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Seasonal and Spatial Abundance and Size Distribution of Fishes Associated With a Petroleum Platform in the Northern Gulf of Mexico.

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SEASONAL AND SPATIAL ABUNDANCE AND SIZE DISTRIBUTION OF FISHES ASSOCIATED WITH A PETROLEUM PLATFORM IN THE NORTHERN GULF OF MEXICO

A Dissertation

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by
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ABSTRACT

The purpose of this study was to demonstrate the utility of dual-beam hydroacoustics in measuring abundance and target strength of fishes near a petroleum platform in the northern Gulf of Mexico. From September to November 1990 fish densities ranged from 0 to 1.88 fish/m^3 and varied with platform side, depth, time of day and month. Densities were highest adjacent to the platform and decreased significantly beyond 9 m. Approximately 2,400 to 8,300 fish were associated with the platform depending on month. Target strengths ranged from -56 to -24 dB and varied with side of the platform and month. Mean monthly target strengths ranged from -39.4 to -34.3 dB.

The effect of the presence of SCUBA divers on fish density and target strengths was examined during November 1991 and February, March, and June of 1992. Mean densities and fish target strengths declined significantly when divers were present. Densities dropped from 41.5% to 76.5% and target strength decreased by 0.5% to 9.1% when divers were present. The decrease in target strengths were not uniform; fish with target strengths from -43 to -37 dB decreased at the highest rate.

Stationary dual-beam hydroacoustics and visual point count surveys were used in tandem to measure the density, target strength and species composition of fishes associated with a petroleum platform. Fish densities ranged from 0 to 10.5 fish/m^3 for monthly sampling trips from January 1991 to May 1992. Density and target strength were spatially and temporally variable. Target strengths varied significantly with side of the platform, month, and east and

north current vectors. Density varied significantly with platform side, month, east current vector and depth. No variation in density or target strength was detected over 24 hour periods or with water temperature. Fish densities were highest adjacent to the platform and decreased significantly beyond 16 m. Approximately 1,990 to 28,100 fish were associated with the platform depending on month. A total of 19 species were observed at the platform with Atlantic spadefish, bluerunner, bluefish, greater amberjack, gray triggerfish, red snapper and sheepshead constituting 97% of observed species.

GENERAL INTRODUCTION

Placement of offshore petroleum production structures in the northern Gulf of Mexico has undoubtedly influenced the marine environment and its inhabitants. To date, research has been centered on environmental impacts of petroleum production, focusing on effects of discharges such as produced waters, drilling fluids and spills (Boesch and Rabalais 1987). The significance of habitat modification due to the presence of petroleum platforms is unknown and much is left to speculation.

Approximately 4,500 petroleum platforms had been placed in the northern Gulf of Mexico by 1990; the placement of these structures significantly increasing available hard substrate (Reggio and Kasprzak 1991). Parker et al. (1983) estimated that natural reefs constitute only 1.6% or 2,571 km^2 (737 to 6,385 km^2, 95% CL) of the total substrate from Pensacola, Florida, to Pass Cavallo, Texas. Gallaway (1981) calculated that petroleum platforms provided 5,000 km^2 of "reef" habitat. Therefore, the addition of petroleum platforms has provided an estimated 78% to 195% of new reef habitat in the northern Gulf of Mexico. Substrate in the northern Gulf of Mexico is dominated by clay, silt and/or sand with little relief or hard bottom. The addition of 4,500 petroleum platforms, and the potential doubling of hard substrate, has undoubtedly had some effect on fish populations, although the effects are not well understood. Because fish populations are limited by available energy and habitat, as well as recruitment, competition, and predation (Connell 1978; Menge and Sutherland 1987; Doherty and Williams 1988; Bohnsak 1989; Bohnsak et al. 1991), the

additional habitat provided by petroleum platforms can potentially influence all of these processes. Information on population dynamics acquired from the measurement of fish assemblages associated with offshore structures may help to determine whether these structures aggregate prey or predators, or provide critical habitat for reproduction or survival of fragile life history stages.

Coral reef communities are among the most diverse and taxonomically rich found in nature, and many of the fish associated with them are thought to be habitat limited due to their dependence on hard bottom (Moran 1986; Parrish 1987; Sale 1991). Although habitat limited fish may venture away from the reef at various times, the reef is critical to their survival; providing protection from predation, sites for spawning and recruitment, and a source of food. Even though coral reef fishes have adopted a myriad of behavioral and life history patterns, one life history trait is nearly constant. The vast majority of coral reef fishes are iteroparous spawners with pelagic larvae; this life history strategy an attempt "to win the space competition lottery" associated with the limited amount of reef habitat (Sale 1991). Since the larvae of reef fish spend up to 100 days in the pelagic phase and can travel great distances before settling, it is thought that offspring rarely settle on the same reef from which they were spawned (Doherty and Williams 1988). This dispersal of reef fish larvae ensures that colonization of existing or new reefs occurs rapidly, in the case of artificial reefs often as soon as new reefs are deployed, suggesting that supply of potential recruits is not the limiting factor but that availability of suitable habitat may be (Jones 1991).

The abundances of fishes at temperate reefs often follow different patterns than those in tropical environments. Fewer species exploit reefs in temperate environments (Gascon and Miller 1981; Schoener 1983). Many temperate species undergo seasonal migrations which cause large fluctuations in their numbers (Kock 1982; Alevizon et al. 1985; Bohnsak et al. 1991). Since the northern Gulf of Mexico is classified as a temperate/sub-tropical system, the abundance of fishes associated with reefs in this area will likely exhibit characteristics of both tropical coral reef and temperate reef systems. Large fluctuations in abundance and composition of reef populations during cool seasons may result from meteorological changes associated with the passage of winter fronts, whereas abundances may remain more stable in the summer when meteorological fluctuations are minimal.

In spite of the popularity among fisheries agencies of utilizing artificial reefs to augment existing habitat or mitigate aquatic impacts, a debate among biologists exists as to the exact effect of artificial reefs. Do artificial reefs create additional biomass or simply attract existing organisms to this new site. This issue cannot be viewed in black and white, and Bohnsak (1989) theorized a continuum between production of additional organisms and the attraction of existing organisms to artificial reefs. In an attempt to clarify the issue, he proposed that the addition of artificial reefs would increase productivity of reef dependent species in areas with limited hard substrate habitat; whereas in areas with abundant reef habitat the increase in productivity would not be as great and fish would be attracted from other reef habitats. Because the northern Gulf

of Mexico has only a small amount of natural reef habitat, it is unlikely that the introduction of 4,500 petroleum platforms has simply attracted fish from other areas. Stone et al. (1979) compared recruitment to small artificial reefs and nearby patch reefs in south Florida and found that both juveniles and subadults were recruited to artificial reefs while fish abundance at adjacent natural reefs did not decrease. Alevizon et al. (1985) found that only adults were recruited to artificial reefs in Bahamian waters, but made no attempt to measure abundance at nearby natural reefs. Obviously, the potential doubling of reef habitat in the northern Gulf of Mexico due to the introduction of petroleum platforms has had some effect on reef fish populations.

Many species of fish are trophically independent of reef habitat but are thought to utilize reefs for other purposes, such as habitat for spawning, shelter and protection from predation, and for orientation. Factors thought to influence the abundance of fish at artificial reefs include:

1) Current speed and direction: Many fish appear to congregate on the up-current side of artificial reefs to increase the chance of capturing food and avoid lee waves (Klima and Wickham 1971; Grove and Sonu 1983). Sanders (1983) found that fish abundance was negatively correlated with current speed for fishes near artificial reefs in the northern Gulf of Mexico.

2) Shape and complexity: Three-dimensional structure, increased number of interstitial spaces, and horizontal and diagonal panels have been demonstrated to increase the attraction of fish to artificial reefs (Hunter

and Mitchell 1967; Buckley 1982; Grove and Sonu 1983; Stanley and Wilson 1991).

3) Size of an artificial reef: Generally, as size of an artificial reef increases the abundance of fish increases, although an optimal size may exist (Hunter and Mitchell 1967; Turner et al. 1969; Grove and Sonu 1983; Rountree 1989; Stanley and Wilson 1991).

4) Age and seasonality: Initial colonization of artificial reefs can often occur within hours (Stone et al. 1979). Smith (1979) and Lukens (1981) found that artificial reefs in the northern Gulf of Mexico were fully colonized after approximately 15 months. Large fluctuations in abundance and species composition are common, especially in temperate climates and during frontal passages such as are prevalent in the northern Gulf of Mexico (Smith 1979; Lukens 1981; Putt 1982; Sanders 1983; Prince et al. 1985; Bohnsack et al. 1991).

Petroleum platforms are also an important component of the recreational and commercial fisheries and have long been recognized as defacto artificial reefs by fishermen. Reggio (1987) estimated that petroleum platforms were the destination of over 70% of all recreational fishing trips in the Exclusive Economic Zone off coastal Louisiana, and Avanti (1991) estimated that 30% of the recreational fisheries catch, 14,900,000 fish, off the Texas and Louisiana coasts were caught near petroleum platforms based on his analysis of data from the Marine Recreational Fisheries Survey. Although these resources are important to fishermen, there is little information upon which fisheries scientists can base

management decisions. This paucity of available information is primarily due to the difficulty of sampling these habitats with traditional fisheries sampling techniques. The purpose of this dissertation is to demonstrate the utility of the relatively new fisheries sampling technique, dual-beam hydroacoustics, in conjunction with standard reef fish assessment techniques to document the abundance, size distribution and species composition of fishes associated with a petroleum platform in the northern Gulf of Mexico.

The subsequent chapters are organized as follows: Chapter 1 illustrates the initial setup of the dual-beam system and its use in measuring *in situ* target strengths and density of fishes. Due to difficulties with the remotely operated underwater vehicle (ROV) and in securing permission to dive from the platform operator, species composition data were not available. Chapter 2 measures the effect of SCUBA diver presence on fish density and size distribution. This chapter provides evidence that the presence of SCUBA divers greatly influences fish behavior and that visual survey results alone may be biased. Chapter 3 synthesizes fish density and size distribution from dual-beam hydroacoustic data and models these variables with time, physical platform factors, depth and environmental variables. Species compositions are estimated from ROV and SCUBA diver visual point count surveys. The chapters included in this dissertation were written as manuscripts for publication in peer reviewed journals. Therefore each chapter contains separate Introduction, Materials and Methods, and Results and Discussion sections. As a result of duplication of many of the references between chapters, a single reference section has been

included. Chapters 1 and 2 are to be published in *Transactions of the American Fisheries Society* (Stanley and Wilson, in review). Chapter 3 is being prepared for submission to an appropriate journal.

CHAPTER I

HYDROACOUSTICAL MEASUREMENT OF FISH DENSITY AND TARGET STRENGTH AT A PETROLEUM PLATFORM

Introduction

Attempts have been made to document the abundance and composition of fishes associated with petroleum platforms with a variety of methods (Sonnier et al. 1976; Gallaway et al. 1981; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982; Stanley and Wilson 1990, 1991). Except for Putt (1982) and Stanley and Wilson (1990, 1991), most were short-term studies, often only "snapshots" of the abundance and species composition of fishes associated with platforms. Results of these studies provided some insight into fish populations at specific sites; however, gear bias, limited visibility, diver/remotely operated underwater vehicle (ROV) avoidance and a lack of standard survey techniques make results difficult to interpret and compare.

Despite the range of methodologies, investigators found that fish abundance ranged from a few hundred to several thousand depending on platform size, location and time of the survey (Continental Shelf Associates 1982; Putt 1982). Gerlotto et al. (1989) found that fish densities were 5 to 50 times higher immediately adjacent to the platform than at distances 50 m away. Species composition appeared similar between studies at platforms in the northern Gulf of Mexico; the dominant fish species observed in water depths between 10 and 60 m included red snapper (*Lutjanus campechanus*), bluefish (*Pomatomus saltatrix*), Atlantic spadefish (*Chaetodipterus faber*), blue runner (*Caranx crysos*), gray triggerfish (*Balistes capriscus*), grunts (Haemulidae), greater amberjack (*Seriola dumerili*), sheepshead (*Archosargus probatocephalus*), and groupers (Serranidae) (Gallaway 1980; Continental Shelf Associates 1982;

Gallaway and Lewbel 1982; Putt 1982; Stanley and Wilson 1990). Longer-term studies reported that fish populations at oil and gas platforms were variable. Putt (1982), using fixed underwater cameras, observed that fish abundance varied by a factor of 2, whereas species composition remained constant, from June through September. Stanley and Wilson (1990, 1991), using catch records from recreational and charter boat anglers, found that catch rates and species composition of the catch varied with season, platform size and water depth. These results suggest that abundances of fish species at petroleum platforms are transient in nature, although no long term data exists.

Accurate estimation of abundance and size distribution of fishes associated with petroleum platforms requires a fishery-independent and unobtrusive sampling methodology such as dual-beam hydroacoustics. Stationary dual-beam hydroacoustics have been utilized in a variety of environments (i.e., hydroelectric dams, ice packs, bridges and artificial reefs) to detect fish, and determine size distribution and estimate fish abundances (Thorne 1979; Dawson et al. 1985; Raemhild et al. 1985; Thorne et al. 1989; MacLennan and Simmonds 1992; Thorne and Johnson 1993). Dual-beam hydroacoustics has an advantage over single-beam acoustics in that it can provide *in situ* measurements of target strength which can then be converted into estimates of fish length and absolute abundance. As its name implies, dual-beam hydroacoustics receives two beams, the effect of beam pattern can be factored out, and *in situ* target strengths estimated (Ehrenberg 1983; Thorne 1983; Burczynski and Johnson 1986). Target strengths then provide estimates

of fish size based on a relationship derived by Love (1971). Echo integration analysis from dual-beam hydroacoustic data can estimate absolute abundance of animals, as the mean backscattering cross section of the targets is known from the target strength analysis. This mean backscattering cross section can then be input into echo integration analysis to determine absolute biomass and/or numerical density of targets in the insonified volume (Thorne 1983; MacLennan and Simmonds 1992; Appendix). Stationary dual-beam hydroacoustics has several advantages over traditional fisheries methodologies. Hydroacoustic techniques:

1) are unobtrusive and non-lethal,

2) do not influence fish behavior,

3) can provide an absolute estimate of abundance,

4) can differentiate fish within 0.5 m of boundaries, and

5) are not affected by changes in environmental conditions such as turbidity or currents; however they can be influenced by thermoclines and pycnoclines (Thorne 1983; Dawson et al. 1985; MacLennan and Simmonds 1992).

The complex architecture of petroleum platforms, the varying environmental conditions in the northern Gulf of Mexico, and the forementioned biases of traditional fisheries sampling, limit the effectiveness and value of previous abundance estimates near petroleum platforms. Because of problems with traditional fisheries sampling gear, stationary dual-beam hydroacoustics was used to monitor abundance and size distribution of fishes associated with a

petroleum platform. I designed a study to:

1) determine the ability of dual-beam hydroacoustics to quantify and measure target strength of fishes associated with a petroleum platform,

2) measure and compare the density and size frequency distribution of fishes associated with the petroleum structure over a 3 month period,

3) define the spatial near-field area of influence of the platform on fish abundance, and

4) document the near-field behavior patterns of fishes around the platform.

Methods

Site Description

The study site was a steel template petroleum platform, West Cameron 352A (WC 352), operated by Mobil USA Inc. located at 28° 59.35' N, 93° 30.35' W, 80 km south of Cameron LA, in 22 m of water. The platform was 45 m in length by 20 m in width and enclosed approximately 19,800 m^3 of water. It was installed in 1978 with the nearest platform situated 14.5 km away.

Sampling Design

Stationary dual-beam hydroacoustic surveys were conducted monthly on the platform for three months, September, October and November 1990. Two arrays of stationary dual-beam hydroacoustic equipment were used. Array 1 was designed to measure the target strength distributions and density of fishes associated with the platform (Figure 1.1). It consisted of four vertically oriented transducers; two transducers (120 kHz) suspended at the surface facing

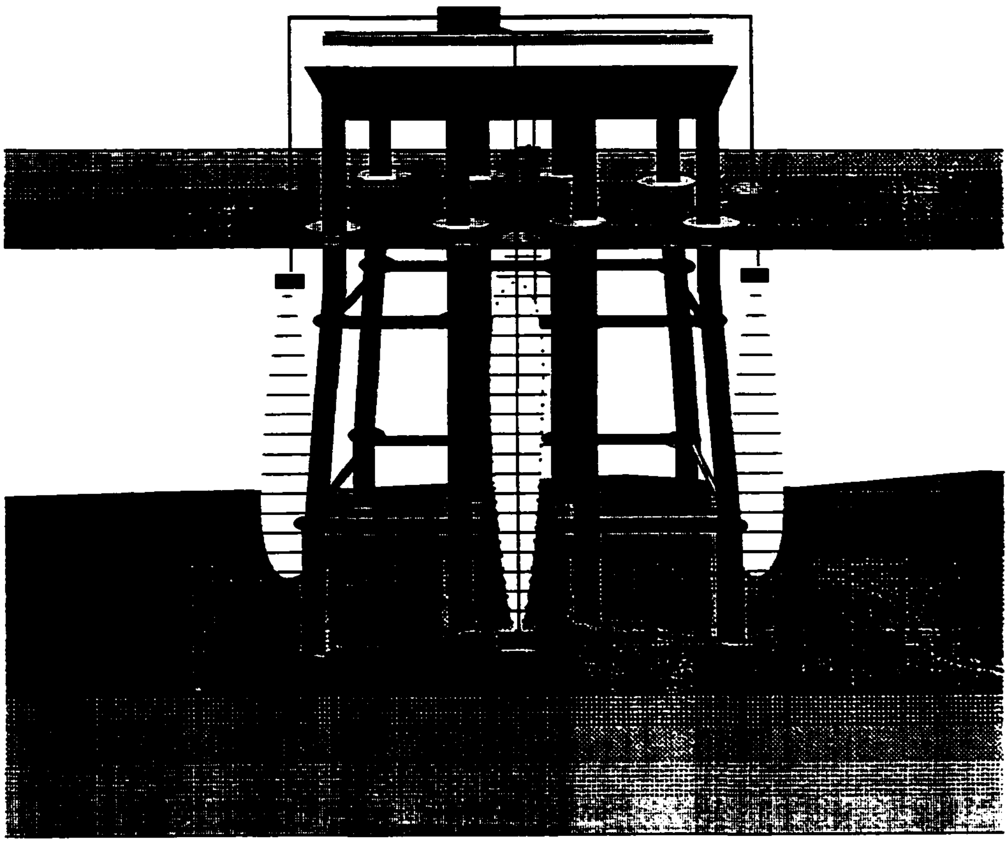

Figure 1.1. Schematic view of stationary hydroacoustic transducer deployment to measure target strength and density of fish associated with a petroleum platform in the northern Gulf of Mexico.

downwards on the east and north sides of the platform; and two transducers (420 kHz) placed on the bottom oriented upwards, on the west and south sides of the platform. The downward facing transducers provided acoustic coverage sufficient to collect acoustic data from 2 m below the transducer to 1 m above the bottom. The two upward facing transducers provided acoustic data from 2 m above the bottom to within 1 m of the surface. Use of both upward and downward oriented transducers enabled calculation of density and target strength distributions in 2 m strata throughout the water column.

Array 2 was designed to estimate the near-field density of fishes associated with the structure (Figure 1.2). It consisted of four horizontally oriented transducers deployed off each side of the platform at a depth of 11 m; 120 kHz transducers on the east and north sides and 420 kHz transducers on the west and south sides. This arrangement allowed for estimates of relative density from 2 to 72 m away from the platform in 7 m strata.

Horizontal and vertical sampling took place over consecutive 24 hour intervals for each of the three months; two hours of hydroacoustic data were collected encompassing four time periods (dawn, noon, dusk and midnight) over each 24 hour interval. Hydroacoustic data were collected sequentially from each of the transducers in five minute intervals after random selection of the starting transducer for each month's sampling period. Stationary hydroacoustics allows for collection of many samples or "snapshots" of density and size distribution over time. Time allotted for an individual sample is dependent on the variance of fish density. An analysis of the variance of density estimates for sample times

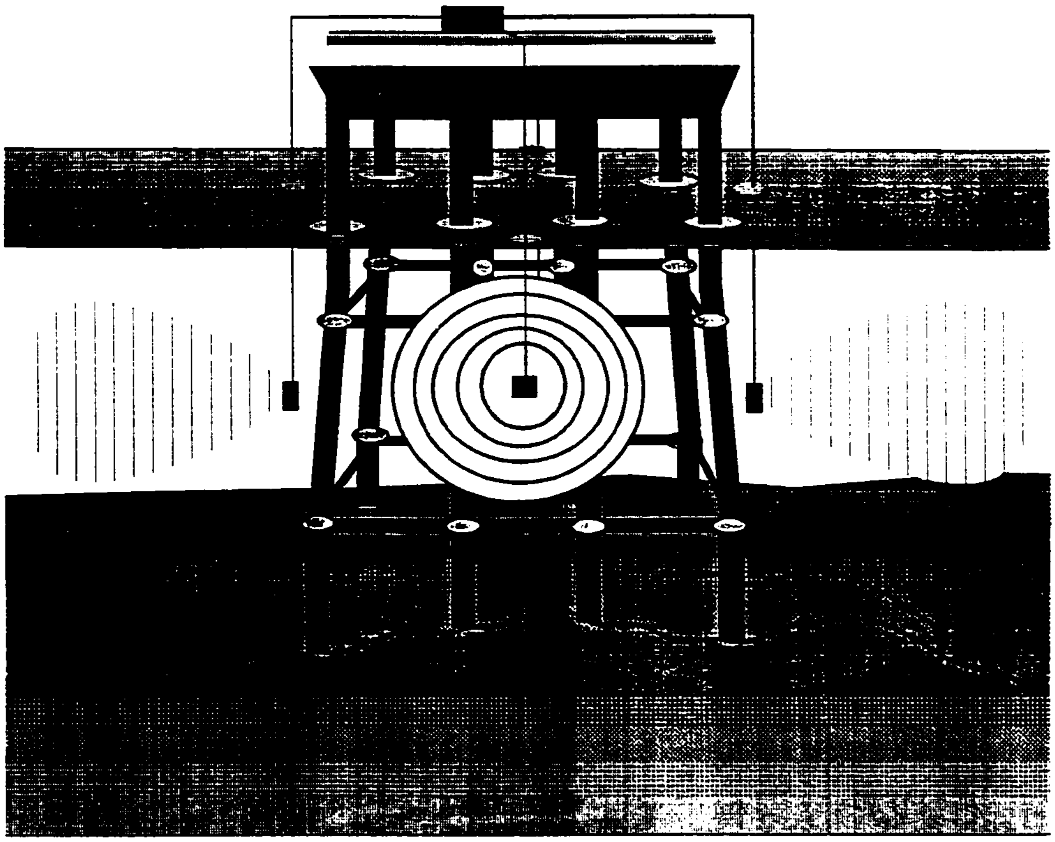

Figure 1.2. Schematic view of stationary hydroacoustic transducer deployment to measure near-field density of fish associated with a petroleum platform in the northern Gulf of Mexico.

ranging from 30 seconds to 15 minutes, in 30 second increments, at the study site revealed that the variances of density estimates were not significantly different after a sample duration of five minutes (Gary Johnson, Biosonics, personal communication). Therefore five minutes was used as the duration of an individual sample and 6 five minute samples were collected for each transducer for each time period.

Acoustic data were collected with a Biosonics model 102 echosounder, Biosonics multiplexer equalizer and Biosonics model 111 thermal chart recorder. Two 120 kHz dual-beam transducers (7°, 18° beam widths), and two 420 kHz dual-beam transducers (7°, 15° beam widths) were used to measure size distribution and fish abundance. Source levels ranged from 216.5 to 219.6 dB//1volt/uPa varying with transducer. System gains ranged from -178.1 to -184.0 dB and -178.0 to -184.4 dB for 20 log R and 40 log R depending on the transducer. Echosounder transmit power was 0 dB for 120 kHz transducers and -6 dB for 420 kHz transducers. Received acoustic signals (0.4 ms pulse width generated at 10 sec^{-1} for Array 1 and 5 sec^{-1} for Array 2) were amplified at 40 log R time varied gain, digitized, and recorded on digital audio tape. Reference voltages (approximately 5v AC) were recorded on each DAT tape and were used to calibrate the acoustical software prior to echo integration and target strength analyses. During data collection, background noise levels were measured at approximately 20 mV at 21 m for Array 1 and 40 mV at 72 m for Array 2. The voltage threshold used in later analyses was 100 mV, corresponding to a minimum detectable target strength of -56 dB.

The hydroacoustic system was calibrated during each research trip with tungsten carbide reference spheres (Foote and MacLennan 1984). Reference targets were suspended approximately 8 m below each transducer and their measured target strengths were compared with reference values to provide system calibration.

Digitized hydroacoustic data were processed with a Biosonics 281 dual-beam processor and software; target strengths and an average backscattering cross section (σ) for each horizontal and vertical strata were then estimated using Biosonics TS software (version 2.04). Echo integration of digitized hydroacoustic data was undertaken with a Biosonics 281 echo integrator and absolute density estimates were calculated using Biosonics Crunch software (version 2.01) and the σ for each strata. Fish densities were calculated in 2 m depth vertical strata for Array 1 and in 7 m horizontal strata for Array 2 for each transducer and sample based on software criteria. Target strength distributions were calculated in 2 m vertical depth strata for Array 1 for each transducer and sample. Target strength results were not calculated from Array 2 as the target strength relationship is valid only for dorso-ventral and not horizontal insonification of fishes.

Data Analysis

Fish density data (number of fish/m^3) from echo integration analysis contained a large number of zero values, similar to catch data from more common fisheries sampling techniques (Pennington 1983, 1985; Shaw et al. 1985; Stanley and Wilson 1990). Therefore, hydroacoustic density data from

both Arrays 1 and 2 were transformed by log(density + 1) to approximate the normal distribution.

Separate randomized block ANOVAs using SAS (1986) GLM procedures were performed with vertical target strength data, log(density + 1) of vertical density data and horizontal log(density + 1) density data. Separate randomized block ANOVAs were performed with depth, distance from the platform, time of day, month and their interactions, blocking on side of the platform to examine differences due to these variables. The interaction term platform side * month * time of day * depth was used as the experimental error term to test all other main effects and interactions. This approach was employed because of the large number of observations (10 depth strata by six samples per transducer per time period). Tukey's studentized range tests (Ott 1982) were used to compare the means of significant main effect terms for vertical and horizontal analyses. Tests are reported as significant at alpha $\leq$ 0.01 unless otherwise stated.

Results

Vertical Density Distribution

Densities of fishes larger than -56 dB (approximately 2.5 cm) around WC 352 ranged from 0 to 1.88 fish/m^3 during the study. Density varied significantly with side of platform, month and the time of day * month interaction based on the randomized block ANOVA (Table 1.1). While fish densities were not significantly different at the 1% level of significance for depth, the probability of a greater F was 0.0294 and could not be easily dismissed. Temporally, fish densities were significantly higher in November than in September and October,

Table 1.1. Randomized block analysis of variance (block on platform side) results of fish density (log (number of fish/m^3 + 1)) around a petroleum platform to determine the effects of platform side, month, time of day, water depth and their interactions.

Dependent variable: log (fish density + 1)

Source	D.F.	SS	MS	F	Prob
Model	375	16.3477	0.4360	6.97	0.001
Error	1917	11.9843	0.0063		
Total	2293	28.3320		$r^2 = 0.58$	

Source	D.F.	Type III SS	MS	F	Pr>F
Platform side	3	1.7481	0.5829	18.85	0.0001
Month	2	0.7062	0.3531	11.42	0.0001
TOD [(1)]	3	0.1926	0.0642	2.08	0.1038
Depth	8	0.5387	0.0673	2.18	0.0294
Month*TOD	6	1.0845	0.1808	5.85	0.0001
Month*Depth	16	1.0783	0.0674	2.18	0.0610
TOD*Depth	24	0.6897	0.0287	0.93	0.5618
Month*TOD*Depth	48	1.3581	0.0283	0.92	0.6345

[(1)] Time of Day

whereas September and October densities were not significantly different (Table 1.2). A plot of density by month and time of day revealed that densities were highest at noon and lowest at midnight during November and October, and highest at midnight and lowest at noon in September (Figure 1.3).

Spatial density distributions varied significantly with depth and platform side. In the vertical dimension, densities of fishes from 2 to 12 m were significantly higher than densities from 18 to 20 m, but otherwise did not vary with depth (Table 1.3). Mean fish density varied significantly with side of the platform. Significantly higher densities were detected on the west side when compared with all other sides of the platform, and densities were significantly higher on the south side than the east, but otherwise were not significantly different (Table 1.2).

Horizontal Density Distribution

The platform had a near-field effect on fish density as horizontal densities were approximately 5 to 8 times higher in the 2 to 9 m strata than in any other strata (Table 1.4). Based on a randomized block ANOVA, only side of the platform, distance from the platform and the distance*month interaction significantly affected horizontal fish density (Table 1.5). While platform side was not significant at the 1% level, the probability of a greater F value was 0.0177 and therefore was included as a significant variable. Horizontal fish density only varied spatially, with distance from the platform and side of the

Table 1.2. Mean fish density (number of fish/m^3) and 95% CL for each side of the platform and month at a petroleum platform in the northern Gulf of Mexico. Tukey's studentized means test results by month and side of the platform.

Month	Fish Density (number fish/m^3) (95% CL)					Tukey's [1] Means Test for Month
	Platform side				Mean Month	
	North	West	South	East		
September	0.052 (0.021)	0.096 (0.045)	0.062 (0.021)	0.022 (0.009)	0.058 (0.004)	B
October	0.035 (0.020)	0.093 (0.058)	0.040 (0.017)	0.034 (0.013)	0.051 (0.005)	B
November	0.046 (0.031)	0.203 (0.053)	0.091 (0.042)	0.319 (0.053)	0.112 (0.007)	A
Mean Side	0.044 (0.004)	0.139 (0.008)	0.066 (0.005)	0.031 (0.003)		
Tukey's Means Test for Side	B C	A	B	C		

[1] Means with the same letter are not significantly different at the 1% level.

Table 1.3. Mean density (number of fish/m^3) of fishes and 95% CL for depth strata at a petroleum platform in the northern Gulf of Mexico. Tukey's studentized means test results by depth strata.

Depth Strata (m)	Fish Density (95% CL) (number fish/m^3)	Tukey's Means Test [1]	
2 - 4	0.073 (0.010)	A	
4 - 6	0.078 (0.007)	A	
6 - 8	0.082 (0.007)	A	
8 - 10	0.085 (0.007)	A	
10 - 12	0.099 (0.010)	A	
12 - 14	0.085 (0.010)	A	B
14 - 16	0.071 (0.011)	A	B
16 - 18	0.046 (0.007)	A	B
18 - 20	0.027 (0.010)		B

[1] Means with the same letter are not significantly different at the 5% level.

Table 1.4. Horizontal density (number of fish/m^3) of fishes with 95% CL for each side of a petroleum platform in the northern Gulf of Mexico from 2 to 72 m in 7 m strata. Tukey's studentized means test results by distance strata.

Distance (m)	Horizontal Mean Fish Density (95% CL) (number fish/m^3)	Tukey's Means Test [1]
2 - 9	0.058 (0.014)	A
9 - 16	0.019 (0.003)	B
16 - 23	0.023 (0.002)	B
23 - 30	0.021 (0.002)	B
30 - 37	0.022 (0.002)	B
37 - 44	0.022 (0.002)	B
44 - 51	0.016 (0.002)	B
51 - 58	0.016 (0.002)	B
58 - 65	0.019 (0.002)	B
65 - 72	0.015 (0.002)	B

[1] Means with the same letter are not significantly different at the 1% level.

Table 1.5. Randomized block analysis of variance (block on platform side) results of horizontal log fish density (log (number of fish/m^3 + 1)) around a petroleum platform to determine the effects of platform side, month, time of day, distance and their interactions.

Dependent variable: log (density + 1)

Source	D.F.	SS	MS	F	Prob
Model	92	1.9729	0.0214	21.40	0.0001
Error	1927	1.9517	0.0010		
Total	2019	3.9246		$r^2 = 0.50$	

Source	D.F.	Type III SS	MS	F	Pr>F
Platform side	3	0.0532	0.0177	3.43	0.0177
Month	2	0.0270	0.0135	2.61	0.0754
TOD [1]	3	0.0108	0.0036	0.70	0.5534
Distance	9	0.1343	0.01492	2.89	0.0029
Month*TOD	3	0.0106	0.0035	0.68	0.5645
Distance*Month	18	0.2359	0.0131	2.54	0.0007
Distance*TOD	27	0.1381	0.0051	0.99	0.4830
Month*TOD*Distance	27	0.0938	0.0035	0.67	0.8909

[1] Time of Day

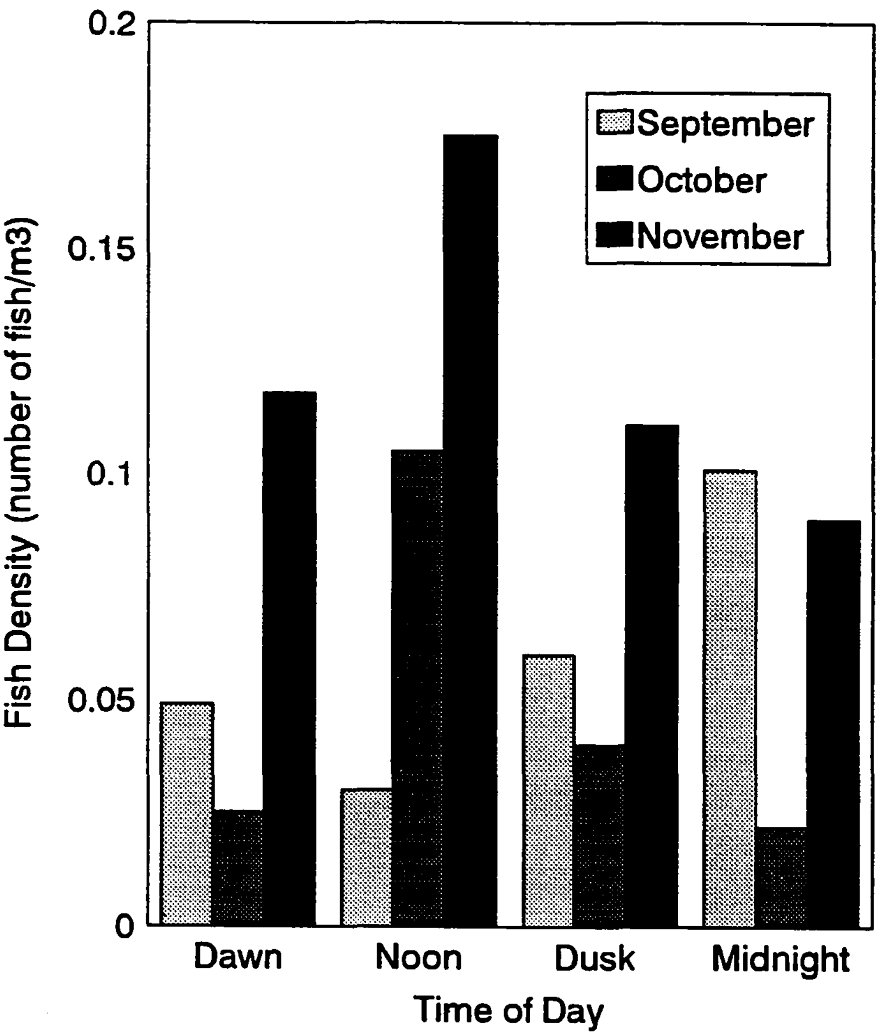

Figure 1.3. Density distribution of fishes (number of fish/m^3) by time of day for September, October and November at a petroleum platform in the northern Gulf of Mexico.

platform. Temporally, horizontal fish density did not vary as the main effect terms of month and time of day were not significant.

Horizontal fish density decreased with distance from the platform (Table 1.4). Based on Tukey's means tests, fish densities were significantly greater from 2 m to 9 m than for all other horizontal strata examined. Horizontal fish densities were not significantly different from 9 m to 72 m (Table 1.4). Therefore the near-field effect of the platform was estimated to be 9 m, as densities were significantly lower beyond this distance.

The total number of fish around the platform was estimated with mean vertical fish density values for each side of the platform, and extrapolated to 9 m (the estimated near-field area of influence away from the platform) for each month. Fish densities in the center of the platform were not directly measured and were estimated by averaging the fish density estimates of the four sides of the platform. Total number of fish associated with the platform was calculated by multiplying the mean number of fish/m^3 per side for each month by the volume of water on each side and adding that to the mean estimated number of fish/m^3 in the center for each month by the volume in the center of the platform. The estimated number of fish around the platform ranged from 2,417 in October to 8,329 in November (Table 1.6). The total number of fish at the platform was highly variable as November's estimate was over three times higher than those of earlier months (Table 1.6).

Table 1.6. Estimates of the number of fishes and 95% confidence limits for each side and center of a petroleum platform in the northern Gulf of Mexico by month.

Platform Side	Number of fish (95% CL)		
	September	October	November
North	282.0 (33.4)	188.8 (32.1)	245.8 (39.1)
West	949.2 (127.7)	926.8 (160.3)	2002.5 (128.7)
South	340.1 (23.4)	215.5 (26.7)	490.5 (60.7)
East	218.5 (25.8)	335.4 (37.8)	3151.3 (1056.2)
Center	864.6 (2263)	750.8 (214.3)	2438.8 (907.6)
Total	2654.4 (436.6)	2417.3 (471.2)	8328.9 (2192.3)

Target Strength

Target strength values ranged from -56 to -24 dB during the study and varied spatially and temporally. A randomized block design ANOVA, with platform side as a block, was used to examine differences between months, time of day, depth and their interactions (Table 1.7). Mean target strengths were significantly different between months and platform side.

Temporally, mean target strengths were highest in October (-34.3 dB), and November target strengths (-37.5 dB) were significantly higher than those measured in September (-39.4 dB) (Table 1.8). Target strength did not vary over any 24 hour period, indicating that both time of day and the interaction of time of day*month were not significant (Table 1.8).

Target strength varied spatially; mean target strengths were significantly different with side of the platform (Table 1.8). Target strength was highest on the south side of the platform and lowest on the east side (Table 1.8). Target strength did not vary significantly with water depth (Table 1.7).

Discussion

A primary objective of this research was to determine if stationary dual-beam hydroacoustics could be used to estimate abundance and size distribution, and describe the behavioral patterns of fishes associated with a petroleum platform. At WC 352 the low acoustic background noise level provided an environment that easily allowed the resolution of targets to -56 dB, corresponding to a fish of 2 cm total length (Love 1971). With low acoustical background levels and the use of transducer arrays, target strength distribution,

Table 1.7. Randomized block analysis of variance (block on platform side) results of target strength (dB) of fishes associated with a petroleum platform to determine the effects of platform side, month, time of day, water depth and their interactions.

Dependent variable: Target Strength (dB)

Source	D.F.	SS	MS	F	Prob
Model	347	72773.90	209.72	17.89	0.0001
Error	1448	16976.33	11.72		
Total	1795	89750.23		r^2 = 0.81	

Source	D.F.	Type III SS	MS	F	Prob
Platform side	3	17891.67	593.89	48.53	0.0001
Month	2	5256.84	2628.42	21.39	0.0001
TOD [(1)]	3	2423.49	807.83	6.57	0.67
Depth	8	717.27	89.66	0.73	0.67
Month*TOD	6	1270.05	211.68	1.72	0.12
Month*Depth	16	955.65	59.73	0.49	0.95
TOD*Depth	24	1698.68	70.78	0.58	0.95
Month*TOD*Depth	48	1707.96	35.58	0.29	1.00

[(1)] Time of Day

Table 1.8. Mean target strengths (dB) and estimated total lengths (cm) of fishes with standard deviations for each month and side of a petroleum platform. Tukey's studentized means test results of target strength for each month and side of the platform.

Month	Platform Side								Mean Month		Tukey's [1] Means Test for Month
	North		West		South		East				
	TS[2] (SD)	TL[3] (SD)	TS (SD)	TL (SD)	TS (SD)	TL (SD)	TS (SD)	TL (SD)	TS (SD)	TL (SD)	
September	-43.7 (5.2)	13.9 (9.4)	-39.2 (3.4)	21.9 (8.3)	-30.0 (5.4)	59.3 (27.4)	-43.0 (3.1)	12.4 (5.6)	-39.4 (6.9)	24.5 (21.6)	C
October	-34.7 (6.8)	38.3 (26.3)	-34.4 (5.8)	36.6 (25.0)	-29.5 (6.5)	60.7 (27.1)	-39.7 (4.2)	21.9 (14.0)	-34.3 (6.9)	38.3 (25.9)	A
November	-40.7 (5.2)	19.6 (12.6)	-37.2 (6.2)	29.2 (22.9)	-34.2 (6.7)	45.1 (24.0)	-37.4 (6.5)	29.0 (26.7)	-37.5 (6.6)	30.8 (22.8)	B
Mean Side	-40.4 (6.4)	21.3 (17.9)	-37.0 (5.8)	30.2 (21.7)	-31.6 (6.7)	50.9 (25.5)	-41.6 (4.0)	17.4 (10.7)			
Tukey's Means Test for Side	C		B		A		D				

[1] Means with the same letter are not significantly different at the 1% level of significance.
[2] Target strength (dB) with (standard deviation)
[3] Total length(cm) with (standard deviation), estimated from the relationship
$TL = 10^{((TS-2.36092-67)/19.1)}$ derived by Love (1971).

absolute abundance estimates and near-field area of influence could be described with dual-beam hydroacoustics. Target resolution was possible to within 1 m of the sea floor and sea surface, allowing operation in seas of up to 2 m.

There are few studies documenting fishes associated with petroleum platforms (Gallaway 1980; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982; Stanley and Wilson 1990). The scarcity of studies on petroleum platform assemblages is primarily due to the difficulty of quantitatively sampling associated nekton. Impediments to sampling include water depth, low visibility, and the complex architecture and construction of petroleum platforms. Continental Shelf Associates (1982) concluded, after comparisons of visual surveys by fixed cameras, ROVs and SCUBA divers, that these methods were limited in their effectiveness in the northern Gulf of Mexico due to low visibility conditions, diver/ROV avoidance by fish and depth limitations of divers.

Fish populations near reefs, both natural and artificial, are highly variable with respect to time. Variations in abundance are the result of many factors which include, but are not limited to, competition, seasonality, physical perturbation, ontogenetic changes, predation, recruitment, emigration and immigration (see reviews by Sale 1990; Bohnsak et al. 1991; Sale 1991). Reefs are thought to be open nonequilibrial systems with their occupants constantly changing (Sale 1991). Population estimates often vary by an order of magnitude over monthly surveys (Sale 1990; Bohnsak et al. 1991; Sale 1991). The results from this study and from other long-term petroleum platform monitoring (Putt 1982; Stanley and Wilson 1990), indicate that fish populations near petroleum

platforms follow the nonequilibrial hypothesis. Large changes in abundance over time are often driven by density independent factors (e.g., physical perturbation, emigration and/or immigration), whereas density dependent factors (e.g., competition, predation) are usually manifested in less dramatic variations (Bohnsak et al. 1991).

Although abundance and size varied between months, no changes in abundance or mean size over any 24 hour periods were detected. This implies that density independent factors driving the variations in fish abundance were operating at time scales greater than 24 hours. Also, there was little of the short-term movement or visual attraction to the platform as reported by other researchers at artificial reefs (Putt 1982; Grove and Sonu 1983). Diel differences in abundance have been reported on natural reefs, with lowest abundance near the reef at night (Thorne et al. 1989). Putt (1982) detected lower abundances in the morning than during other daylight hours at a petroleum platform; however, because of the visual sampling methods used densities were not measured at night.

Previous research has alluded to, but not documented, the near-field effect of habitat on fish distribution (Continental Shelf Associates 1982; Putt 1982). Using towed hydroacoustics, Gerlotto et al. (1989) described relative fish densities within 10 m of a petroleum platform in the African coastal waters off Cameroon as at least 5 times higher than those 50 m from the platform. Continental Shelf Associates (1982) reported that video cameras placed 8 and 23 m from petroleum platforms in the northern Gulf of Mexico detected fewer

fish than those placed on the platform. Gerlotto et al.'s (1989) use of towed hydroacoustics to examine the abundance of fish associated with a petroleum platform near Cameroon, although useful in documenting the abundance of fish over large areas, does not provide the fine scale spatial and temporal resolution of a stationary array. In addition, there is a possible bias due to boat avoidance and lack of samples close to the transducer in mobile studies (Olsen et al. 1983; Ona and Godo 1990). Neither of these studies provides a continuous measure away from the reef and both may be biased due to boat avoidance and limited visibility. Density estimates sampled from 2 to 72 m away from WC 352 with horizontally oriented transducers revealed that the platform had an area of influence of 9 m on each side and that fish density decreased significantly beyond this distance. Stationary hydroacoustics has another advantage over towed hydroacoustics in that multiple transducers can be deployed allowing for synoptic sampling. It is unobtrusive with little or no influence on fish behavior and has better discrimination in separating targets from boundaries (i.e., sea floor or surface) (Thorne 1983; MacLennan and Simmonds 1992). Results of this study demonstrate the utility of an array of stationary hydroacoustics to estimate the abundance and mean target strength of fishes associated with a platform. A large number of samples could be collected, and data collection was not limited by visibility so sampling could occur at night and under other low light conditions. Because hydroacoustics is an unobtrusive sampling method, data were not biased due to gear avoidance.

Comparison of results at WC 352 with other platform studies revealed similar patterns with respect to high variability in abundance estimates from month to month as opposed to over shorter 24 hour periods (Putt 1982). Surveys by Continental Shelf Associates (1982) at platforms of similar configuration and water depth to WC 352 displayed a wide variation in abundance estimates. Some of the variation may be due to the lack of obligate reef species associated with platforms in the northern Gulf of Mexico (e.g., Pomadasyidae, Pomacentridae, Chaetodontidae). Species associated with petroleum platforms may utilize the habitat for protection, spawning or feeding in the area and leave once local resources are depleted. Other dissimilarities between this and other platform surveys may result from differences in time of year and geographical area. Putt's (1982) use of a fixed stationary camera with a limited viewing area may have overestimated the abundance of some species by counting them on multiple occasions; also a concern of hydroacoustics. However, the use of mean density estimates calculated by the echo integration software over the entire sample period minimized the effect of multiple counts (D. Thorne, Biosonics, personal communication).

Mean target strengths were uniform with depth, and density was only significantly different near the bottom. This is of consequence as many researchers (Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982) have speculated that fish density decreased or species composition varied within the low visibility nephloid layers that are common in the northern Gulf of Mexico. Since hydroacoustics are unaffected by low visibility conditions

and visual surveys are severely biased when visibility decreases below 2 m (Bohnsak and Bannerot 1986), the uniformity of fish density and target strengths with depth suggests that the assemblage did not change due to low visibility, and that visual surveys may severely underestimate fish abundance in these conditions.

Overall measurement of abundance and target strength distribution utilizing dual-beam acoustics at petroleum platforms confirmed that fish assemblages at these artificial reefs are in a state of nonequilibrium, with large fluctuations in abundance and mean target strength. Abundance estimates derived from acoustics were higher than those of past assessments, likely a consequence of the inherent bias of visual surveys due to low visibility and diver/ROV avoidance by fishes. Hydroacoustics does not possess these biases and because of its non-destructive and unobtrusive nature, hydroacoustic sampling may provide a more accurate measure of size distribution, behavior and density.

CHAPTER II

DETECTION OF THE EFFECT OF SCUBA DIVERS ON FISH DENSITY AND TARGET STRENGTH UTILIZING STATIONARY DUAL-BEAM HYDROACOUSTICS

Introduction

SCUBA divers are frequently employed to enumerate fish associated with reefs (both natural and artificial), and fish inhabiting freshwater lakes, streams and other environments. Common visual survey techniques include transects, point counts and species/time random counts. These procedures provide estimates of the number of organisms, species composition and range of size classes, and have been used on pelagic, demersal and cryptic species. There have been several reviews on the evolution of visual survey methodology with emphasis on data analysis, standardization and the limitations of visual assessment techniques (Heffman 1983; Bortone and Kimmel 1991; Gunderson 1993).

As with all sampling techniques, there are shortcomings and biases associated with visual surveys. Limited survey time, depth restrictions, poor visibility (at night or under low visibility conditions), observer variability, low accuracy in enumerating migratory and cryptic species and difficulty in accurately counting and identifying large number of species and individuals simultaneously are documented limitations of visual surveys (Heffman 1983; Greene and Alvezion 1989; Gunderson 1993). Visual estimates have also been compared to other fishery sampling methods to examine sources of bias in the data collected by SCUBA divers (Sale and Douglas 1981; Barans and Bortone 1983; Thresher and Gunn 1986; Greene and Alvezion 1989; St. John et al. 1990; Dibble 1991). General conclusions from comparisons with other sampling

methods are that visual assessments underestimate abundance and species richness.

The effect of SCUBA diver presence on fish density and size distribution has not been directly examined. If the presence of SCUBA divers modifies fish behavior, then the attraction and/or avoidance response of fishes to SCUBA divers could bias visual surveys. Recent advances in the use of stationary dual-beam hydroacoustics have shown it to be an unobtrusive, non-destructive sampling methodology that may serve as a tool to evaluate the effect of SCUBA divers on fish density and size distribution. Dual-beam hydroacoustics has been used to track migrations of fish in hydroelectric facilities, lakes, rivers, estuaries and near artificial reefs (Thorne 1983; Thorne et al. 1989; MacLennan and Simmonds 1992).

The purpose of this research was to use dual-beam hydroacoustics to determine if the presence of SCUBA divers affected density and target strength distribution of fish near a petroleum platform in the northern Gulf of Mexico. To examine this question a study was designed to test the hypothesis that fish density and size distribution near a petroleum platform were not altered by the presence of two SCUBA divers conducting visual point count surveys.

Methods

The experiment was conducted at an oil and gas platform off the Louisiana coast, located at 28° 59.35' N, 93° 30.35' W, approximately 80 km south of Cameron, Louisiana, in 22 m of water. A downward oriented transducer (420 kHz) suspended at the surface was used to measure density

(number of fish/m^3) and target strength (dB) of fishes on the west side of the platform. The transducer provided acoustic coverage sufficient to describe the target strength distribution and density of fish from 2 m below the transducer to 0.5 m above the bottom (Figure 2.1). Visibility during the experiment ranged from less than 1 m to over 15 m, and varied with depth and sample period.

Four research trips were conducted during November 1991 and February, March and June 1992. Sampling consisted of first collecting sixty minutes of control data without SCUBA divers present in the water. After this period, 2 SCUBA divers entered the water and swam to the bottom on the west side of the platform at the edge of the acoustic cone while acoustic data continued to be collected (Figure 2.1). Dive duration for the SCUBA divers varied from 25 to 40 minutes depending on sample period. Data collected during control and diver samples were later analyzed in five minute time intervals providing mean density and target strength distribution for each interval.

Acoustic data were collected using Biosonics equipment including a model 102 scientific echosounder, model 111 thermal chart recorder and 420 kHz dual-beam transducer (7°, 15° beam widths). The source level was 216.5 dB//1volt/*u*Pa at 1 m, system gains were -178.1 and -184.0 dB for 20 log R and 40 log R, pulse width was 0.4 ms, transmit power was -6 dB, receiver gain was 0 dB and ping rate was 10 sec^{-1}. The hydroacoustic data were adjusted for spreading loss by applying a 40 log R time varied gain. Data were digitized and recorded on digital audio tape with a Sony DTC-1000 digital audio tape (DAT) recorder through a Biosonics model 171 tape recorder interface. On each

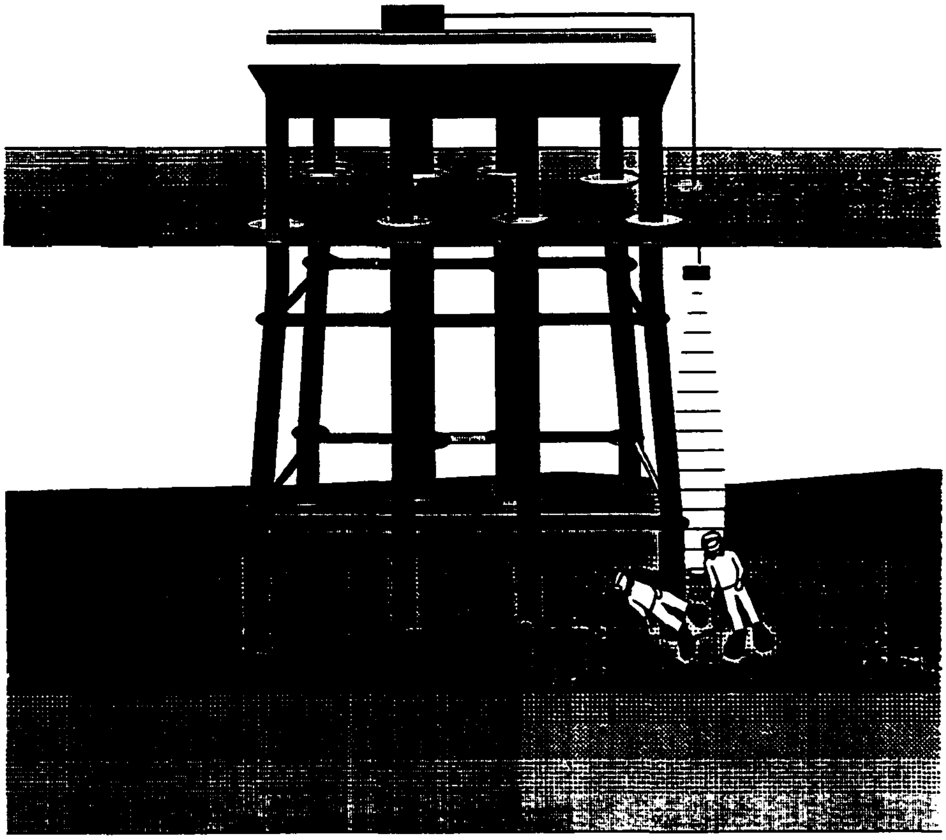

Figure 2.1. Schematic view of the transducer deployment to acoustically sample fish associated with a petroleum platform in the northern Gulf of Mexico. Note the presence of SCUBA divers. Diagram not to scale.

sampling trip the hydroacoustic system was calibrated with a tungsten carbide reference sphere and compared with reference values to ensure system calibration (Foote and MacLennan 1984). Reference voltages (approximately 5v AC) were recorded on each DAT tape and used to calibrate the signal prior to echo integration and target strength analysis. Background noise levels were measured at approximately 20 mV and the voltage threshold used in later analysis was 100 mV, corresponding to a minimum detectable target strength of -56 dB.

Due to the possibility of correlation between adjacent samples a repeated measures ANOVA with SAS (1986) GLM procedures was used to examine for differences in target strength and fish density between diver present and control samples. Greenhouse-Geisser degrees of freedom adjustment within the repeated measures ANOVA was utilized as the covariance matrix may not have been constant (Steel and Torrie 1980). Differences between target strength distributions of SCUBA diver present and control samples were performed with a Chi-squared test (SAS 1986).

Results and Discussion

Stationary hydroacoustics is an unobtrusive sampling technique that is easily adapted to sampling fish density and size distribution adjacent to petroleum platforms. It is non-destructive and undetectable by fish and therefore does not affect fish behavior. Due to the low background noise levels at petroleum platforms and the relatively favorable meteorological conditions in

the northern Gulf of Mexico, dual-beam hydroacoustics is a suitable technique for estimating fish density and target strength distribution in this environment.

The introduction of SCUBA divers caused a dramatic reduction in fish density as measured by dual-beam hydroacoustics. SCUBA diver presence caused a highly significant decrease in fish density when compared with control samples ($P < 0.01$) (Table 2.1). Results were consistent during all four sampling periods; the average reduction in fish density was 60.2% with a range from 41.1% to 76.5% (Table 2.2). The decrease in density occurred immediately with the entrance of SCUBA divers and continued while they were in the water. Target strength of insonified fish also decreased significantly between control and diver present samples ($P < 0.02$) (Table 2.3). Target strength distributions were significantly different with SCUBA divers present ($X^2 = 6654$, df = 16, $P < 0.001$). Larger fish were present during the control period as mean target strength declined from 0.5% to 9.1% when divers were present (Table 2.4). Examination of the target strength distributions showed that while overall target strengths were larger without SCUBA divers, the difference occurred within the range of -43 to -37 dB targets, corresponding with total lengths approximately 12.4 to 25.5 cm based on equations by Love (1971) (Figure 2.2). Differences were also noted at smaller and larger target strengths but were most consistent at mid-range target strengths (Figure 2.2). The decrease in density and target strength suggests that fish, especially fishes from 12 to 26 cm, can detect SCUBA divers and that their response to this potential threat is to leave the area. The implication of these results suggests

Table 2.1. Repeated measures analysis of variance of the effect of SCUBA diver presence on log fish density (log (number of fish/m^3 + 1)) around a petroleum platform in the northern Gulf of Mexico.

Source	D.F.	Type III SS	MS	F	Prob>F
Diver	1	0.8327	0.8327	36.01	0.00011
Error	64	1.4801	0.0231		

Univariate Test of the Effect of Diver Present

Source	D.F.	Type III SS	MS	F	Prob>F	Adj. Prob.(1)
Diver*Sample (2)	8	0.42	0.052	18.37	0.0001	0.0001
Error (Sample)	512	1.458	0.003			

(1) Greenhouse-Geisser adjusted probability accounting for lack of constant covariance matrix structure
(2) Diver*Sample interaction

Table 2.2. Mean density (number of fish/m^3) and 95% confidence limits of fish associated with a petroleum platform without SCUBA divers (Control), with SCUBA divers (Diver), and the percent difference between the mean densities from November 1991, February, March and June 1992.

Month	Control	Diver	% Difference
November	0.090 (0.044)	0.053 (0.238)	-41.1
February	0.304 (0.061)	0.144 (0.220)	-52.6
March	0.567 (0.137)	0.133 (0.252)	-76.5
June	0.456 (0.113)	0.235 (0.366)	-48.5
Mean	0.354 (0.089)	0.141 (0.269)	-60.2

Table 2.3. Repeated measures analysis of variance of the effect of SCUBA diver presence on target strength (dB) of fishes associated with a petroleum platform in the northern Gulf of Mexico.

Source	D.F.	SS	MS	F	Prob>F
Diver	1	1545.7	1545.7	8.07	0.0065
Error	51	1.4801	0.0231		

Univariate Test of the Effect of Diver Present

Source	D.F.	SS	MS	F	Prob>F	Adj. Prob.[1]
Diver*Sample [2]	8	468.91	58.61	3.74	0.0003	0.017
Error (Sample)	408	6388.54	15.68			

[1] Greenhouse-Geisser adjusted probability accounting for lack of constant covariance matrix structure
[2] Diver*Sample interaction

Table 2.4. Mean target strength (dB) and 95% confidence limits of fish near a petroleum platform without SCUBA divers (Control), with SCUBA divers (Diver), and the percent difference between the mean target strengths from November 1991, February, March and June 1992.

Month	Control	Diver	% Difference
November	-42.3 (3.8)	-42.7 (2.9)	-0.9
February	-38.5 (4.3)	-39.1 (4.0)	-1.6
March	-41.0 (5.1)	-41.2 (4.4)	-0.5
June	-46.1 (7.7)	-50.3 (8.4)	-9.1
Mean	-42.0 (5.3)	-43.3 (4.9)	-3.0

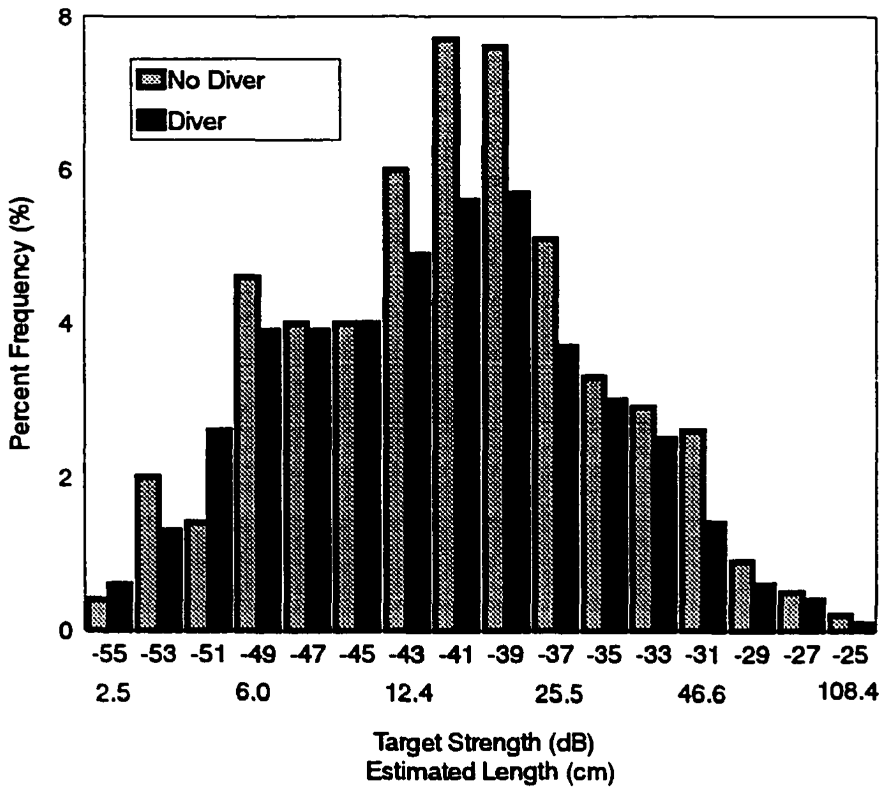

Figure 2.2. Target strength (dB) frequency and estimated total lengths (cm) of fishes with and without SCUBA diver presence at a petroleum platform in the northern Gulf of Mexico.

that the avoidance response of fishes to SCUBA divers may seriously bias visual assessments, and is especially important near petroleum platforms because the most abundant size classes exhibit the greatest avoidance behavior.

Previous researchers compared precision and limitations of visual assessments to other techniques (e.g., cove and reef rotenone, explosive sampling) and found that visual surveys consistently underestimated both species richness and abundance (Bortone and Kimmel 1991; Dibble 1991). Avoidance of survey vessels and experimental trawls is common behavior among many species of fish (Olsen et al. 1983; Ona and Godo 1990), however change in behavior of fishes in response to the presence of SCUBA divers had not previously been investigated. Our results provide direct evidence that fish exhibit avoidance behavior when SCUBA divers are present. Therefore the impact of SCUBA divers on density and size estimates from visual survey techniques should be determined as part of visual surveys whenever possible.

CHAPTER III

SEASONAL AND SPATIAL VARIATION IN THE ABUNDANCE AND SIZE DISTRIBUTION OF FISHES ASSOCIATED WITH A PETROLEUM PLATFORM IN THE NORTHERN GULF OF MEXICO

Introduction

Since the first petroleum platform was installed in the Gulf of Mexico, fishermen and scientists have been aware of their associated nekton assemblages. These petroleum platforms act as defacto artificial reefs; providing habitat which increases the growth and survival of individuals; affording shelter for protection from predation and spawning substrate; and acting as a visual attractant for organisms not trophically dependent on hard bottom (Gallaway et al. 1981; Continental Shelf Associates 1982; Bohnsak and Sutherland 1985; Bohnsak et al. 1991). To date 4,500 petroleum platforms have been placed in the northern Gulf of Mexico, providing an additional 5,000 km^2 of hard substrate to the approximately 2,600 km^2 of natural hard bottom. Unquestionably, the addition of these structures has been one the most extensive habitat modifications in the world, and while the impact of offshore structures on the environment is well documented with respect to discharge of materials and bioaccumulation (Boesch and Rabalais 1987; Avanti 1991), the effect of the habitat modification and its impact on the marine fisheries in the northern Gulf of Mexico has not been measured.

The mechanisms and processes which lead to an increased abundance of fishes near artificial reefs, relative to adjacent environments, are poorly understood (Grove and Sonu 1983; Bohnsak 1989), and will remain difficult to document without standardized fisheries independent sampling methods. This problem is evident in previous research examining abundance and composition of fish assemblages surrounding petroleum platforms (Sonnier et al. 1976;

Gallaway 1980; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982; Stanley and Wilson 1990,1991). These studies used a variety of methodologies including visual surveys by SCUBA divers, remotely operated underwater vehicles (ROVs), fixed underwater cameras, as well as catch per unit effort studies utilizing fish traps and hook and line surveys. The majority of the research to date has been short term, often only a "snapshot" of the abundance and composition of fishes associated with platforms at a single point in time. One goal of many of these previous studies was to quantify abundance of fishes, but by their author's admissions, many problems were encountered in sampling technique including diver avoidance, limited visibility, and the effect of hook and line and trap selectivity.

The complex architecture of platforms, and water depths and low visibility commonly associated with these structures, has made censuring associated fish populations exceedingly difficult. Because of this, few long-term studies of fishes associated with platforms have been undertaken. The first study to encompass a longer time scale utilized an array of 8 mm movie cameras to census the fishes at a platform from July through September (Putt 1982). Putt found that abundance and species composition varied over this relatively short time period. Stanley and Wilson (1990, 1991) used recreational and charter boat sport fishing catches at petroleum platforms to characterize the fish community and catch rates of the associated fishes. They found changes in catch rates dependant on season, size of the platform and water depth. Unfortunately, abundance and species composition estimates of the various

methodologies cannot be directly compared due to individual gear biases and lack of standardization.

The spatial heterogeneity of natural and artificial reefs have limited the use of traditional fisheries gears in evaluating associated fish populations, making visual survey techniques the method of choice for fisheries assessments in these environments (Bortone and Kimmel 1991). However, the presence of SCUBA divers, and possibly ROVs, can bias density and species composition estimates, and in low visibility conditions visual surveys can underestimate abundance and species composition (Sale and Douglas 1981; Brock 1982; Bohnsak and Bannerot 1986; see Chapter 2). As an alternative to visual surveys Gerlotto et al. (1989) demonstrated that towed hydroacoustics could be used to determine relative densities of fish at a petroleum platform off Cameroon. Chapter 1 revealed additional advantages of stationary dual-beam hydroacoustics as a sampling technique in estimating absolute abundance and target strength distribution of fishes. One drawback with the use of hydroacoustics is the lack of species composition data and biological information.

In response to the complex architecture of petroleum platforms and poor environmental conditions (i.e., rough seas and poor visibility) common in the northern Gulf of Mexico and the difficulty of estimating abundance with traditional fisheries and visual survey techniques, a combination of stationary dual-beam hydroacoustics and visual surveys was used to sample composition of fishes associated with a petroleum platform. The use of two techniques takes advantage of both methods; hydroacoustics provides precise and accurate

estimates of species composition, absolute abundance and size distribution, while the visual point count surveys provide species identification and qualitative species composition data. Hydroacoustics has an advantage not found in other reef survey techniques in that it can measure the near-field area of influence of the reef, to reflect the total area affected by the reef. Hydroacoustics is not affected by the poor visibility and nephloid layers common in the northern Gulf of Mexico, has the ability to sample at night, has target detection capabilities to macrozooplankton sizes and a greater range than do visual methods.

The objectives of this research were to use stationary dual-beam hydroacoustics in conjunction with visual point count surveys over a 15 month period to:

1) measure and compare species composition, biomass and target strength distribution of fishes associated with a petroleum structure,
2) determine the effect of environmental variables on abundance and target strength distribution of fish associated with the platform, and
3) define the spatial near-field influence of the platform on the abundance of fishes.

Specific hypotheses examined were:

1) The density and target strength distribution of fishes associated with a petroleum platform does not change with respect to side of the platform, time of day, month, depth, water temperature, current speed or direction.
2) The density of fishes from 2 to 72 m away from the platform does not

change with respect to distance from the platform, side of the platform, time of day or month.

Methods

Site Description

A stationary hydroacoustic survey was conducted at production petroleum platform designated WC 352, operated by Mobil Exploration and Production USA Inc. The platform is located at 28° 59.35' N, 93° 30.35' W, approximately 80 km south of Cameron, LA in 22 m of water. The platform is an eight leg steel template platform with eight active wells; is approximately 20 m wide and 45 m long at the waterline and encloses approximately 19,800 m^3 of water. The platform was installed in 1978, with the nearest platform located 14.5 km away.

Sampling Design

Stationary dual-beam hydroacoustic surveys were conducted monthly on the platform from January 1991 through May 1992, with the exceptions of February and May 1991 due to inclement weather and equipment failure, respectively.

Two arrays of stationary dual-beam hydroacoustic equipment were used. Array 1 was designed to measure the target strength distributions and density of fishes associated with the platform (Figure 3.1). It consisted of four vertically oriented transducers; two transducers (120 kHz) suspended at the surface facing downwards on the east and north sides of the platform; and two transducers (420 kHz) placed on the bottom oriented upwards, on the west and south sides

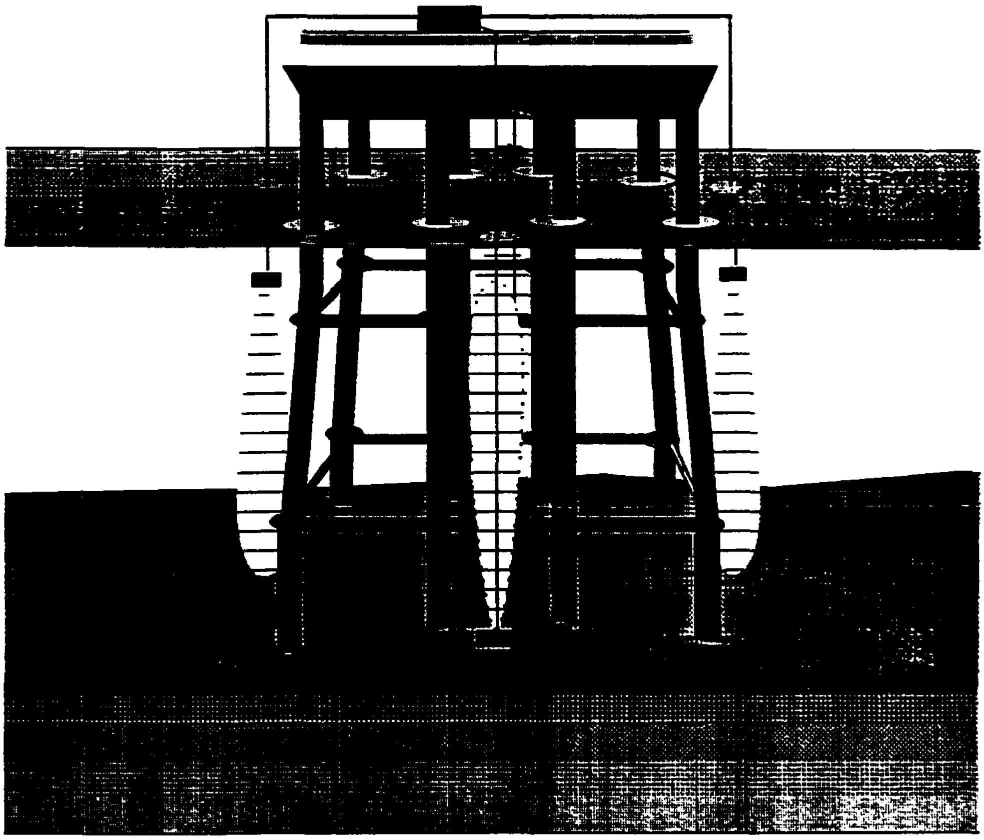

Figure 3.1. Schematic view of stationary hydroacoustic transducer deployment to measure target strength and density of fishes associated with a petroleum platform in the northern Gulf of Mexico.

of the platform. The downward facing transducers provided acoustic coverage sufficient to collect acoustic data from 2 m below the transducer to 1 m from the bottom. The two upward facing transducers provided acoustic data from 2 m above the bottom to 1 m from the surface. Use of both upward and downward oriented transducers enabled the calculation of density and target strength distributions in 2 m strata throughout the water column.

Array 2 estimated the near-field density of fishes associated with the structure (Figure 3.2). It consisted of four horizontally aligned transducers deployed off each side of the platform at a depth of 11 m; 120 kHz transducers on the east and north sides and 420 kHz transducers on the west and south sides. This arrangement allowed for estimates of relative density from 2 to 72 m away from the platform in 7 m intervals.

Horizontal and vertical sampling were carried out over consecutive 24 hour intervals for each month; two hours of hydroacoustic data were collected encompassing four time periods (dawn, noon, dusk and midnight) over each 24 hour interval. Hydroacoustic data were collected sequentially from each of the transducers in five minute intervals following random selection of the starting transducer for each month. Stationary hydroacoustics allows for the collection of many samples or "snapshots" of density and size distribution over time. Time allotted for an individual sample is dependent on the variance of fish density; and analysis of the variance of density estimates for sample times ranging from 30 seconds to 15 minutes in 30 second increments at the study site revealed that the variance of density estimates were not significantly different after a

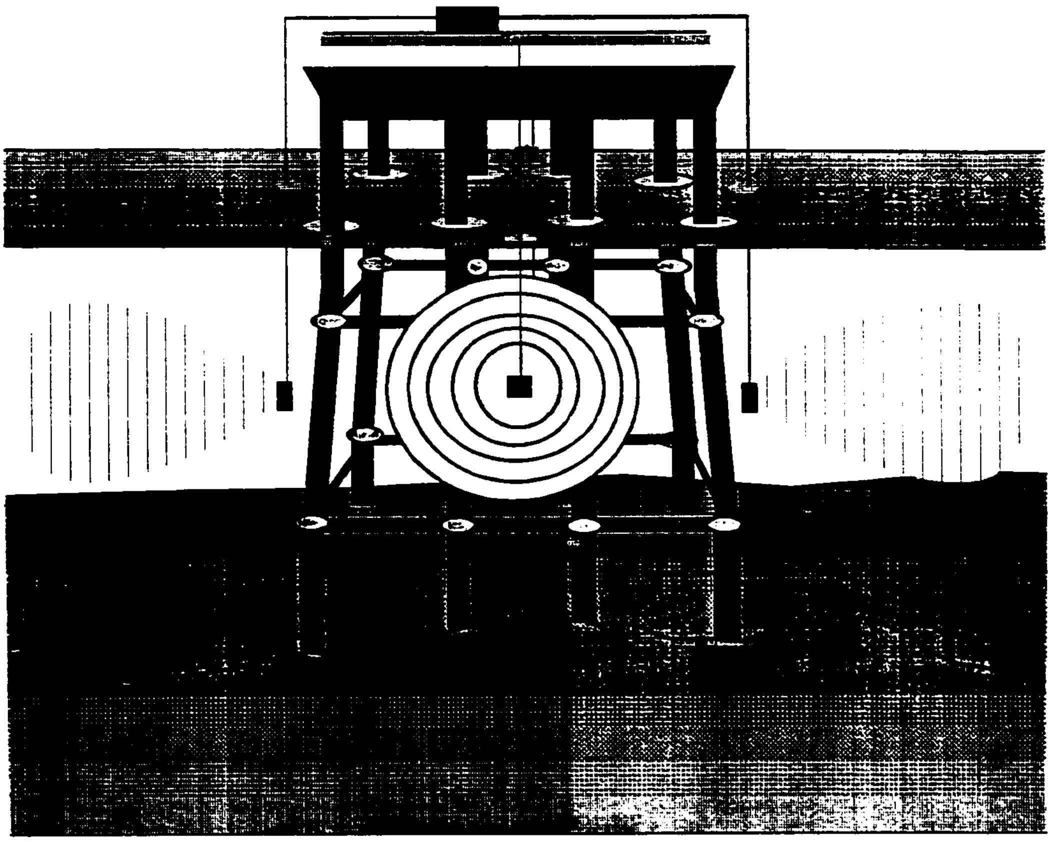

Figure 3.2. Schematic view of stationary hydroacoustic transducer deployment to measure near-field density of fishes associated with a petroleum platform in the northern Gulf of Mexico.

sample duration of five minutes (Gary Johnson, Biosonics, personal communication). Therefore five minutes was used as the duration of an individual sample, and 6 five minute samples were collected for each transducer over each time period.

Acoustic data were collected using a Biosonics model 102 echosounder, Biosonics multiplexer equalizer and Biosonics model 111 thermal chart recorder. Two 120 kHz dual-beam transducers (7°, 18° beam widths), and two 420 kHz dual-beam transducers (7°, 15° beam widths) were used to measure size distribution and density of fishes. Source levels ranged from 216.5 to 219.6 dB//1volt/*u*Pa varying with transducer. System gains ranged from -178.1 to -184.0 dB and -178.0 to -184.4 dB for 20 log R and 40 log R depending on the transducer. Echosounder transmit power was 0 dB for 120 kHz transducers and -6 dB for 420 kHz transducers. From January 1992 to May 1992 a Biosonics model ES2000 scientific echosounder/multiplexer-equalizer was substituted into the suite of equipment replacing the Biosonics model 102 scientific echosounder and multiplexer equalizer. The source levels ranged from 214.0 to 219.6 dB//1volt/*u*Pa depending on the transducer. The system gains for the narrow beam ranged from -182.3 to -147.3 dB and varied with transducer. The wide beam system gains ranged from -180.0 to -146.1 dB varying with transducer. Transmit power was 0 dB for 120 and 420 kHz transducers and the receiver gains were 10 dB for 420 kHz transducers and -10 dB for 120 kHz transducers. Received signals, 0.4 ms pulse width generated at 10 sec^{-1} for Array 1 and 5 sec^{-1} for Array 2, were amplified at 40 log R time varied gain, digitized and

recorded on digital audio tape. Reference voltages (approximately 5v AC) were recorded on each DAT tape and used to calibrate the acoustic system prior to echo integration and target strength analyses. During data collection background noise levels were measured at approximately 20 mV at 21 m for Array 1 and 40 mV at 72 m for Array 2. The voltage threshold used in later analyses was 100 mV corresponding to a minimum detectable target strength of -56 dB, or a fish of 2.5 cm total length according to Love (1971).

The hydroacoustic system was calibrated on each research trip with tungsten carbide reference spheres (Foote and MacLennan 1984). Reference targets were suspended approximately 8 m below the transducer and measured target strengths were compared with reference values to provide system calibration.

Digitized hydroacoustic data were processed by a Biosonics model 281 dual-beam processor, target strengths and an average backscattering cross section (σ) for each depth strata was then estimated using Biosonics TS software (version 2.04). Digitized hydroacoustic data were echointegrated with a Biosonics model 281 echo integrator and absolute density estimates were calculated using Biosonics Crunch software and the σ for each depth strata. Fish densities were calculated for 2 m depth vertical intervals for Array 1 and for 7 m horizontal strata for Array 2. Target strength distributions were calculated for 2 m vertical depth intervals for Array 1 for each transducer and sample. Target strength results were not calculated from Array 2 as target strength data is valid only for dorso-ventral and not horizontal insonification of fish.

During collection of vertical acoustic data an Interocean S4 current meter was suspended at a depth of approximately 10 m. The current meter collected current speed (± 0.2 cm/s), direction (± 0.5°) and temperature (± 0.1° C) every 10 minutes throughout the sample period.

Visual point count surveys identifying individual fish to species were performed on each sampling expedition, with the exception of January and December 1991 due to equipment difficulties. Visual point count surveys are a standard technique used for assessing abundance and species composition on both natural and artificial reefs (Bohnsak and Bannerot 1986). This technique has been used in numerous SCUBA diver, submersible and ROV surveys (Bohnsak and Bannerot 1986; Bortone et al. 1986, 1989; Shinn and Wicklund 1989). Visual point count surveys were performed using either a Hydrobotics model Orpheus ROV, a Benthos model Mini-Rover ROV or by SCUBA divers on the east and west sides of the platform. Survey methodology was based on criteria from Bohnsak and Bannerot (1986) and was consistent between ROVs and/or SCUBA divers. Visual surveys done with ROVs were recorded on videocassette and the point counts performed later. Species composition data from the visual point counts were then applied to the quantitative abundance estimates based on the hydroacoustics data to estimate fish abundance by species.

Data Analysis

Fish density data (number of fish/m^3) from echo integration analysis contained a large number of zero values, similar to catch data from more

common fisheries sampling techniques (Pennington 1983, 1985; Shaw et al. 1985; Stanley and Wilson 1991). Therefore hydroacoustic density data from both Arrays 1 and 2 were transformed by log(density + 1) to approximate the normal distribution.

Two vectors describing current speed and direction to the east-west and north-south were calculated (Pond and Pickard 1982). Currents from the east and north were scaled to positive values; west and south currents were scaled to negative values. This scaling provided two vectors which represented current speed and direction in later analyses.

Separate randomized block ANOVAs using SAS (1986) GLM procedures were performed with vertical target strength data and log(density + 1) of vertical density data on depth, time of day, month, temperature, east and north current vectors, squared east and squared north current vectors and their interactions, blocking on side of the platform to examine differences due to these variables. For horizontal density data a randomized block ANOVA using SAS (1986) GLM procedures was performed with horizontal log(density + 1) of data on distance from the platform, time of day, month and their interactions, again blocking on side of the platform to examine differences due to the variables. Tukey's studentized range tests (Ott 1982) were used to compare the means of significant variables for vertical and horizontal analyses. Tests were reported as significant at the alpha $\leq$ 0.01 level.

Fish abundance estimates at the platform were calculated by determining the near-field area of influence of the platform, then multiplying mean density

values for each month and platform side, in number of fish/m^3, by the volume of water on each side of the platform. Fish density in the center of the platform was calculated by averaging 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 at the center by the volume of water in the center of the platform.

Results

Target Strength

Analysis of the target strength data collected at WC 352 revealed changes in size of fishes over the course of the study. Target strength values ranged from -56 dB to -24 dB, corresponding to total lengths of 2.5 cm to 129.8 cm, and varied spatially and temporally. To examine for differences between month, time of day, depth, temperature, and current vectors a randomized block design (RBD) ANOVA was used with platform side as a block (Table 3.1). The RBD ANOVA detected significant differences in target strength between platform side, month, east vector, squared east vector and squared north vector variables (Table 3.1). The variables north current vector and the interaction of month*time of day were also considered to be significant as the probabilities of greater F values were close to 0.01 (Table 3.1).

Significant temporal variation of target strength was detected over the longest time scale measured (i.e., months), evidence that mean fish size changed between months over the course of the study. Largest target strengths were found in January 1992 (-36.9 dB) while the smallest target strengths were

Table 3.1. Randomized block analysis of variance (block on platform side) results of target strength (dB) with platform side, month, time of day, depth, current vectors, temperature and their interactions for a petroleum platform in the northern Gulf of Mexico.

Dependent variable: Target strength

Source	**D.F.**	**SS**	**MS**	**F**	**Prob**
Model	470	36369.8446	77.3826	3.56	0.0001
Error	1229	76719.3807	21.7407		
Total	1699	63089.2253		r^2 = 0.577	

Source	**D.F.**	**Type III SS**	**MS**	**F**	**Pr>F**
Platform side	3	9060.8021	3020.2674	138.92	0.0001
Month	12	17018.5305	1418.2109	65.13	0.0001
TOD [1]	3	85.5980	28.5327	1.31	0.2688
Depth	8	338.0401	42.2550	1.94	0.0503
East vector	1	425.4606	425.4606	19.57	0.0001
East vector^2	1	358.2685	358.2685	16.48	0.0001
North vector	1	122.1085	122.1085	6.45	0.0179
North vector^2	1	162.0569	162.0569	7.45	0.0064
Temperature	1	58.2670	58.2670	2.68	0.1019
Month•TOD	36	1263.4683	35.0963	1.61	0.0127
Month•Depth	96	1355.1263	14.1159	0.65	0.9962
East•North [2]	1	2.7348	2.7348	0.13	0.7229
Month•TOD•Depth	306	1630.9832	5.3500	0.25	1.0000

[1] Time of Day
[2] East•North vector interaction

detected in April, May and July 1991 (-41.1, -40.5 and -40.7 dB) (Table 3.2). The general pattern in mean target strengths observed at WC 352 was a maximum in the winter, a decrease through the spring to a minimum in the late spring and summer and then an increase through the fall (Table 3.2). Target strength did not change in a consistent pattern over 24 hour periods for the entire study, as the variable time of day was not significant ($P > 0.270$). However, mean target strength did vary within months over a 24 hour period as the month*time of day interaction was considered significant ($P < 0.013$) (Table 3.1). A plot of target strengths by month and time of day did not reveal a consistent pattern (Figure 3.3). Generally, target strengths were larger at low light periods (dawn, dusk or midnight) than at high light periods (noon) (Figure 3.3), although this pattern was not consistent throughout the sampling period.

Spatially, target strength varied only in the horizontal plane (side of the platform) and not in the vertical plane (depth) (Table 3.1). Mean target strengths were significantly larger on the south side (-36.5 dB) of the platform than on all other sides, while mean target strengths were significantly smaller on the north (-40.4 dB) and east (-40.5 dB) sides of the platform (Table 3.3).

Target strength varied with current speed and direction as the north current vector, north squared current vector and east squared current vector were significant. The relationship between mean target strength and current vectors appeared to be bell shaped as mid-range target strengths (approximately -40 dB) were found at the highest current vector values, with smaller and larger target strengths more common at low vector values (Figures 3.4 and 3.5).

Table 3.2. Mean target strengths (dB), estimated total lengths [1] (cm) and 95% confidence limits with Tukey's studentized means test results by month for the sample period from January 1991 to May 1992 at a petroleum platform in the northern Gulf of Mexico.

Month		Target Strength (95% CL) dB	Total Length (95% CL) cm	Tukey's Means Test [2]						
1991	January	-36.9 (5.4)	31.9 (18.2)	A	B					
	March	-37.0 (5.5)	32.6 (21.7)	A						
	April	-41.1 (6.9)	22.2 (19.8)							G
	May	-40.5 (5.1)	20.7 (13.1)							G
	July	-40.7 (4.4)	19.3 (11.3)							G
	August	-39.5 (4.8)	22.6 (12.8)			C	D	E	F	
	September	-38.8 (6.0)	27.0 (18.7)		B	C	D	E	F	
	October	-39.9 (5.3)	23.1 (17.6)					E	F	
	November	-39.4 (4.1)	22.1 (10.7)			C	D	E	F	
	December	-39.5 (4.6)	22.9 (14.1)			C	D	E	F	
1992	January	-35.4 (6.0)	40.7 (29.9)	A	B					
	February	-38.8 (4.0)	24.6 (13.8)	A	B	C	D	E	F	
	March	-39.7 (3.2)	23.0 (12.7)				D	E	F	G
	April	-37.8 (3.0)	25.5 (11.6)	A	B	C	D			
	May	-37.8 (3.1)	25.9 (12.4)	A	B	C				

[1] Total length estimated from the relationship $TL = 10^{((TS\ 2.36092.62)/19.1)}$ derived by Love (1971).
[2] Means with the same letter are not significantly different at the 1% level.

Table 3.3. Mean target strengths (dB) and estimated total lengths [1] (cm) with 95% confidence limits for each side of a petroleum platform with Tukey's studentized mean test results for platform side.

Platform Side	Target Strength (95% CL)	Total Length (95% CL)	Tukey's Means Test [2]		
North	-40.4 (5.0)	20.3 (17.7)	A		
West	-37.5 (4.3)	29.2 (16.8)		B	
South	-36.5 (5.4)	31.5 (19.0)			C
East	-40.5 (4.5)	21.1 (17.0)	A		

[1] Total length estimated from the relationship $TL = 10^{((TS-2.36092\ 62)/19.1)}$ derived by Love (1971).
[2] Means with the same letter are not significantly different at the 1% level.

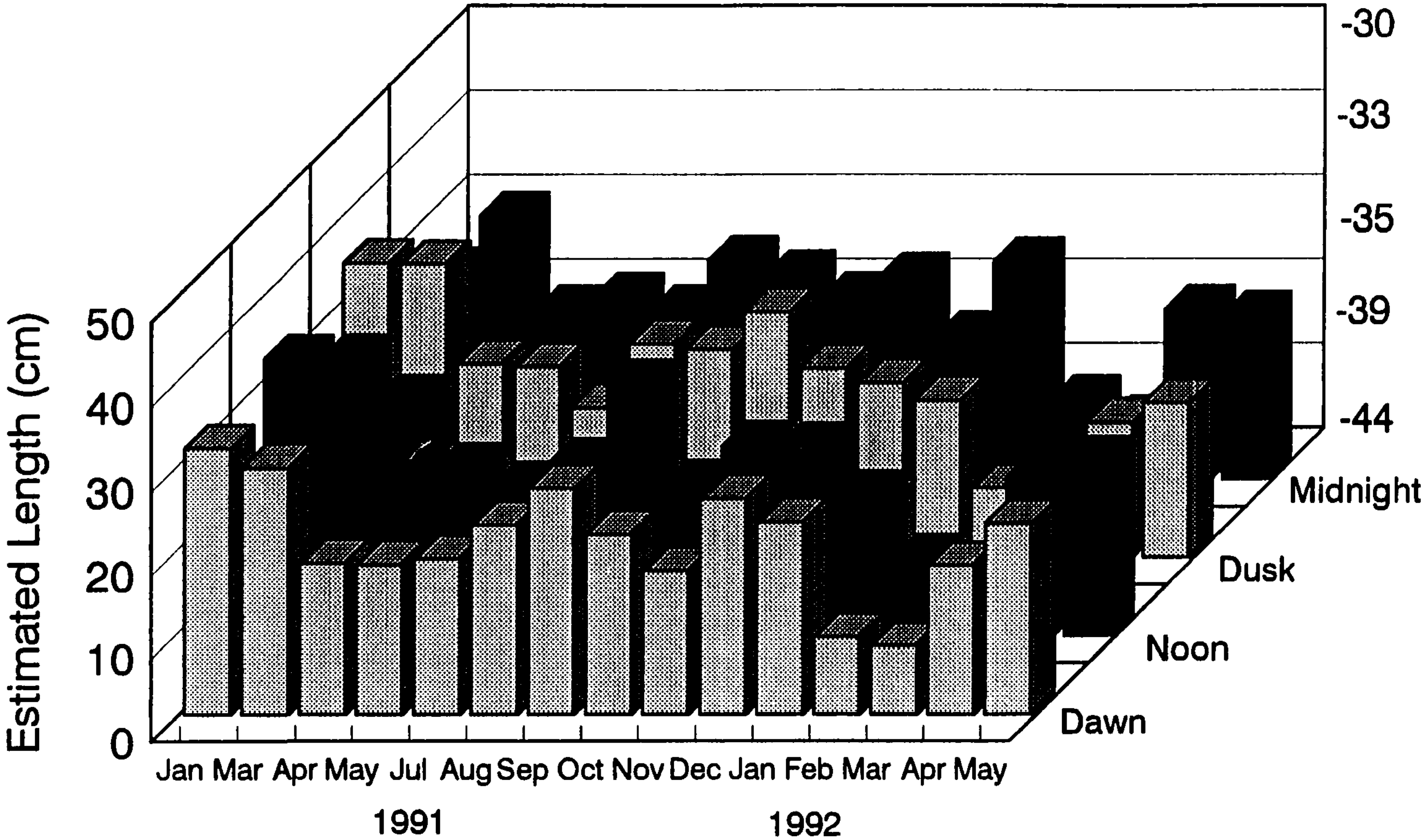

Figure 3.3. Mean target strength (dB) and estimated length (cm) of fishes associated with a petroleum platform in the northern Gulf of Mexico by month and time of day for the study period of January 1991 to May 1992.

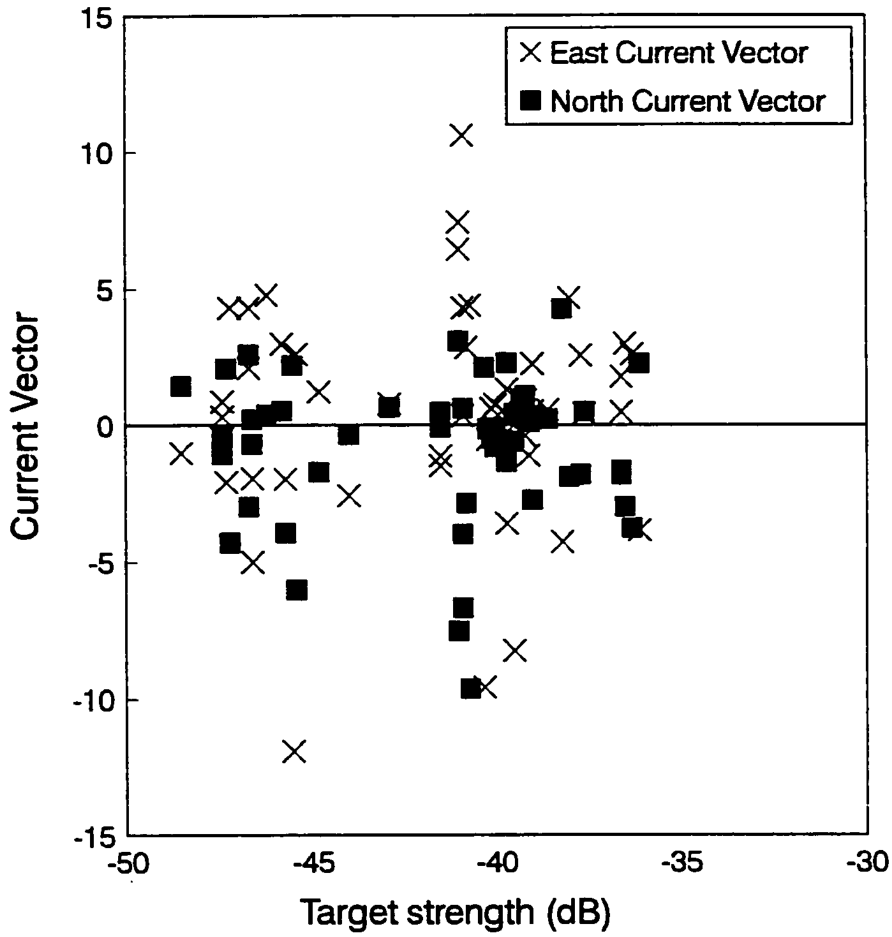

Figure 3.4. Plot of mean east and north current vectors with mean target strength (dB) by each month and time of day for the study period of January 1991 to May 1992.

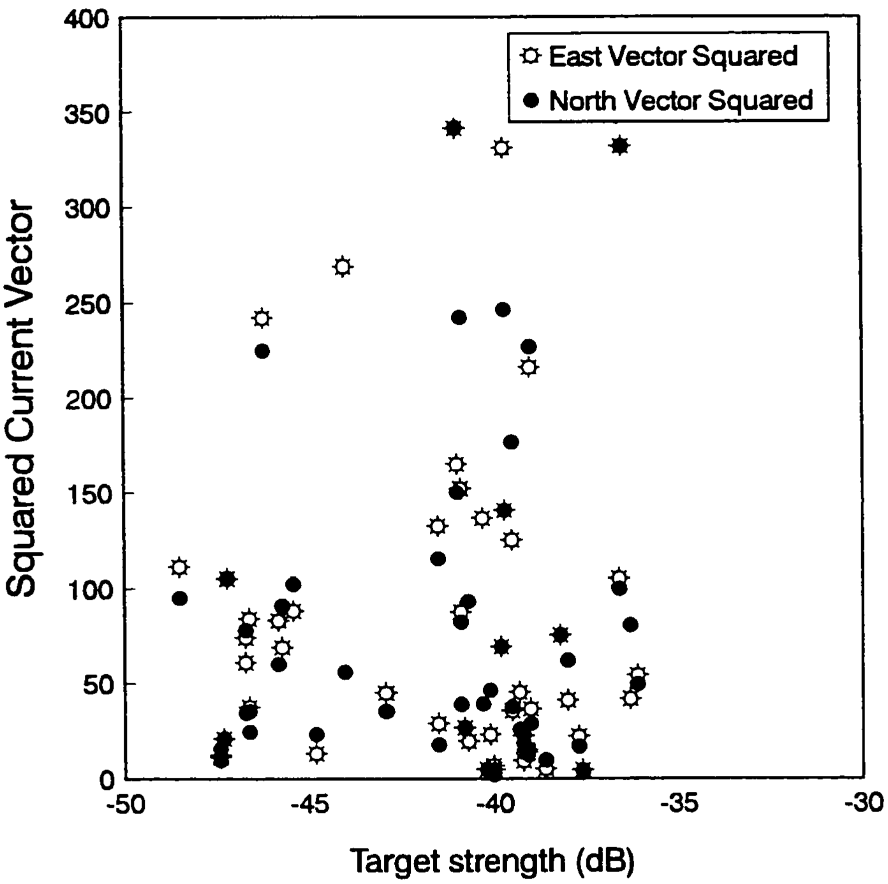

Figure 3.5. Plot of mean squared east and north current vectors with mean target strength (dB) by each month and time of day for the study period of January 1991 to May 1992.

Vertical Density Distribution

Densities of fishes at the WC 352 production platform were highly variable over the study period ranging from 0 to over 10.5 fish/m^3. A RBD ANOVA with platform side as a block was used to examine for differences in density due to month, time of day, current vectors, temperature, depth and their interactions. Density varied significantly with month, platform side, east current vector and the month*time of day interaction (Table 3.4). Depth was also considered significant as probability of a greater F value was 0.0372, relatively close to the 0.01 significance level criteria, and merited examination (Table 3.4).

Temporal differences in fish density were detected between months and the interaction of month*time of day (Table 3.4). No overall trend with fish densities and time of day could be detected over the entire study period ($P > 0.6566$) (Table 3.4). Within month, fish densities varied significantly with time of day although the pattern was not consistent; generally fish densities were lowest at noon and then increased with maximums occurring at dusk or midnight (Figure 3.6). By month, fish densities were highest in February 1992 (0.503 fish/m^3) and lowest in January 1991 (0.039 fish/m^3) and, with the exception of January 1991, mean densities were not significantly different in 1991 (Table 3.5). During 1992 mean fish densities in February were significantly higher than in other months except for May (Table 3.5). Little pattern in fish densities from month to month was observed; densities varied by as much as a factor of 5 between months (Table 3.5).

Table 3.4. Randomized block analysis of variance (block on platform side) results of log fish density (log (number of fish/m^3 + 1)) with platform side, month, time of day, depth, current vectors, temperature and their interactions for a petroleum platform in the northern Gulf of Mexico.

Dependent variable: log(density + 1)

Source	D.F.	SS	MS	F	Prob
Model	467	41.141365	0.086431	2.27	0.0001
Error	1350	51.485783	0.038137		
Total	1826	92.627147		r^2 = 0.444	

Source	D.F.	Type III SS	MS	F	Pr>F
Platform side	3	9.176940	3.058980	80.21	0.0001
Month	12	9.928392	0.827366	21.69	0.0001
TOD [1]	3	0.061512	0.020504	0.54	0.6566
Depth	8	0.627121	0.078390	2.06	0.0372
East vector	1	0.275294	0.275294	7.22	0.0073
East vector^2	1	0.000413	0.000413	0.01	0.9172
North vector	1	0.037160	0.037160	0.97	0.3238
North vector^2	1	0.191614	0.191614	5.02	0.252
Temperature	1	0.010699	0.010699	0.28	0.5964
Month*TOD	36	7.703529	0.213987	5.61	0.0001
Month*Depth	96	3.920235	0.048358	1.07	0.3068
East*North [2]	1	0.014546	0.014546	0.38	0.5370
Month*TOD*Depth	306	6.428990	0.020606	0.54	1.0000

[1] Time of Day
[2] East*North vector interaction

Table 3.5. Mean fish densities (number of fish/m^3) and 95% confidence limits of fishes associated with a petroleum platform in the northern Gulf of Mexico by month with Tukey's means test results for the study period of January 1991 to May 1992.

Month		Fish Density (95% CL) number of fish/m^3	Tukey's Means Test [1]					
1991	January	0.039 (0.013)						F
	March	0.337 (0.094)		B	C	D	E	
	April	0.209 (0.092)				D	E	F
	May	0.066 (0.024)					E	F
	July	0.279 (0.100)			C	D	E	
	August	0.098 (0.030)				D	E	F
	September	0.435 (0.235)		B	C	D	E	
	October	0.073 (0.024)				D	E	F
	November	0.259 (0.213)				D	E	F
	December	0.084 (0.044)				D	E	F
1992	January	0.272 (0.132)		B	C	D		
	February	0.503 (0.234)	A					
	March	0.304 (0.125)		B	C			
	April	0.300 (0.125)		B	C			
	May	0.416 (0.187)	A	B				

[1] Means with the same letter are not significantly different at the 1% level.

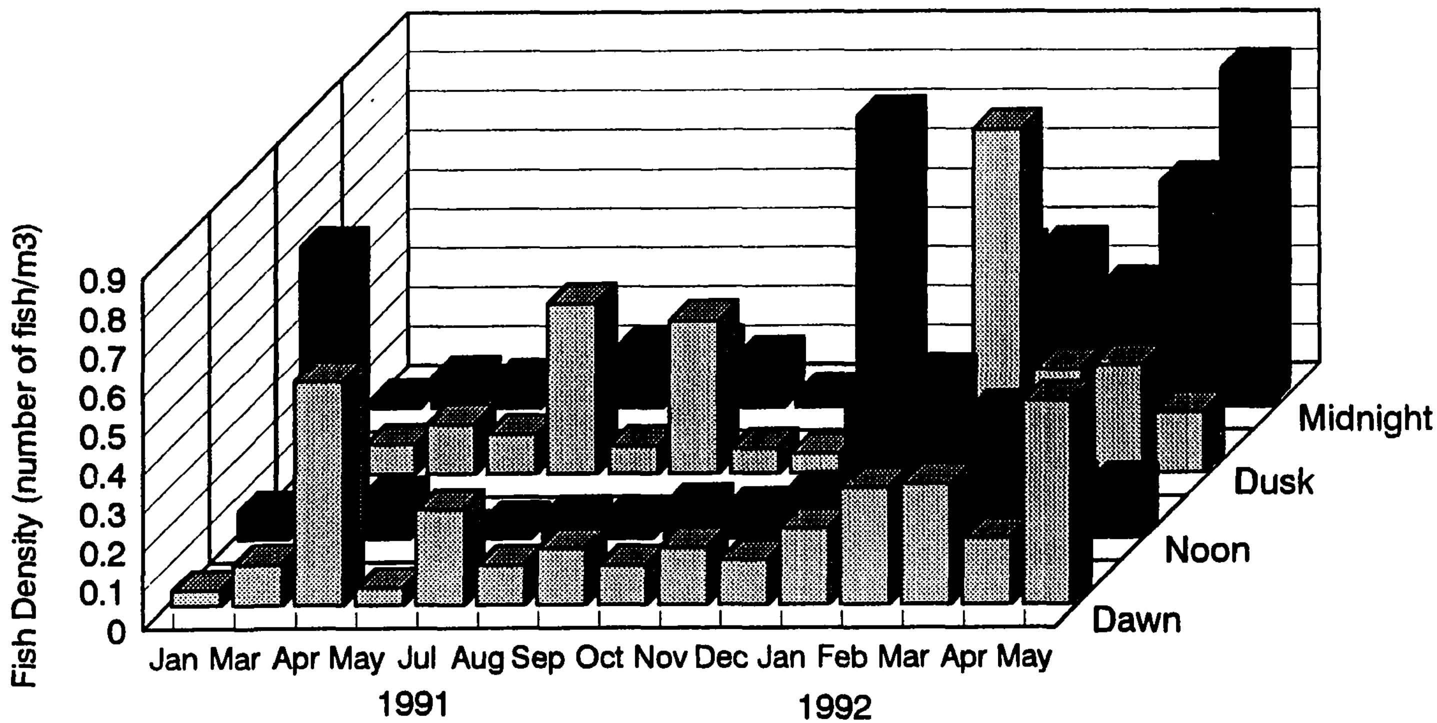

Figure 3.6. Mean density (number of fish/m^3) of fishes at a petroleum platform in the northern Gulf of Mexico by month and time of day for the study period of January 1991 to May 1992.

Spatially, density of fishes varied significantly with side of the platform and water depth (Table 3.4). Highest fish densities were observed on the north (0.330 fish/m^3) and the east (0.373 fish/m^3) sides of the platform, while significantly lower densities were found on the south (0.186 fish/m^3) and west (0.081 fish/m^3) sides (Table 3.6). Fish density also varied in the vertical plane as fish densities were significantly higher from 4 to 12 m than from 16 to 20 m (Table 3.7).

Only the east current vector significantly influenced fish density (Table 3.4). A plot of fish density with the east current vector revealed that highest fish densities were found at lower current vector values; as the current vector value became more positive or negative, fish densities generally decreased (Figure 3.7). Other current variables or water temperature did not significantly affect fish density (Table 3.4).

Horizontal Density Distribution

Horizontal density of fishes varied temporally and spatially at the platform. A RBD ANOVA revealed that month, platform side, distance from the platform and the distance•month interaction significantly affected horizontal fish density (Table 3.8).

Horizontal fish density varied spatially with side of the platform and distance from the platform (Table 3.8). Horizontal fish density was significantly higher on the east side of the platform than on all other sides (Table 3.9). Results were similar to vertical densities from Array 1 as horizontal densities were also higher on the east side (Table 3.6). Fish density decreased

Table 3.6. Mean fish densities (number of fish/m^3) and 95% confidence limits for each side of a petroleum platform with Tukey's means test results for the study period of January 1991 to May 1992.

Platform Side	Fish Density (95% CL) (number fish/m^3)		Tukey's Means Test [1]		
North	0.330	(0.089)	A		
West	0.081	(0.062)			C
South	0.186	(0.082)		B	
East	0.373	(0.085)	A		

[1] Means with the same letter are not significntly different at the 1% level.

Table 3.7. Mean fish densities (number of fish/m^3) and 95% confidence limits by depth strata for a petroleum platform in the northern Gulf of Mexico with Tukey's studentized means test results for the study period of January 1991 to May 1992.

Depth Strata (m)	Fish Density (95% CL) (number fish/m^3)	Tukey's Means Test [1]	
2 - 4	0.235 (0.035)	A	B
4 - 6	0.345 (0.034)	A	
6 - 8	0.295 (0.016)	A	
8 - 10	0.226 (0.038)	A	
10 - 12	0.265 (0.084)	A	
12 - 14	0.209 (0.084)	A	B
14 - 16	0.206 (0.083)	A	B
16 - 18	0.186 (0.080)		B
18 - 20	0.177 (0.055)		B

[1] Means with the same letter are not significantly different at the 1% level.

Table 3.8. Randomized block analysis of variance (block on platform side) results of log horizontal fish density (log (number of fish/m^3 + 1)) with platform side, month, time of day, distance and their interactions for a petroleum platform in the northern Gulf of Mexico.

Dependent variable: log (density + 1)

Source	D.F.	SS	MS	F	Prob
Model	526	7.765838	0.014734	1.80	0.0001
Error	1413	11.604944	0.008213		
Total	1939	19.370782		r^2 = 0.40	

Source	D.F.	Type III SS	MS	F	Prob
Platform Side	3	0.165177	0.055059	6.70	0.0001
Month	12	0.553437	0.046120	5.62	0.0001
TOD [1]	3	0.014514	0.004839	0.59	0.6222
Distance	11	1.887866	0.171624	20.90	0.0001
Month*TOD	36	0.434518	0.017070	1.47	0.367
Month*Distance	108	2.422520	0.022431	2.73	0.0001
Distance*TOD	29	0.124195	0.004283	0.52	0.9835
Month*TOD*Distance	324	2.297071	0.007088	0.87	0.9499

[1] Time of Day

Table 3.9. Mean horizontal fish density (number of fish/m^3) with 95% confidence limits by side of the platform and distance from a petroleum platform. Tukey's means test results by distance from the platform and side of the platform.

Distance (m)	North		West		South		East		Mean Distance		Tukey's [1] Means Test by Distance
	Mean	(95% CL)	Mean	(95% CL)	Mean	(95% CL)	Mean	(95% CL)	Mean	(95% CL)	
2 - 9	0.138	(0.103)	0.309	(0.261)	0.153	(0.032)	0.270	(0.226)	0.196	(0.155)	A
9 - 16	0.044	(0.018)	0.178	(0.076)	0.047	(0.023)	0.129	(0.100)	0.100	(0.054)	A
16 - 23	0.026	(0.013)	0.034	(0.032)	0.042	(0.022)	0.056	(0.040)	0.039	(0.026)	B
23 - 30	0.024	(0.022)	0.012	(0.008)	0.035	(0.018)	0.033	(0.020)	0.026	(0.017)	B
30 - 37	0.018	(0.012)	0.011	(0.009)	0.030	(0.015)	0.066	(0.014)	0.031	(0.013)	B
37 - 44	0.008	(0.004)	0.010	(0.006)	0.020	(0.011)	0.020	(0.017)	0.012	(0.010)	B
44 - 51	0.005	(0.003)	0.007	(0.004)	0.020	(0.013)	0.022	(0.018)	0.011	(0.013)	B
51 - 58	0.004	(0.003)	0.008	(0.004)	0.018	(0.015)	0.051	(0.010)	0.017	(0.008)	B
58 - 65	0.003	(0.003)	0.010	(0.008)	0.024	(0.022)	0.023	(0.016)	0.010	(0.012)	B
65 - 72	0.003	(0.005)	0.008	(0.007)	-	-	0.019	(0.012)	0.011	(0.008)	B
Mean Side	0.023	(0.010)	0.030	(0.042)	0.027	(0.017)	0.050	(0.047)			
Tukey's [1] Means Test by Side	B		B		B		A				

[1] Means with the same letter are not significantly different at the 1% level.

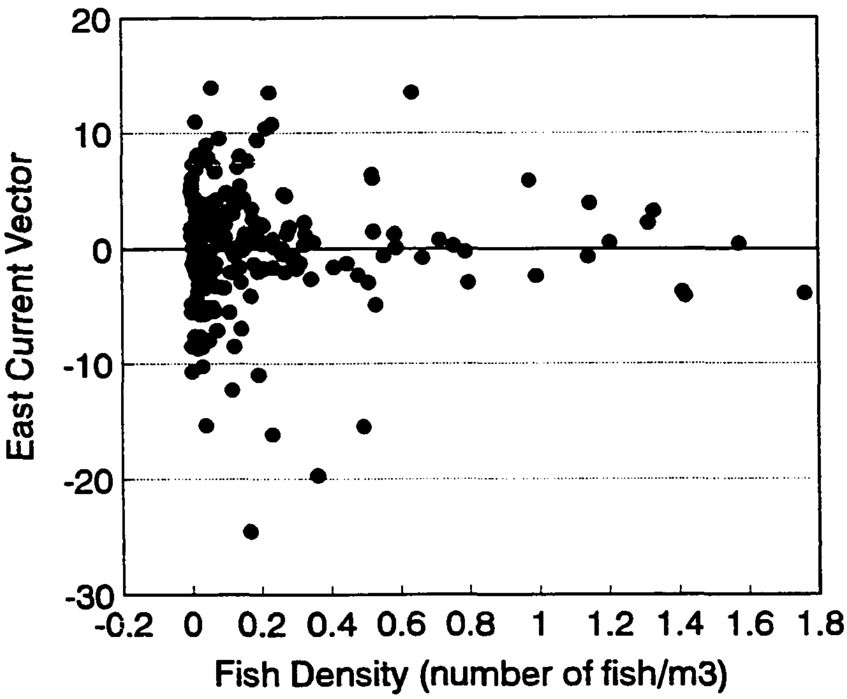

Figure 3.7. Plot of mean density (number of fish/m^3) of fishes with east current vector for each month and time of day for the study period of January 1991 to May 1992.

significantly with distance from the platform (Table 3.9). Fish densities from 2 to 9 m and from 9 to 16 m were not significantly different, but they were significantly higher than fish densities from 16 to 72 m (Table 3.9). Horizontal fish densities were 3 to 16 times higher from 2 to 16 m than from 16 to 72 m (Table 3.9). Although densities varied with side, the pattern of decreasing fish density with distance was consistent for each side of the platform (Table 3.9). Temporally, horizontal fish density varied significantly between months, but did not vary with time of day (Table 3.8). Despite the change in fish density with month, an overall trend of decreasing fish density with distance from the platform for each month was consistant (Table 3.10). Generally, fish densities were much higher within 16 m of the platform than in any other horizontal strata, despite overall changes in fish density from month to month (Table 3.10).

Horizontal fish densities were used to measure the near-field area of influence of the platform, and based on the decrease in fish density with distance from the platform (Tables 3.9 and 3.10) the near-field area of influence was estimated at 16 m. Beyond 16 m fish density dropped off significantly and fish densities were not significantly different from 16 to 72 m (Table 3.9). While fish densities were not significantly different, densities were lower in the 9 to 16 m strata than in the 2 to 9 m strata. Since fish density decreased in the 9 to 16 m strata, to calculate a conservative abundance estimate, fish densities in this strata were scaled by 0.510, the ratio of mean horizontal fish density from 9 to 16 m divided by the mean horizontal fish density from 2 to 9 m (i.e., 0.100 fish/m^3 ÷ 0.196 fish/m^3).

Table 3.10. Horizontal fish density (number of fish/m^3) and 95% confidence limits with distance from a platform for each month from January 1991 to May 1992.

Month	Distance from Platform (m)									
	2-9	9-16	16-23	23-30	30-37	37-44	44-51	51-58	58-65	65-72
Jan 1991	0.128 (0.004)	0.010 (0.002)	0.005 (0.001)	0.008 (0.002)	0.013 (0.003)	0.020 (0.004)	0.031 (0.006)	0.042 (0.008)	0.065 (0.016)	0.032 (0.004)
Mar	0.103 (0.040)	0.154 (0.049)	0.102 (0.029)	0.062 (0.016)	0.016 (0.009)	0.020 (0.006)	0.032 (0.013)	0.140 (0.090)	0.037 (0.010)	0.002 (0.001)
Apr	0.023 (0.005)	0.015 (0.006)	0.014 (0.004)	0.0012 (0.004)	0.008 (0.004)	0.005 (0.003)	0.009 (0.005)	0.005 (0.001)	0.012 (0.003)	0.001 (0.001)
May	0.088 (0.006)	0.057 (0.003)	0.033 (0.003)	0.030 (0.003)	0.026 (0.003)	0.015 (0.002)	0.020 (0.004)	0.025 (0.004)	0.023 (0.004)	0.032 (0.007)
Jul	0.121 (0.021)	0.084 (0.008)	0.036 (0.003)	0.045 (0.014)	0.042 (0.009)	0.021 (0.002)	0.007 (0.002)	0.005 (0.001)	0.003 (0.001)	0.004 (0.001)
Aug	0.173 (0.023)	0.132 (0.051)	0.039 (0.005)	0.023 (0.003)	0.019 (0.002)	0.026 (0.011)	0.017 (0.003)	0.013 (0.002)	0.011 (0.005)	0.011 (0.005)
Sept	0.885 (0.229)	0.542 (0.211)	0.047 (0.007)	0.031 (0.005)	0.022 (0.002)	0.015 (0.002)	0.010 (0.001)	0.004 (0.001)	0.002 (0.001)	0.002 (0.001)
Oct	0.257 (0.062)	0.092 (0.019)	0.049 (0.011)	0.029 (0.003)	0.027 (0.003)	0.019 (0.003)	0.015 (0.004)	0.015 (0.004)	0.014 (0.003)	0.050 (0.011)
Nov	0.158 (0.020)	0.056 (0.007)	0.020 (0.003)	0.011 (0.002)	0.009 (0.002)	0.006 (0.002)	0.005 (0.001)	0.005 (0.001)	0.005 (0.001)	0.007 (0.002)
Dec	0.409 (0.109)	0.023 (0.002)	0.008 (0.001)	0.006 (0.001)	0.005 (0.001)	0.003 (0.001)	0.002 (0.001)	0.003 (0.001)	0.004 (0.002)	0.006 (0.002)
Jan 1992	0.060 (0.011)	0.030 (0.005)	0.009 (0.002)	0.006 (0.002)	0.015 (0.004)	0.009 (0.002)	0.008 (0.002)	0.002 (0.001)	0.004 (0.001)	0.008 (0.002)
Feb	0.176 (0.040)	0.113 (0.018)	0.075 (0.012)	0.047 (0.009)	0.029 (0.008)	0.011 (0.003)	0.004 (0.001)	0.003 (0.001)	0.002 (0.001)	0.003 (0.001)
Mar	0.086 (0.027)	0.057 (0.018)	0.025 (0.008)	0.014 (0.004)	0.009 (0.004)	0.003 (0.001)	0.003 (0.002)	0.004 (0.001)	0.005 (0.002)	0.014 (0.048)
Apr	0.145 (0.020)	0.036 (0.010)	0.039 (0.011)	0.035 (0.010)	0.034 (0.009)	0.021 (0.007)	0.017 (0.006)	0.023 (0.008)	0.021 (0.008)	0.007 (0.005)
May	0.088 (0.009)	0.058 (0.005)	0.034 (0.003)	0.030 (0.003)	0.026 (0.003)	0.015 (0.002)	0.020 (0.004)	0.025 (0.004)	0.023 (0.004)	0.033 (0.007)

Total Abundance Estimates

Total number of fish around the platform was estimated using vertical density estimates averaged for each month and platform side, and then extrapolated to 9 m away from the platform for each side of the platform. Vertical fish densities from 9 to 16 m were scaled by 0.510, the average decrease in horizontal fish density in this strata. Fish density in the center of the platform was not directly measured and was estimated by averaging the density estimates of the four sides of the platform. The total number of fish associated with each side of the platform was estimated by multiplying the mean number of fish/m^3 by the volume of water on each side and the center of the platform; these numbers were then summed to estimate total number of fish by month associated with the platform (Table 3.11).

Estimated total number of fish varied with month from a low of 1,987.9 ± 412.9 in January of 1991 to a high of 28,138.2 ± 5,532.0 in February 1992 (Table 3.11). Total abundance estimates were highly variable from month to month (Table 3.11). The maximum variation of fish abundance by month was approximately 6.6 times, between January and February 1991 (Table 3.11). Little pattern in abundance estimates was detected with respect to month or season; the only describable pattern detected was higher densities in 1992 than in 1991 (Table 3.11). The average number of fish at the platform over the study period was 12,472.7 ± 3,251.3.

Table 3.11. Estimated number of fishes and 95% confidence limits for the center and each side of a petroleum platform and totals by month for the study period of January 1991 to May 1992.

Platform Side	1991										1992				
	Jan	Mar	Apr	May	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
North	262.6 (34.5)	3165.9 (799.4)	338.8 (76.2)	682.6 (55.5)	876.3 (65.6)	613.1 (40.7)	8444.7 (3500.0)	406.6 (35.1)	626.6 (51.3)	68.6 (21.1)	1066.6 (109.1)	6959.5 (425.7)	3454.7 (402.9)	4216.3 (452.4)	6449.7 (941.7)
West	200.8 (37.6)	1588.2 (341.9)	6270.6 (1035.3)	237.1 (31.0)	170.7 (19.2)	423.6 (31.3)	1575.3 (648.4)	302.4 (50.0)	790.8 (58.5)	339.8 (58.9)	1685.4 (359.5)	159.9 (75.1)	237.0 (98.2)	76.1 (14.8)	206.9 (30.0)
South	566.0 (97.2)	3249.0 (891.1)	659.0 (89.5)	871.5 (69.0)	3526.8 (1422.0)	734.3 (60.1)	1666.0 (358.0)	550.7 (61.7)	731.8 (91.3)	696.9 (45.6)	1129.2 (132.0)	1498.9 (101.1)	1275.7 (107.3)	1833.5 (158.6)	1768.1 (118.4)
East	386.9 (47.6)	1255.9 (151.3)	2566.0 (1035.3)	459.7 (55.5)	3739.3 (1070.8)	2387.8 (473.3)	3958.0 (709.8)	1878.4 (122.1)	12785.3 (762.5)	2794.0 (240.8)	9122.0 (1883.0)	12016.1 (1457.3)	7607.6 (450.4)	5276.6 (595.9)	7974.1 (1252.9)
Center	571.6 (196.1)	3964.9 (1404.2)	2884.4 (1369.5)	962.6 (350.5)	3250.2 (1487.9)	1430.9 (439.0)	6532.7 (3473.7)	1066.2 (358.4)	4344.6 (3159.6)	1228.0 (656.1)	4013.7 (1949.9)	7503.9 (3472.8)	4476.2 (1856.9)	3596.2 (1610.1)	6304.9 (2783.4)
Total	1987.9 (412.9)	13224.4 (3587.9)	12718.7 (3605.8)	3213.6 (614.9)	11563.2 (4065.5)	5589.6 (1044.3)	22176.4 (8789.9)	4204.3 (627.0)	19278.9 (4123.1)	5127.2 (1022.4)	17016.9 (4433.4)	28138.2 (5532.0)	17051.2 (2915.7)	14998.7 (2831.8)	22703.7 (5126.4)

Visual Survey Results

A total of 19 species were observed over the study, however only five species, consisting of Atlantic spadefish, blue runner, greater amberjack, red snapper and sheepshead, were observed on every visual survey (Table 3.12). Two additional species, gray triggerfish and bluefish, were observed on 9 and 10, respectively, of the thirteen visual surveys (Table 3.12). These seven species made up an average of 97.3% of the species surveyed over the study period. The same species were observed in surveys conducted both by SCUBA divers and the ROVs (Table 3.12).

Estimated number of fish for each species was calculated by multiplying estimated total abundance by percent composition of that species for each month. Atlantic spadefish, blue runner and red snapper were the most numerically dominant species observed during the study as they constituted over 55% (in February 1992) to 9% (in May 1992) of the fishes found during the study (Table 3.12). Over the study period Atlantic spadefish abundance was highly variable. Little pattern was detected, with the exception of its being the most common fish found (Figure 3.8). Bluefish numbers were highly variable ranging from a high of 23.8% of fish observed in April 1992 to 0% on numerous occasions (Table 3.12). Blue runner presence was also variable, with a high of 45.3% in May of 1992 to 0% in January 1992 (Table 3.12). Over the study period the percent composition of blue runners was approximately 20% and abundance appeared to decrease during winter (Figure 3.8). Gray triggerfish were observed on nine of the thirteen point count surveys and constituted less

Table 3.12. Results of ROV or diver visual point count surveys and estimated number of fish for each species present by month at the petroleum platform West Cameron 352.

Method - ROV
March 1991

Species	Water Depth (m) (Visibility m) 0-5 (12)	5-10 (5)	10-15 (5)	15-20 (2)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	169	3	8	-	180	41.5	6046.1 ± 3456.9
Bluefish (*Pomatomus saltatrix*)	100	-	-	-	100	23.0	3350.8 ± 1915.9
Blue runner (*Caranx crysos*)	5	-	-	6	11	2.5	364.2 ± 208.2
Black drum (*Pogonias cromis*)	-	-	2	-	2	0.2	29.2 ± 16.7
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	4	3	1	8	1.9	276.8 ± 158.3
Greater amberjack (*Seriola dumerili*)	2	2	4	11	19	4.4	641.0 ± 1366.5
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	1	2	16	17	36	8.3	1209.2 ± 2691.4
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	-	-	-	-	-	-
Sheepshead (*Archosargus probatocephalus*)	11	57	11	-	79	18.1	2636.9 ± 150.77
					433		14568.9 ± 8329.8

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - ROV
April 1991

Species	Water Depth (m) (Visibility m) 0-5 (10)	5-10 (6)	10-15 (6)	15-20 (0)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	356	72	55	-	483	53.3	6164.4 ± 1407.8
Bluefish (*Pomatomus saltatrix*)	-	-	1	-	1	0.1	11.6 ± 2.6
Blue runner (*Caranx crysos*)	5	105	-	-	110	12.1	1399.4 ± 370.0
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	2	-	7	-	9	1.0	115.7 ± 26.4
Greater amberjack (*Seriola dumerili*)	-	7	16	-	23	2.5	289.1 ± 66.0
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	-	17	78	95	10.5	1214.4 ± 277.3
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	-	-	-	-	-	-
Sheepshead (*Archosargus probatocephalus*)	48	74	63	-	185	20.4	2359.3 ± 538.8
					906		11565.4 ± 2641.2

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - Diver
May 1991

Species	Water Depth (m) (Visibility m) 0-5 (8)	5-10 (10)	10-15 (10)	15-20 (1)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	219	130	54	12	415	35.5	1062.1 ± 367.4
Bluefish (*Pomatomus saltatrix*)	-	6	-	-	6	0.5	15.0 ± 5.2
Blue runner (*Caranx crysos*)	71	180	22	-	273	23.4	700.1 ± 242.1
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	4	2	-	6	0.5	15.0 ± 5.2
Greater amberjack (*Seriola dumerili*)	-	4	13	-	17	1.5	44.9 ± 15.5
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	2	-	-	-	2	0.2	6.0 ± 2.1
Red snapper (*Lutjanus campechanus*)	-	122	185	8	315	26.9	804.8 ± 278.4
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	-	1	-	1	0.1	3.0 ± 1.0
Sheepshead (*Archosargus probatocephalus*)	34	58	33	8	133	11.4	341.1 ± 118.0
					1169		2992.2 ± 1034.8

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - Diver
July 1991

Species	Water Depth (m) (Visibility m) 0-5 (12)	5-10 (20)	10-15 (15)	15-20 (0)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	415	426	165	-	1006	41.6	5601.1 ± 4402.4
Bluefish (*Pomatomus saltatrix*)	-	1	9	-	10	0.4	53.9 ± 42.3
Blue runner (*Caranx crysos*)	260	107	10	-	377	15.6	2100.4 ± 1650.9
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	1	-	-	1	0.1	13.5 ± 10.6
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	-	-	-	-	-	-
Greater amberjack (*Seriola dumerili*)	-	45	37	-	82	3.4	457.8 ± 359.8
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	2	-	-	2	0.1	13.5 ± 10.6
Gray snapper (*Lutjanus griseus*)	11	5	-	-	16	0.7	94.3 ± 74.1
Red snapper (*Lutjanus campechanus*)	-	278	264	-	542	22.4	3016.0 ± 2370.5
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	-	1	-	1	0.1	13.5 ± 10.6
Sheepshead (*Archosargus probatocephalus*)	62	42	278	-	382	15.8	21273.3 ± 1672.1
					2418		13464.2 ± 10582.8

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - Diver
August 1991

Species	Water Depth (m) (Visibility m) 4 (25)	10 (15)	15 (5)	20 (1)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	100	200	100	-	400	36.9	1922.0 ± 820.9
Bluefish (*Pomatomus saltatrix*)	-	-	-	-	-	-	-
Blue runner (*Caranx crysos*)	150	200	5	-	355	32.7	1703.3 ± 727.5
Black drum (*Pogonias cromis*)	-	-	2	-	2	0.2	10.4 ± 4.5
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	10	5	-	15	1.4	72.9 ± 31.2
Greater amberjack (*Seriola dumerili*)	-	1	10	-	11	1.0	52.1 ± 22.3
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	1	-	-	1	0.1	5.2 ± 2.2
Little tunny (*Euthynnus alletteratus*)	-	15	-	-	15	1.4	72.9 ± 31.2
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	150	60	-	210	19.3	1005.3 ± 429.4
Sailors choice (*Haemulon parra*)	-	-	-	2	2	0.2	10.4 ± 4.5
Scamp (*Mycteroperca phenax*)	-	-	1	-	1	0.1	5.2 ± 2.2
Sheepshead (*Archosargus probatocephalus*)	12	20	40	-	72	6.6	343.8 ± 146.8
					1084		5208.0 ± 2224.8

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - Diver
September 1991

Species	Water Depth (m) (Visibility m) 0-5 (25)	5-10 (10)	10-15 (10)	15-20 (2)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	120	170	80	-	370	36.7	7578.2 ± 6892.6
Bluefish (*Pomatomus saltatrix*)	-	62	8	-	70	7.0	1445.4 ± 1314.7
Blue runner (*Caranx crysos*)	180	110	4	3	297	29.5	6091.4 ± 5540.4
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	2	6	-	8	0.8	165.2 ± 150.2
Greater amberjack (*Seriola dumerili*)	-	3	5	-	8	0.8	165.2 ± 150.2
Jack crevelle (*Caranx hippos*)	-	-	4	-	4	0.4	82.6 ± 75.1
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	22	112	18	152	15.1	3118.0 ± 2835.9
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	1	-	-	1	0.1	20.7 ± 18.8
Sheepshead (*Archosargus probatocephalus*)	52	14	28	3	97	9.6	1982.3 ± 1804.0
					1007		20650.6 ± 18783.4

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - Diver
October 1991

Species	Water Depth (m) (Visibility m) 0-5 (25)	5-10 (15)	10-15 (5)	15-20 (0)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	1	-	1	-	2	0.2	7.8 ± 2.1
Atlantic spadefish (*Chaetodipterus faber*)	200	110	125	-	322	27.9	1093.2 ± 298.6
Bluefish (*Pomatomus saltatrix*)	200	30	10	-	240	20.8	815.0 ± 22.6
Blue runner (*Caranx crysos*)	100	110	20	-	230	19.9	779.7 ± 213.0
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	2	-	2	0.2	7.8 ± 2.1
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	-	1	-	1	0.1	3.9 ± 1.1
Greater amberjack (*Seriola dumerili*)	-	-	8	-	8	0.7	27.4 ± 7.5
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	20	-	-	-	20	1.7	66.6 ± 18.2
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	4	150	-	154	13.3	521.1 ± 142.3
Sailors choice (*Haemulon parra*)	-	-	30	-	30	2.6	101.9 ± 27.8
Scamp (*Mycteroperca phenax*)	-	-	2	-	2	0.2	7.8 ± 2.1
Sheepshead (*Archosargus probatocephalus*)	94	20	50	-	144	12.5	489.8 ± 133.8
					1155		3918.5 ± 1070.2

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - Diver
November 1991

Species	Water Depth (m) (Visibility m) 0-5 (12)	5-10 (10)	10-15 (5)	15-20 (0)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	2	-	1	-	3	0.2	36.0 ± 9.1
Atlantic spadefish (*Chaetodipterus faber*)	186	459	178	-	823	41.6	7478.9 ± 1881.6
Bluefish (*Pomatomus saltatrix*)	15	20	2	-	37	1.9	341.6 ± 85.9
Blue runner (*Caranx crysos*)	306	239	22	-	567	28.7	5159.7 ± 1298.1
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	2	-	2	0.1	18.0 ± 4.5
Gray triggerfish (*Balistes capriscus*)	-	-	-	-	-	-	-
Greater amberjack (*Seriola dumerili*)	-	16	32	-	48	2.4	431.5 ± 108.6
Jack crevelle (*Caranx hippos*)	-	5	3	-	8	0.4	71.9 ± 18.1
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	10	-	10	0.5	90.0 ± 22.6
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	30	348	-	378	19.1	3422.8 ± 863.9
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	-	1	-	1	0.1	18.0 ± 4.5
Sheepshead (*Archosargus probatocephalus*)	56	12	33	-	101	5.1	916.9 ± 230.7
					1977		17979.3 ± 4523.0

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - Diver
January 1992

Species	Water Depth (m) (Visibility m) 0-5 (5)	5-10 (5)	10-15 (15)	15-20 (5)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	8	19	33	22	82	18.4	2919.2 ± 1713.8
Bluefish (*Pomatomus saltatrix*)	-	-	-	-	-	-	-
Blue runner (*Caranx crysos*)	-	-	-	-	-	-	-
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	-	-	1	1	0.2	31.7 ± 18.6
Greater amberjack (*Seriola dumerili*)	-	-	-	18	18	4.0	634.6 ± 372.6
Jack crevelle (*Caranx hippos*)	-	1	-	-	1	0.2	31.7 ± 18.6
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	-	-	231	231	51.7	8202.4 ± 4815.3
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	-	-	-	-	-	-
Sheepshead (*Archosargus probatocephalus*)	9	19	44	42	114	25.5	4045.7 ± 2375.1
					447		15868.6 ± 9314.8

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - ROV
February 1992

Species	Water Depth (m) (Visibility m) 0-5 (3)	5-10 (3)	10-15 (3)	15-20 (2)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	6	22	74	106	208	54.9	14393.6 ± 4717.9
Bluefish (*Pomatomus saltatrix*)	-	1	9	-	10	2.6	681.6 ± 223.4
Blue runner (*Caranx crysos*)	-	7	20	-	27	6.9	1808.9 ± 593.0
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	-	-	-	-	-	-
Greater amberjack (*Seriola dumerili*)	-	-	-	7	7	1.8	471.9 ± 154.7
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	-	3	102	105	27.0	7078.3 ± 2320.3
Sailors choice (*Haemulon parra*)	-	-	-	22	22	5.7	1494.3 ± 489.8
Scamp (*Mycteroperca phenax*)	-	-	-	-	-	-	-
Sheepshead (*Archosargus probatocephalus*)	2	2	6	-	10	2.6	681.6 ± 223.4
					389		26216.9 ± 8594.2

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - ROV
March 1992

Species	Water Depth (m) (Visibility m) 0-5 (12)	5-10 (5)	10-15 (3)	15-20 (1)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	60	75	20	10	165	32.4	5147.6 ± 1407.8
Bluefish (*Pomatomus saltatrix*)	60	-	-	-	60	11.8	1874.8 ± 512.7
Blue runner (*Caranx crysos*)	50	32	-	-	82	16.1	2557.9 ± 700.0
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	-	-	-	-	-	-
Greater amberjack (*Seriola dumerili*)	-	-	2	7	9	1.4	222.4 ± 60.8
Jack crevelle (*Caranx hippos*)	-	-	-	-	-	-	-
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	18	-	-	-	18	3.5	556.1 ± 152.1
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	-	-	-	-	-	-	-
Red snapper (*Lutjanus campechanus*)	-	-	50	31	81	15.9	2526.1 ± 690.9
Sailors choice (*Haemulon parra*)	-	-	-	50	50	9.8	1557.0 ± 425.8
Scamp (*Mycteroperca phenax*)	-	-	1	-	1	0.2	31.8 ± 8.7
Sheepshead (*Archosargus probatocephalus*)	25	16	4	-	45	8.8	1398.1 ± 382.4
					509		15889.0 ± 4346.5

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - ROV
April 1992

Species	Water Depth (m) (Visibility m) 0-5 (10)	5-10 (30)	10-15 (6)	15-20 (1)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola ri.oliana*)	-	-	-	-	-	-	-
Atlantic spadefish (*Chaetodipterus faber*)	160	25	1	-	186	12.8	1858.6 ± 592.0
Bluefish (*Pomatomus saltatrix*)	200	143	2	-	345	23.8	3455.9 ± 1100.7
Blue runner (*Caranx crysos*)	200	112	-	-	312	21.5	3121.9 ± 994.3
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	1	-	1	0.1	14.5 ± 4.6
Gray triggerfish (*Balistes capriscus*)	-	5	2	-	7	0.5	72.6 ± 23.1
Greater amberjack (*Seriola dumerili*)	-	45	30	-	75	5.2	755.1 ± 240.5
Jack crevelle (*Caranx hippos*)	-	-	1	-	1	0.1	14.5 ± 4.6
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	-	-	-	-	-	-	-
Gray snapper (*Lutjanus griseus*)	6	-	2	-	8	0.6	87.1 ± 27.8
Red snapper (*Lutjanus campechanus*)	2	168	200	-	370	25.5	3702.7 ± 1179.3
Sailors choice (*Haemulon parra*)	-	-	-	50	50	3.4	493.7 ± 157.2
Scamp (*Mycteroperca phenax*)	-	-	-	-	-	-	-
Sheepshead (*Archosargus probatocephalus*)	40	22	33	-	95	6.6	958.4 ± 305.2
					1450		14521.6 ± 4624.4

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

(Continued)

Method - ROV
May 1992

Species	Water Depth (m) (Visibility m) 0-5 (12)	5-10 (20)	10-15 (10)	15-20 (0)	Sum	Percent Composition	Estimated Number [1]
Almaco jack (*Seriola rivoliana*)	-	-	1	-	1	0.1	21.2 ± 8.7
Atlantic spadefish (*Chaetodipterus faber*)	30	33	4	-	67	8.6	1818.7 ± 749.4
Bluefish (*Pomatomus saltatrix*)	1	-	-	-	1	0.1	21.2 ± 8.7
Blue runner (*Caranx crysos*)	94	258	-	-	352	45.3	9579.9 ± 3947.4
Black drum (*Pogonias cromis*)	-	-	-	-	-	-	-
Cobia (*Rachycentron canadum*)	-	-	-	-	-	-	-
Cubbyu (*Equetus umbrosus*)	-	-	-	-	-	-	-
Gag (*Mycteroperca microlepis*)	-	-	-	-	-	-	-
Gray triggerfish (*Balistes capriscus*)	-	5	-	-	5	0.6	126.9 ± 52.3
Greater amberjack (*Seriola dumerili*)	5	27	12	-	44	5.7	1205.4 ± 496.7
Jack crevelle (*Caranx hippos*)	-	1	-	-	1	0.1	21.2 ± 8.7
King mackerel (*Scomberomorus cavalla*)	-	-	-	-	-	-	-
Little tunny (*Euthynnus alletteratus*)	-	-	-	-	-	-	-
Lookdown (*Selene vomer*)	2	2	-	-	4	0.5	105.7 ± 43.6
Gray snapper (*Lutjanus griseus*)	11	5	-	-	16	0.7	148.0 ± 61.0
Red snapper (*Lutjanus campechanus*)	-	18	142	-	160	20.6	4356.4 ± 1795.1
Sailors choice (*Haemulon parra*)	-	-	-	-	-	-	-
Scamp (*Mycteroperca phenax*)	-	-	-	-	-	-	-
Sheepshead (*Archosargus probatocephalus*)	23	50	69	-	142	18.3	3870.0 ± 1594.6
					777		21152.1 ± 8713.9

[1] Estimated number of fish for each species was calculated by multiplying the percent composition with the total estimate of that month from the hydroacoustic results.

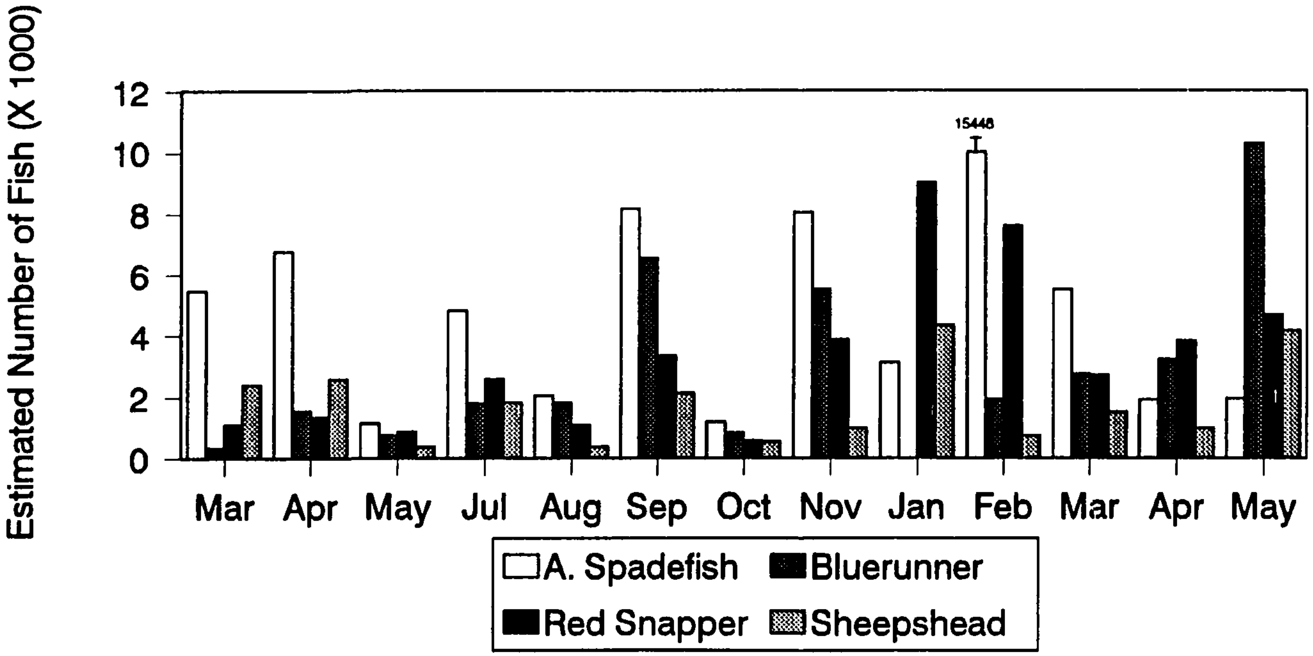

Figure 3.8. Estimated abundances of the most common fish based on hydroacoustic abundance estimates and visual survey species composition results at a petroleum platform from March 1991 to May 1992.

than 2% of the fishes found (Table 3.12). Greater amberjack were common at WC 352, and found on every point count survey, although their numbers were low and generally constituted 1% to 4% of the fishes (Table 3.12). Red snapper were one of the most common species observed over the study period. Red snapper constituted 8.3% to 51.7% of the species found at WC 352 (Table 3.12). Red snapper abundance was quite variable with respect to time and changed by up to a factor of 4 between months (Figure 3.8). Red snapper abundance appeared to increase from November through February (Figure 3.8). Sheepshead were also observed on every visual survey and was one of the most common species observed constituting approximately 10% of fish found at WC 352 (Table 3.12). Little or no pattern to sheepshead abundance could be detected over the study period (Figure 3.8).

Twelve other species of fish were observed at WC 352. The other species observed during the point count surveys individually accounted for less than 1% of the fish associated with the platform with the exception of sailors choice. Sailors choice are a small (<20 cm) schooling demersal grunt (Haemulidae) which may be abundant, however due to low visibility conditions near the bottom, visual detection of this species was probably inadequate.

Discussion

Temporal and spatial variation was observed in species composition, abundance and size distribution of fishes associated with a standard petroleum platform in the northern Gulf of Mexico. Variations in the assemblage of fishes around this defacto artificial reef are the result of ecological forces that drive fish

abundance; which can be generalized to include physical (density independent) and biological (density dependent) factors, stochastic and deterministic effects, and habitat versus recruitment limitation (see reviews by Bohnsak et al. 1991; Sale 1991).

Fish density varied with both platform side and depth, whereas target strength varied only with side of the platform. Comprehensive spatial sampling to describe assemblages associated with artificial reefs is needed to interpret spatial differences in fish densities and target strengths. The ability to measure changes in density throughout the water column is crucial, although previous researchers were unable to accurately survey nekton in the low visibility zones of the nephloid layers. While I found fish density to be significantly lower in these low visibility regions, visual surveys alone could not enumerate these fishes and would underestimate total fish numbers.

The effect of current on spatial variation in fish density has been observed by other researchers. Putt (1982) and Continental Shelf Associates (1982) speculated that higher fish densities were found up-current of petroleum platforms while Chang (1985) concluded that fish were found down-current of artificial reefs. Since the predominant current over the course of the study was from the east-south-east, and highest densities were detected on the east (up-current) and north (down-current) sides of the platform, with respect to platform side no significant relationship was established between current direction and fish density.

The relationship between current speed and density at WC 352 was such that highest fish densities were observed at the lowest current vector values, however the relationship was not as pronounced as past research would suggest (Continental Shelf Associates 1982; Putt 1982). The maximum current speed measured at WC 352 was 48 cm/s and mean total lengths of fish ranged from 19 to 41 cm, depending on month. Blaxter (1969) noted that most fish can withstand current speeds 3 to 4 times their body length for extended periods of time and it would appear that even maximum current speeds were not strong enough to produce a significant effect on fish density in the average size ranges.

A stronger relationship between target strength and current speed and direction existed at WC 352. Mid-range target strengths (approximately -40 dB) were detected at the highest current vector values, whereas the smallest target strengths (greater than -45 dB) were associated with low current vector values. The decrease in target strength with increasing current speed suggests that smaller fish left the platform as current speed increased, possibly due to the additional energy required to maintain position. This conclusion appears to be supported by the density data as highest densities were found at low current vector values.

Lowest densities were consistently detected on the west side of the platform and may not have been related to current speed or direction but to the presence of a produced water outfall located approximately 5 m below the surface on that side. Produced water has been separated from hydrocarbons and treated to decrease contaminants and, at WC 352, was typically 30 to 40°C

with an average salinity of 70 ppt. With the beam of the transducer within 6 m of the outfall, and depending on concentration, the outfall may have caused a detectable decrease in density since the predominant current at WC 352 was toward the west transducer. The presumed effect of the produced water would be localized to the west side of the platform as the total output was 760 - 1900 liters per day and dilution would occur within a few meters.

Temporal variation in fish density and mean target strength at WC 352 occurred over the longest time scale measured (i.e., months). Density and target strength did not vary consistently over shorter time periods (24 hours), indicating a lack of the diel variation observed near other artificial and natural reefs. Past studies have documented off-reef feeding and the subsequent drop in fish densities at reefs during the night for many species (Hobson 1972, 1975; McFarland et al. 1979; Heffman et al. 1982; Thorne et al. 1989). Based on the potential visual acuity of reef fishes, Munz and McFarland (1973) and Collins and Pettigrew (1988) hypothesized that reef fishes should exhibit diurnal behavior with increased presence at reef sites during the day due to heightened visual acuity. As light levels decrease, visual acuity decreases and fishes become less attracted to the structure. If fishes at WC 352 exhibited phototaxis, or if off-reef feeding was prevalent at night, then densities would decrease during the low-light periods. However densities were generally higher, but not significantly so, at low light levels, perhaps evidence that fishes were attracted to the artificial lights present on the structure. No significant overall pattern in fish density or target strength with respect to time of day was

observed at WC 352 over the course of the study. This lack of a consistent diel pattern with respect to fish abundance and size distribution has two possible explanations. The first is that no overall diel movement of fishes occurred at the platform; an unlikely explanation based on the large changes in abundance observed from month to month. The second is that movement to and from the reef during the day or at night was approximately equal and therefore no change was detected. This interpretation, that approximately equal diel immigration (due to attraction to artificial light) and emigration (due to off-reef feeding) were occurring, is more likely because density and size distributions did change within months but with no consistent diel pattern.

The large monthly variation observed in size distribution and density of fishes at WC 352 is consistent with previous research at natural and artificial reefs in temperate and tropical environments. A constant with nearly all research on fish assemblages at reefs is the large variation in density with time (see reviews by Bohnsak et al. 1991; Ebeling and Hixon 1991; Sale 1991). As previously mentioned, abundances of fishes at reefs are thought to be regulated by physical (density-independent) and biological (density-dependent) factors, deterministic or stochastic effects, and habitat versus recruitment limitation. The current hypothesis regarding the abundance of fish at reefs is one of an open nonequilibrial system that is recruitment limited (Doherty and Williams 1988; Ebeling and Hixon 1991; Sale 1991). The open nonequilibrium hypothesis suggests that substantial spatial and temporal change occurs in the local reef populations and that this change is primarily due to variable

recruitment of fish to reefs. Along with variable recruitment, extreme physical conditions (e.g., turbidity, temperature changes) as well as biological factors such as competition and predation affect assemblages (Talbot et al. 1978; Bohnsak and Talbot 1980; Gascon and Miller 1982; Bohnsak and Sutherland 1985; Doherty and Sale 1985; Shulman and Ogden 1987; Doherty and Williams 1988; Mapstone and Fowler 1988; Jones 1991). Physical factors are reported to cause large changes in fish abundances at reef systems (Talbot et ai. 1978; Lukens 1981; Bohnsak and Talbot 1980; Bailey-Brock 1989; Relini and Relini 1989), while biological factors reportedly cause a more gradual change in abundance and species composition (Menge and Sutherland 1976; Connell 1980; Bohnsak et al. 1991). Attempting to fit the fish abundance patterns observed at WC 352 to hypothesized models favors the open nonequilibrium hypothesis. The density and size distribution of fishes at WC 352 was highly variable from month to month suggesting emigration, immigration and possibly recruitment were driving these changes. Since the variations in target strength and density could vary by up to a factor of 5 between months, it is unlikely that competition and/or predation caused these large observed fluctuations. Physical factors apparently regulating the large changes in abundance were not documented by this study. During sampling periods temperature had no relationship with density and target strength, and while current speed and direction influenced target strength significantly, only a small effect on density was observed. Possibly, stochastic events (e.g., extremes in temperature, dissolved oxygen, storms, strong currents) occurring between sampling trips,

and not measured, may have caused the changes. The large fluctuations in fish abundances near artificial reefs in the northern Gulf of Mexico have been attributed to seasonal changes and physical disturbances (e.g., low water temperatures), with lowest abundances in the winter (Gallaway 1980; Lukens 1981; Gallaway and Lewbel 1982; Putt 1982). However, I detected high abundances of fishes in the winter; differences with past research are likely due to survey techniques. The low abundances previously reported in the winter may be an artifact of the low visibilities known to bias visual survey techniques. Bohnsak and Bannerot (1986) reported that accuracy of visual survey techniques decreased when visibility was less than 3 m, a common condition during winter in the northern Gulf of Mexico.

Comparison of results from WC 352 with those from studies on other petroleum platforms in the northern Gulf of Mexico revealed similar results; significant differences in density and abundance occurred spatially and temporally. Mean monthly densities at WC 352 were highly variable and ranged from 0.039 ± 0.007 fish/m^3 to 0.507 ± 0.117 fish/m^3. Putt (1982) estimated that densities ranged from 0.270 to 0.397 fish/m^3 for a petroleum platform off the Texas coast. These numbers are probably an overestimate as densities were calculated over 80 minute periods with a fixed camera system, allowing for multiple detection of the same fish. According to visual point count criteria developed by Bohnsak and Bannerot (1986), stationary visual fish count observations should be limited to 2 five minute periods; the first to document the species present and the second to enumerate the fish detected. When

observation times greater than five minutes were utilized, repetitive enumeration of the same individuals was common. Continental Shelf Associates (1982) used three minute point count video surveys from a ROV to enumerate the fish associated with four petroleum platforms in June 1980. Densities ranged from 0.002 to 0.027 fish/m^3. The densities from previous studies are comparable to those estimated at WC 352 using hydroacoustics, however the visual techniques utilized are of limited value in low visibility and restricted the authors' conclusions to characterizations of fish populations under high visibility conditions.

The species composition at WC 352 consisted primarily of Atlantic spadefish, bluerunner, greater amberjack, red snapper and sheepshead. Grey triggerfish were common and large schools of bluefish appeared in the fall and winter. These seven species constituted over 97% of the fishes observed. Some species may have been under-represented, such as sailors choice, a small grunt that was commonly noted in visual surveys when visibility near the bottom was not effected by nephloid layers. Cryptic species (e.g., Blennidae) were not enumerated as they could not be accurately counted using either the hydroacoustic equipment or the ROV, which had a minimum focal distance of 0.3 m. The species observed during this study were also commonly found in other petroleum platform studies (Sonnier et al. 1976; Gallaway 1980; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982; Stanley and Wilson 1990). Sonnier et al. (1976) and Stanley and Wilson (1990) noted that over 40 species were associated with platforms in the

northern Gulf of Mexico, but only 19 of these were found at WC 352. Disparities in species composition and frequency between this and other platform studies are likely due to geographical and temporal variation.

The species composition at WC 352 helped to explain some of the variation in fish abundance. Blue runner is a semi-pelagic tropical carangid that appears to decrease in numbers with decreasing temperature (Stanley and Wilson 1991). Their abundance at WC 352 generally followed this trend and decreased somewhat during winter months. Red snapper abundance at WC 352 was highest in the winter, consistent with past research. During the winter red snapper congregate at reefs (Moran 1986), and then disperse during the summer to spawn (Thresher 1984). Other fluctuations detected in the fish abundances at WC 352 by month and year are most likely due to physical processes. Substantial monthly variations indicate that many of the fish found at the platform were transient, with little or no fidelity to that particular habitat. The large changes in estimates of total abundance demonstrate that platform assessments can be highly variable and that it may prove difficult to extrapolate results of a single platform to large areas on any time scale. The transient nature of fishes at WC 352 was reinforced by tag and recapture studies. Tag and recapture studies conducted at WC 352, in conjunction with and over the same period as this study, resulted in the recapture of 6 of 49 tagged greater amberjack and 8 of 140 tagged red snapper (Beasley 1993; Jeff Render personal communication). Time at large ranged from 1 to 9 months for greater amberjack and 1 to 13 months for red snapper. Since the majority of tagged individuals

were not recaptured or observed during the visual surveys, it is assumed that they left the study site. This supports the hydroacoustic results exhibiting a large variance in the number of fish over time.

Total fish abundance estimates at WC 352 were higher than those from other platform studies, with an average of 12,473 fish documented over the study period. Putt (1982) estimated that a platform with a water depth of 20 m, had an average of 1,924 fish from July through September. Single point count estimates by Continental Shelf Associates (1982) at four platforms off the Louisiana coast, in water depths from 28 to 31 m, found 283 to 3,955 fish associated with individual platforms. Differences in the estimated fish abundances between the WC 352 study and previous studies may be due to the larger near-field area of influence measured in this study. Earlier researchers did not directly measure the near-field area of influence and assumed it to be 5 m. The near-field area of influence measured at WC 352 was 16 m, comparable with that detected by Gerlotto et al. (1989). They found relative fish densities were significantly higher within 10 m of a petroleum platform than those measured 50 m away. Another possible explanation for the higher total fish abundance estimates at WC 352 may be size of the platform. Previous research (Grove and Sonu 1983; Rountree 1989; Stanley and Wilson 1990) indicated that fish densities increase with increasing artificial reef size, and the WC 352 petroleum platform was larger than three of the four platforms compared in other studies.

The coupling of two fisheries independent techniques, dual-beam hydroacoustics and visual point count surveys, has provided the best estimates of fish assemblages associated with a petroleum platform to date. Absolute abundance and size distributions were determined with dual-beam hydroacoustics while visual point counts provided species compositions. Hydroacoustics also gave the first quantified measurement of the near-field area of influence surrounding an artificial reef. This effect was estimated to be 16 m on each side of the platform based on continuous density estimates from 2 to 27 m. The assemblage of fishes at WC 352 was highly variable, both temporally and spatially, in support of the open nonequilibrial system hypothesis describing fish abundance at reefs. The variation observed at WC 352 occurred over moderate time scales with no overall diel pattern. The higher abundance of fishes detected at WC 352 than described during other studies was probably due to the utilization of dual-beam hydroacoustics which did not influence fish behavior, was not limited by visibility and could determine the area of influence of the reef. The effect of current on fish density was not as pronounced as that noted in earlier research. Overall, the fish assemblage at WC 352 was similar to that observed in past research, with the main differences occurring in higher abundances, a larger near-field area of influence and a lack of diel variation in abundance and size distribution.

GENERAL CONCLUSIONS

Hydroacoustics, in conjunction with stationary point count techniques, provided size distribution and absolute abundance information, by species, on fishes associated with a petroleum platform. Due to the low visibility conditions common in the northern Gulf of Mexico and the influence of SCUBA divers on fish behavior, as documented in Chapter 2, stationary point count surveys alone would not have provided accurate estimates of fish abundance or size distribution.

The abundance and mean size of fishes associated with the platform appeared to conform with the open nonequilibrial hypothesis of fish abundance at coral reefs, and were highly variable with respect to time and space. Temporal variation occurred over moderate time scales (i.e., months) with no consistent diel pattern detected. Spatial variation of fish occurred with depth and side of the platform. While a total of 19 species were observed at WC 352, numerically the assemblage was not diverse as 7 species constituted over 97% of the species detected. It would seem that fishes associated with the petroleum platform were highly transient and, while they may be dependent on the habitat, they have the capability of migration to other areas.

Future research at petroleum platforms should encompass the time scales between 24 hour and monthly time periods. Continuous measurement of density and target strengths, in conjunction with environmental variables (e.g., temperature, dissolved oxygen, current speed and direction), over weeks or

perhaps months may reveal the forces driving the larger changes in the fish assemblages associated with petroleum platforms.

Management of fisheries resources associated with petroleum platforms may prove challenging due to large temporal and spatial variations in the abundance of fishes. The large number of platforms with varying sizes, water depths and geological locations will affect the assemblage of fishes at each structure uniquely. To obtain accurate estimates of the fisheries resources it is unlikely that extrapolation of estimates from a few sites would be suitable. Because of the lack of diel variation, a single one day estimate would adequately describe fish abundance, but the survey must include all depths and sides of the platform. Due to the temporal variation observed, surveys of multiple sites should occur over the shortest time periods practical, or be sufficiently geographically separated to minimize the effect of possible migrations.

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APPENDIX

BASIC FISHERIES ACOUSTICS

The theory of sound is very similar to that of light. Both consist of waves which propagate through a media, and both are subject to phenomena such as reflection, scattering and absorption. By applying these phenomena, sound in water can be used to detect differences in the density of various materials (i.e., fish, zooplankton, the differences between two water masses).

Scientific acoustic systems function by generating a pulse of electrical energy with specific characteristics to a transducer, which then converts the electrical signal of known strength and duration to an acoustic signal through vibration of the transducer face. The pulse radiates from the transducer and as the pulse encounters objects in the water some of the energy is reflected. This mechanical reflected acoustic energy is detected by the transducer, which then reconverts this signal to electricity and sends it to the echosounder. Detection of targets in the water depends on many factors and can be described in the equation:

$$V_{out} = SL + TS - 40\log R - 2\alpha R + G_t + 2B(\Theta), \text{ where}$$

a) V_{out} is the voltage output of the echosounder measured in dB volts.

b) SL is the source level or intensity of the echosounder measured in dB.

c) TS is the reflected target strength of an object measured in dB. Based on empirical formulae developed by Love (1971), fish size can be estimated from target strength.

d) R is the range of the object (m). Since sound is absorbed by water, acoustic

power loss from the transmitted and reflected signal is estimated by -40 log R. To describe identical objects at two distances the power loss is calculated and incorporated into the time varied gain (TVG) circuit of scientific echosounders, otherwise more distant objects would appear smaller due the energy lost by absorption.

e) $2\alpha R$ is the energy loss due to the conversion of sound energy to heat. This loss is an attenuation coefficient alpha (α) and is dependent on frequency, temperature and salinity and can easily be calculated.

f) G_{r}, is receiver sensitivity, the amount of power out of the receiver relative to sound incident upon the transducer. Receiver sensitivity includes transducer performance and receiver amplification.

g) $2B(\Theta)$, is the position of an object in the acoustic beam. Sound energy decreases away from the center of the beam, therefore to compensate for off-axis targets this function is calculated.

Background noise also affects the ability of the system to detect objects. Background noise is expressed in dB and can be measured at the onset of the experiment. Although noise does not appear in the sonar equation, it determines the size of the smallest target that can be studied, that is, noise establishes a threshold below which returning signals cannot be distinguished from background return. Pulse width is also a consideration as short pulse widths provide a finer discrimination of distances and allow more individual targets to be identified.

Abundance of fish is determined through echo integration. Since the intensity of an echo is directly proportional to the average voltage squared (v^2) returning to the echosounder, and since we can apply a TVG to correct for energy loss due to the distance of the target, fish density can be estimated from the average of v^2. With the use of dual-beam transducers the backscattering cross section of targets is known and the density estimates generated are absolute estimates, rather than the relative estimates generated with single-beam techniques.

Fish size or target strength is also measured and since dual-beam transducers were used, an accurate target strength could be estimated. Dual-beam hydroacoustics operates by transmitting sound impulses on a narrow beam and receives on narrow and wide beams. By receiving on narrow and wide beams the effect of beam pattern can be factored out and *in situ* target strengths can be measured which can then provide estimates of fish size based on Love's equation (1971).

VITA

David Robert Stanley was born March 22, 1962 in Simcoe, Ontario, Canada. His interest in the aquatic environment and its inhabitants was cultivated during time spent fishing with his father on Long Point, Lake Erie. In 1985 he received a Honour's B.Sc., specializing in Fisheries Biology, from the University of Guelph. As an undergraduate he worked as a fisheries technician for the Ontario Ministry of Natural Resources which further broadened his background in fisheries. In 1986 he moved to Louisiana to attend graduate school at LSU and received a M.Sc. in Marine Sciences in May 1989, documenting the assemblage of fish near petroleum platforms in the northern Gulf of Mexico. These assemblages continued to fascinate him, and with a desire to better understand them, he continued his education, enrolling in the Ph.D. program at LSU in 1989. He will receive his Ph.D. from the Department of Oceanography and Coastal Studies in August of 1994.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: David Robert Stanley

Major Field: Oceanography and Coastal Sciences

Title of Dissertation: Seasonal and Spatial Abundance and Size Distribution of Fishes Associated with a Petroleum Platform in the Northern Gulf of Mexico

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

April 28, 1994