution of errors (Trexler and Travis 2001, Garrison et al 2000).

The Statistical Analysis System (SAS Institute Incorporated 2000) includes a program called Proc Logistic that uses logistic analysis . When run with the intercept option, it produces a Type III analysis of main effects, which provides an estimate of the significance of class variables, based on a maximum likelihood test (Chi Square test of significance $p=0.01$) that is used for comparing within class variables. When run without an intercept, Proc Logistic provides an odds ratio estimate; in our use it is the probability of finding fish in a given class variable cell compared to another cell. Output also includes percent concordance, which is the percent of the time that the model correctly predicts the outcome.

2.4.4 Fish Abundance Estimation

Total fish abundance estimates at each site were calculated by determining a 20m near-field area of influence of each reef site or platform, then multiplying estimated fish density for each stratum and side (number of fish/m^3) by the volume of water on each side of or over the platform (Stanley and Wilson 1998). Fish density within the center of each platform was not measured with acoustics due to interference by structural members and was assumed to be the average of the density estimates of the four sides of the platform. Fish abundance in the center of the platform was calculated by multiplying the estimated fish density of the center by the volume of water in the center of the platform. Fish abundance estimates of the WFGB were based on the average density by stratum, within terrace times the area of each terrace and summed over all strata.

2.5 Visual Surveys

Visual surveys were conducted with a Deep Ocean Engineering Phantom HD2 ROV with standard visual census techniques and recording video on S-VHS tape (Bohnsack and Bannerot 1986). ROV based S-VHS recordings were made by flying the ROV on the down current side of each structure, along major legs, the ROV was paused at 10 m intervals from the surface to the bottom. Cryptic fishes were not included in the video surveys results since they could not be assessed in the acoustic surveys. Point counts were made from the S-VHS recordings and individual fish were identified to the lowest taxonomic level possible. Results and data were expressed as percent species composition by stratum at each site. Species abundances were estimated by multiplying the percent composition of a given species by the total number of fish estimated to be at that site (after Stanley and Wilson 1997).

During mobile surveys, the ROV was deployed from the M/V Epic Mariner or R/V Pelican. The vessel was anchored near each artificial reef site, and the ROV deployed to dive and capture video images over the toppled and partially-removed platforms. During the survey of the partially removed platform (HI A355), the ROV was flown from the top of the structure down to the bottom, stopping every 10 m for approximately 1 minute. During the survey of the toppled platform (WC 617A), the ROV was flown down to the top of the structure and then run along the south side, east side, and over the top of the toppled platform. Video surveys of the standing platform (HI A350), were conducted directly from the standing platform. The ROV was flown from the surface to the bottom, stopping every 10 m for approximately 5 minutes. Video data from the WFGB were collected along random transects designed to represent the three major terrace regions and geologic features located throughout the WFGB. The ROV was flown just above the bottom where it traveled at a speed of 1 knot for 45 minutes along a transect through each of the three major terraces.

3.0 RESULTS

3.1 High Island A350 (standing platform) Results

The stationary hydroacoustic survey of HI A350 was conducted in June 1999. A five-day trip was made to the platform where acoustic data and ROV data were collected.

3.1.1 Fish Energy (from Sv)

Volume Backscatter (Sv), the measure of the amount of reflected acoustic energy, or fish biomass /m^3 was converted to Fish Energy using Equation 1 in the Materials and Methods. Fish Energy ranged from 0.0 to 2.2 x 10^{-4} /m^3; the mean value at HI A350 was 1.2 x 10^{-6} /m^3. Based on ANOVAs, Fish Energy was affected by depth, time of day, and the interactions of side and depth (Table 2). Fish Energy was highest at the surface and lowest near the bottom. The upper two strata (10 and 20m) were significantly different from one another and both were significantly higher than the remaining deeper strata (30 - 80m) (Figure 6). Fish Energy also varied significantly with time of day (TOD) and was highest at dusk followed by noon, morning, and midnight (Figure 7).

3.1.2 Density Estimates

Estimates of fish density were based on Sv divided by the average sigma for fish in the same volume of water (See Equation 2) and in general followed Fish Energy patterns. Estimated fish densities ranged from 0.0 to 0.7 fish/m^3; the mean fish density at HI A350 was 0.015 ± .003 (mean ± std error) fish/m^3. Based on RBD ANOVAs, density was affected by depth, TOD and their interactions. Densities were highest in the upper part of the water column and generally decreased with depth (Figure 8). Density also varied with TOD and was highest at dusk and lowest at midnight (Figure 9). The results of the ANOVA are shown in Table 3.

3.1.3 Target Strength

Target strength (TS) is an acoustic measure of fish size which was used as a dependent variable to test for relationships between fish size with TOD, orientation, and depth and their interactions. TS ranged from -52.46 to -30.75 dB; the average TS at HI A350 was - 40.73 dB which is equivalent to a 12.5 cm fish. No singel targets were identified in the 10m or 80m strata. Based on the RBD ANOVAs, TS at the standing platform was affected by depth and time of day (Table 4). Targets ranged from -39.2 to -36.4 dB in the upper three strata (20, 30, and 40m), peaked at -32.5 dB at 50m, and dropped to near -45 dB in the 60 and 70m strata (Figure 10). Targets were also significantly larger in the morning than at noon, dusk, and midnight (Figure 11).

Table 2.

RBD ANOVA (block on side) results (significant) of fish energy (arithmetic form of volume backscatter) with platform side (Ornt), depth stratum (Stratum), TOD, and selected interactions at High Island A350.

Source	**DF**	**SS**	**MS**	**F**	**Prob > F**
Model	95	0.00000001	0	12.56	0.0001
Error	573	**0**	**0**		
Corrected Total	668	0.00000001			
	R-Squared	**C.V.**	**Root MSE**		**Energy Mean**
	0.67	131.735	0.00000212		0.00000161
Variables	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Stratum	7	0	0	61.53	0.0001
Time of day	3	0	0	5.73	0.0007
Ornt*Time of day	6	0	0	4.69	0.0001
Stratum*Time of day	21	0	0	7.59	0.0001

Table 3.

RBD ANOVA (block on side) results (significant) of log10 (fish density) with platform side (Ornt), depth stratum (Stratum), TOD, and selected interactions at High Island A350.

Source	**DF**	**SS**	**MS**	**F**	**Prob > F**
Model	95	0.071	0.000755	4086	0.0001
Error	432	0.067	0.00015541		
Corrected Total	527	0.13			
	R-Squared	**C.V.**	**Root MSE**		**LogDEN Mean**
	0.51	319.73	0.012		0.0038
Variables	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Stratum	7	0.039109	0.000558	35.95	0.0001
Time of day	3	0.00167	0.0005583	3.59	0.0137
Ornt*Stratum	14	0.00824	0.0005889	3.79	0.0001
Stratum*Time of day	21	0.01283	0.000611	3.93	0.0001

Table 4.

RBD ANOVA (block on side) results (significant) of target strength with, depth stratum (Stratum), TOD, and selected interactions at High Island A350.

Source	**DF**	**SS**	**MS**	**F**	**Prob > F**
Model	33	0.071	0.0008	4086	0.0001
Error	55	0.067	0.00016		
Corrected Total	88	0.13			
	R-Squared	**C.V.**	**Root MSE**		**LogDEN Mean**
	.55	319.73	0.012		0.0038
Variables	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Stratum	6	0.039	0.0005	35.95	0.0001
Time of day	3	0.001	0.0005	3.59	0.0137
Ornt*Stratum	14	0.008	0.0005	3.79	0.0001
Stratum*Time of day	21	0.012	0.0006	3.93	0.0001

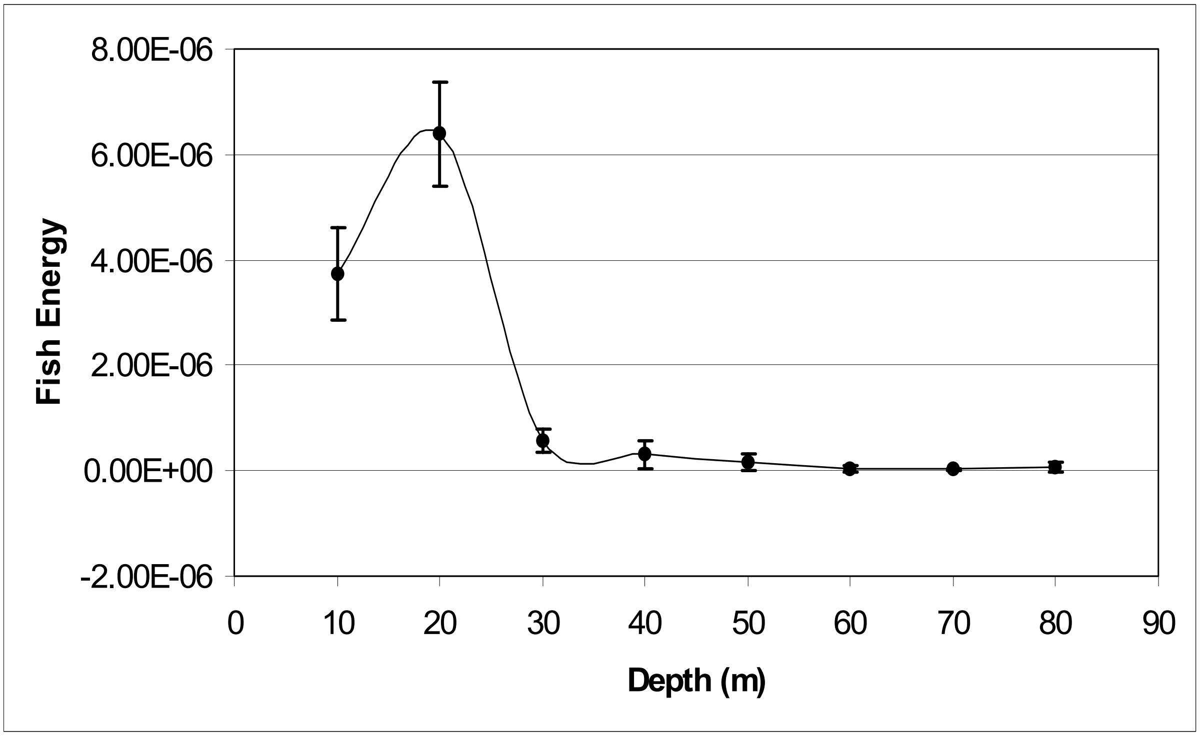


Figure 6. Mean fish energy/m^3 (antilog of volume backscatter) by depth stratum for HI A350. Error bars are 95% confidence intervals.

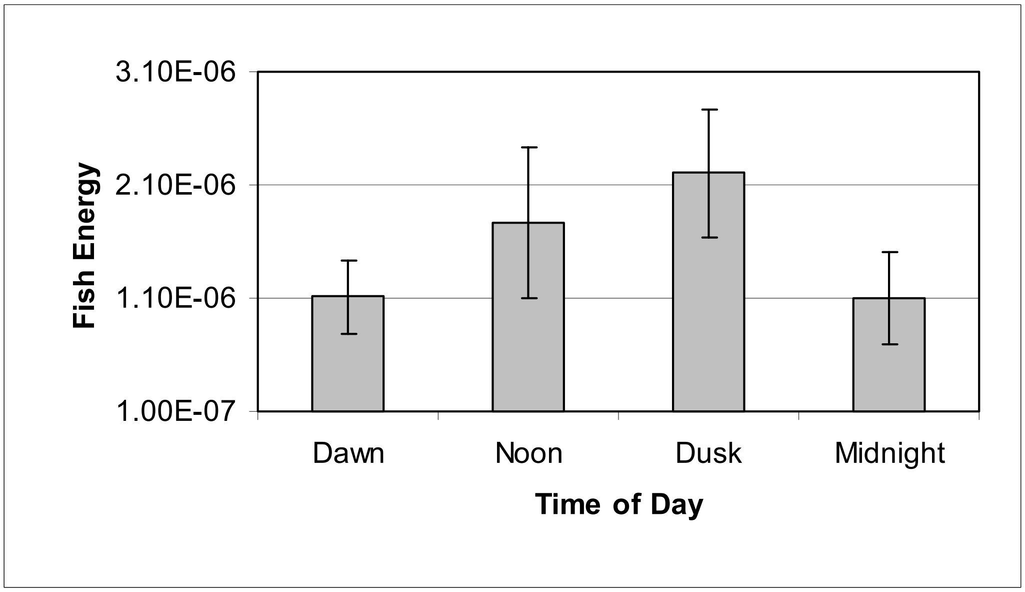


Figure 7. Mean fish energy/m^3 (antilog of volume backscatter) at TOD for HI A350. Error bars are 95% confidence intervals.

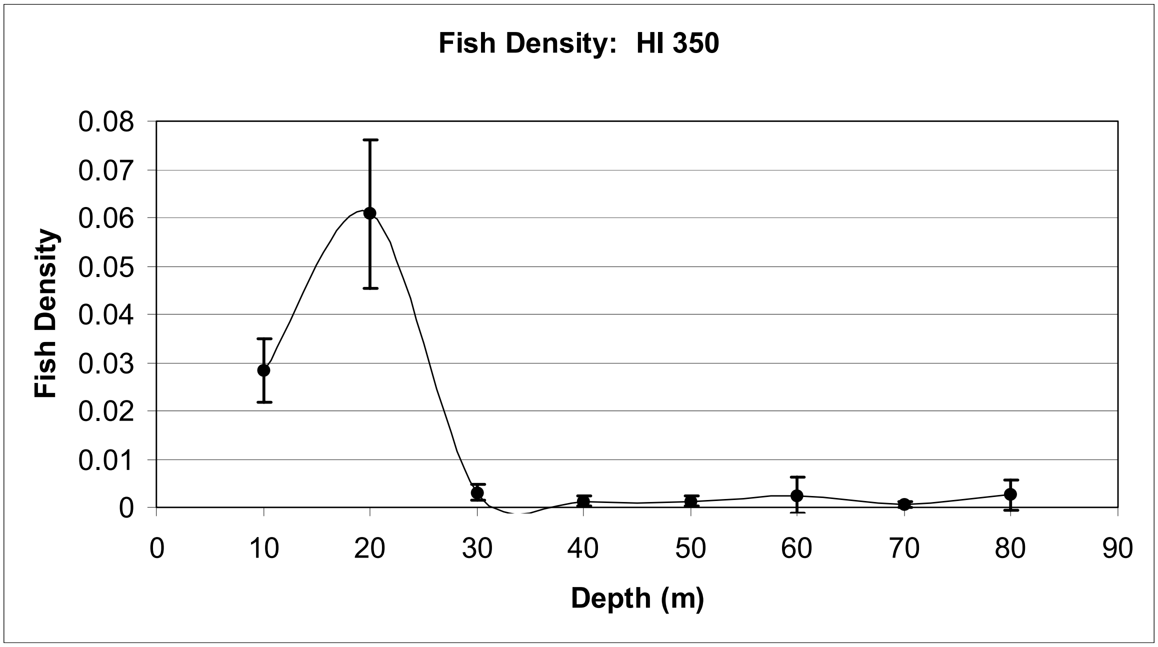


Figure 8. Estimated mean fish density (#/m^3) at depth for HI A350. Error bars are 95% confidence intervals.

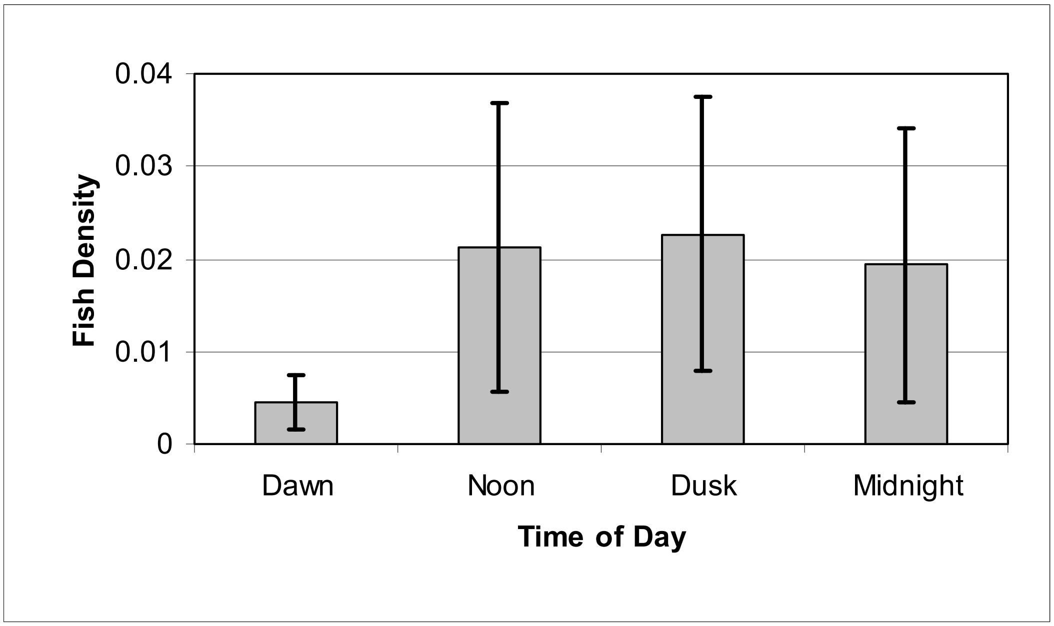


Figure 9. Estimated mean fish density (#/m^3) at TOD for HI A350. Error bars are 95% confidence intervals.

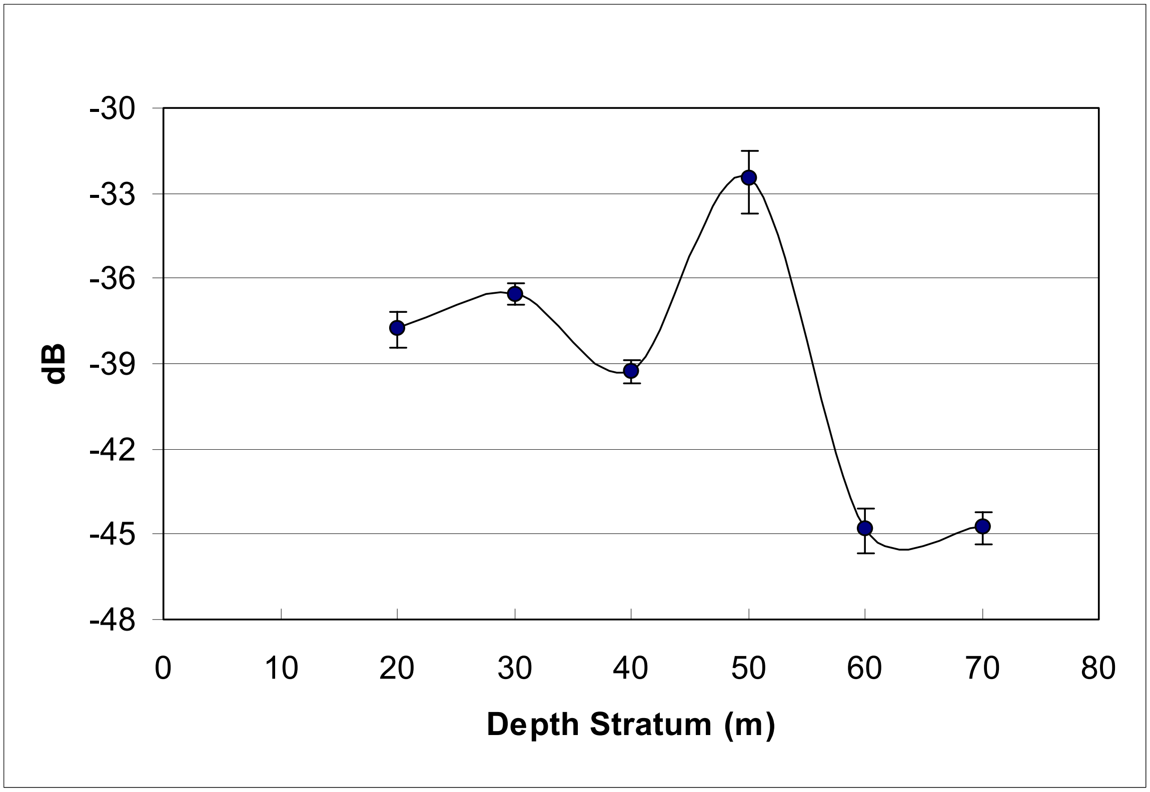


Figure 10. Estimated mean target strength (dB) (Love 1971) by depth stratum around HI A350. Error bars are 95% confidence intervals.

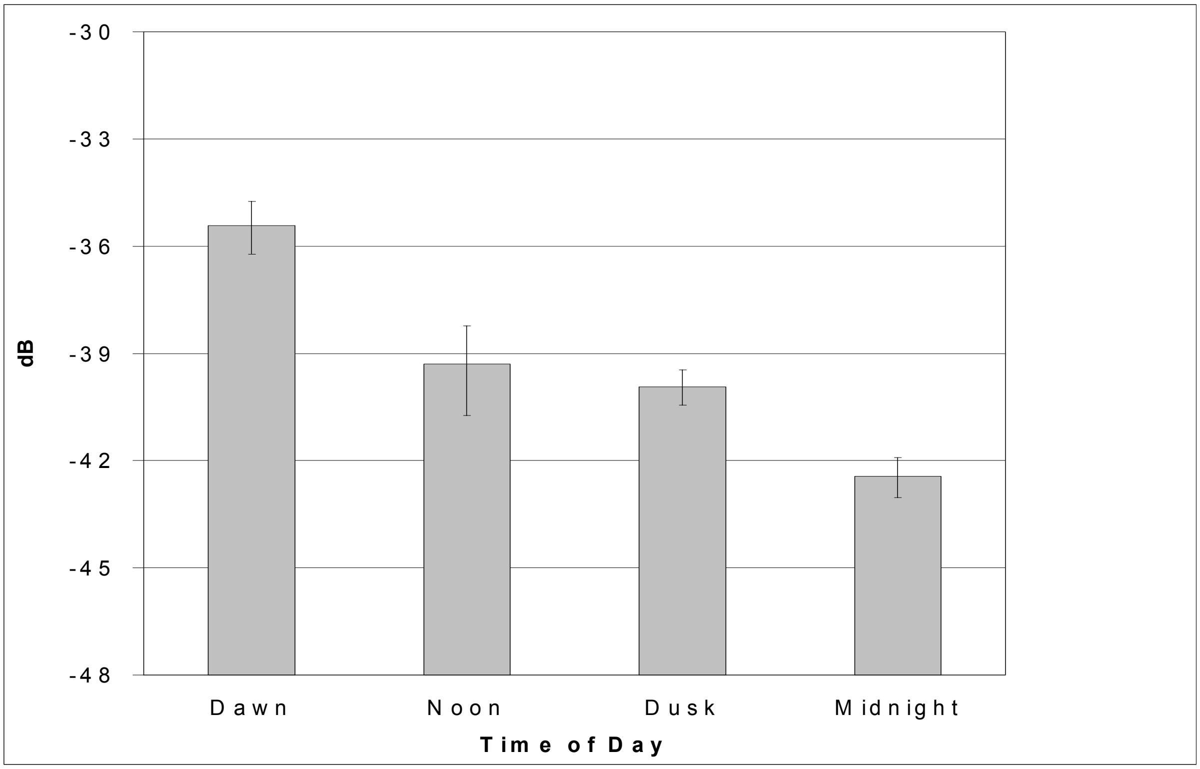


Figure 11. Estimated mean target strength (dB) (Love 1971) by TOD around HI A350.
Error bars are 95% confidence intervals.

3.1.4 Species Composition and Abundance

The fish community observed by ROV at HI A350 was very similar to previous studies and consisted of pelagic planktivores near the surface and reef-associated species near the bottom (Appendix). Bermuda chub and blue runner were the most abundant species making up more than 50 percent of the fish observed on the ROV survey; they were most common near the surface. Creole-fish, scamp, and red snapper were also fairly abundant and made up approximately one-third of the species present. Red snapper and scamp were most numerous at 40-50m and creole-fish were most abundant at mid-depth (30m). Species composition at HI A350 is shown in Table 5.

We estimate that there were 7,100 fish at HI A350 within a 20 m radius. Based on a combination of ROV data and acoustic data, there were approximately 2,100 blue runner, 1,000 Bermuda chub, 1,000 creole fish, 500 scamp, and 400 red snapper.

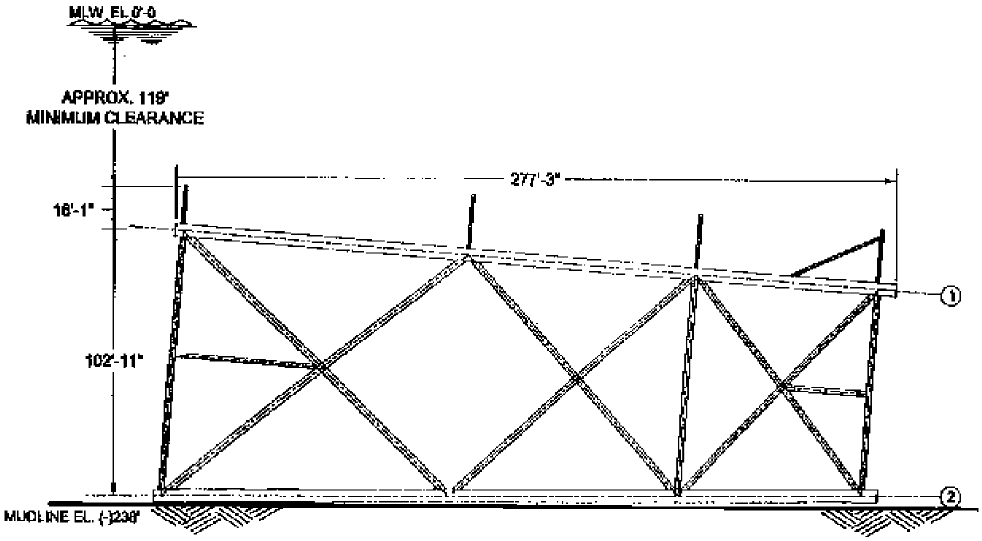
3.2 West Cameron 617A and High Island A355 Results

Schematic diagrams of both WC 617A (toppled platform) and HI A355 (partially removed platform) are shown in Figure 12, and depict the orientations and configurations of the platforms at the times of conversion into reef sites. Bottom depth was extracted from our acoustic surveys and a plot of the vessel track lines and extracted bottom contours is shown in Figure 13. Figure 14 shows a three-dimensional representation of the current configuration and bathymetry at each RTR site.

Sample color enhanced echograms of transects are shown in Figure 15. These echograms represent several seconds of data taken over each site. The images clearly illustrate the outlines of each structure and the acoustic comparison of structure and bottom hardness. Figure 15A is an echogram of the toppled platform with several fish located above the structure. Cross members and legs appear in bright red indicating that the platform is much harder (and more reflective) than the bottom. Figure15B is from the partially removed platform and shows a distinct water mass at 50-60 m that populated by scattered small targets. Several fish can be seen near the top in Figure 15B.

Acoustic data were used to determine fish presence based on volume backscatter, to estimate density /m^3, and to estimate fish size above, around, and away from the reef sites. One concern was that transect number might lead to a decrease in fish density as multiple passes of the vessel over each site might scare away fish. Including transect number (n=100) as a class variable in the logistic regression for the 1999 data at both sites indicated a significant effect; however, there was no pattern indicating a predictable decrease or increase in the probability of finding fish with consecutive transects or TOD (Figure 16). We therefore combined all transects for further analysis. Results of our analysis are discussed below by site.

A.



B.

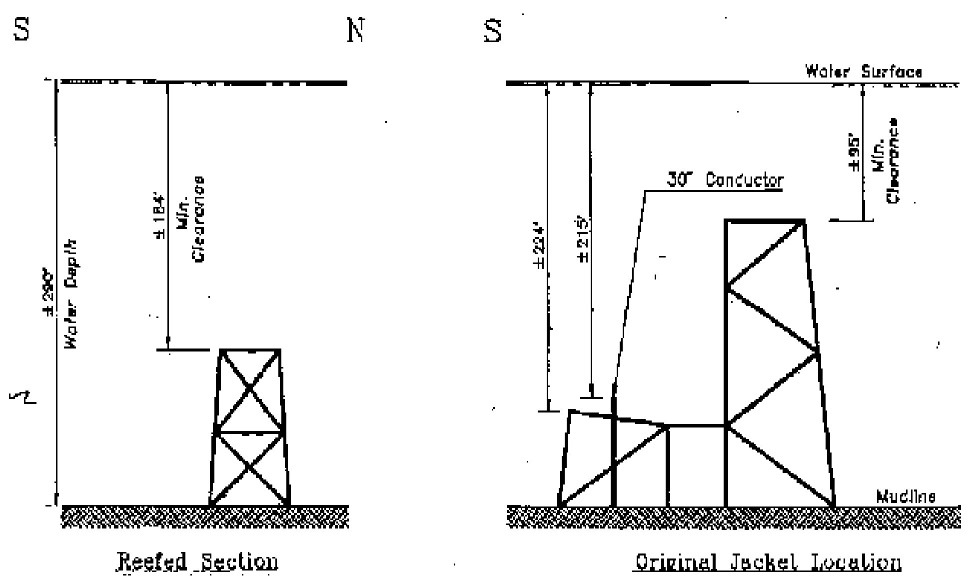
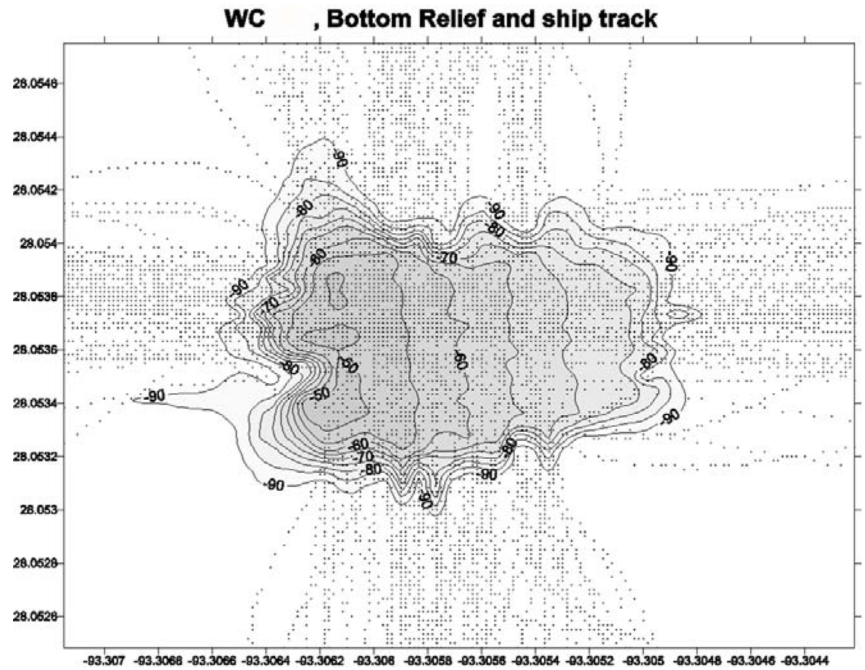


Figure 12. Line drawings of WC 617A (toppled platform) and HI A355 (partially removed platform with a small 4-leg section to the southwest).

A.



B.

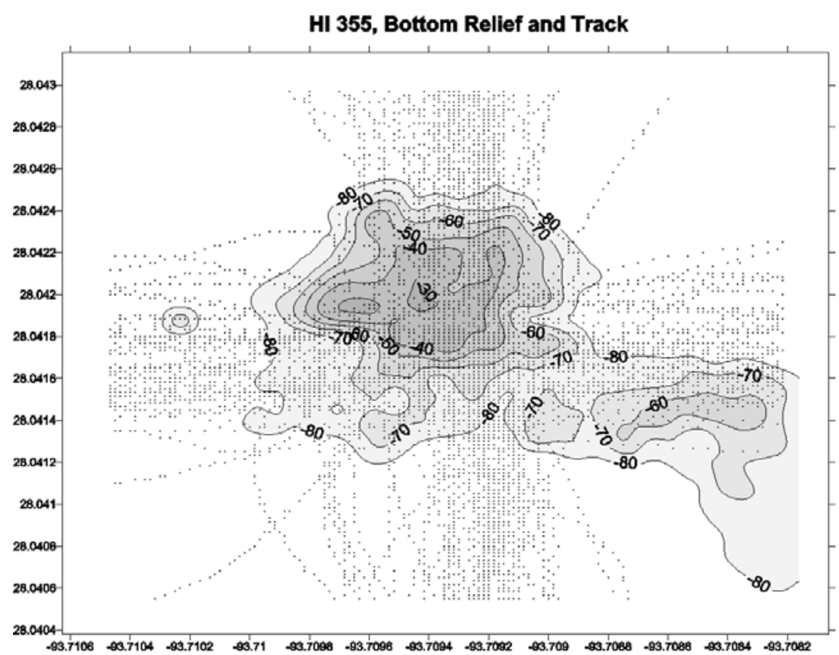
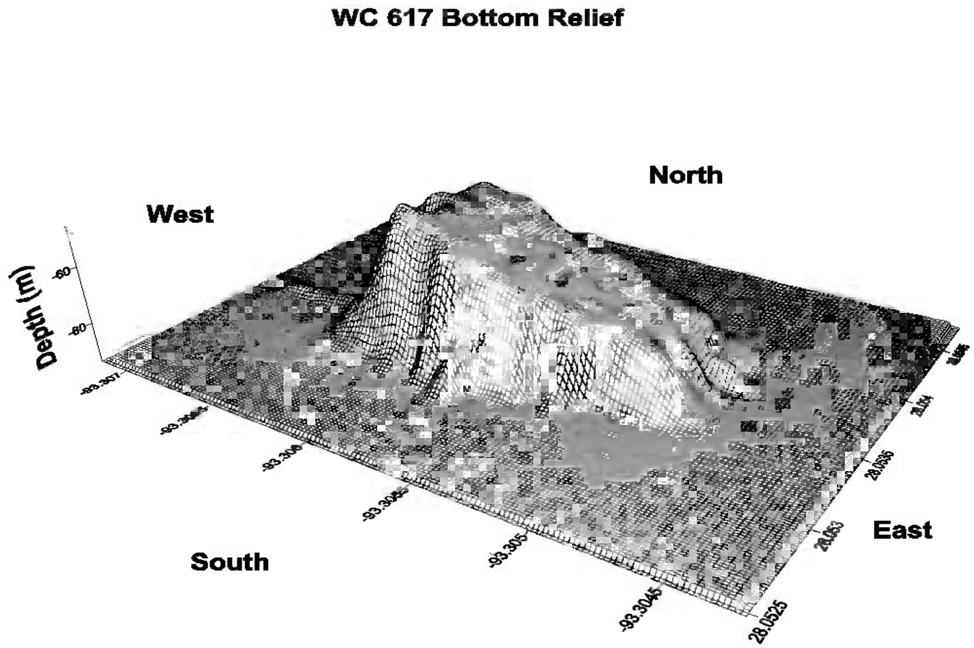


Figure 13. Plot of vessel track (dotted lines) over WC 617A (A) and HI A355 (B) for surveys conducted June 1999 and June 2000. Bathymetry contour show depths at each reef site and indicate the platforms. North is up in both figures.

A.



B.

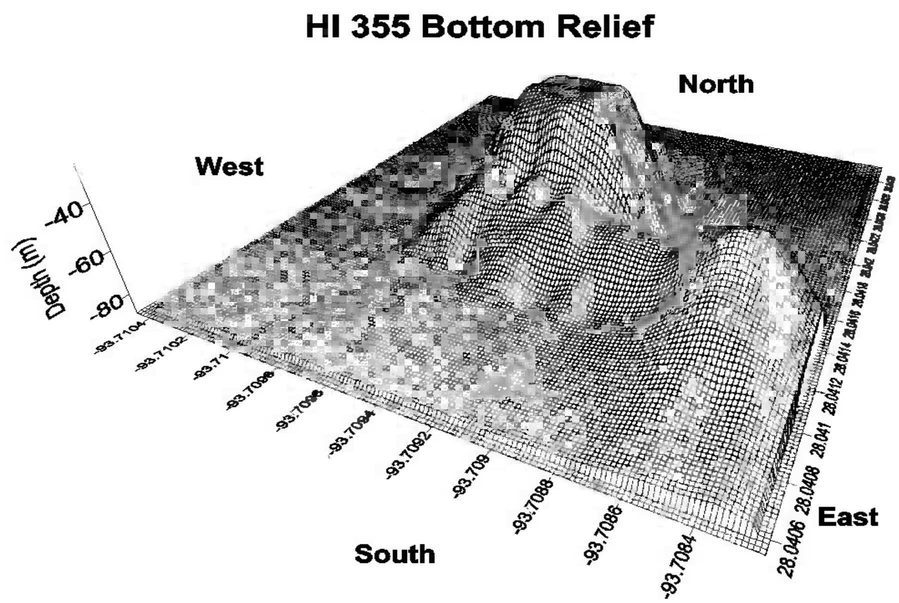
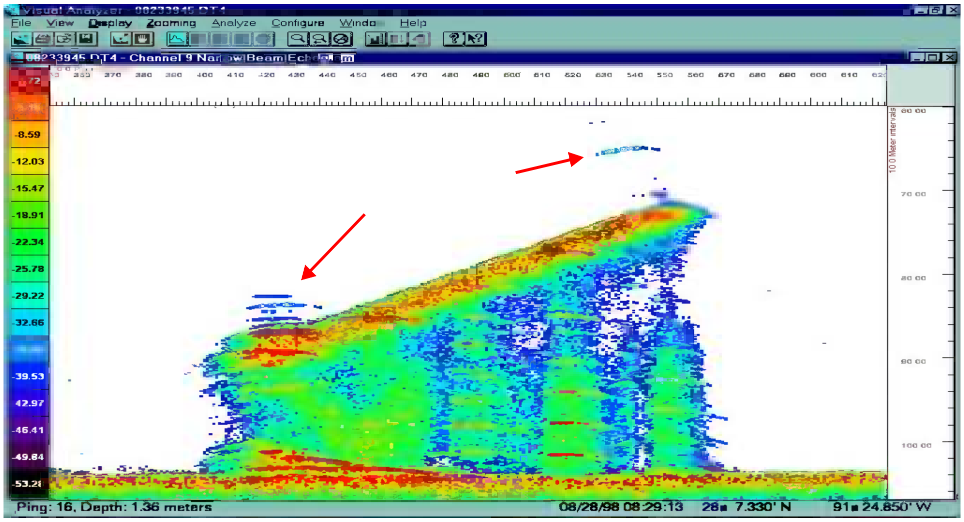


Figure 14. Acoustic depth profiles of WC 617A and HI A355 based on a geo-referenced plot of depth from the hydroacoustic survey conducted in June 1999 and 2000. Outlines of both structures are evident based on bottom depth.

A.



B.

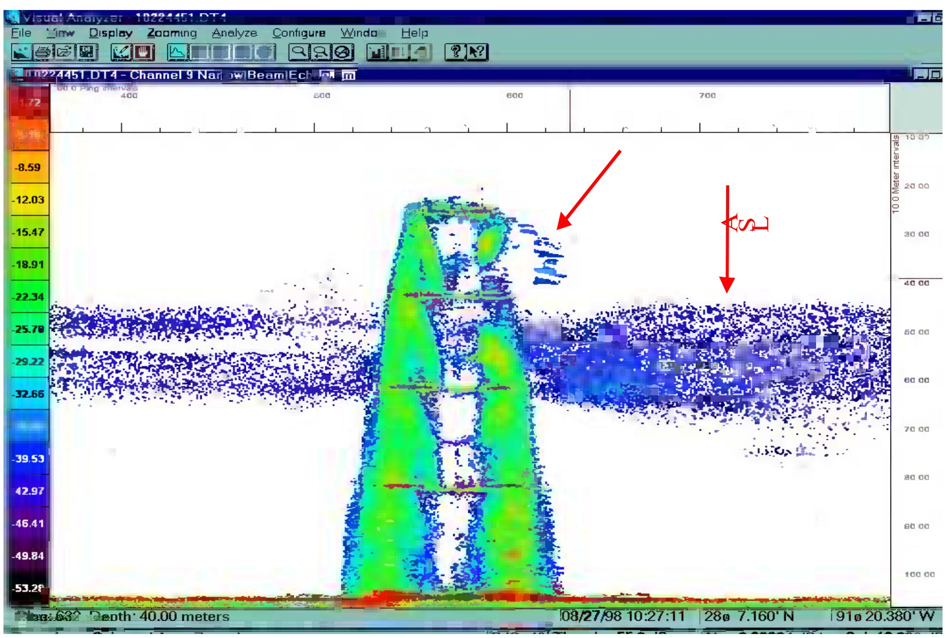
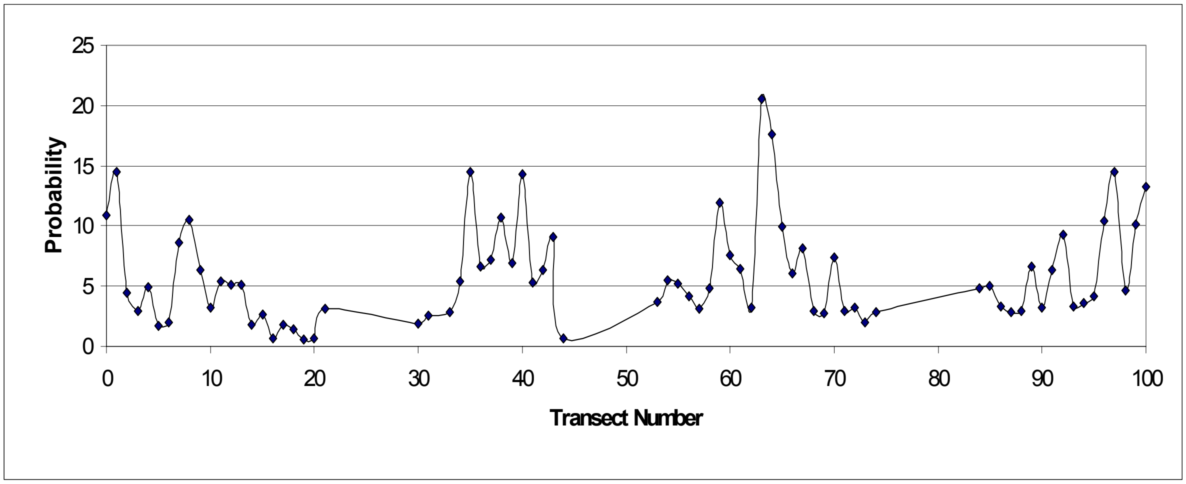


Figure 15. Color enhanced echograms of WC 617A (A) and HI A355 (B) from BioSonics Visual Analyzer (v4.02) analysis viewer. Arrows point toward fish. Acoustic Scattering Layer (ASL) in B is likely due to plankton.

A.



B.

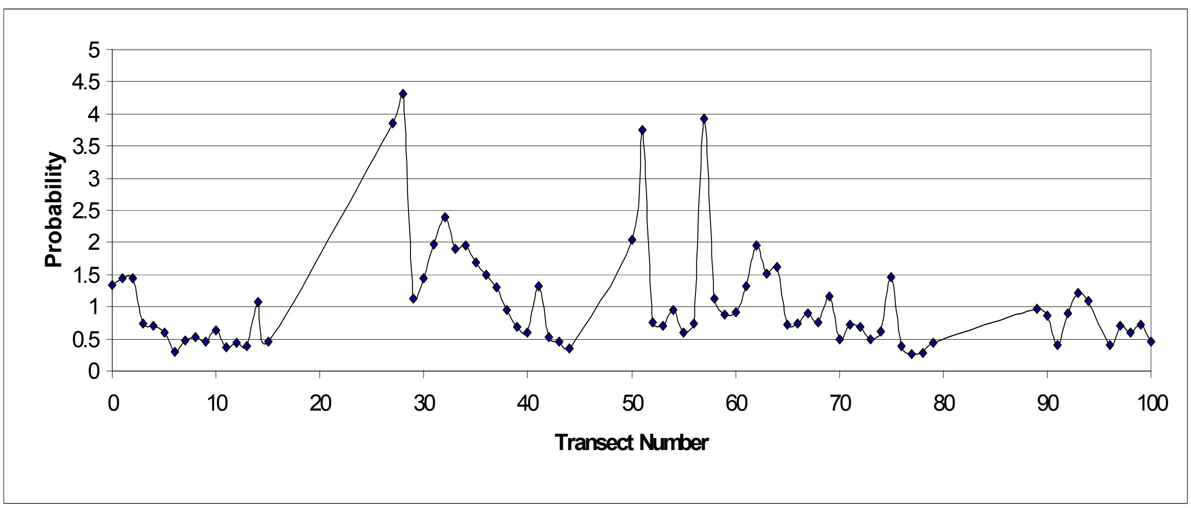


Figure 16. Change in probability of finding a fish with consecutive transect number for WC 617A (A) and HI A355 (B) during 1999 referenced to the final transect.

Table 5.

Species common names and scientific names, numbers of individuals by stratum, totals, and percent composition from visual point counts using video from a remotely operated vehicle (ROV) from High Island A350, June 1999.

High Island A350	June 1999										
Common Name	**Scientific Name**	**0 m**	**10 m**	**20 m**	**30 m**	**40 m**	**50 m**	**60 m**	**70 m**	**Totals**	**% comp**
Almaco jack	*Seriola rivoliana*	5	1	22	9	-	1	-	-	38	3.6
Bermuda chub	*Kyphosus sectatrix*	280	-	-	-	-	-	-	-	280	26.8
Bar jack	*Caranx ruber*	1	-	-	-	-	-	-	-	1	0.1
Great barracuda	*Sphyraena barracuda*	6	10	2	-	-	-	-	-	18	1.7
Blue angelfish	*Holacanthus bermudensis*	-	6	10	5	-	-	-	-	21	2.0
Blue runner	*Caranx crysos*	92	33	182	-	-	-	-	-	307	29.4
Blue tang	*Acanthurus coeruleus*	-	2	4	1	-	-	-	-	7	0.7
Creole-fish	*Paranthias furcifer*	-	-	94	53	-	-	-	-	147	14.1
Crevalle jack	*Caranx hippos*	-	9	-	-	-	-	-	-	9	0.9
French angelfish	*Pomacanthus paru*	-	-	4	3	-	-	-	-	7	0.7
Gag	*Mycteroperca microlepis*	-	-	1	-	-	1	-	-	2	0.2
Greater amberjack	*Seriola dumerili*	-	2	4	4	2	8	1	-	21	2.0
Gray triggerfish	*Balistes capriscus*	1	-	1	2	4	-	-	-	8	0.8
Rainbow runner	*Elagatis bipinnulata*	-	-	11	-	-	-	-	-	11	1.0
Red snapper	*Lutjanus campechanus*	-	-	-	-	11	50	-	-	61	5.8
Rock beauty	*Holacanthus tricolor*	-	-	-	1	-	-	-	-	1	0.1
Reef butterflyfish	*Chaetodon sedentarius*	-	-	-	-	1	-	-	-	1	0.1
Scamp	*Mycteroperca phenax*	-	-	2	17	7	37	10	-	73	7.0
Sergeant major	*Abudefduf saxatilis*	6	1	7	-	-	-	-	-	14	1.3
Spanish hogfish	*Bodianus rufus*	-	-	9	1	1	-	-	-	11	1.0
Squirrelfish	*Holocentrus adscensionis*	-	-	3	-	-	-	-	-	8	0.8

3.2.1 West Cameron 617A Results

3.2.1.1 Fish Energy

A binomial logistic regression model was constructed to analyze WC 617A acoustic data with presence/absence of Sv (Fish Energy) in 1 second intervals as the dependent variable with class variables, orientation, stratum, away, TOD, and year and all two way interactions. All class variables were significant indicating their influence on the probability of fish occurring (Table 6). Two-way interactions were evaluated and found to be either insignificant or of no biological meaning, so they were removed from the model as they confounded the class variables interpretation.

Odds ratio estimates produced in Proc Logistic without an intercept provided insight into how the probability of finding fish varied within each class variable. Analysis outputs indicated that there was a difference between years as the chance of finding a fish in 1999 was approximately 2.5 times that in 2000. In addition, there was a higher probability of finding a fish over than any of the four sides or away from the platform . Not only was the probability of finding fish higher over the platform, but also there was higher mean biomass (measured as Fish Energy) over the platform than on the sides. Hence when fish were present, higher biomass was found over the reef site than on any of its sides. Logistic regression analysis also indicated that fish were more likely to occur near the bottom.

Mean Fish Energy was highest over the platform and declined with distance (Figure 17A). Fish Energy also varied by side (orientation), but was lower on all sides compared to over the platform (Figure 18A). Beyond 30 m away from WC 617 Fish Energy was similar to open water levels. We therefore assigned a 20 meter area of influence of this site. Mean Fish Energy also varied with depth and time of day, tending to be higher near the bottom (Figure 19A) and higher at midnight (Figure 20A).

3.2.1.2 Target Strength

The relationship between TS and associated class variables was modeled with RBD ANOVAs. TS was affected by side, depth stratum, and TOD and all interactions (Table 7). Fish were, on average, larger over the platform (Figure 21A) and decreased with increased distance from the site (Figure 22A). Fish size also varied with depth and targets tended to be larger immediately above the structure and near the surface (Figure 23A). Average acoustic size at WC 617A was - 46 dB (8.6 cm) and ranged from -62 to -26 dB (1.2 to 96 cm) (Love 1971). Target size changed with TOD, and fish were larger at dawn followed by midnight, dusk, and noon (Figure 24A).

Table 6.

Logistic regression analysis results of fish energy (antilog of volume backscatter) with platform side (Ornt), depth stratum (Stratum), and TOD at WC 617A.

Type III Analysis of Effects			
Effect	**DF**	**WaldChi-Square**	**Pr > ChiSq**
ORNT	4	115.50	<.0001
Stratum	6	5102.70	<.0001
Time of day	3	871.32	<.0001
YEAR	1	1073.04	<.0001
away	7	80.46	<.0001

Analysis of Maximum Likelihood Estimates						
Parameter		**DF**	**Estimate**	**Standard Error**	**Chi-Square**	**Pr > ChiSq**
Intercept		1	-1.10	0.03	1027.14	<.0001
ORNT	1	1	-0.47	0.07	41.97	<.0001
ORNT	2	1	-0.63	0.07	76.85	<.0001
ORNT	3	1	-0.44	0.07	35.87	<.0001
ORNT	4	1	-0.30	0.07	16.25	<.0001
Stratum	1	1	-1.08	0.04	713.04	<.0001
Stratum	2	1	-1.00	0.04	654.75	<.0001
Stratum	3	1	-0.31	0.03	98.96	<.0001
Stratum	4	1	0.01	0.03	0.06	0.81
Stratum	5	1	0.02	0.03	0.75	0.39
Stratum	6	1	1.25	0.02	2856.71	<.0001
Time of day	1	1	0.33	0.03	137.86	<.0001
Time of day	2	1	-0.33	0.03	140.19	<.0001
Time of day	3	1	-0.51	0.02	546.49	<.0001
YEAR	1999	1	-0.52	0.02	1073.04	<.0001
away	0	1	-2.36	0.30	60.11	<.0001
away	10	1	0.31	0.06	32.11	<.0001
away	20	1	0.39	0.06	47.52	<.0001
away	30	1	0.37	0.06	42.67	<.0001
away	40	1	0.27	0.06	21.43	<.0001
away	50	1	0.26	0.06	19.94	<.0001
away	60	1	0.29	0.06	24.25	<.0001
away	70	0	0.29		.	.

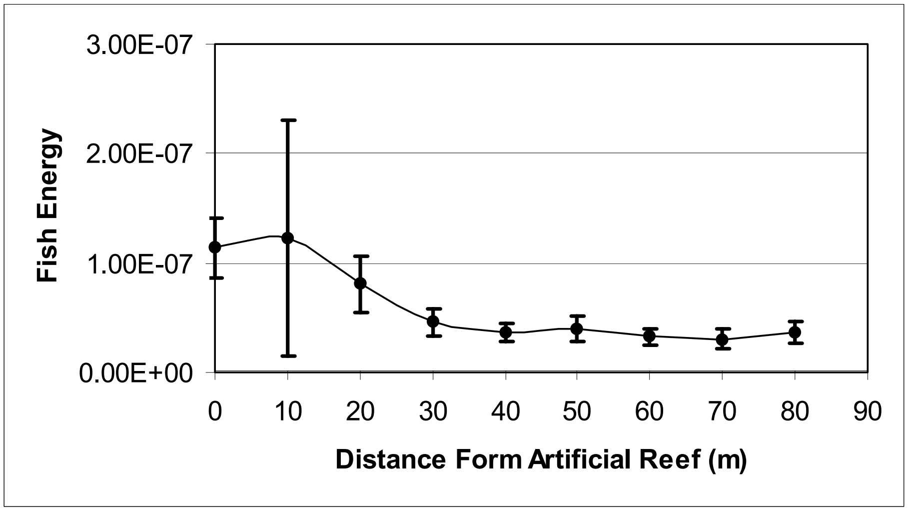
Association of Predicted Probabilities and Observed Responses				
Percent	Concordant	73.4	Somers' D	0.479
Percent	Discordant	25.5	Gamma	0.484
Percent	Tied	1.2	Tau-a	0.148
Pairs		528577500	c	0.739

Table 7.

RBD ANOVA (block on side) results of target strength with platform side (Side), depth stratum (Stratum), distance away from the platform (Away) and TOD (Time of day), and selected interactions at WC 617A.

Source	DF	SS	MS	F	Prob > F
Model	89	107215.16	1204.66	66.75	0.0001
Error	9910	178858.04	18.048		
Corrected Total	9999	286073.2			
	R-Squared	**C.V.**	**Root MSE**		**TS Mean**
	0.37	-9.35	4024832		-45.42
Variables	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Ornt	3	3318.04	1106.01	61.28	0.0001
Stratum	6	7213.15	1202.19	66.61	0.0001
Time of day	3	649.24	216.41	11.99	0.0001
Ornt*Away	3	852.43	284.14	15.72	0.0001
Ornt*Stratum	18	4043.77	224.65	12.45	0.0001
Ornt*Time of day	9	1633.80	181.53	10.06	0.0001
Stratum*Away	6	1311.37	218.56	12.11	0.0001
Stratum*Time of day	18	12305.13	683.61	37.88	0.0001
Away*Time of day	3	383.450	127.81	7.08	0.0001
Ornt*Away*Time of day	9	737.99	81.99	4.54	0.0001

A.



B.

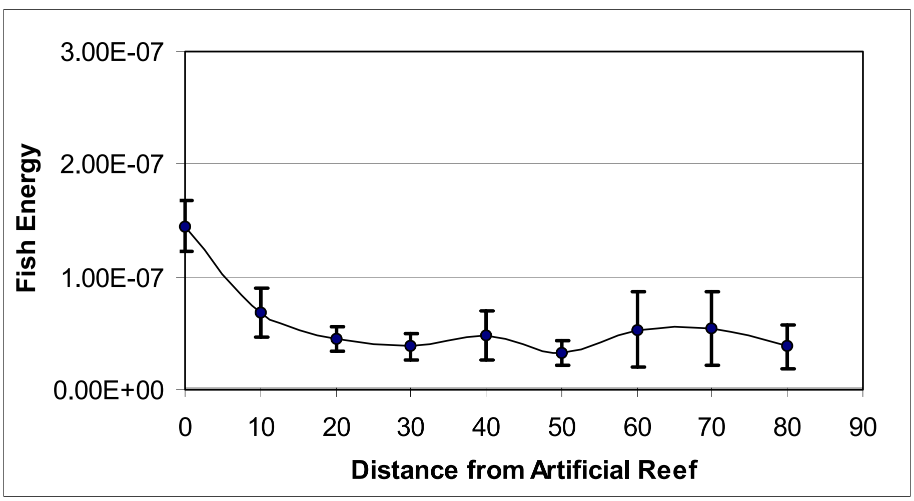
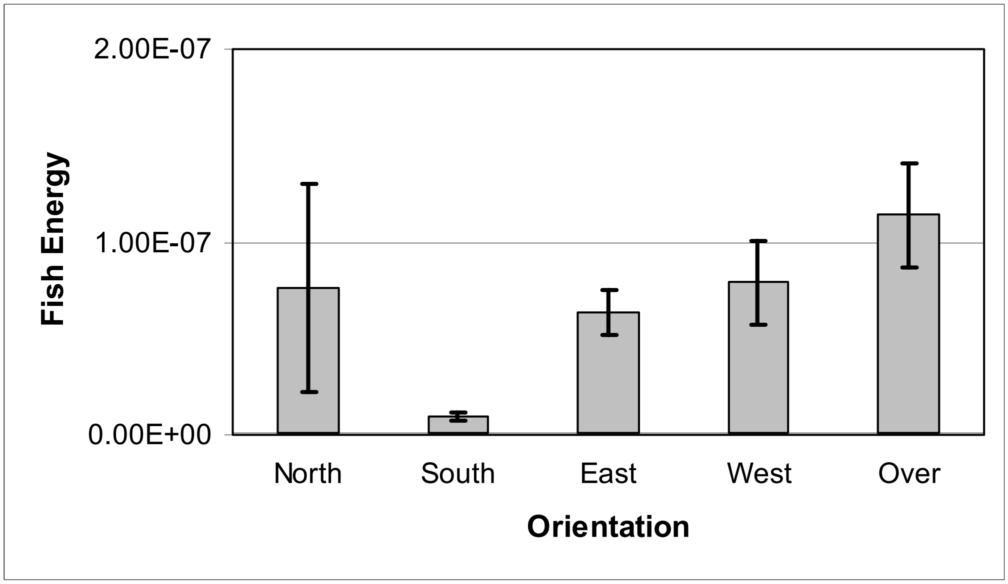


Figure 17. Estimated mean fish energy /m^3 (antilog of volume backscatter) at distance from reef site for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

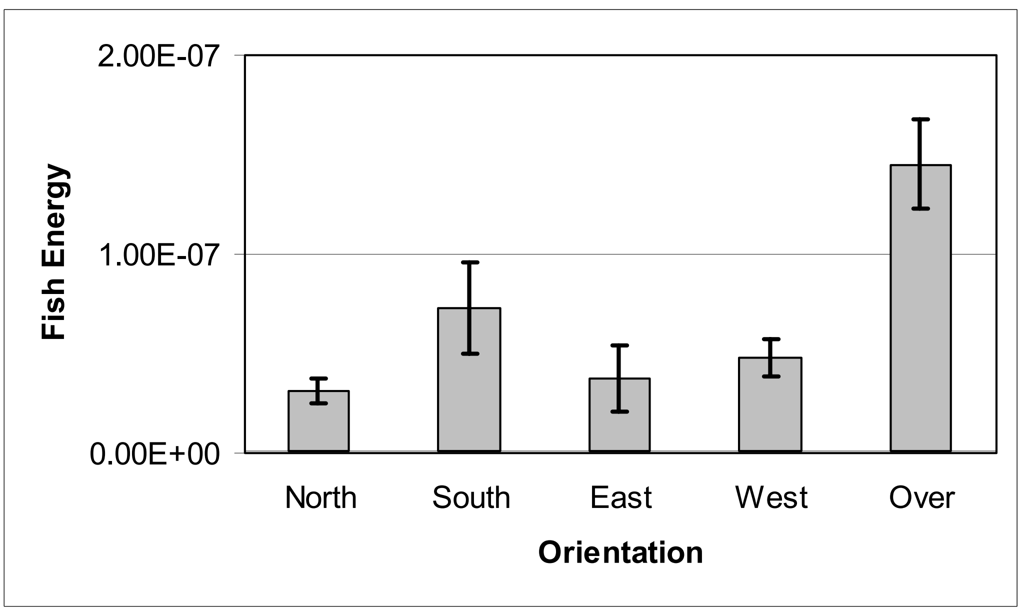
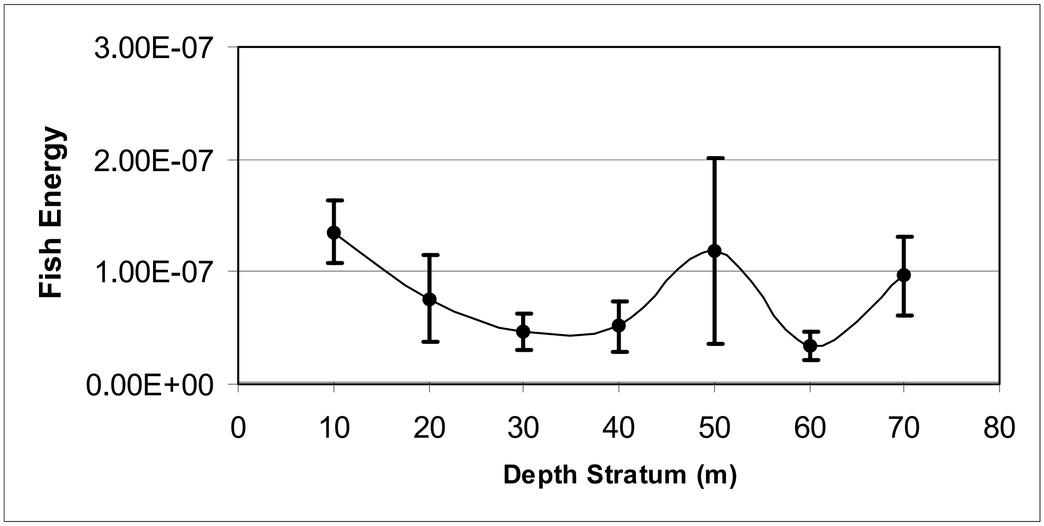


Figure 18. Estimated mean fish energy /m^3 (antilog of volume backscatter) at orientation for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

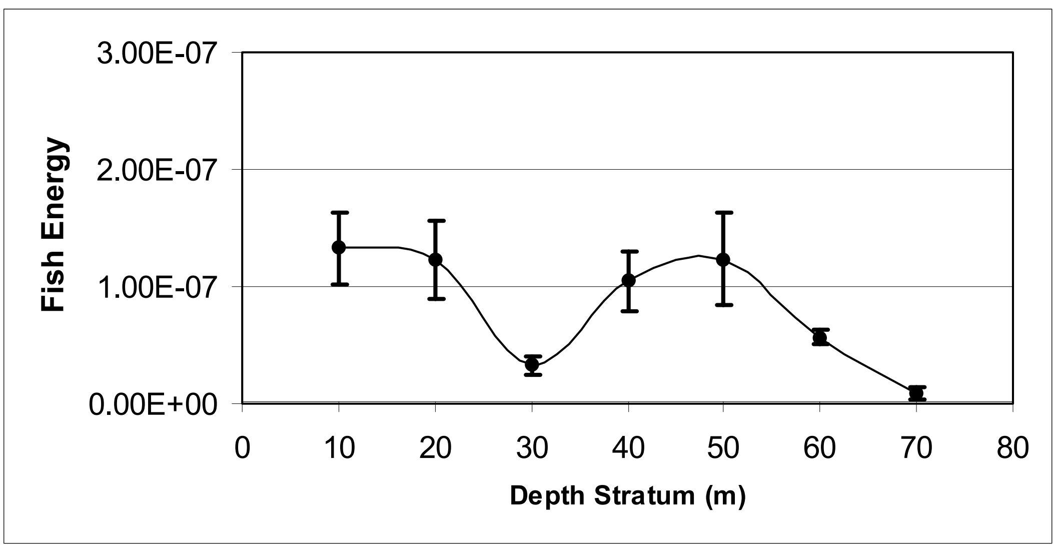
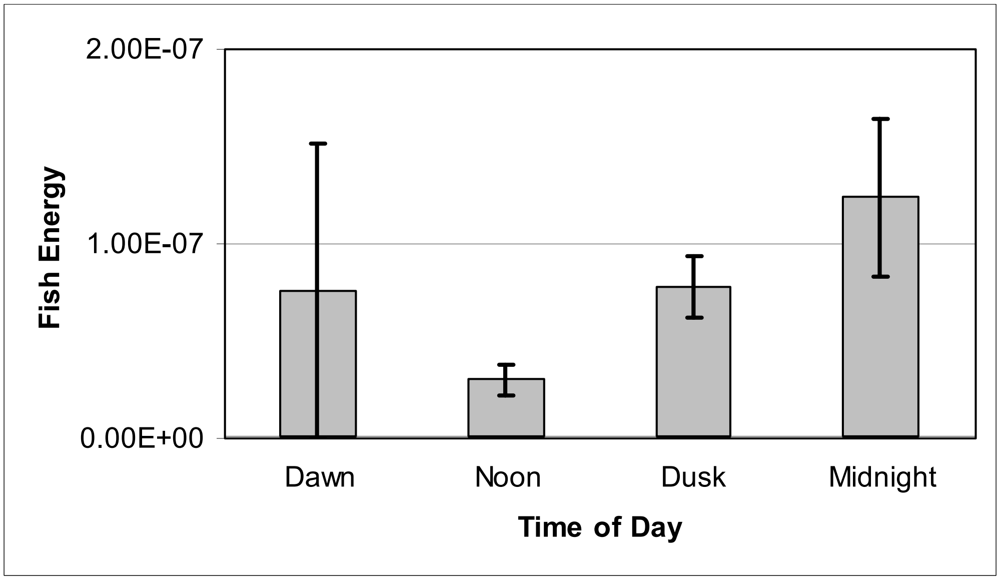


Figure 19. Estimated mean fish energy /m^3 (antilog of volume backscatter) at depth stratum for WC 617 (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

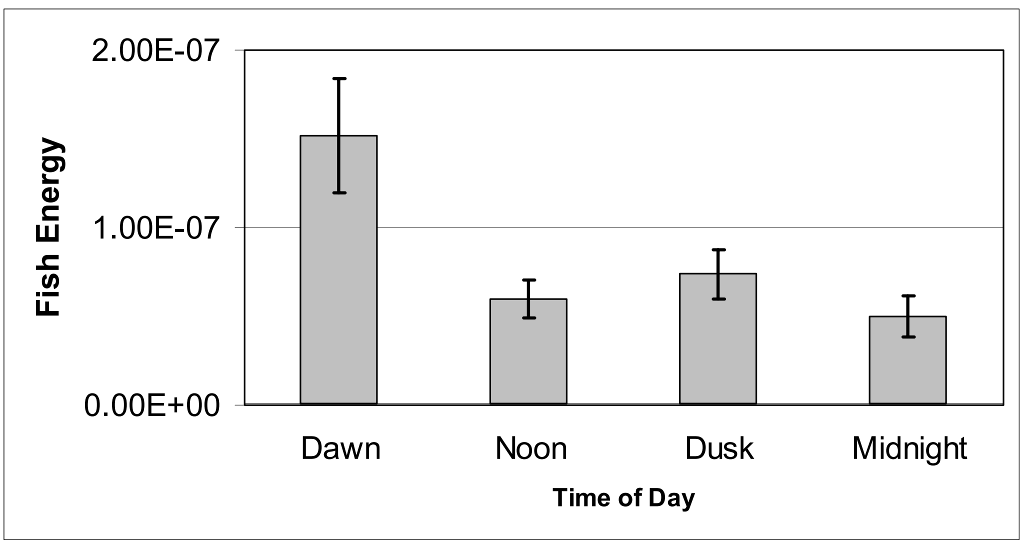
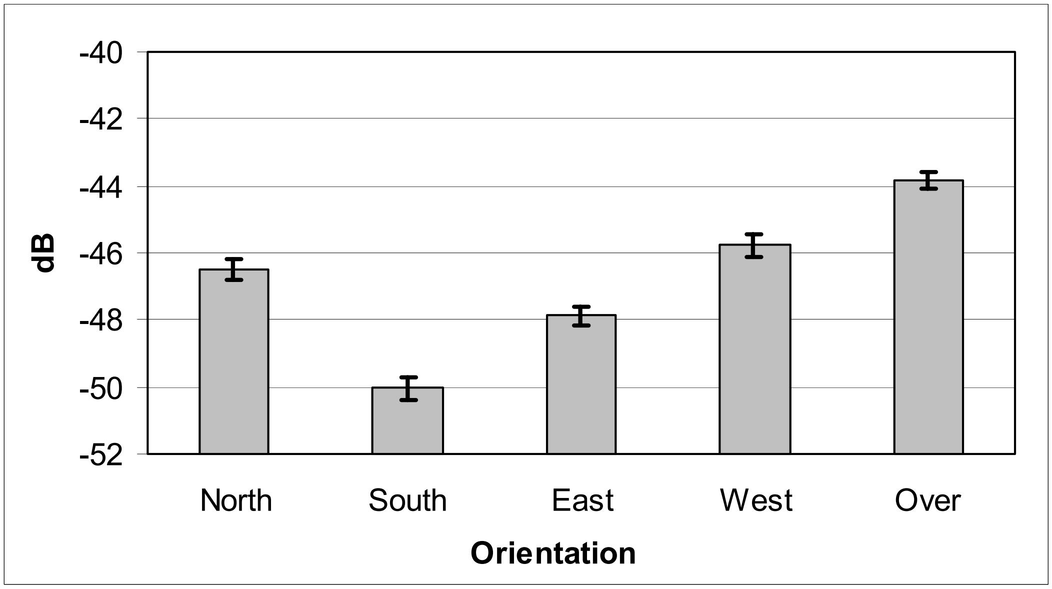


Figure 20. Estimated mean fish energy /m^3 (antilog of volume backscatter) by TOD for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

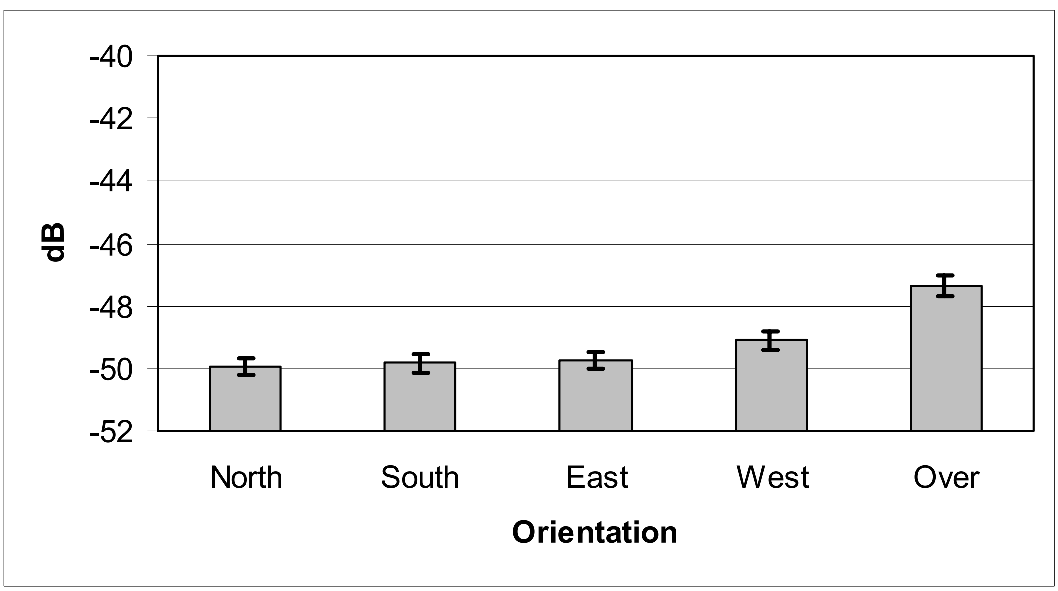
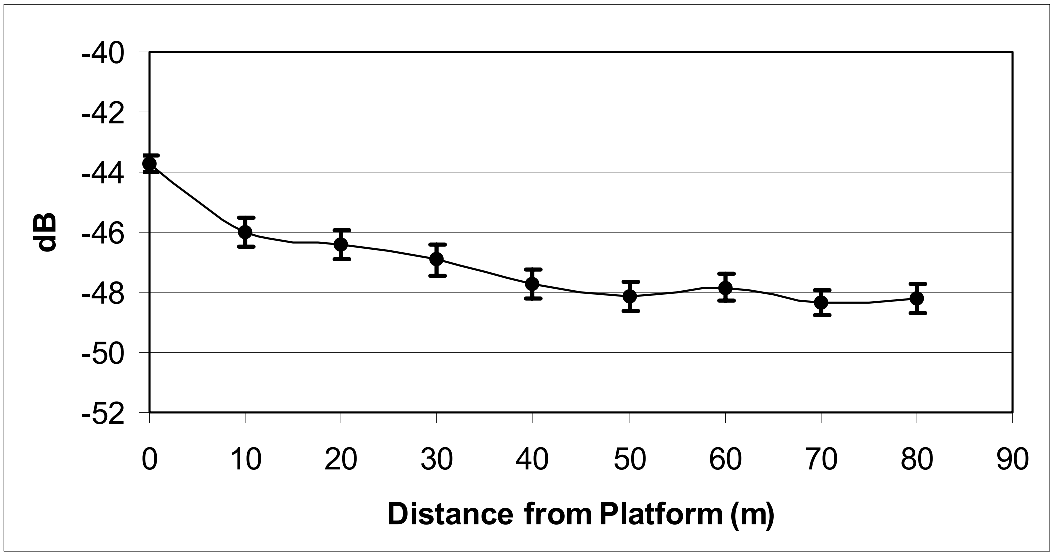


Figure 21. Estimated mean target strength by orientation for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

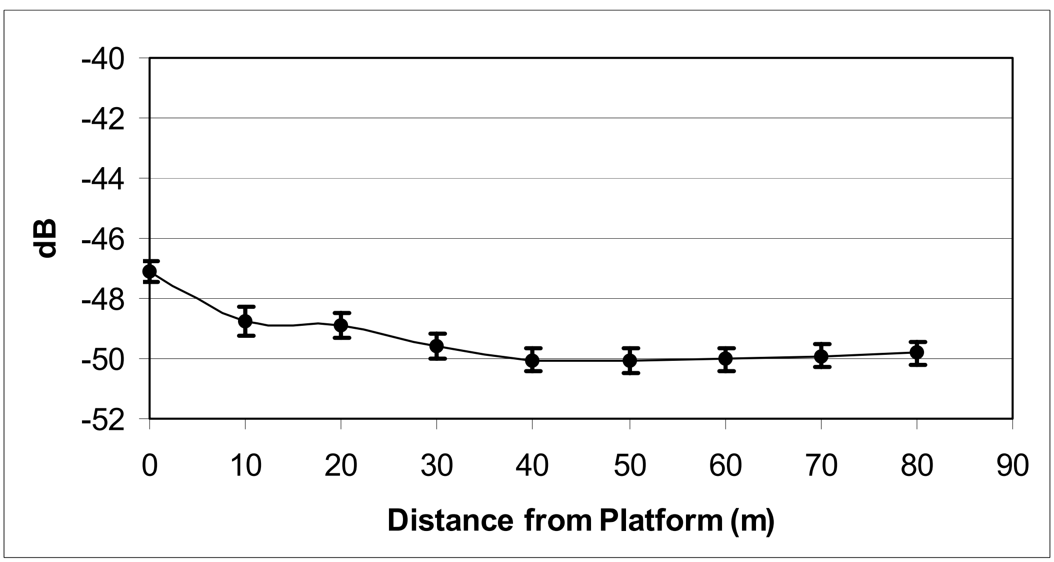
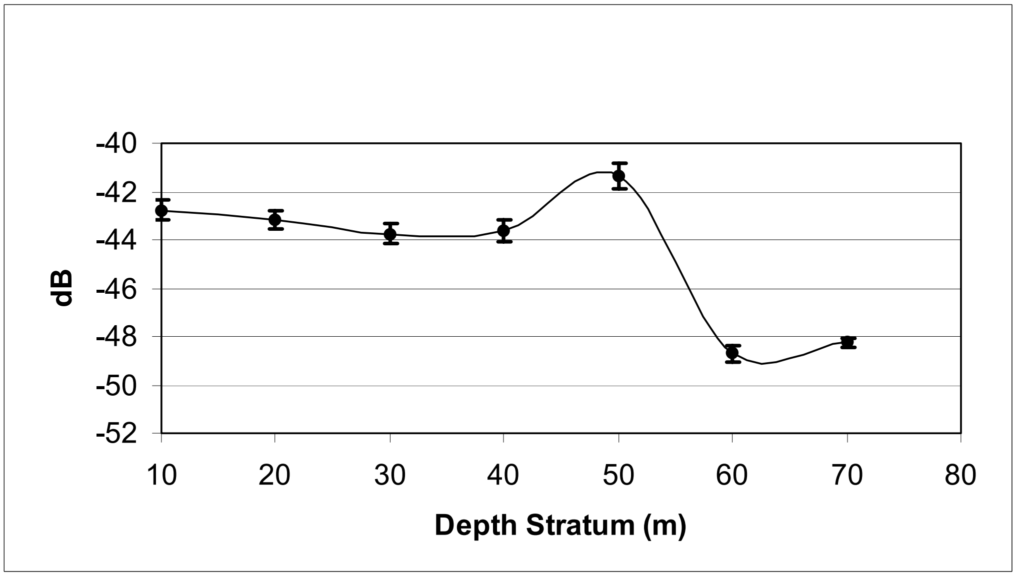


Figure 22. Estimated mean target strength at distance from reef site for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

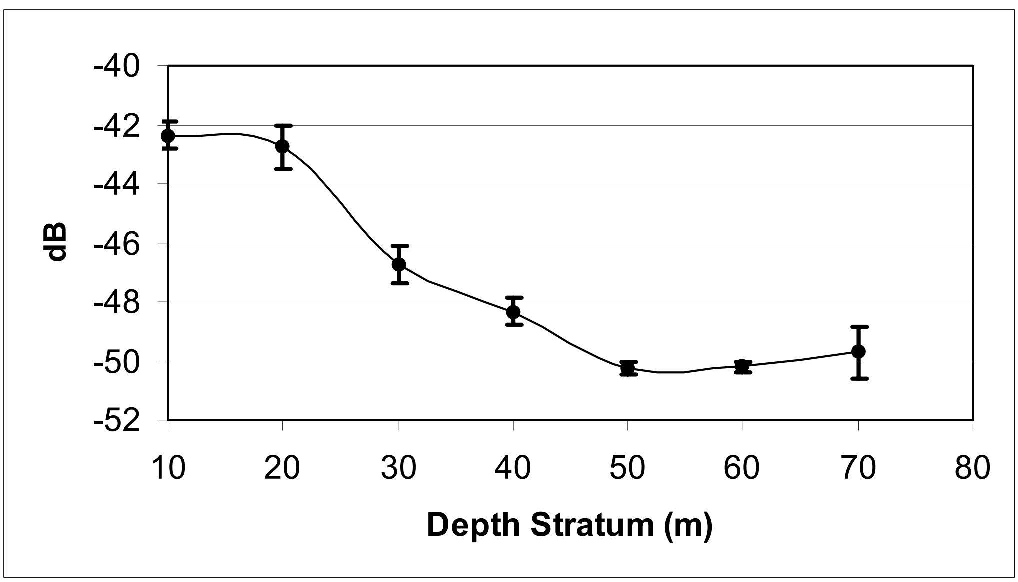
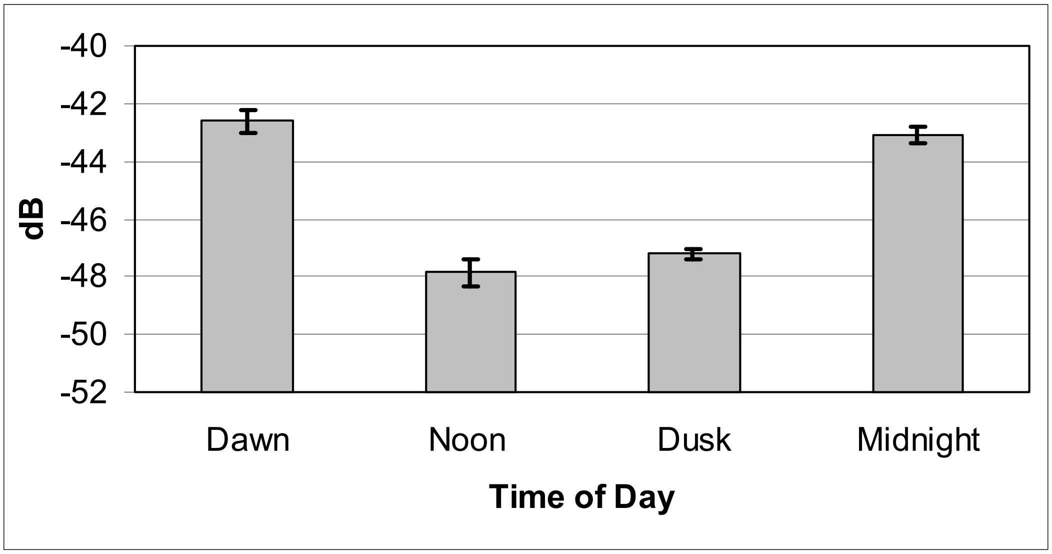


Figure 23. Estimated mean target strength (dB) at depth stratum for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

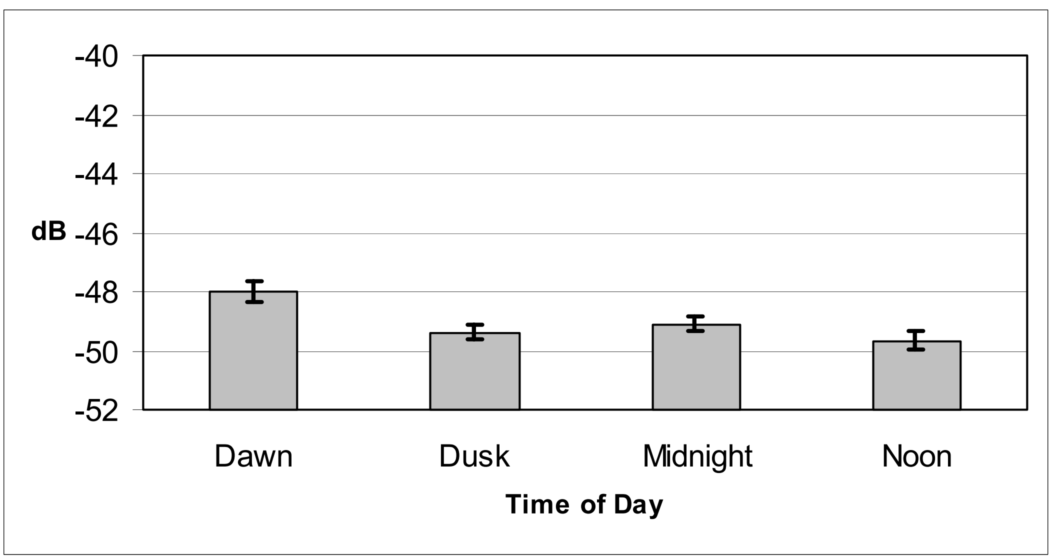


Figure 24. Estimated mean target strength (dB) at time of day for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

3.2.1.3 Density Estimates

Fish density was calculated based on acoustic volume backscatter and TS (mean target strength/m^3 or its proxy described in Materials and Methods). Plots of the mean density values provide actual density estimates for comparison to earlier studies. Density over and away from WC 617A ranged from 0 to 0.5 fish/m^3 and the overall mean density of the site within 20 m was 0.0015 fish/m^3. Mean density decreased slightly beyond 30 meters (Figure 25A) and did not vary greatly. Mean density was slightly higher over the platform compared to the east, west, north and south sides (Figure 26A). Density also varied with depth and was highest at the surface and immediately above the bottom (Figure 27A). Density varied with time of day and was highest during midnight followed by dusk, noon and morning (Figure 28A). Although density did not vary greatly, it should be noted that Fish Energy was higher over WC 617A where the fish were also larger.

3.2.1.4 Species Composition and Abundance

Species present at WC 617A were to the reef-associated communities tht we have seen around platforms in the past (Stanley and Wilson 1997). Based on ROV surveys, seven species made up 90% of the community (Table 8). Red snapper were the most abundant and made up over 45% of the population followed by greater amberjack, Spanish hogfish, gray triggerfish, and creole-fish.

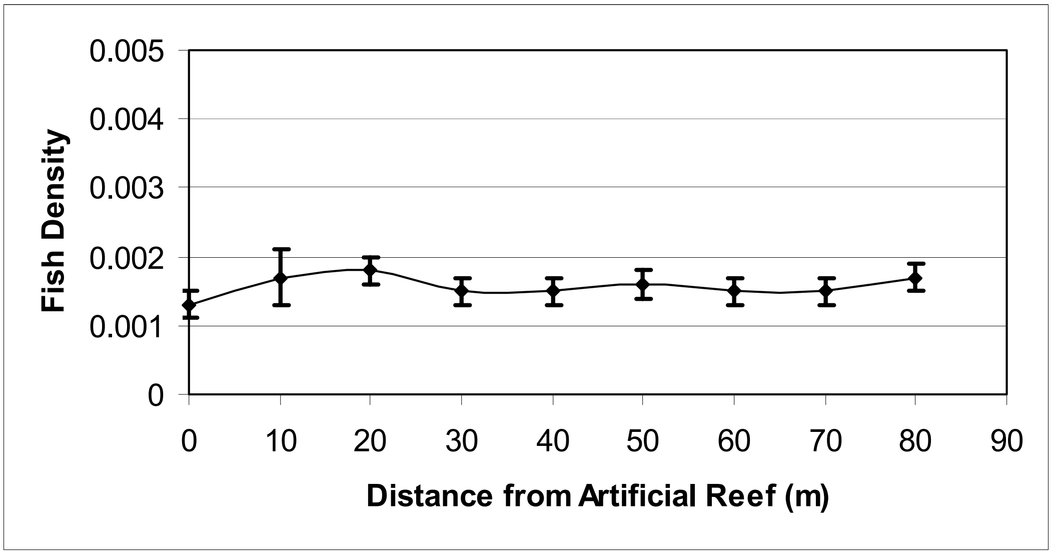
Total fish abundance at WC 617A within a 20 m area of influence was estimated at 2,700. Combining this acoustic density estimate with the relative proportions of species observed in ROV surveys (Table 8), there were approximately 1,220 red snapper, and 405 amberjack, followed by 270 Spanish hogfish and 216 gray triggerfish.

3.2.2 HI A355 (Partially Removed Platform) Results

3.2.2.1 Fish Energy

A binomial logistic regression model was constructed for HI A355 with presence/absence of Sv (hence fish) over 1 second intervals as the dependent variable with class variables: orientation, depth stratum, away, time of day, year and all two-way interactions. Significant effects were found with orientation, away, time of day, and year. (Table 9). Two way interactions were evaluated and determined to be either insignificant or of no biological significance, so they were removed from the model as they confounded the class variables interpretation.

A.



B.

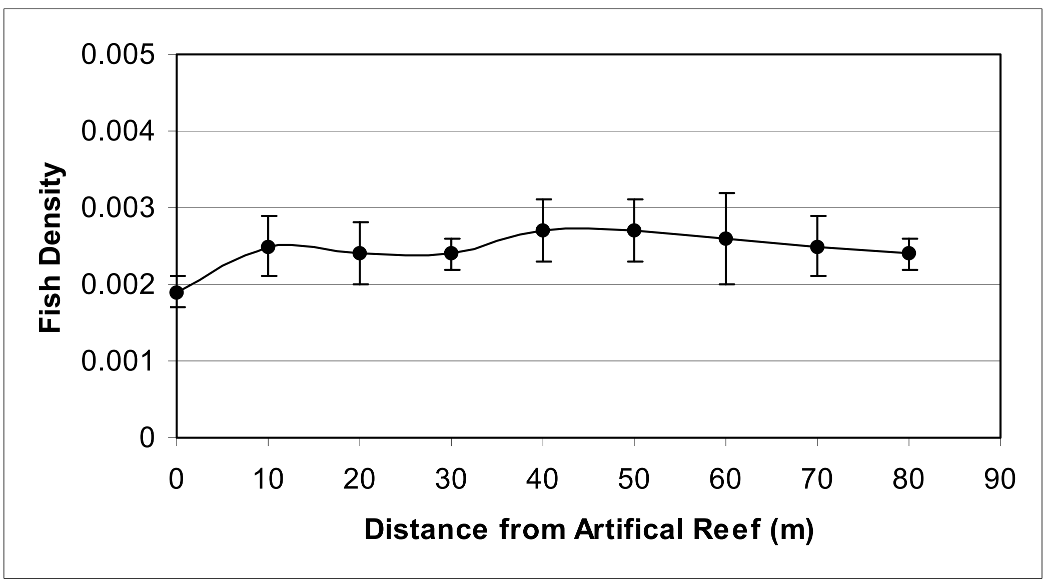
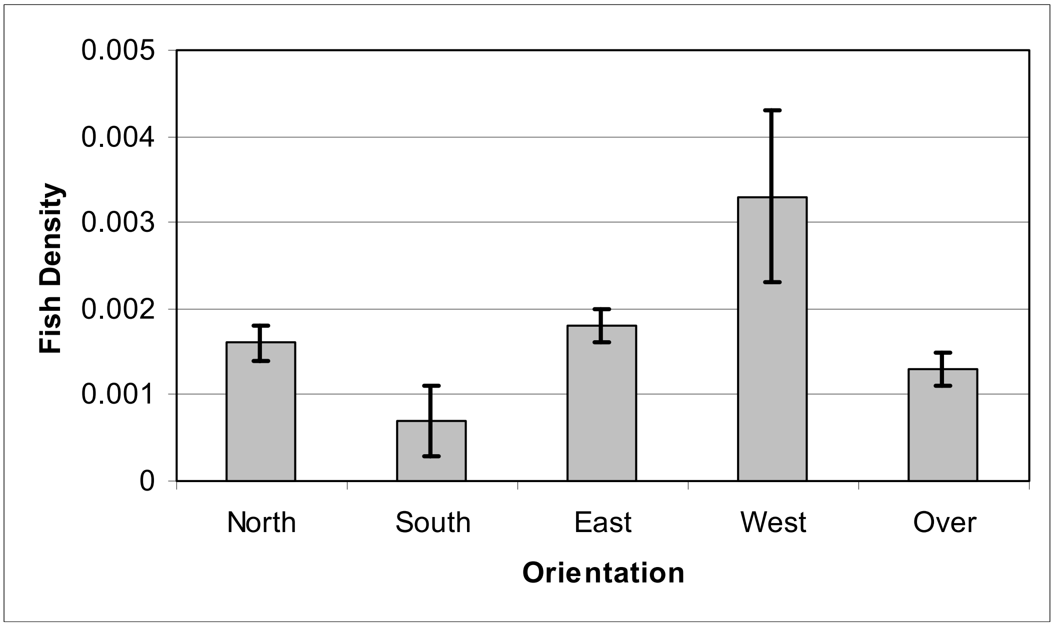
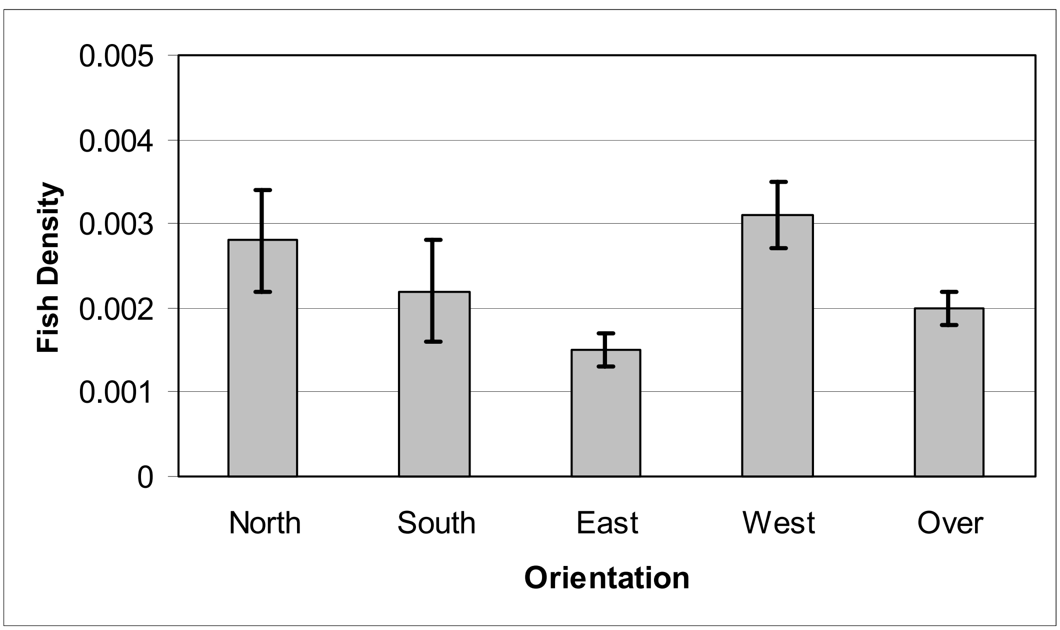


Figure 25. Estimated mean fish density (fish/m^3) at distance for the reef site for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.

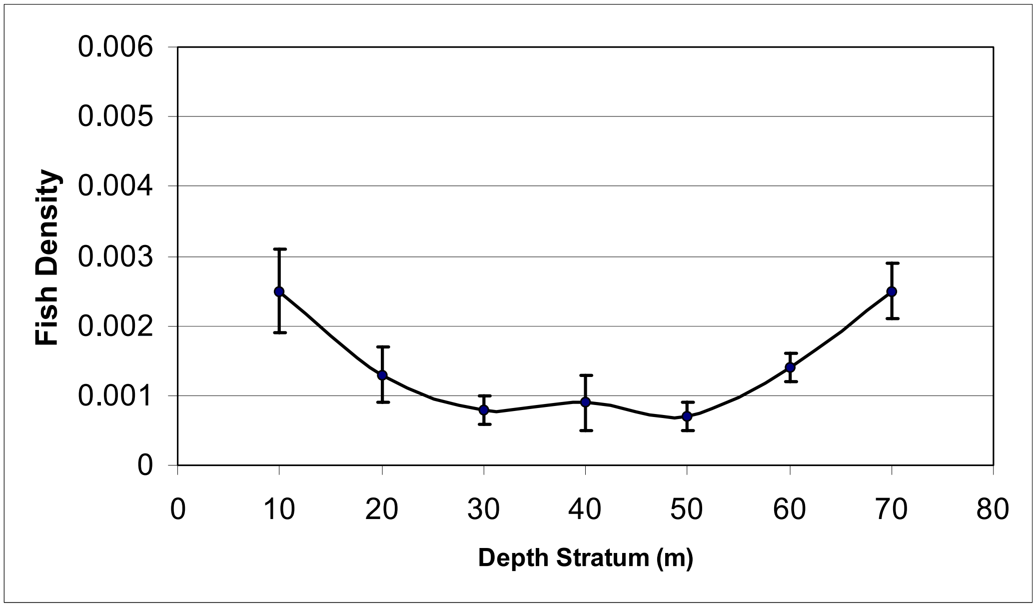


B.



Figur
e 26. Estimated mean fish density (fish/m^3) by orientation for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

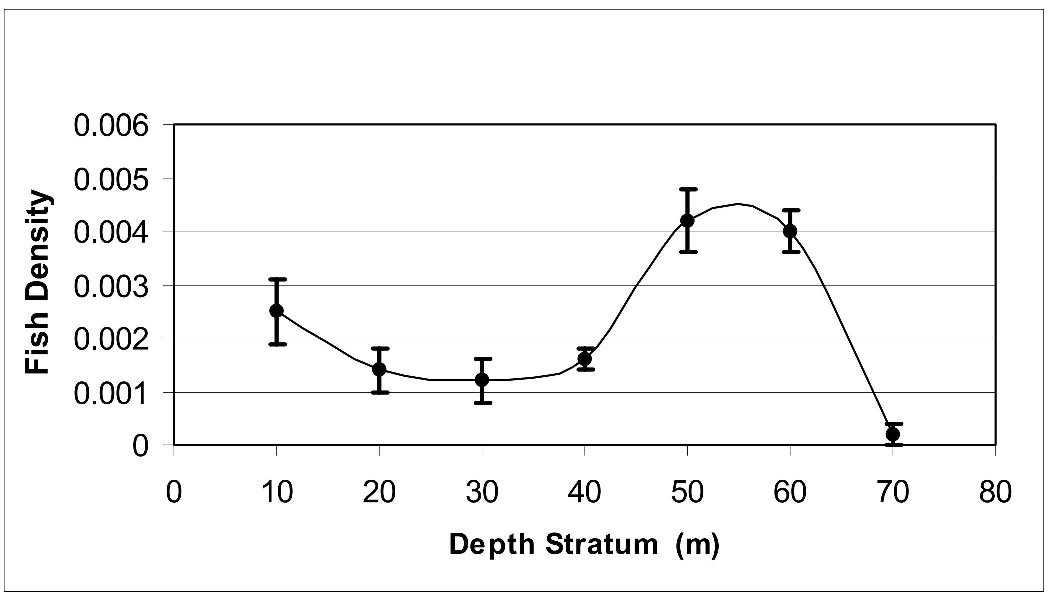
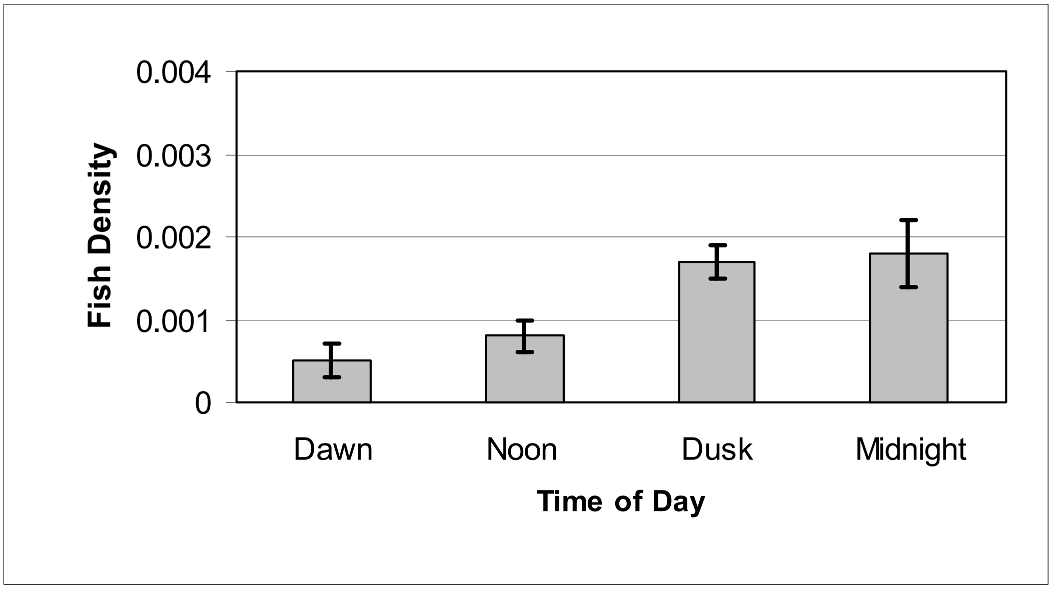


Figure 27. Estimated mean fish density (fish/m^3) by depth stratum for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

A.



B.

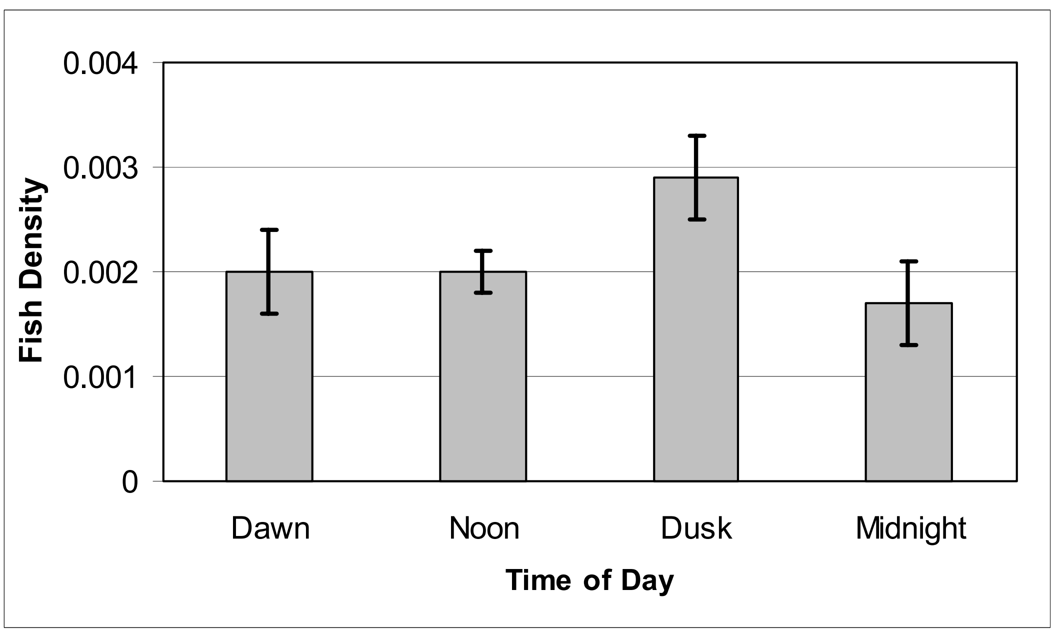


Figure 28. Estimated mean fish density (fish/m^3) by TOD for WC 617A (A) and HI A355 (B). Error bars are 95% confidence intervals.

Table 8.

Species common names and scientific names along with numbers of individuals by stratum, totals, and percent composition from visual point counts using video from a remotely operated vehicle (ROV) from a toppled platform (West Cameron 617A) June 1999.

Common Name	**Scientific Name**	**0m**	**10m**	**20m**	**30m**	**40m**	**50m**	**60m**	**70m**	**Totals**	**% comp**
Almaco jack	*Seriola rivoliana*	-	-	-	-	1	9	4	-	14	7.4
Creole-fish	*Paranthias furcifer*	-	-	-	-	-	-	9	-	9	4.8
Gag	*Mycteroperca microlepis*	-	-	-	-	-	-	3	-	3	1.6
Greater amberjack	*Seriola dumerili*	-	-	-	-	2	25	2	-	29	15.4
Gray triggerfish	*Balistes capriscus*	-	-	-	-	-	8	7	-	15	8.0
Red snapper	*Lutjanus campechanus*	-	-	-	-	7	32	46	-	46	45.2
Reef butterflyfish	*Chaetodon sedentarius*	-	-	-	-	-	-	-	1	-	1.5
Scamp	*Mycteroperca phenax*	-	-	-	-	-	6	6	-	12	6.4
Spanish hogfish	*Bodianus rufus*	-	-	-	-	-	6	14	-	20	10.6
											149

Table 9.

Logistic analysis results of fish energy (antilog of volume backscatter) with class variables platform side (Ornt), depth stratum (Stratum), and time of day at High Island A355.

Type III Analysis of Effects			
Effect	DF	Wald Chi-Square	Pr > ChiSq
ORNT	4	74.02	<.0001
Stratum	6	9422.52	<.0001
Time of day	3	626.95	<.0001
YEAR	1	133.74	<.0001
AWAY	7	18.17	0.0112

Analysis of Maximum Likelihood Estimates						
Parameter		DF	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept		1	-0.79	0.03	546.82	<.0001
ORNT	1	1	0.37	0.07	25.71	<.0001
ORNT	2	1	0.32	0.07	18.85	<.0001
ORNT	3	1	0.13	0.07	3.05	0.08
ORNT	4	1	0.40	0.07	29.12	<.0001
Stratum	1	1	-2.17	0.05	1949.78	<.0001
Stratum	2	1	-1.64	0.04	1650.81	<.0001
Stratum	3	1	-0.07	0.03	6.42	0.01
Stratum	4	1	0.82	0.03	1033.99	<.0001
Stratum	5	1	1.88	0.03	4733.73	<.0001
Stratum	6	1	1.56	0.03	3524.16	<.0001
Time of day	1	1	0.55	0.02	518.06	<.0001
Time of day	2	1	-0.18	0.02	92.00	<.0001
Time of day	3	1	-0.17	0.03	46.86	<.0001
YEAR	1999	1	-0.18	0.02	133.74	<.0001

Association of Predicted Probabilities and Observed Responses				
Percent	Concordant	83.1	Somers' D	0.67
Percent	Discordant	16.4	Gamma	0.67
Percent	Tied	0.5	Tau-a	0.30
Pairs		5.32E+08	c	0.83

Odds ratio estimates from Proc Logistic run without an intercept provided insight into how the probability of finding fish varied within each class variable. Analysis outputs indicated that there was a difference between years as the chance of finding a fish in 1999 was 1.3 times higher than that in 2000. A difference in orientation was also found with the probability of a fish presence was highest on the south side. There was a slightly greater chance of finding fish within 30 m rather than immediately over the reef (Table 9). Analysis also indicated that the probabilty of fish occurring was higher near the bottom and closer to the reef.

The biological significance of these differences was best appreciated by plotting mean fish energy and estimated fish density (with 95% confidence intervals) for each class variable. The mean fish energy values plotted on these graphs is greatly influenced by the larger number of zero values, but they allow for comparisons. Mean fish energy was highest over HI A355 and reached a minimum beyond 30 meters away from the reef so we assigned a 20 meter area of influence to this site. Mean fish energy was highest over the reef and declined with distance from the reef (Figure 17B, 18B). Mean fish energy also varied with depth and time of day, tending to be higher near the surface of the water column (Figure 19B) and higher in the morning (Figure 20B).

3.2.2.2 Target Strength

The relationship between TS and associated class variables was modeled with RBD ANOVAs. TS was affected by orientation, depth, TOD and all two way interactions (Table 10). Fish were, on average, larger over the reef and smallest on the south side (Figure 21B). Mean TS within 20 meters of HI A355 was -48 dB (equivalent to a 6.7 cm fish); TS ranged from -62 to -25 dB (1.2 to 108 cm) (Love 1971). Fish size decreased with increased distance from the site (Figure 22B). Size also varied with depth as targets tended to be larger near the surface and decreased in size toward the bottom. (Figure 23B). Target size changed with TOD and was greatest in the morning followed by midnight, dusk, and noon (Figure 24B).

3.2.2.3 Density Estimates

Fish density was calculated based on acoustic volume backscatter and sigma (or its proxy value described in Materials and Methods). The results of the density estimates showed similar trends to the analysis of Fish Energy presented in the previous section. Density over and away from HI A355 ranged from 0 to 0.55 fish per cubic meter and averaged 0.002 fish per cubic meter within 20 meters of the reef. However, mean density varied little with distance (Figure 25B). Mean density was slightly higher on the west side of the reef than the other sides, but there was little difference in mean density among its four sides (Figure 26B). Density also varied with depth and was highest 10 to 20 m above the bottom (Figure 27B). Highest density occurred at dusk, although there was little difference among times of day (Figure 28B).

3.2.2.4 Species Composition and Abundance

Species compositions in June 1999 and June 2000 are given in Table 11 and some sample images are included in the Appendix. During both surveys greater amberjack were the most

Table 10.

RBD ANOVA (block on side) results of target strength with platform side (Side), depth stratum (Stratum), distance away from the platform (Away), time of day, and selected interactions at High Island A355.

Source	**DF**	**SS**	**MS**	**F**	**Prob > F**
Model	89	73368.6688	824.367	48.14	0.0001
Error	10825	185377.4073	17.1249337		
Corrected Total	10914	258746.0762			
	R-Squared	**C.V.**	**Root MSE**		**TS Mean**
	0.28	-8.544507	4.12822		-48.43
Variables	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Ornt	3	122.9	41	2.39	0.0665
Stratum	6	187572.6	3095.4	180.76	0.0001
Away	1	615.8	615.8	35.96	0.0001
Time of day	3	367.5	122.5	7.15	0.0001
Ornt*Stratum	18	288.7	158	9.23	0.0001
Ornt*Time of day	9	809.6	90	5.25	0.0001
Stratum*Away	6	556.9	93.8	5.42	0.0001
Stratum*Time of day	18	6160.9	342.3	19.99	0.0001
Away*Time of day	3	229.6	76.5	4.47	0.0038

Table 11.

Species common and scientific names, along with numbers of individuals by stratum, totals, and percent composition from visual point counts using video from a remotely operated vehicle (ROV) from a partially removed platform (High Island A355), June 1999 and 2000.

High Island A355	**June 1999**										
Common Name	**Scientific Name**	**0 m**	**10 m**	**20 m**	**30 m**	**40 m**	**50 m**	**60 m**	**70 m**	**Totals**	**% comp**
Almaco jack	*Seriola rivoliana*	-	-	-	-	-	17	-	-	17	12.9
Blue angelfish	*Holacanthus bermudensis*	-	-	-	-	-	7	-	-	7	5.3
Creole-fish	*Paranthias furcifer*	-	-	-	-	-	2	-	-	2	1.5
Greater amberjack	*Seriola dumerili*	-	-	-	-	-	78	-	-	78	59.1
Gray triggerfish	*Balistes capriscus*	-	-	-	-	-	3	-	-	3	2.3
Red snapper	*Lutjanus campechanus*	-	-	-	-	-	17	-	-	17	12.9
Scamp	*Mycteroperca phenax*	-	-	-	-	-	5	-	-	5	3.8
Spanish hogfish	*Bodianus rufus*	-	-	-	-	-	3	-	-	3	2.3
High Island A355	**June 2000**										
Common Name	**Scientific Name**	**0 m**	**10 m**	**20 m**	**30 m**	**40 m**	**50 m**	**60 m**	**70 m**	**Totals**	**% comp**
Almaco jack	*Seriola rivoliana*	-	-	2	7	2	-	2	-	13	6.9
Blackfin tuna	*Thunnus atlanticus*	-	-	9	-	-	-	-	-	9	4.8
Blue angelfish	*Holacanthus bermudensis*	-	-	-	2	5	1	2	1	11	5.9
Creole-fish	*Paranthias furcifer*	-	-	-	11	7	-	-	-	18	9.6
Crevalle jack	*Caranx hippos*	-	-	2	1	-	-	-	-	3	1.6
Greater amberjack	*Seriola dumerili*	-	-	-	1	6	22	17	10	56	29.9
Gray triggerfish	*Balistes capriscus*	-	-	-	-	-	-	3	-	3	1.6
Ocean surgeon	*Acanthurus bahianus*	-	-	-	2	-	-	-	-	2	1.1
Red snapper	*Lutjanus campechanus*	-	-	-	-	3	12	28	7	50	26.7
Spanish hogfish	*Bodianus rufus*	-	-	-	-	18	3	-	-	21	11.2
Warsaw grouper	*Epinephelus nigritus*	-	-	-	-	-	-	1	-	1	0.5
										187	

abundant species. In 1999, greater amberjack made up almost 60% of the fish community compared to 30% in 2000. Red snapper were the second most abundant species both years and ranged from 13% in 1999 to 27% in 2000 (Table 11).

Total fish abundance at HI A355 within a 20 m area of influence was estimate at 2,850 individuals. The most abundant fishes at HI A355 were greater amberjack and red snapper. Averaging percent species compositions for both years, we estimate there were approximately 1,200 greater amberjack and 500 red snapper followed by 250 Spanish hogfish and 225 creole-fish.

3.3 West Flower Garden Bank Results

Intended track lines for the June 2000 of the WFGB survey are shown in Figure 4. Individual survey lines covered a linear distance from 2.5 to13.5 km with a line spacing of 300 m. The survey took 29 hours to cover approximately 160 km of survey lines. The actual survey lines are shown in Figure 29. Transducer cable problems prevented data collection over a portion of the upper terrace.

Analysis of the acoustic data produced some very interesting results reflecting topography, fish biomass, and general geology. The three terraces were very obvious based on bottom depth; each terrace had different reflectance patterns indicative of different benthic communities. Figure 30A shows a transition from the middle to the upper terrace. Figure 30B is an enlargement of the area indicated in 30A showing a dense fish community just above the bottom. The acoustic system, not only provided quantification of the fish community and insight into geological properties of the bottom (Figure 31-A), but also location of natural gas seeps (Figure 31 B).

3.3.1 Fish Energy

For analysis purposes, we divided WFGB into three terraces: upper = 20 – 50 m, middle = 51 – 80 m, lower = 81 – 100 m based on description by Dennis and Bright (1998). We considered depths greater than 100 m to be open water in our analysis.

A binomial logistic regression with the presence/absence of Sv as the dependent variable was used to model the relationship between fish presence and class variables: terrace, time of day, and stratum (Table 12). All class variables were significant.

Proc Logistic run without an intercept provided insight into the relative differences within the class variables. The chance of encountering a fish was highest over the upper terrace and lowest over open water. Illustrations of the change in acoustic energy with depth can be seen in Figures 32 and 33, which show horizontal volume backscatter (sum of mean Sv) throughout the water column. Figure 32 shows that the horizontal backscatter (HSV) is highest over the upper

Table 12.

Logistic analysis results of fish energy (antilog of volume backscatter) with class variables terrace level (Terrace), depth stratum (Stratum), and time of day (TOD) at WFGB.

Type III Analysis of Effects			
Effect	**DF**	**Wald Chi-Square**	**Pr > ChiSq**
TERRACE	3	5778	<.0001
Stratum	9	4852	<.0001
TOD	3	122	<.0001
Stratum*TOD	27	9329	<.0001

Analysis of Maximum Likelihood Estimates						
Parameter		**DF**	**Estimate**	**Standard Error**	**Chi-Square**	**Pr > ChiSq**
Intercept		1	-3.82	1.49	6.56	0.0104
TERRACE	1	1	0.39	0.01	1313.54	<.0001
TERRACE	2	1	0.66	0.01	3116.01	<.0001
TERRACE	3	1	0.18	0.01	273.18	<.0001

Association of Predicted Probabilities and Observed Responses				
Percent	Concordant	80.6	Somers' D	0.62
Percent	Discordant	17.8	Gamma	0.63
Percent	Tied	1.6	Tau-a	0.17
Pairs		5.5E+10	c	0.81

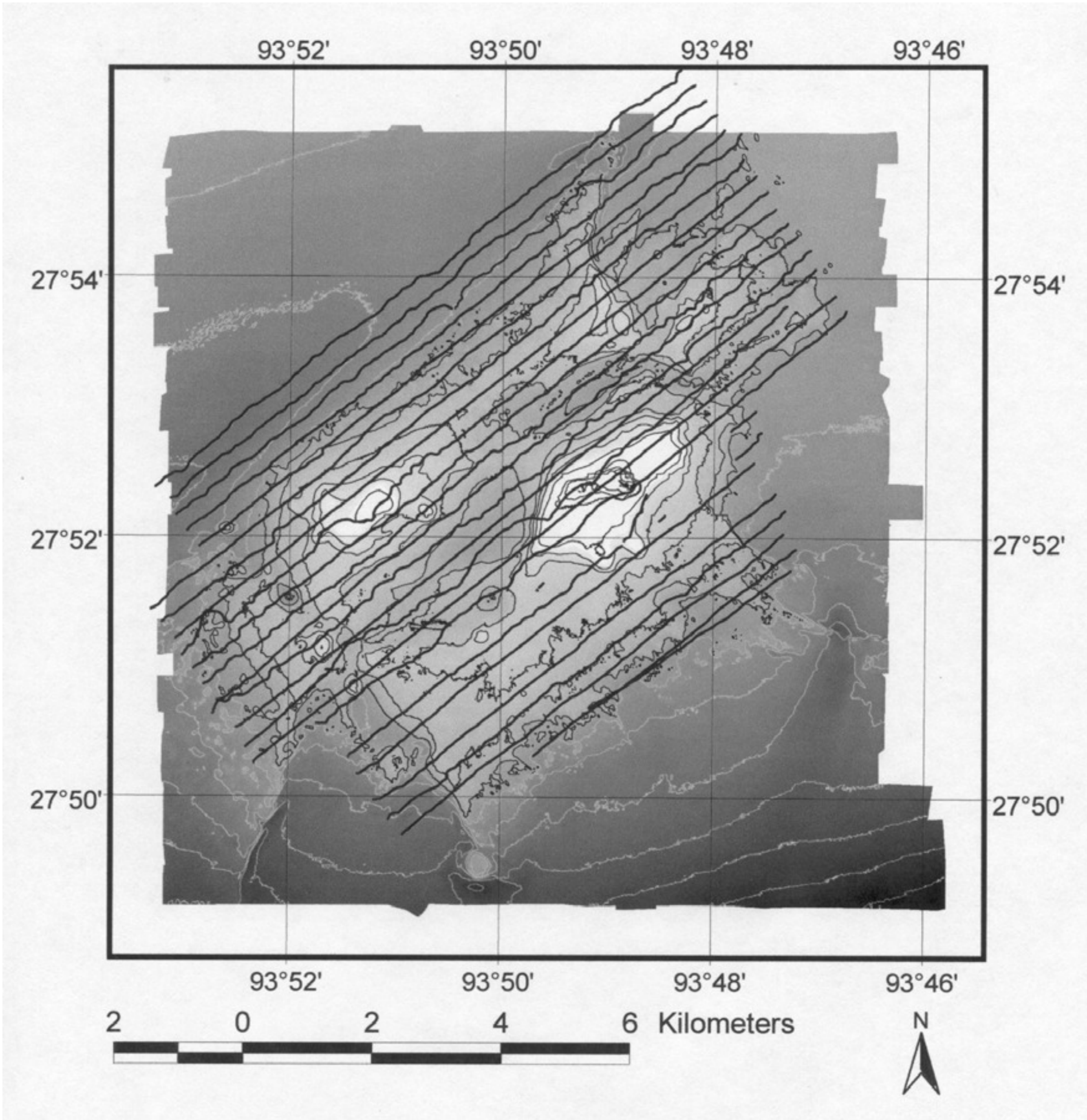
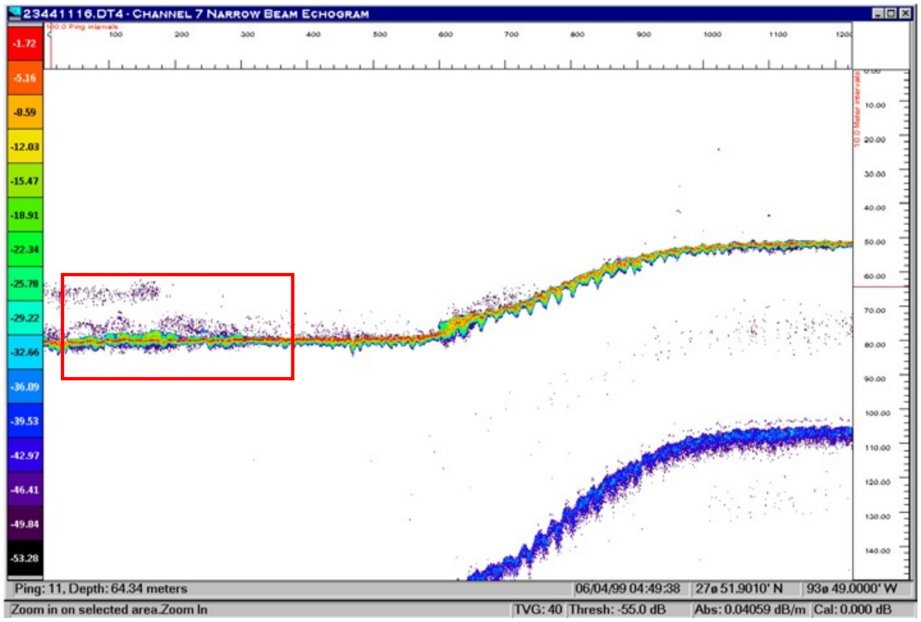


Figure 29. Actual track lines of the WFGB hydroacoustic survey conducted in June 2000.

A.



B.

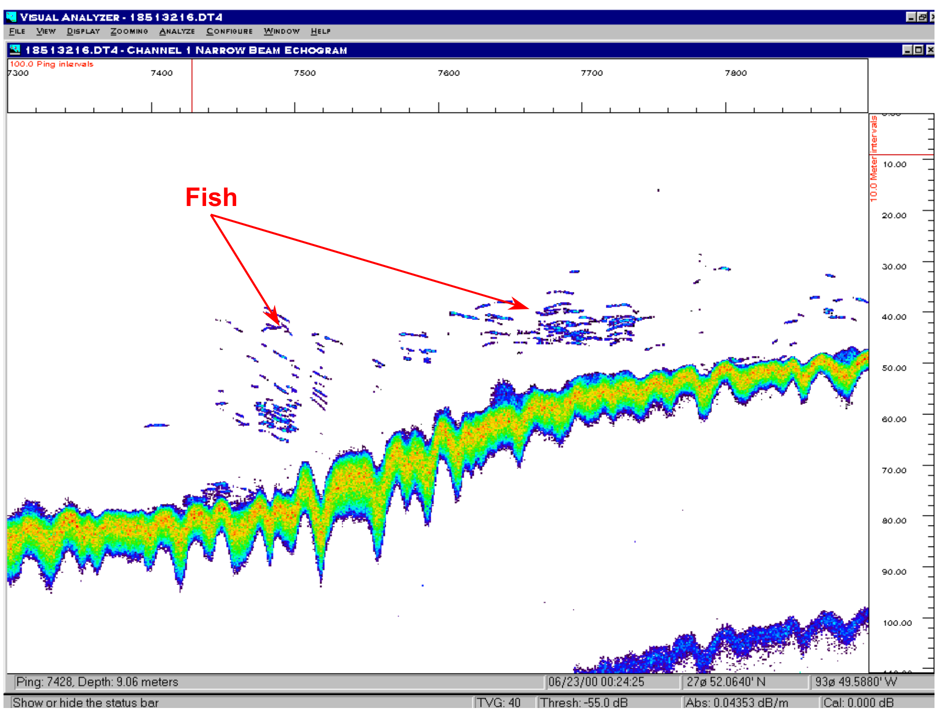
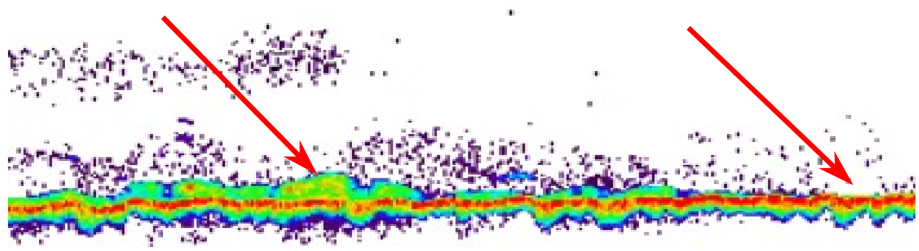


Figure 30. Echogram of WFGB survey conducted June 2000. (A). Screen image includes dB color scale on left and depth on the right side; red box highlights an area of high acoustic reflectance presumed to be fish and plankton. (B). Magnified image of a gentle slope onto the upper Terrace (@40m); arrows highlight fish targets.

A.



B.

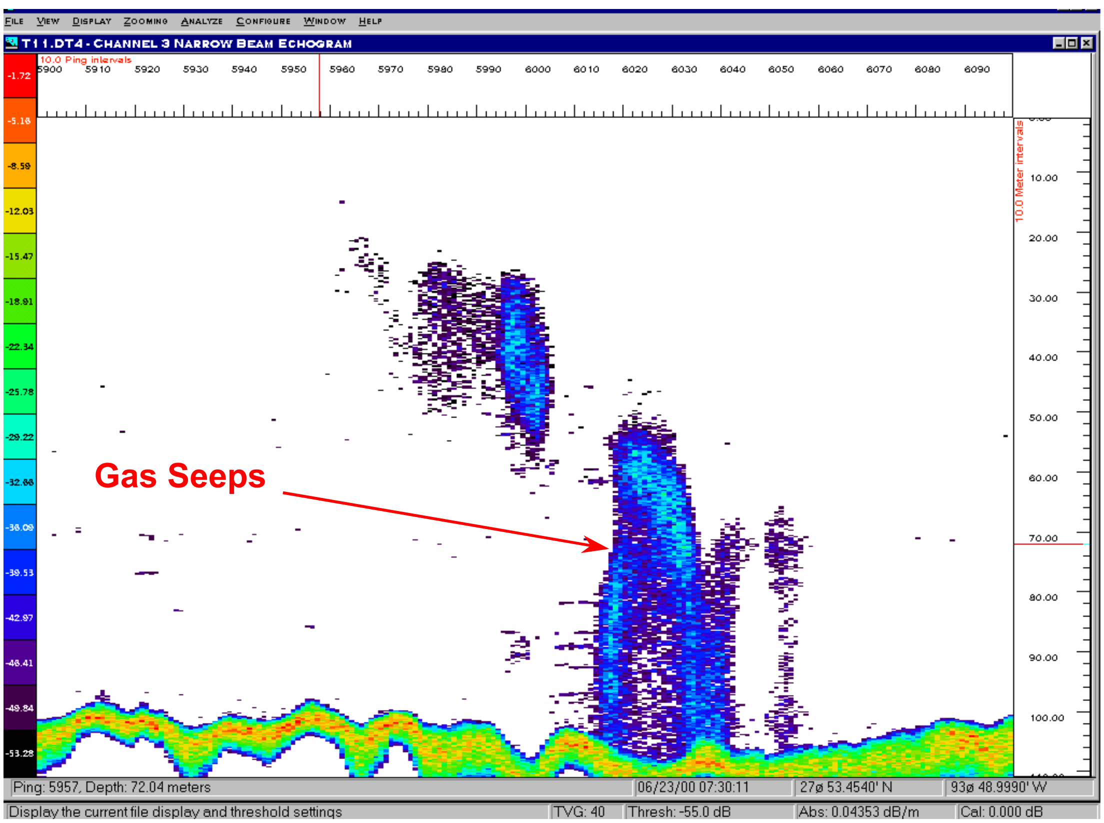


Figure 31. Echograms from June 2000 hydroacoustic survey of the WFGB. (A) Linear changes in reflectance illustrate the value of hydroacoustics in characterizing bottom type. (B) Large areas of low reflectance on the bottom are thought to be gas seeps.

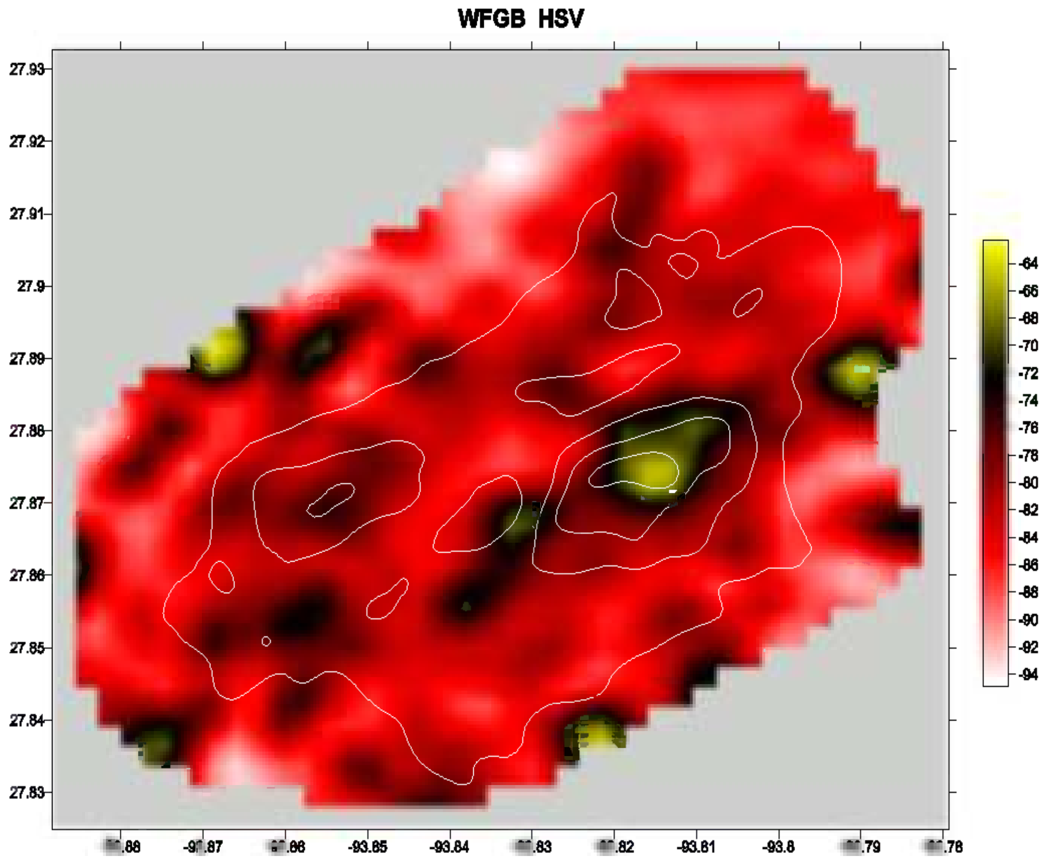


Figure 32. A color enhanced image of the relative horizontal acoustic reflectance over a bathymetry outline of the WFGB. Yellow areas are highest acoustic energy and white are the lowest as indicated on the scale to the right. These data are not corrected for depth as HSV is the sum of energy from the surface to the bottom.

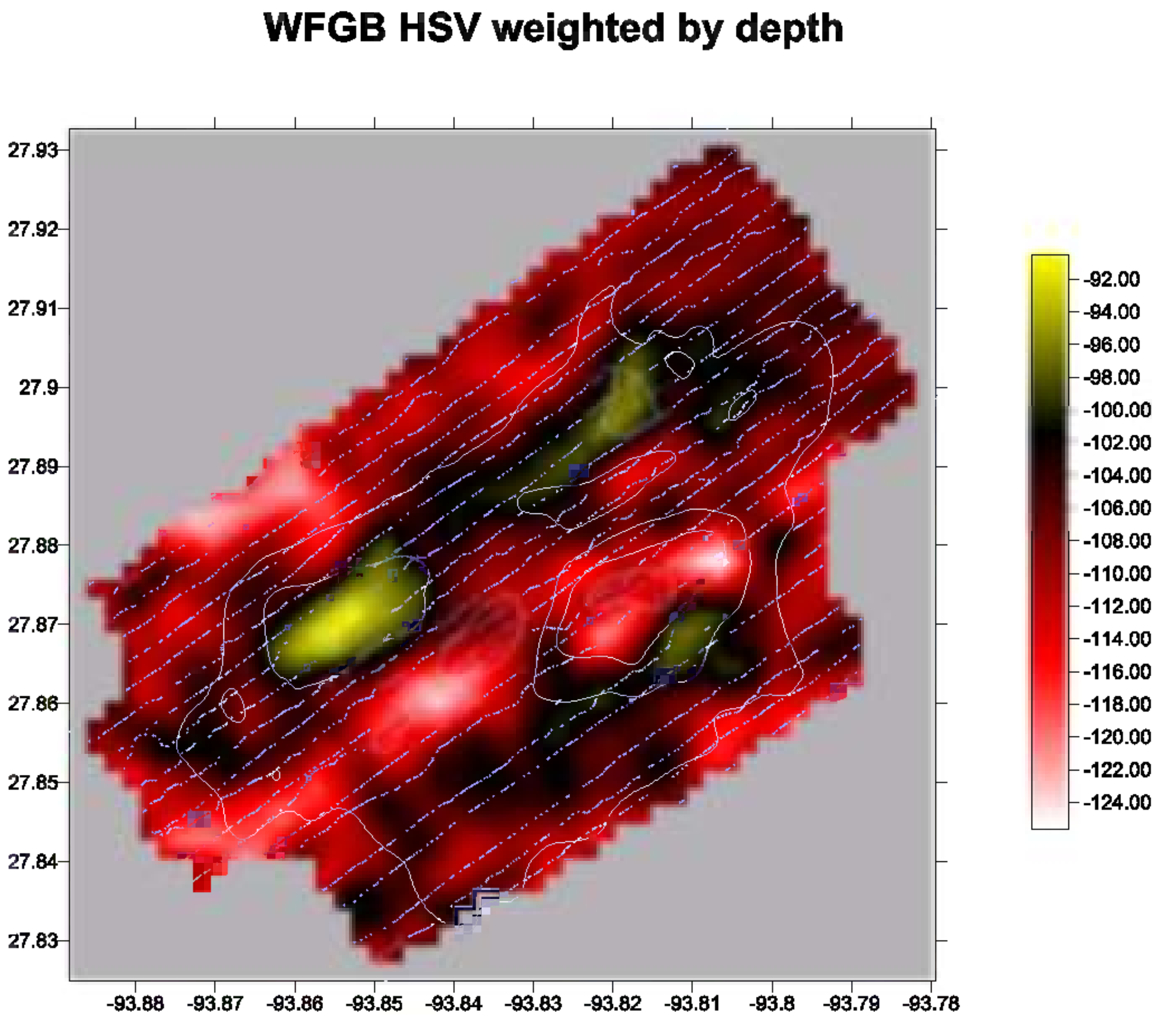


Figure 33. A color enhanced image of the relative horizontal acoustic reflectance over a bathymetry outline of the WFGB. Yellow areas are highest acoustic energy and white are the lowest as indicated on the scale to the right. Data are corrected for depth (HSV/depth in meters).

terrace and middle terrace areas. When corrected for depth, (HSV/water depth) as in Figure 33, it is clear that the highest fish biomass occurs in the shallower areas. Based on logistic regression (without intercept), there was a 35 and 100 times greater chance of finding fish over the upper terrace compared to the middle and lower terraces.

We generated several plots to visualize significant variables in the logistic model. Mean fish energy was an order of magnitude higher over the upper terrace compared to the middle and lower terrace and over open water (Figure 34). Fish energy also varied with TOD as energy over the WFGB was an order of magnitude lower at noon that at other times of day (Figure 35).

3.3.2 Density Estimates

Estimated fish density ranged from 0 to 0.005 fish/m^3 over the WFGB. When broken down by terrace, fish densities were highest over the upper terrace just above the bottom at about 30 meters and just above the bottom of the middle terrace at about 70 meters (Figure 37). Similarly, densities on the lower terrace peaked just above the bottom at 90 meters but were almost an order of magnitude less than the highest densities observed on the upper terrace. Figure 38 is a color enhanced illustration of the variation in fish density over different portions of WFGB.

3.3.3 Target Strength

Using RBD ANOVA to model the effect of class variables on fish size, fish size varied with terrace and depth and their interactions (Table 13). Fish were significantly larger over the upper terrace and near the surface (Figure 36). Mean fish size over the WFGB was - 47dB (6.7 cm), and ranged from -65 to -25 dB (1 to 108 cm) (Love 1971).

3.3.4 Species Composition and Abundance

The fish community at the WFGB was very diverse and reflected that of a typical coral reef community. Creole-fish and Bermuda chub were the most abundant species present followed by great barracuda and black durgon (Table 14). The ROV survey results likely represent only a small cross-section of the total species present as we did not include cryptic species in the visual survey.

Fish abundance at the WFGB was estimated at 2,500,000 (Table 15). The most abundant fishes at the WFGB were Bermuda chub and creole-fish and, as observed at the standing platform, these fish were most commonly observed in the upper depth strata. Combining acoustic density estimates and ROV species composition results, there were roughly 630,000 bermuda chub and 485,000 creole-fish followed by 261,000 great barracuda 130,000 and black durgon.

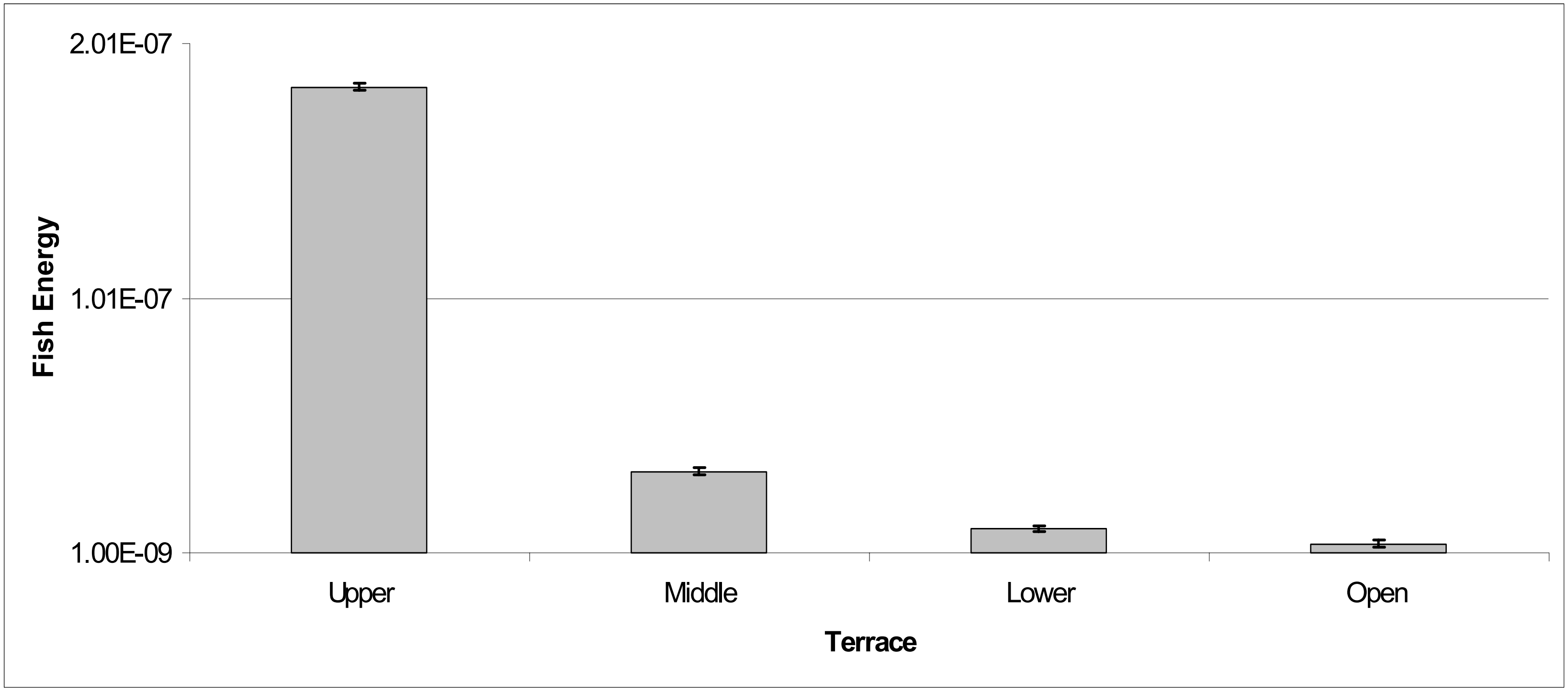


Figure 34. Mean fish energy (from volume backscatter) by Terrace over the West Flower Garden Bank based on a dual beam hydroacoustic survey conducted in June 2000.

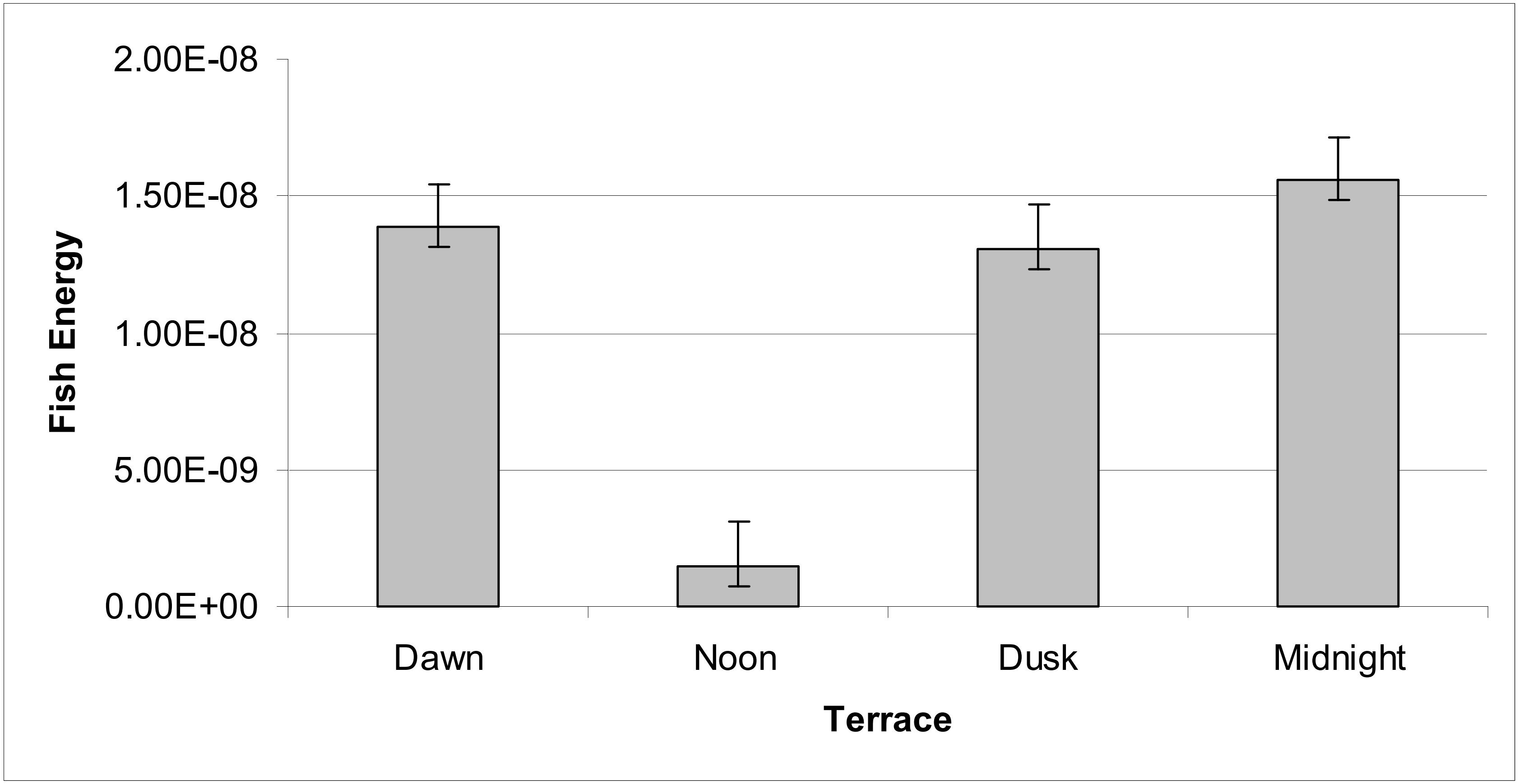


Figure 35. Mean fish energy (from volume backscatter) by time of day over the West Flower Garden Bank based on a dual beam hydroacoustic survey conducted in June 2000. Error bars are 95% confidence intervals

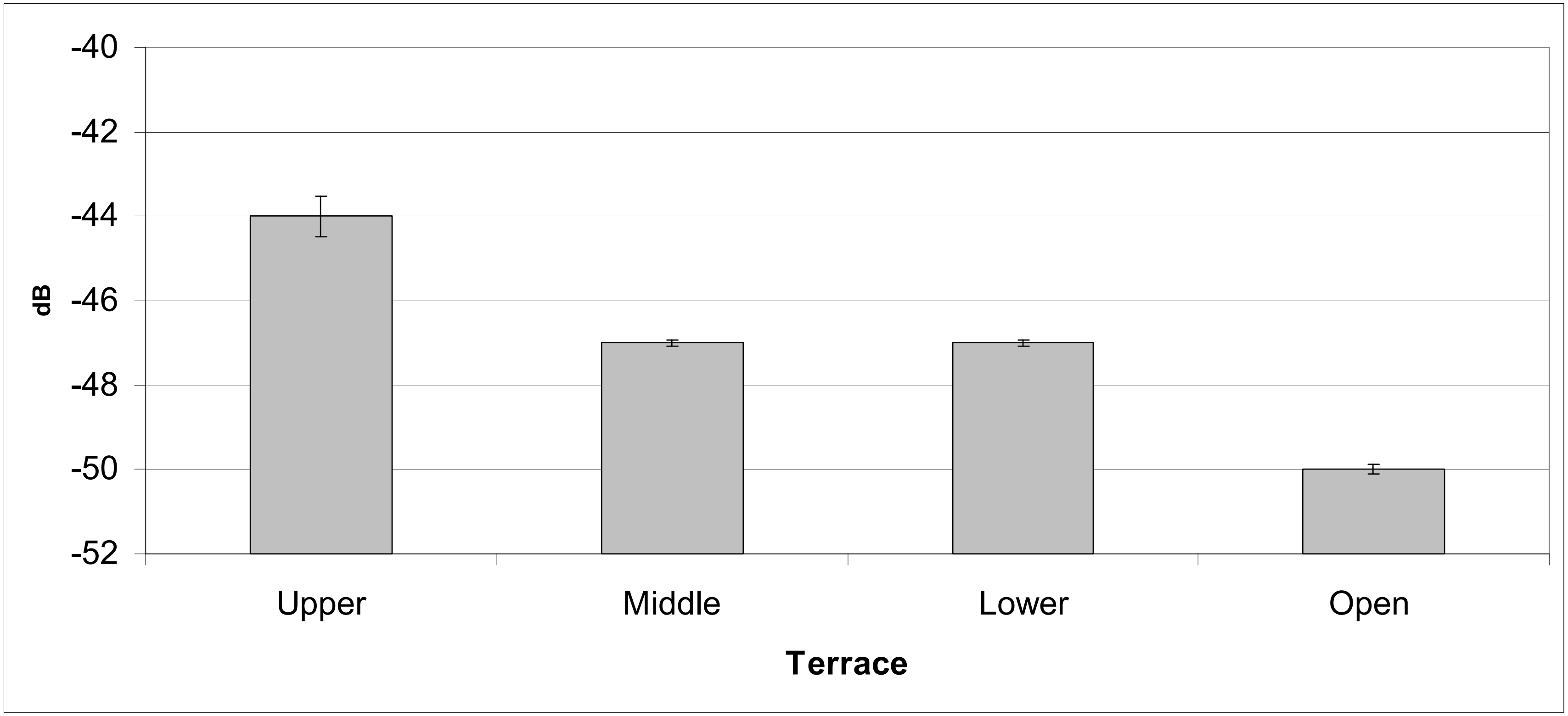


Figure 36. Mean target strength (dB) by Terrace over the West Flower Garden Bank based on a dual beam hydroacoustic survey conducted in June 2000. Error bars are 95% confidence intervals.

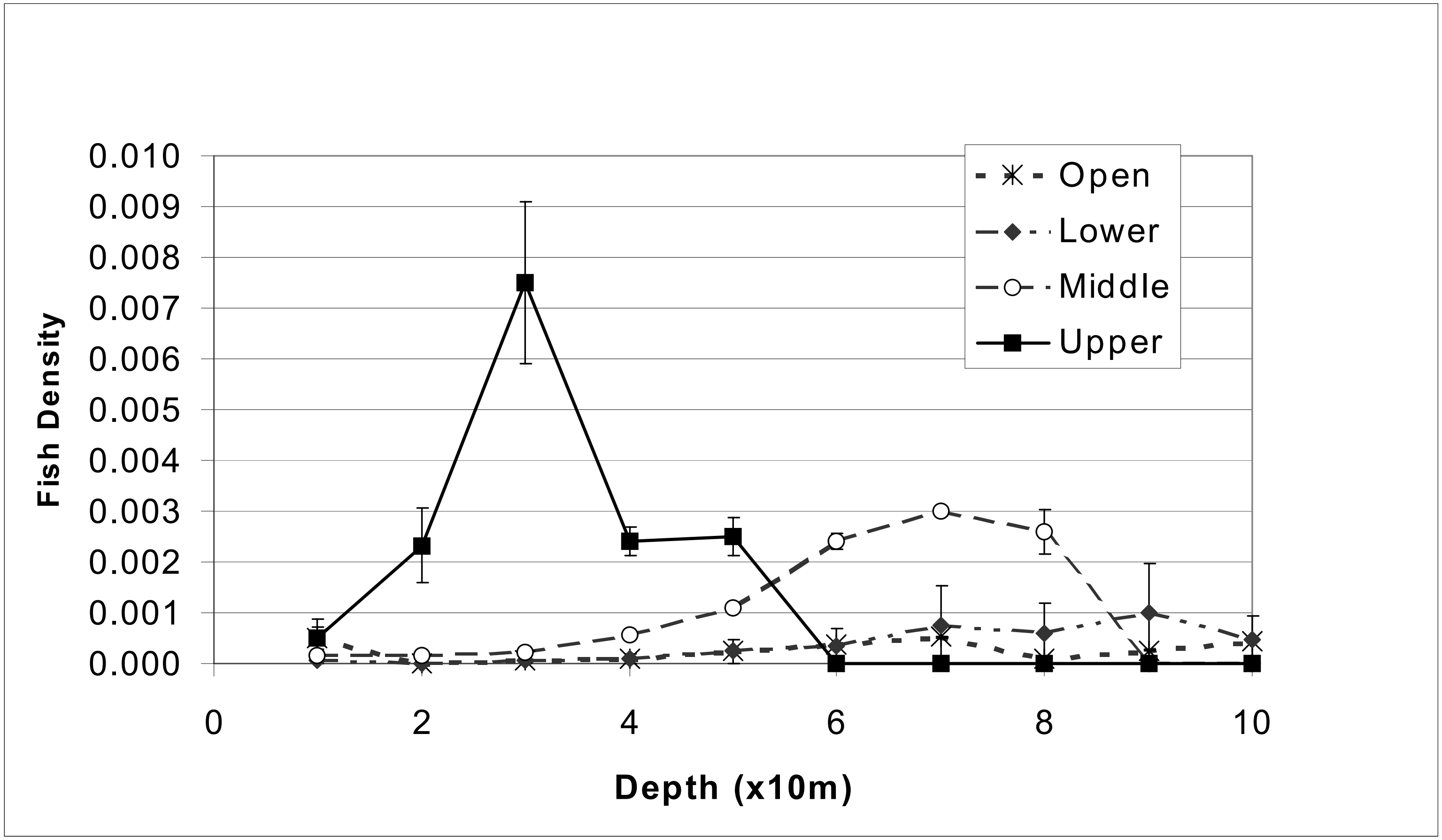


Figure 37. Estimated density of fish (fish/m^3) over the West Flower Garden Bank based on a dual beam hydroacoustic survey conducted in June 2000. Error bars are 95 % confidence intervals.

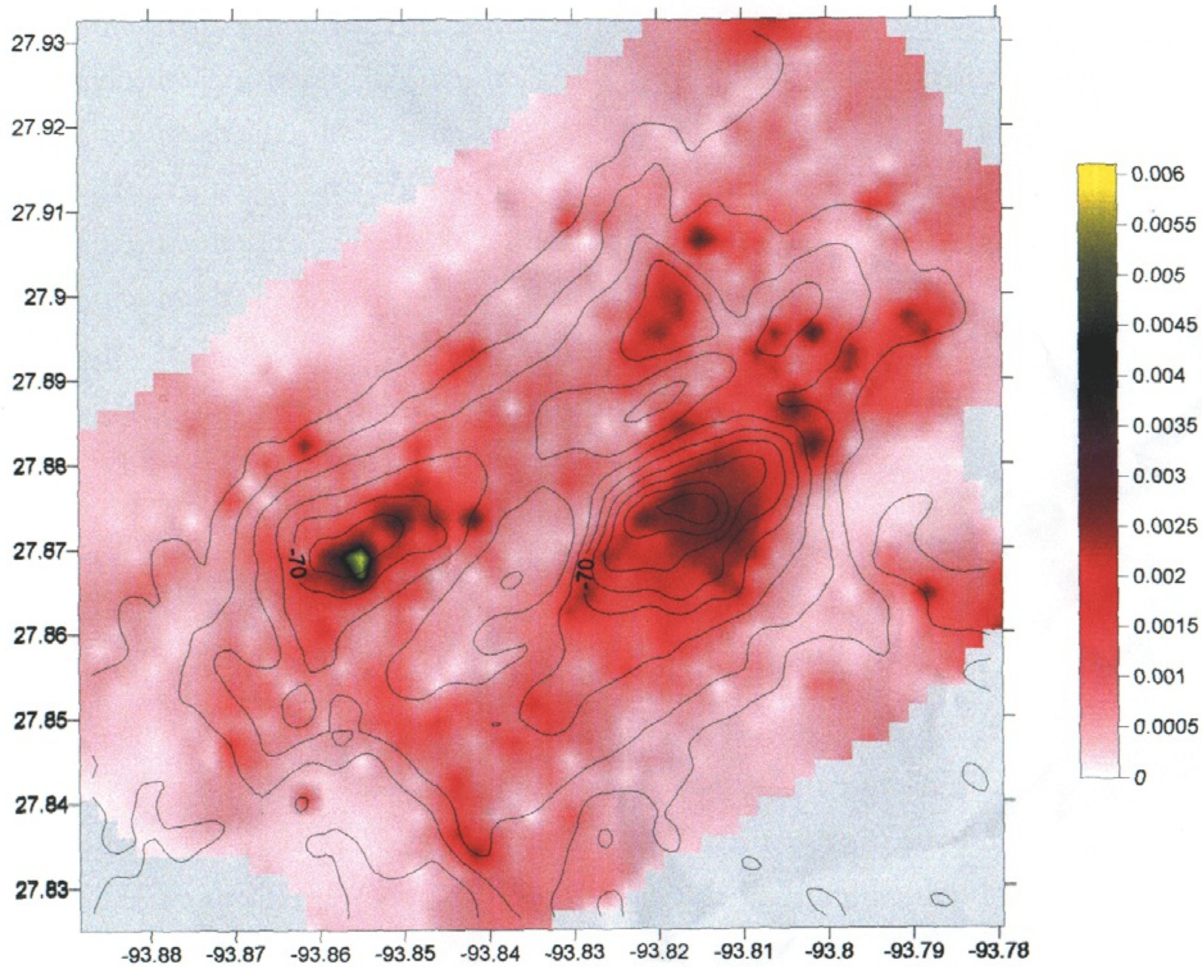


Figure 38. A color enhanced image of the estimated density of fish (#/m^3) over a bathymetry outline of the WFGB. Yellow areas are highest density and white areas are the lowest density as indicated on the scale to the right.

Table 13.

RBD ANOVA (block on Terrace) results (significant) of target strength with, stratum (Strata), and time of day and selected interactions at WFGB.

Source	**DF**	**SS**	**MS**	**F**	**Prob > F**
Model	42	79751	1898	95.8	0.0001
Error	30874	611741	19		
Corrected Total	30916	691493			
	R-Squared	**C.V.**	**Root MSE**		**TS Mean**
	.12	-9.4	4.45		-47.4
Variables	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Terrace	3	1436	478	24.2	0.0001
Strata	9	11543	1282	64.73	0.0001
Diel	3	245	82	4.13	0.0062
Terrace*Strata	20	10234	512	25.83	0.0001
Terrace*Diel	7	12122	1731	87.4	0.0001

Table 14.

Species common names and scientific names along with numbers of individuals by stratum, totals, and percent composition from visual point counts using video from a remotely operated vehicle (ROV) from the West Flower Garden Banks, June 2000.

West Flower Garden Banks June 2000

Common Name	**Scientific Name**	**0 m**	**10 m**	**20 m**	**30 m**	**40 m**	**50 m**	**60 m**	**70 m**	**80m**	**90 m**	**Totals**	**%**
Almaco jack	*Seriola rivoliana*	-	-	-	-	-	-	2	-	-	-	2	1.1
Bermuda chub	*Kyphosus sectatrix*	-	56	1	-	-	-	-	-	-	-	57	32.0
Bar jack	*Caranx ruber*	-	1	1	-	-	-	-	-	-	-	2	1.1
Great Barracuda	*Sphyraena barracuda*	-	22	-	-	-	-	-	-	-	-	22	12.4
Black durgon	*Melichthys niger*	-	-	11	-	-	-	-	-	-	-	11	6.2
Black jack	*Caranx lugubris*	-	1	-	-	-	-	-	-	-	-	1	0.6
Bluehead	*Thalassoma bifasciatum*	-	-	1	-	-	-	-	-	-	-	1	0.6
Blue runner	*Caranx crysos*	-	-	-	8	-	-	-	-	-	-	8	4.5
Blue tang	*Acanthurus coeruleus*	-	-	-	4	-	-	-	-	-	-	4	2.2
Cocoa damselfish	*Pomacentrus variabilis*	-	-	3	-	-	-	-	-	1	-	4	2.2
Creole-fish	*Paranthias furcifer*	-	-	38	-	-	-	-	-	-	3	41	23.0
Dog snapper	*Lutjanus jocu*	-	-	1	-	-	-	-	-	-	-	1	0.6
French angelfish	*Pomacanthus paru*	-	-	-	-	2	-	-	-	-	-	2	1.1
Grey triggerfish	*Balistes* capriscus	-	-	-	-	1	-	-	-	-	-	1	0.6
King mackerel	*Scomberomorus cavalla*	-	-	-	-	-	-	-	-	1	-	1	0.6
Knobbed porgy	*Calamus nodosus*	-	-	-	-	1	-	-	-	-	-	1	0.6
Ocean triggerfish	*Balistes vetula*	-	1	-	-	-	-	-	-	-	-	1	0.6
Bank butterflyfish	*Chaetodon aya*	-	-	-	-	-	-	-	-	-	6	6	3.4
Scamp	*Mycteroperca phenax*	-	-	-	-	-	-	2	-	-	-	2	1.1
Short bigeye	*Pristigenys alta*	-	-	-	-	-	-	-	-	1	4	5	2.8
Spanish hogfish	*Bodianus rufus*	-	-	-	1	-	-	-	-	-	-	1	0.6
Squirrelfish	*Holocentrus adscensionis*	-	-	-	-	-	-	-	-	-	2	2	1.1
Trumpetfish	*Aulostomus maculatus*	-	-	-	-	1	-	-	-	-	-	1	0.6

Table 15.

Estimated numbers of fish over the West Flower Garden Bank based on a dual beam hydroacoustics survey conducted in June 2000. Depth refers to a 10 m depth stratum and Area is the spatial extent of the WFGB that falls within that depth range . Total is the number of fish estimated to be within each depth range summed across all 10m stratum. Upper Terrace = 10-50m, Middle Terrace = 50-80m, and Lower Terrace = 80-100m. Population size is the sum of the total number of fish by Terrace.

Depth	**area (m^2)**	**Stratum 1**	**Stratum 2**	**Stratum 3**	**Stratum 4**	**Stratum 5**	**Stratum 6**	**Stratum 7**	**Stratum 8**	**Stratum 9**	**Stratum 10**	**Totals**
10-20	144,800	724	3,910									4,634
20-30	200,000	1,000	5,400	15,200								21,600
30-40	195,800	979	5,287	14,881	4,699							25,846
40-50	1,668,700	8,344	45,055	126,821	40,049	41,718						261,986
50-60	1,752,200	4,030	2,804	4,030	9,988	19,274	42,438					82,564
60-70	2,215,800	5,096	3,545	5,096	12,630	24,374	53,667	67,139				171,547
70-80	8,290,900	19,069	13,265	19,069	47,258	91,200	200,806	251,214	215,563			857,445
80-90	16,403,700	10,466	2,264	9,662	18,700	39,369	57,413	124,668	96,782	162,397		521,720
90-100	15,653,200	9,987	2,160	9,220	17,845	37,568	54,786	118,964	92,354	154,967	73,570	571,420

Terrace	**Population size**	**Mean density (#/m^2)**
Upper	314,065	0.1422
Middle	1,111,556	0.0907
Lower	1,093,140	0.0341
Total	2,518,761	0.0541

4.0 DISCUSSION

This project demonstrates the advantages of dual beam hydroacoustics coupled with visual survey techniques to characterize, quantify, and compare fish communities associated with standing platforms, artificial reefs, and natural reefs. The close geographical proximity of the four study sites allowed us to run coincident surveys and compare fish community characteristics at each of these unique sites without the confounding effects of season, depth, and large spatial separation. Inclusion of the WFGB in this study afforded us the first direct acoustic and visual comparison of fish communities between natural reefs and artificial reefs in the same geographic region.

In this study we used two modes of data collection and statistical analysis. At High Island A350, we used stationary transducers that resample the same volume of space at synoptic intervals. Using log transformed data, we could analyze the data set with ANOVAs to determine if factors such as platform side, depth, or time of day significantly affected fish biomass (after Stanley and Wilson 1996). Significant effects were then graphed as appropriate for comparison. The mobile acoustic surveys covered the WFGB, the toppled platform (WC617A) , and the partially removed platform (HI A355). In this design, the transducer was towed a 2m/sec so it did not sample the same volume of water, however we achieved repeated measures by running multiple transects in the case of the reef sites. We were concerned about vessel effect, however, we did not observe a change in fish biomass with repeated passes over the same site (Figure 15). These data were analyzed using logistic regression to determine if factors such as side, depth, time of day, or distance from the site significantly affected fish biomass. Since the acoustic data are averaged on a per ping basis, data collected in five-minute blocks at HI350 and previous studies by Stanley and Wilson (2000a, 2000b) and Stanley (1994) are comparable to the mobile acoustic data collected in 1 sec blocks reported in this study.

Traditional parametric analyses were not used for analysis of mobile acoustic data, given the large number of zero values and the problem of autocorrelation that occurs in mobile surveys. The use of logistic regression in ecological sampling was described by Trexler and Travis (2001) as a nonlinear way of expressing ecological data. Logistic regression has been shown to be useful with data sets that have a large number of zero values which are usually not normally distributed. For regression analysis, the dependent variable was converted into a binomial array of presence/absence of acoustic reflectance (fish measured as acoustic energy)/m^3 to evaluate the probability or chance of finding a fish in a given cell. A cell was a one second block (@2m linear distance) of time divided into 10 m depth strata. The presence/absence of volume backscatter (Sv) was used as a dependent variable in performing logistic regression because Sv is the mean measured amount of acoustic energy returned from each acoustic ping, scaled for a cubic meter of water.

Stanley and Wilson (1997) used fish density (#/m^3) as the dependent variable, but this value is very sensitive to cross-sectional backscatter (sigma) of individual targets which is used to estimate fish size (fish size). Sigma accuracy increases with the number of times a single target is pinged. In our mobile survey, the vessel traveled at 2 m/sec, therefore the chance of hitting a single target, numerous times, was low. Due to the uncertainty of the accuracy of TS, the accuracy of density becomes uncertain. We therefore used Sv as a proxy for fish presence, hence the dependent variable in our models. If there was a statistically significant effect by a class variable indicated in the logistic regression analysis, then the procedure was re-run using a no intercept option. The resultant Odds Ratio Estimates provide a comparison of probabilities of fish occurring within each class variable. Significant class variables were visualized and compared within and between sites by plotting Sv and estimated fish density by significant class variables.

Overall, we found that fish biomass and density and around the standing oil and gas platform were higher than the artificial reefs or natural reef. Comparison of the mean Sv found at the standing platform and over and immediately around the two reef sites and the WFGB terraces clearly indicate an order of magnitude difference in fish biomass between the standing platform and other sites (Figure 39), suggesting that standing platforms support greater fish biomass. Our results are in support of the findings reported by Stanley and Wilson (2000a), that when a platform is converted into a artificial reef by toppling in place or by partial removal, it loses a significant portion of the fish community. Fish biomass at the artificial reef sites were similar to the upper terrace of the nearby natural reef. In each habitat, we tended to find higher fish densities in habitats with more vertical structure.

We found significant effects of orientation, distance, and depth with both artificial reefs. The probability of finding a fish at WC 617A was highest over the toppled platform and within 30 m of the reef, which is similar to the survey of EI 313 done by Stanley and Wilson (1999). This is also similar to a reported 16 m area of influence by Stanley (1994) at platforms from 50-100m depths. Platforms appear to have a finite reef effect that does not extend beyond visual range of the associated species. The probability of finding a fish at HI A355 was highest around the sides of the partially removed platform and within 30 m of the structure, although fish biomass was highest directly over the reef site. Stanley and Wilson (1999) reported higher numbers of fish directly over another artificial reef (EI 313), and reported the same high fish densities within 30 m of the artificial reef. The significant effect of orientation (north, south, east, and west) at HI A355 could be related to a section of the jacket being placed roughly 30m away from the partially removed platform on the southeast side. Stanley and Wilson (1997) also reported differences in density between platform side and suggested that these differences may be due to platform configuration as higher densities tended to be associated with the conductor bays. Fish biomass near the bottom was approximately the same for the standing platform and artificial reef sites suggesting that the artificial reef sites retain the community found at the lower portion of the standing platform.

Density patterns were basically the same as fish energy. Fish density at the standing platform was an order of magnitude greater than those found at the RTR sites or the WFGB (Figure 40). Density at the two artificial reef sites ranged from 0 to 0.7 fish/m^3 and the partially removed platform had a slightly higher fish density than the toppled platform with overall mean values (within 20m of each site) of 0.002 vs. 0.0015, respectively. Both sites had highest fish

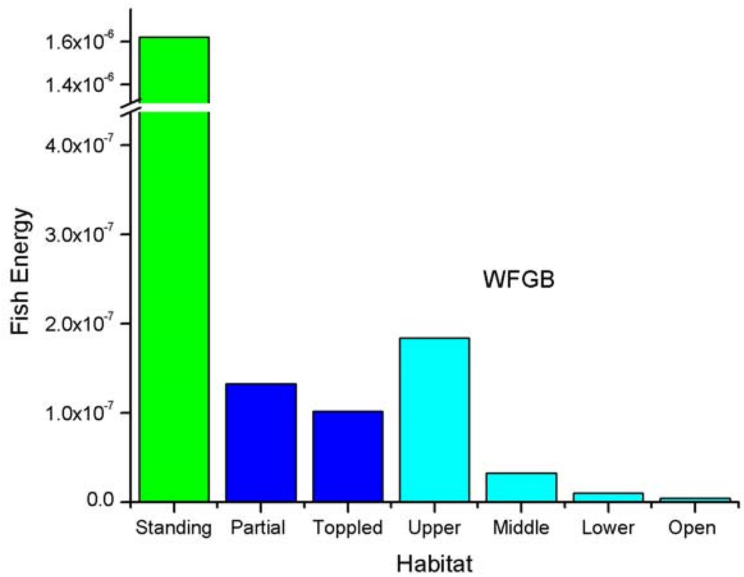


Figure 39. Comparison of the mean fish energy observed over and immediately around the standing (HI 350A), partially removed (WC 617A), and Toppled (HI A355) platforms and the upper, middle, and lower terraces of the WFGB.

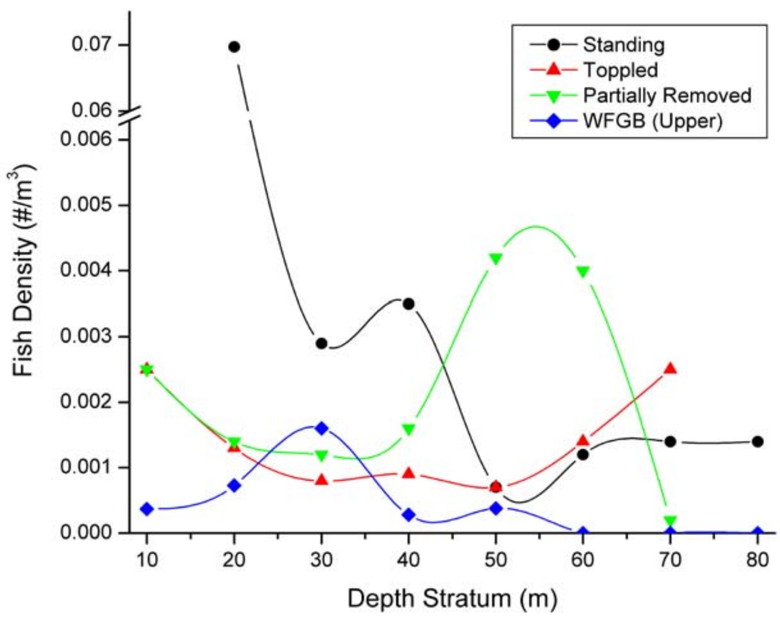


Figure 40. Estimated fish density at depth for all sample locations. Note axis shift for the standing platform.

densities below 50m, which is opposite the pattern observed at the standing platform. However, the partially removed platform, HI A355, also had elevated estimated densities closer to the surface than WC 617A resembling fish distribution at the standing platform. Time of day and depth stratum had an effect on fish density as had been reported previously (Stanley and Wilson 2000a), however the density patterns exhibited at different times of day do not follow a predictable pattern and are likely site-specific. In addition, the short duration of this study make comparison to the longer term studies of Stanley and Wilson (various) inappropriate. We continue to see fish density and size being greater near the surface than the bottom and of standing oil and gas platforms.

We conclude that fish density around a standing platform and the resultant artificial reef configurations of toppled in place or partially removed, are greater than that nearby WFGB habitat on a per unit area basis. The highest densities at the WFGB were found over the upper terrace where they were two to three orders of magnitude greater than the middle or lower terraces and similar to artificial reef sites. Densities associated with the upper terrace were similar to the artificial reef sites. While densities associated with the remaining terraces were more similar to those found away from the 30m area of influence surrounding RTR structures.

Target strength data were not only used in estimating fish density at each site, but also shed some light on the change in community structure between sites as target strength data reveals information about fish size distribution. In general, slightly larger fish were associated with the standing platform, particularly in the middle and upper water column, compared to the partially removed or toppled platforms, where they are larger over the reef sites. Mean target strengths observed at the standing platform ranged from 39 to -33 dB, or fish sizes of 20 - 41 cm (Love 1971). The larger species were shown to be pelagic planktivores and piscivores by Stanley and Wilson (1997). These species appear to be lost when a platform is converted into an artificial reef. Target strengths around the lower portion of the standing platform were similar to the same depths at both reef sites. Fish around the standing platform and reef sites, were in general larger than those found over the WFGB. Within the WFGB complex, fish size was largest over the upper terrace and smallest over the open water areas.

Species composition at the standing platform and two reef sites were fairly similar at depth, but both were different than the WFGB. In general, the greater percentage of fish observed with the ROV were found associated with vertical profile (Figure 41). The most obvious difference between the standing platform and reef sites was that pelagic planktivores such as blue runner and Bermuda chub were present in the upper part of the water column at HI 350A, but not at the reef sites. The species composition around both reef sites was basically the same and were similar to the lower portion (>50 m) of HI 350A (Table 16). ROV surveys of HI A355 in June 1999 and in June 2000 indicated that red snapper and amberjack were the two most abundant species both years, and together they made up over 70 percent of the fish community. Similarly, the survey of WC 617A, conducted in June 1999 only, indicated that amberjack, almaco jack, and red snapper were the most abundant species (Table 16). The standing platform, and the two reef sites were inhabited by the same type of depth-specific fish community that

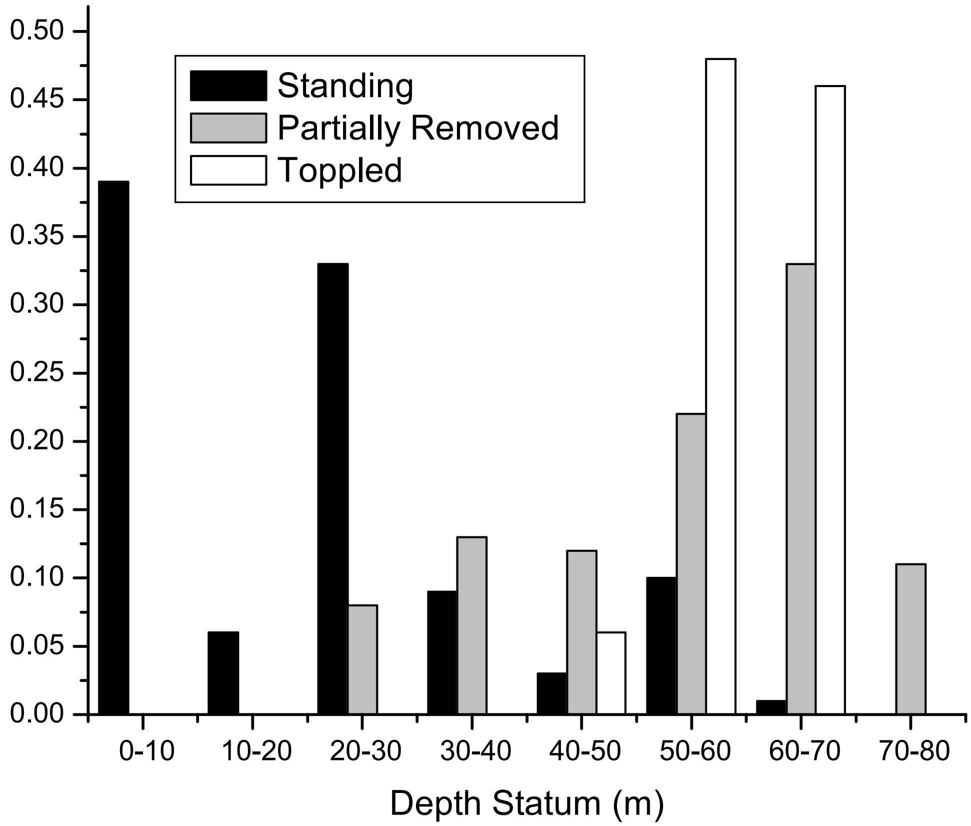


Figure 41. Proportion of fish by depth at each survey site (platforms) based on ROV surveys.

Table 16.

Percent species composition at the standing platform (HI 350A), partially removed (HI A355) and toppled platform (WC 617A), based on ROV surveys.

	Standing	Partial	Toppled
Almaco Jack	3.83%	8.50%	8.38%
Amberjack	2.11%	36.60%	17.37%
Bermuda Chub	28.20%		
Bar Jack	0.10%		
Barracuda	1.81%		
Bluerunner	30.92%		
Creole fish	14.80%	11.76%	
Crevalle jack	0.91%	1.96%	5.39%
Gag Grouper	0.20%		1.80%
Rainbow Runner	1.11%		
Red Snapper	6.14%	32.68%	50.90%
Scamp	7.35%		7.19%
Triggerfish	0.81%	1.96%	8.98%
Blackfin Tuna		5.88%	
Warsaw Grouper		0.65%	

Stanley and Wilson (1997, 2000a) reported for other structures in similar water depths. These included important to recreational and commercial species such as amberjack, red snapper, creole fish, trigger fish, and almaco jack. Stanley and Wilson (2000a) referred to this suite of species as reef- associated.

Since densities were highest in the upper strata of the standing platform, and ROV surveys indicated that these communities were dominated by pelagic planktivores, we believe that vertical profile plays an important role in the attracting/maintaining blue runner and chub in upper depths. By design, both RTR structures had much lower vertical profile to avoid hazard to navigation. We found very few fish in the shallower open waters above the RTR structure (Figure 41). We presume most of pelagic planktivores such as blue runner and Bermuda chub are "lost" following creation of reef sites. However, creation of a reef site using a platform does not seem to reduce production at lower strata as the number of species such as red snapper, grouper, creole fish, etc were similar. Red snapper, amberjack, and scamp were the dominant species between 40-60m at all platform sites. They made up 94% of fish species observed with the ROV at 40-60m near the standing platform and 67% and 76% of fish observed at WC617A and HIA355, respectively, in 1999. These data suggest that the fish community in the lower depth strata may be uncoupled from the community found in the upper strata. Fish at these lower depths may instead be relying more heavily upon benthic or open water prey production. This observation warrants further detailed investigation because red snapper and amberjack tend to be most heavily targeted by recreational and commercial fishers.

Species composition at the WFGB was quite different than the standing platform and reef sites. We found 23 species of fish at the WFGB compared to 7 and 8 at the two reef sites and 13 at the standing platform. The WFGB community was dominated by Bermuda chub and barracuda over the upper terrace and creole fish closer to the bottom. We also found a much greater proportion of reef-dependent species (Stanley and Wilson 20021a) at the WFGB than the standing platform or reef sites. There is a possibility that vessel or ROV avoidance may have been an issue, but it was not apparent in the acoustic survey. The most extensive historical study of the fish community and WFGB was conducted by Boland et al. (1983). Boland et al. (1983) used video surveys to document species composition at the both Flower Garden Banks. Most of their efforts were focused on reef species with a few meters of the bottom. Boland et al. (1983) identified more than twice the number of species that we found, including many cryptic reef species that live close to or within the reef structure. We found eight of the 16 primary species reported by Boland et al. (1983) from the WFGB, of these 16, seven were cryptic and not targeted in our study. The difference in species composition and density between the WFGB and the platform sites is evidence that oil and gas platforms serve as a different type of habitat than a natural reef; the fish communities are different.

One of our main goals was to estimate and compare the total number of fish associated with each site. This number is dependent upon density and "area of influence" of a reef site. We found that both reef sites had an area of influence of 30 m as densities beyond 30 were basically the same as open water, particularly at WC 617A. Based on the reports by Stanley and Wilson

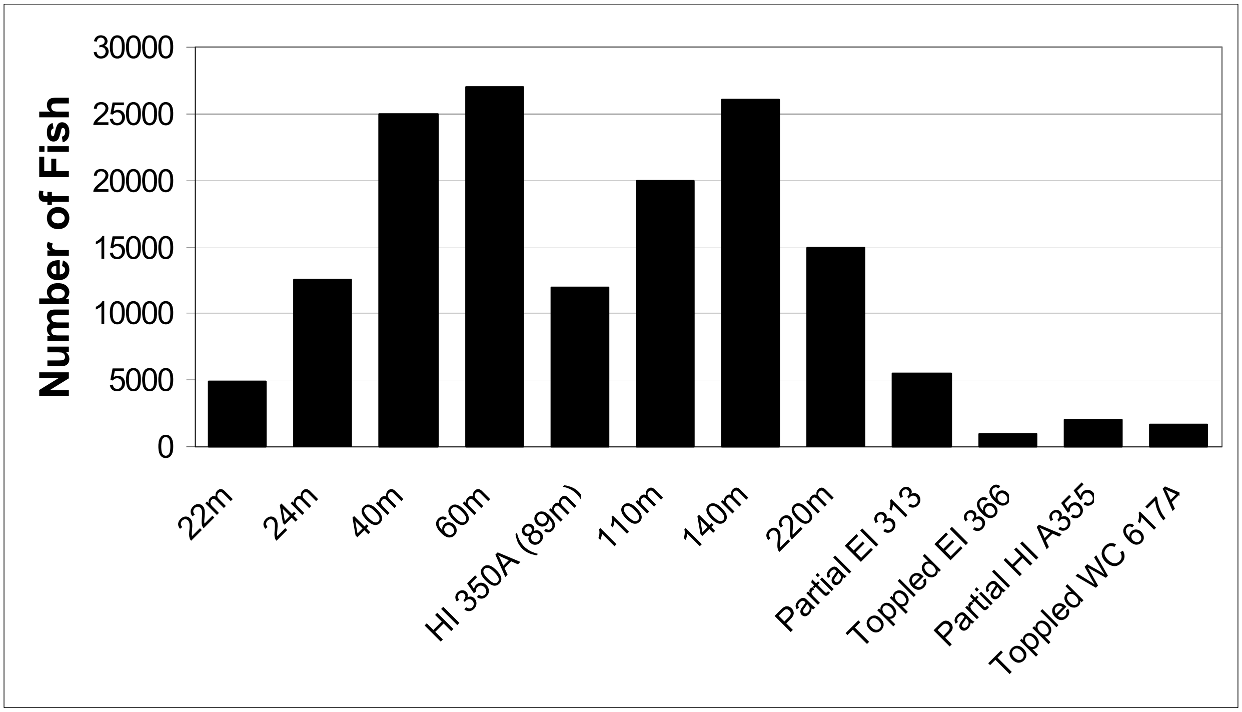


Figure 42. Average number of fish found at platforms and platforms used as artificial reefs as determined with dual beam hydroacoustics (Jan 1992 - Jan 2002). Depths indicate the depth of standing platforms.

(various) we used a 20 m area of influence for the standing platform. We estimate that total fish numbers at WC617 and HIA355 were 2,850 and 2,700, respectively. We also estimated that there were approximately 12,000 fish around HI A350. These "total community" estimates along with those of Stanley and Wilson (various) illustrate the change in fish biomass that occurs when a platform is converted into an artificial reef. As mentioned previously, however, the majority of these changes occur with the loss of pelagic planktivores and piscivores in the upper depth strata. There were approximately 2,000 fish below 40 m at HI A350 which was similar to the number of fish around both reef sites. The number of fish at HI A350 is consistent with the estimates of fish communities reported by Stanley and Wilson (2000b, 1997) for platforms in similar water depths. They reported 10,000 to 20,000 fish inhabited each of the four oil and gas platforms they had studied (Figure 42).

Similarly, fish density estimates for each terrace at the WFGB and the spatial extent of each terrace were used to estimate that there were approximately 2,500,000 fish associated with the WFGB. This estimate is on the same order of magnitude as reported in Boland et al. (1983) who assigned estimates to the abundance of individual species. For example, Boland et. al. (1983) reported from 400,000 - 900,000 creole-fish on the WFGB. We estimate that 23% of 2,500,000, or 575,000 creole-fish were present at the time of our survey. Note that these studies were nearly 20 years apart.

Acoustic surveys have been conducted at several artificial reef sites. As mentioned previously, Stanley and Wilson (1999) conducted a mobile acoustic survey of the Penrod drilling rig at EI 313. Although their data were not published, they found approximately 7,000 fish around the Penrod drilling rig in EI 313 (Wilson and Stanley 1999). The Penrod drilling rig was located in shallower water than these sites reported herein and the drilling rig had a more complex inner-structure of decking and cross-member material; this more complex structure combined with vertical relief likely influenced fish populations. In a survey of the Tenneco II artificial reef off southern Florida, Seaman et al. (1989), found that the solid deck portion of the platform did not contain the diversity and abundance of fishes found on the grated surface section of the platform deployed 30m away. They postulated that the grating likely afforded more hiding places for small fishes, thereby increasing diversity of small species and also food supply for predatory species. Openings in the grated surface would also permit access to the upper surface for animals living in protected areas under the deck (Seaman et al. 1989). It is likely that the greater number of fish around the Penrod drilling rig was due to the different type of material such as decking and shallower water depths. Studies suggest that optimal artificial reef configurations exist, but vary, depending on the target species (Stanley and Wilson 1990).

Reef configuration (toppled vs partially removed) appeared to have no discernable impact on fish production. Taken over the entire water column, mean fish density within 20m of the partially removed platform (0.0020 fish/m^3 2,850 fish) was only slightly higher than observed at the toppled platform (0.0015 fish/m^3, 2,700 fish) and is likely insignificant. However, partial removal would be the preferred option as it can avoid the use of explosives which has been shown to kill many of the resident species and poses a general hazard to human safety.

Red snapper and amberjack populations at the two reef sites were similar in number to the populations estimated to be at the standing platform in similar water depths. These artificial reef sites, like their platform predecessors, have significant fishing value since the majority of species associated with these reef sites are targeted by commercial and recreational fishers. When a standing platform is converted into an artificial reef site, it appears that the pelagic planktivores make up the greatest biomass that is lost, and the more desirable recreational species are retained. According to survey results from HI A355 and WC 617A, we estimate a loss of approximately 50-80 percent of the fish population when a standing platform is converted (toppled or partially removed) into an artificial reef site in 100 m of water. Each artificial reef site harbored approximately 2,500 fish compared to 12,000 fish around the HI A350 and the 10,000- 20,000 reported by Stanley and Wilson (1998). This decline of fish numbers was also observed during a pre- and post- toppling survey of EI 367 (Wilson and Stanley 1998).

We recognize some that the absolute estimates of fish numbers are likely skewed due to the uncertainty of target strength estimates. However, these data do provide a basis for comparisons between the different habitat types. The WFGB, for example, supports well over 2 million fish that can be detected by acoustics. This fish biomass is comparable to the combined fish populations of 150 standing platforms and or 1000 "reefed" platforms in similar water depths (ranging from 100 to 500 m) . Future refinements in the approach to stationary and mobile acoustic studies will lead to even more accurate assessments of fish habitat. Integration of these types of study results into a comprehensive spatial database will go far to improving management of these resources.

This research continues to support the working hypothesis that platforms do make useful artificial reefs since they tend to support a population of fish that can be 10 to over 1000 times greater in density than the adjacent sand and mud bottom habitats, and are equal to or even exceed that of natural coral reef habitat like the WFGB. The species associated with the artificial reefs (including standing platforms) do however, differ from those found on natural reef habitats. Future research efforts might be directed toward determining the reasons for this difference.

Completion of this research has provided quantitative data on the effect of vertical profile on fish abundance, assessed the effectiveness of retired platforms sited as artificial reefs, provided comparison to a natural reef, and presented the differences in abundance and species composition among sites. Since the reef sites are of similar age and size, and are located within a radius of 48 km, comparison of the production platform and the partial removal with the toppled platform has provided valuable insight into the effect of platform configuration on the assemblage of fishes while minimizing confounding effects.

To date over 150 retired petroleum platforms from Texas to the Atlantic coast of Florida have been converted to artificial reefs. A variety of removal techniques and placement configurations have been employed in siting these reefs. While numerous qualitative studies documenting the colonization and relative abundance of organisms associated with production platform have been undertaken, it has proven difficult to conduct quantitative studies at artificial reefs. Consequently, very little could be said about how different reef configurations impacted fish abundances and, further, how these abundances compared to abundances at natural reefs. Development of artificial reefs has been advocated by government and the Gulf of Mexico Fishery Management Council (GMFMC 1989). They identified several research needs and goals, including general information on the effects of artificial reefs, improving the quantitative assessment techniques used to describe artificial reef communities, monitoring biological changes at reef sites, assessing the importance of fish attraction versus fish production, and quantifying the relationships between reef fish production and habitat. This research provides information critical in fulfilling these goals.

5.0 REFERENCES

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. 15 pp.

Bohnsack, J.A., D.L. Johnson, and R.F. Ambrose. 1991. Artificial habitats for marine and freshwater fisheries. Ecology of Artificial Reef Habitats. Academic Press. New York, New York. Pp. 61-108.

Boland, G.S., B.J. Gallaway, J.S. Baker, and G.S. Lewbel. 1983. Ecological effects of energy development on reef fish of the Flower Garden Banks. Ecological Research Associates, Inc., Bryan, Texas. 466 pp.

Bortone, S.A. and J.J. Kimmel. 1991. Environmental assessments and monitoring of artificial habitats. Artificial Habitats for Marine and Freshwater Fisheries. New York: Academic Press. Pp. 177-236.

Bright, T.J., J.W. Tunnell, L.H. Pequegnat, T.E. Burke, C.W. Cashman, D.A. Cropper, J.P. Ray, R.C. Tresslar, J. Teerling, and J.B. Wills. 1974. Biotic zonation on the West Flower Garden Bank. Texas A&M University, University of Southwestern Louisiana and University of Houston. Pp. 1-54.

Bright, T.J. and C.W. Cashman. 1974. Fishes. Biotic zonation on the West Flower Garden Bank. Texas A&M University, University of Southwestern Louisiana and University of Houston. Pp. 340-409.

Bright, T.J. and G.S. Boland. 1985. Biotic zonation, East and West Flower Garden Banks. In: The Flower Gardens: A compendium of information. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 85-0024. Pp 53-90.

Brock, R.E. 1982. A critique of the visual census method for assessing coral reef fish populations. Bulletin of Marine Science. 32:269-276.

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

Dennis, G.D. and T.J. Bright. 1988. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. Bulletin of Marine Science. 43(2):280-307.

Doherty, P.J. and D. McB. Williams. 1988. The replenishment of coral reef fish populations. Oceanography and Marine Biology. 26:487-551.

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell, C.R. Beaver, G.S. Boland, and D.K. Hagman. 1999. Long- Term Monitoring at the East and West Flower Garden Banks,1996-1997. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 99-0005. Pp. 1-7.

Elvers, D.J. and C.W. Hill, Jr. 1985. History of activities at the Flower Garden Banks. In: The Flower Gardens: A compendium of information. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 85-0024. Pp. 3-10.

Gallaway, B.J. and G.S. Lewbel. 1982. The ecology of petroleum platforms in the northwestern Gulf of Mexico: A community profile. USFWS Office of Biology Services, Washington, D.C. FWS 10BS-82/27. Open File Report. Pp. 82-103.

Gallaway, B.J., L.R. Martin, R.L. Howard, G.S. Boland, and G.D. Dennis. 1981. Effects on artificial reefs and demersal fish and macrocrustacean communities. Marine Science. 14:237-299.

Gardner, J.V., L.A. Mayer, J.E. Hughes Clarke, and A. Kleiner. 1998. High-resolution multibeam bathemetry of East and West Flower Gardens and Stetson Banks, Gulf of Mexico. Gulf of Mexico Science. 16(2):131-143.

Garrison, L.P., W. Michaels, J.S. Link, and M.J. Fogarty. 2000. Predation risk on larval gadids by pelagic fish in the Georges Bank ecosystem. I. Spatial overlap associated with hydrographic features. Canadian Journal of Fisheries and Aquatic Sciences. 57:2455-2469.

Gerlotto, F., C. Bercy, and B. Bordeau. 1989. Echo Integration Survey Around O ffshore Oil Extraction Platforms off Cameroon: Observations of the Repulsive Effect on Fish of Some Artificially Emitted Sounds. Proceedings of the Institute of Acoustics. (19):79-88.

GMFMC (Gulf of Mexico Fisheries Management Fisheries Council). 1989. Amendment 1 of the Reef Fisheries Management Plan for the Fisheries Resources of the Gulf of Mexico. GMFMC. Tampa FL. 420 pp.

Gittings, S.R. and E.L. Hickerson. 1998. Introduction. Gulf of Mexico Science. 16(2):128.

Love, R.H. 1971. Dorsal aspect target strength of an individual fish. Journal of Acoustic Society of America. 62:1,397-1,403.

Menge, B.A. and J.P. Sutherland. 1987. Community regulation: Variation in disturbance competition and predation in relation to environmental stress and recruitment. American Naturalist. 130:730-757.

NRC (National Research Council). 1996. An assessment of techniques for removing offshore structures. Washington, DC: National Academy Press.

Ott, L. 1982. An introduction to statistical methods and data analysis. 2nd Edition. Duxbury Press. Boston, Mass. 774 pp.

Parker, Jr., R.O., D.R. Colby, and T.P. Willis. 1983. Estimated amount of reef habitat on a portion of the U.S. South Atlantic and Gulf of Mexico Continental Shelf. Bulletin of Marine Science. 33:935-940.

Putt, Jr., R.E. 1982. A quantitative study of fish populations associated with a platform within Buccaneer oil field, northwestern Gulf of Mexico. M.Sc. Thesis. Texas A&M University. College Station, Texas.

Rooker, J.R., Q.R. Dokken, C.V. Pattengill, and G.J. Holt. 1997. Fish assemblages on artificial and natural reefs in the Flower Garden Banks National Marine Sanctuary, USA. Coral Reefs. 16:83-92.

Sale, P.F. 1990. Recruitment of marine species: Is the bandwagon rolling in the right direction? Trends in Evolutionary Ecology. 5:25-27.

Sale, P.F. 1991. Reef fish communities: Open nonequilibrial systems. In: Sale, P.F. editor. The ecology of fishes on coral reefs. New York: Academic Press. Pp. 564-600.

Sale, P.F. and W.A. Douglas. 1981. Precision and accuracy of visual census technique for fish assemblages on coral patch reefs. Environmental Biology of Fish. 6:333-339.

SAS Institute Incorporated. 2000. SAS user's guide: Statistics. Version 8. SAS Institute. Cary, NC. 1,290 pp.

Seaman, Jr., W.J. Lindberg, C.R. Gilbert and T.K. Frazer. 1989. Fish habitat provided by obsolete petroleum platforms off Southern Florida. Bulletin of Marine Science. 44(2):1014-1022.

Seaman Jr., W.J. and A. Jensen 2001. Purposes and practice of artificial reef evaluation. In: Seaman, W.A., editor. Artificial Reef Evaluation. CRC Press. Pp. 1-20.

Sonnier, F., J. Teerling, and H.D. Hoese. 1976. Observations on the offshore reef and platform fish fauna of Louisiana. Copeia. No. 1.

Stanley, D.R. 1994. Seasonal and spatial abundances and size distribution associated with a petroleum platform in the Northern Gulf of Mexico. Dissertation. Louisiana State University.

Stanley, D.R. and C.A. Wilson. 1990. A fishery-dependent based study of fish species composition and associated catch rates around oil and gas structure off Louisiana. Fishery Bulletin. 88(4):719-730.

Stanley, D.R. and C.A. Wilson. 1991. Factors affecting the abundance of selected fishes near oil and gas platforms in the northern Gulf of Mexico. Fishery Bulletin. 89(1):149-159.

Stanley, D.R. and C.A. Wilson. 1995. Detection of the effect of scuba divers on fish density and target strength utilizing dual-beam hydroacoustics. American Fisheries Society. 124:946-949.

Stanley, D.R. and C.A. Wilson. 1996. Abundance of fishes associated with a petroleum platform as measured with dual-beam hydroacoustics. ICES Journal of Marine Science. 53: 473-475.

Stanley, D.R. and C.A. Wilson. 1997. Seasonal and spatial variation in 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.

Stanley, D.R. and C.A. Wilson. 1998. Spatial variation in fish density at three petroleum platforms as measured with dual-beam hydroacoustics. Gulf of Mexico Science. 1998(1):73-82.

Stanley, D.R., and C.A. Wilson. 1999. Survey of the fisheries resources at the toppled jackup drilling rig in Eugene Island 313. A report to Texaco Inc.

Stanley, D.R. and C.A. Wilson. 2000a. Seasonal and spatial variation in the biomass and size frequency distribution of fish associated with oil and gas platforms in the northern Gulf of Mexico. A final report for the U.S. Department of Interior, Minerals Management Service Gulf of Mexico OCS Region, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 2000-005.

Stanley, D.R. and C.A. Wilson. 2000b. Variation in the density and species composition of fishes associated with three petroleum platforms using dual beam hydroacoustics. Fisheries. 47:161-172.

Trexler, J.C. and J. Travis. 2001. Nontraditional regression analysis. Ecology. 74(6):1629-1637.

Wilson, C.A. and D.R. Stanley. 1991. Technology for assessing the abundance of fish around oil and gas structures. In: Nakamura, M., R.S. Grove, and C.J. Sonu, editors. Recent advances in aquatic habitat technology. Southern California Edison Company. Environmental Research Report Series 91-RD-19. Pp. 115-119.

Wilson, C.A. and D.R. Stanley. 1998. The Louisiana Artificial Reef Research Program Annual Report. Louisiana Department of Wildlife and Fisheries.

Appendix A

Images from ROV Surveys

Conducted in June 1999 and June 2000

of High Island A350, High Island 355A,

and West Cameron 617A.

Figure A1. A school of greater amberjack swims by a severed leg of HI 355 A.

Figure A2. Closeup of a creolefish in the wellbay of HI A350.

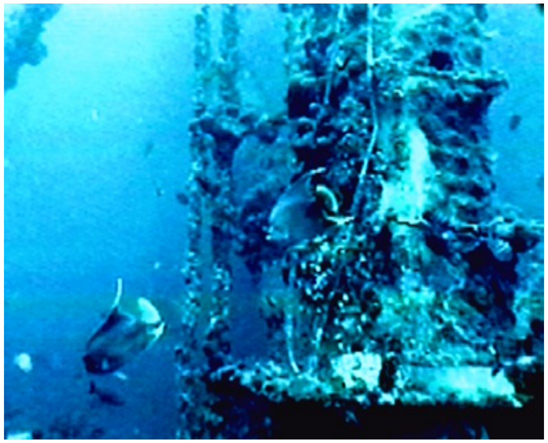


Figure A3. A collection of mixed reef fish along one of the well bay of HI A350.

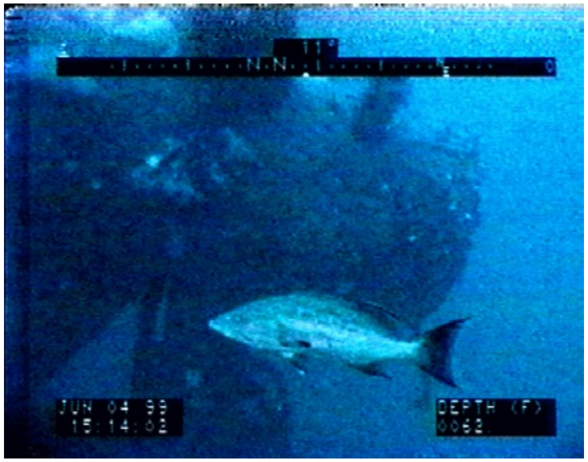


Figure A4. A scamp swims towards the toppled WC 617A platform.

Figure A5. A red snapper swims down through the water column of HI 355 A.

Figure A6. A warsaw grouper swims through the piling of WC 617A; size is estimated ~ 1 meter. Note: laser marks posterior of the right eye are 7 cm apart.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.