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Spatial Variation in Fish Density at Three Petroleum Platforms as Measured with Dual-Beam Hydroacoustics

David R. Stanley and Charles A. Wilson

Despite the number and ubiquitous placement of petroleum platforms in the northern Gulf of Mexico, little information exists on associated fisheries resources due to the difficulties of sampling these sites with traditional fish census methods. From 1994 to 1996 dual-beam hydroacoustics were employed on quarterly research trips to measure the density and in situ target strengths of fishes associated with petroleum platforms in 20, 60, and 219 m of water. Density varied significantly with platform, distance from the platform, depth, and platform side. Platforms on the continental shelf had a near-field area of influence of approximately 18 m, whereas the near-field are of influence for the site on the continental slope was 10 m, although the relationship was not as well defined as the other sites. Average estimated abundance over the study period was 26,347 at the 60-m site, 13,444 at the 20-m site and 11,224 at the 219-m site. Fishes were distributed throughout the water column at the sites on the continental shelf, whereas on the continental slope (water depth 219 m), over 88% of the fishes were found in the upper 60 m of the site.

In the waters of the northern Gulf of Mexico there are approximately 4,000 petroleum platforms functioning as de facto artificial reefs. As reflected by the number and size of these structures, they constitute the largest artificial reef complex, albeit unplanned, in the world. Because of their long history in the region and the characteristic aggregations of valuable species of fish and other marine organisms, platforms are viewed as an important resource by regional fisheries managers and recreational and commercial user groups.

Petroleum platforms differ from traditional artificial reefs in that their vertical profile extends throughout the water column providing habitat in the photic zone, potentially increasing the productivity of these systems. One commonality between platforms and other reefs is the difficulty in assessing the abundance of their associated fishes. To address this sampling problem, we have successfully used dual-beam hydroacoustics to accurately estimate the abundance of fishes at these structures. Hydroacoustics provides precise estimates of density, size distribution, and the near-field area of influence of the platform, permitting accurate estimates of the total fish abundance at the platform (Wilson and Stanley, 1991; Stanley and Wilson, 1995, 1996, 1997).

Numerous attempts have been made to document the abundance and composition of fishes associated with petroleum platforms (Sonnier et al., 1976; Gallaway et al., 1981; Continental Shelf Associates, 1982; Gallaway and Lewbel, 1982; Putt, 1982; Scarborough-Bull and Kendall, 1987; Stanley and Wilson, 1990, 1991, 1995, 1996, 1997; Wilson and Stanley, 1991; Stanley, 1994), and despite the diversity of methods, sites, and timing, one commonality between all the studies is the high variability in the number and species composition of fishes associated with the sites. Previous research has found that platform size, depth, distance from the platform, location, and time of year dramatically affected fish abundance and species composition (Gallaway et al., 1981; Continental Shelf Associates, 1982; Putt, 1982; Scarborough-Bull and Kendall, 1987; Gerlotto et al., 1989; Stanley, 1994; Stanley and Wilson, 1996, 1997). These past studies have documented a zonation of the assemblage of fishes and recognized three characteristic assemblages in the northern Gulf of Mexico. The three zones are coastal (water depth < 27 m), offshore (water depth 27–64 m), and bluewater (water depth > 64 m) (Gallaway, 1980; Gallaway et al., 1981; Gallaway and Lewbel, 1982), each have characteristic species composition and abundances.

Despite the number of structures in the region and the perceptions of managers and user groups, little quantitative data exist on the fisheries value of these structures. Since previous research efforts were snapshots at a single sites or covered short time periods, the goal of this research project was to seasonally examine the density of fishes at petroleum platforms in 20, 60, and 219 m of water over a 2-yr period using dual-beam hydroacoustics. Specific objectives were to examine the effect of water

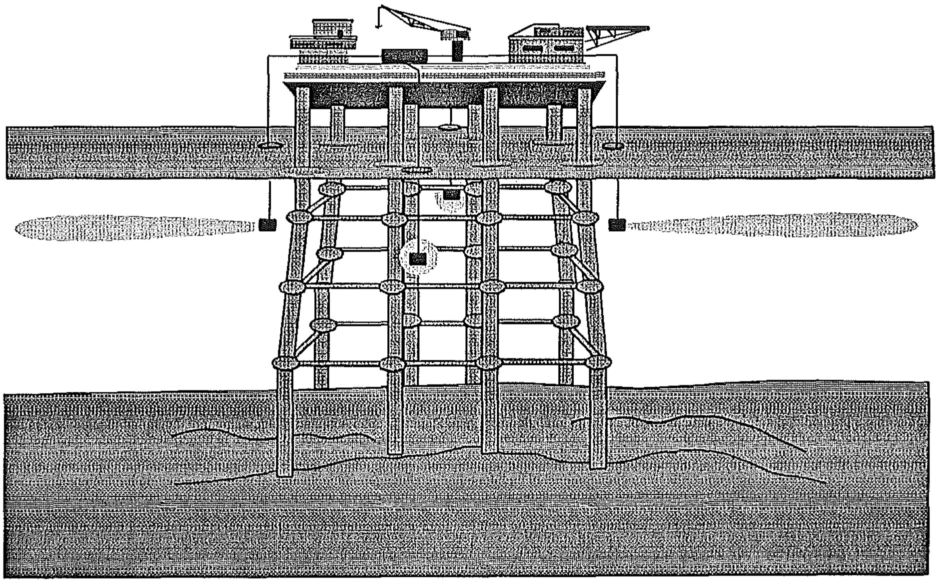

Fig. 1. Schematic view of stationary hydroacoustic transducer deployment to measure horizontal relative density of fishes associated with petroleum platforms.

depth and seasonality on the fish abundance at these sites.

Methods

Research trips were conducted quarterly (August 1994–1996) to petroleum platforms Grand Isle 94 (GI94; 28°31.33′N, 90°05.52′W, water depth 60 m, installed 1975) and Green Canyon 18 (GC18; 27°56.48′N, 91°02.28′W, water depth 219 m, installed in 1988) operated by Mobil U.S.A. Inc. and (August 1995 and June 1996) to platform South Timbalier 54 G (ST54; 28°50.01′N, 90°22.40′W, water depth 22 m, installed 1956) operated by Exxon U.S.A. Inc.

Three arrays of stationary dual-beam hydroacoustic equipment developed through our past research were used to determine the density of fishes associated with the study sites (Wilson and Stanley, 1991; Stanley and Wilson, 1995, 1996, 1997). Arrays 1 and 2 (Fig. 1) were designed to measure in situ target strength distribution and density of fishes immediately adjacent to each side of the platform. Array 1 consisted of four upward-oriented transducers (120 kHz) suspended approximately 25 m below the surface (at ST 54 they were placed on the bottom), one on each side of the platform. The upward-facing transducers provided acoustic coverage from the surface to a depth of 10–15 m (Fig. 1). Array 2 consisted of four downward-oriented transducers (120 kHz) placed approximately 3 m below the surface, one on each side of the platform. The downward-facing transducers provided acoustic coverage from a depth of 10 m to 1–5 m from the substrate, depending on the site. The use of four transducers (both upward and downward orientations) enabled the estimation of fish densities throughout the water column and on all sides of the platform.

Array 3 was designed to examine the near-field density of fishes associated with the structure and consisted of four horizontally aligned dual-beam transducers (120 kHz) deployed off each side of the platform at depth of 12 m (Fig. 2). This arrangement enabled near-field density estimates to a distance of approximately 82 m from the platform. The total number of fishes associated with the platform were then calculated using density estimates from arrays 1 and 2 and the near-field distance estimates from array 3.

Horizontal and vertical acoustic sampling was conducted over three consecutive 24-hr intervals for each month's sampling trip; 2 hr of hydroacoustic data were collected encompassing four periods (dawn, noon, dusk, and midnight) over each 24-hr interval. Hydroacoustic data were collected sequentially from each of the transducers in 5-min intervals for each trip.

Acoustic data were collected using a Biosonics model ES2000 scientific echosounder/multiplexer–equalizer. The source levels ranged from 218.5 to 220.5 dB re μPa at 1 m, depend-

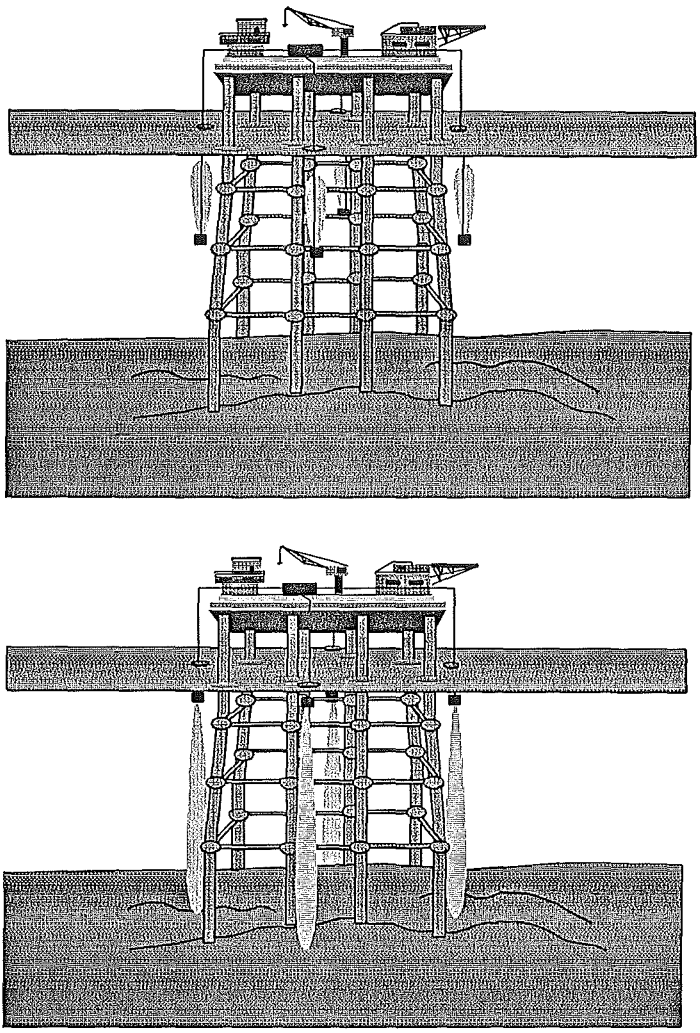

Fig. 2. Schematic view of stationary hydroacoustic transducer deployment to measure in situ target strength and density of fishes throughout the water coumn on each side of the platform for the three study sites.

ing on the transducer. The 20 log R system gains ranged from −156.4 to −146.8 dB re V μPa, and the 40 log R system gains ranged from −168.9 to −165.8 dB re V μPa varying with transducer. Sampling rate ranged from 2 sec^{-1} to 10 sec^{-1} depending on array and sampling depth. Pulse width was 0.4 msec. Received signals were adjusted for spreading loss by applying a 40 log R time-varied gain, digitized and recorded on digital audio tape (DAT). Reference voltages (approximately 5 V AC) were recorded on each DAT tape and used to calibrate the acoustic system prior to echo integration and target strength analyses. Prior to data collection, background noise levels were measured and did not exceed 40 mV on any sampling trip. 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).

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 were estimated using Biosonics TS software, and density estimates were calculated using Biosonics Crunch software with σ for each sample and depth strata. Fish densities were calculated for 5-m vertical depth intervals for GI94 and ST54 and 20-m depth intervals for GC18.

Fish density data (number of fish/m^3) from

TABLE 1. Randomized block analysis of variance of horizontal fish densities at Grand Isle 94, Green Canyon 18, and South Timbalier 54 petroleum platforms.

Source	df	SS	MS	F	Prob > F
Horizontal fish density, Green Canyon 18					
Model	399	9.3624	0.0234	7.40	0.0001
Error	1,960	6.2131	0.0031		
Total	2,359	15.5756			
Variables	df	Type III SS	MS	F	Prob > F
Platform side	3	2.1530	0.7177	39.81	0.0001
Season	2	0.0253	0.0127	0.70	0.4959
Diel	3	0.7520	0.2417	13.41	0.0001
Distance	9	0.0884	0.0100	0.55	0.8409
Season*diel	4	0.1833	0.0458	2.54	0.0399
Season*distance	18	0.4899	0.0272	1.51	0.0850
Diel*distance	27	0.2960	0.0109	0.61	0.9350
Horizonial fish density, Grand Isle 94					
Model	479	436.10	0.91	33.31	0.0001
Error	2,300	62.86	0.03		
Total	2,779	498.97			
Variables	df	Type III SS	MS	F	Prob > F
Platform side	3	28.74	9.58	27.77	0.0001
Season	2	143.51	71.76	207.95	0.0001
Diel	3	21.22	7.08	20.50	0.0001
Distance	9	21.85	2.43	7.04	0.0001
Season*diel	4	40.82	6.80	19.71	0.0001
Season*distance	18	38.638	2.15	6.22	0.0001
Diel*distance	27	1.51	0.06	0.16	1.0000
Horizontal fish density, South Timbalier 54					
Model	189	89.23	0.47	11.75	0.0001
Error	766	25.43	0.04		
Total	955	114.66			
Variables	df	Type III SS	MS	F	Prob > F
Platform side	3	5.66	0.78	18.45	0.0001
Season	1	22.34	2.43	12.34	0.0001
Diel	3	13.44	1.22	6.77	0.0001
Distance	9	12.22	2.56	7.34	0.0001
Season*diel	3	16.45	3.45	11.21	0.0001
Season*distance	9	14.56	1.56	7.43	0.0001
Diel*distance	27	1.45	0.89	0.22	0.987

echo integration analysis contained a large number of zero values, similar to catch data from traditional fisheries sampling techniques (Pennington, 1983, 1985; Shaw et al., 1985; Stanley and Wilson, 1995, 1996, 1997). Therefore, hydroacoustic density data were transformed by log(density + 1) to approximate the normal distribution.

Separate randomized block ANOVAs (SAS Institute, 1986) were performed with vertical and horizontal and log(density + 1) of density data on depth, time of day (TOD), quarter, and their interactions, blocking on side of the platform to examine differences due to these variables. Tukey's studentized range tests (Ott, 1982) were used to compare the means of significant variables for vertical and horizontal analyses. Statistical tests were reported as significant at the $\alpha \leq 0.01$ level unless otherwise stated.

The total abundance estimates at the platform were calculated by determining the near-field area of influence of the platform then multiplying mean density values (number of fish/m^3) for each month and platform side by the volume of water on each side of the plat-

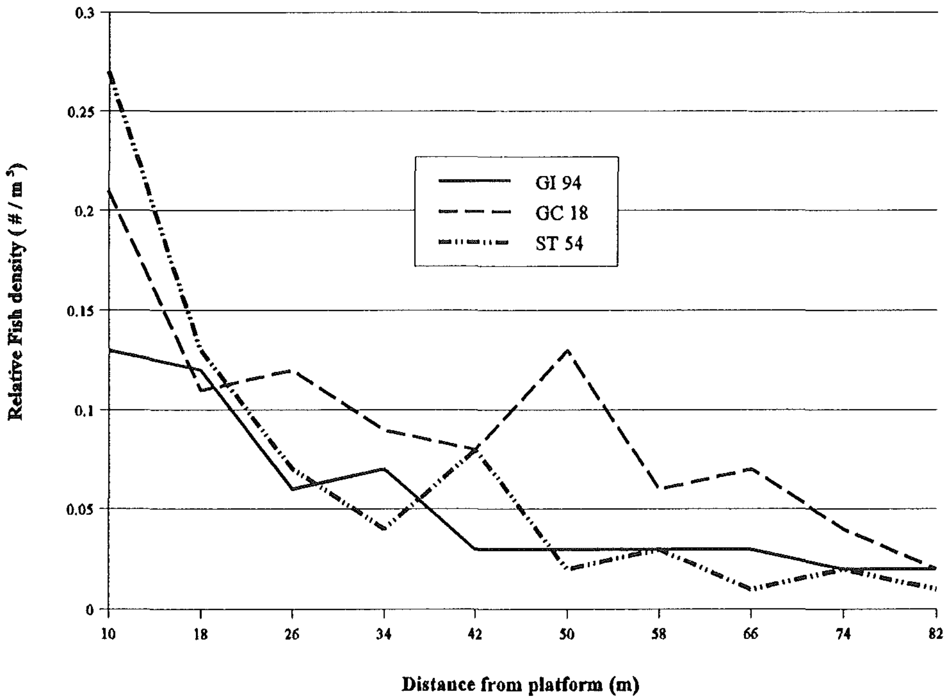

Fig. 3. Mean relative horizontal fish density to a distance of 82 m from petroleum platforms Green Canyon 18 (GC 18), Grand Isle 94 (GI 94), and South Timbalier 54 (ST54).

form. Fish density in the center of the platform, not measured with acoustics due to interference by structural members, was assumed to be the average of the density estimates of the four sides of the platform. Fish abundance in the center of the platform was calculated by multiplying the estimated fish density of the center by the volume of water in the center of the platform.

Results

Dual-beam hydroacoustics revealed several differences between the sites that added to our understanding of the function of platforms as artificial reefs. A significant near-field area of influence was detected at all sites. At platforms GI94 and ST54, horizontal fish densities from 2 to 18 m were significantly greater than those from 18 to 80 m, whereas at GC18 densities were significantly higher from 2 to 10 m than from 10 to 80 m (Table 1, Fig. 3). For the purposes of describing the area of influence of the platform, we chose a cutoff where density dropped significantly, making the area of influence at GI94 and ST54 18 m and 10 m at GC18. Horizontal fish density varied among platforms, but was consistently higher adjacent to the platform (Fig. 3), dropping to densities typical of the open waters of the northern Gulf of Mexico (< 0.02 fish/m^3) after a distance of approximately 50 m, based on acoustic transect surveys by Morgan (1996). The relationship between horizontal fish density and distance from the platform at GC18 was not clearly defined in comparison to sites on the continental shelf because, although density did decline with distance, the decline was not as rapid (Fig. 1). This is likely due to a transition in species composition and water clarity between sites on the continental shelf and on the slope. Horizontal fish density also varied significantly with platform side, season, and time of day at GI94 and ST54, whereas at GC18, significant differences were noted only with time of the day (Table 1).

Differences in vertical fish densities were observed throughout the study and at all sites. Significant differences were found in vertical fish densities between sides of the platform and depth at all of the sites; season at ST54 and GI94; season*depth at ST54 and TOD*depth at GC18 (Table 2). The most dramatic differences observed in density were with respect to side of the platform and depth (Fig. 4). Fish density varied at each site with

TABLE 2. Randomized block analysis of variance of vertical fish densities at Grand Isle 94, Green Canyon 18, and South Timbalier 54 petroleum platforms.

Source	df	SS	MS	F	Prob > F
Vertical fish density, Green Canyon 18					
Model	479	40.749	0.085	2.98	0.0001
Error	2,658	75.947	0.029		
Total	3,137	116.596			
Variables	df	Type III SS	MS	F	Prob > F
Platform side	3	0.584	0.194	3.49	0.0161
Season	2	0.356	0.178	3.19	0.0424
Diel	3	0.409	0.136	2.44	0.0643
Depth	9	11.345	1.261	22.56	0.0001
Season*diel	4	0.182	0.030	0.54	0.7747
Season*depth	18	1.590	0.089	1.59	0.0605
Diel*depth	27	3.540	0.131	2.35	0.0002
Vertical Fish Density, Grand Isle 94					
Model	502	100.742	0.200	33.99	0.0001
Error	2,553	15.074	0.006		
Total	3,055	115.817			
Variables	df	Type III SS	MS	F	Prob > F
Platform side	3	19.894	6.631	73.39	0.0001
Season	2	26.299	13.149	145.53	0.0001
Diel	3	0.461	0.153	1.70	0.1667
Depth	9	3.282	0.298	3.30	0.0002
Season*diel	4	0.392	0.065	0.72	0.6312
Season*depth	18	11.243	0.562	6.22	0.0001
Diel*depth	27	0.706	0.021	M 0.24	1.0000
Vertical fish density, South Timbalier 54					
Model	167	56.78	0.34	21.52	0.0001
Error	852	13.34	0.016		
Total	1,019	70.12			
Variables	df	Type III SS	MS	F	Prob > F
Platform side	3	4.56	0.87	18.78	0.0001
Season	1	12.48	1.77	33.56	0.0001
Diel	3	0.58	0.98	0.65	0.7432
Depth	4	15.67	2.34	12.23	0.0001
Season*diel	3	0.78	0.09	0.68	0.7712
Season*depth	4	3.45	1.43	3.21	0.0034
Diel*depth	12	0.98	0.07	0.61	0.6754

side, although a consistent pattern was not observed at any of the sites (Fig. 4). The greatest differences among platform side were observed at GI94 and ST54, where fish density varied by up to a factor of eight with side, reinforcing the importance of sampling on all sides of a platform to obtain accurate estimates of fish abundance at a site.

The most striking result of the study was the difference in fish density with depth among the three sites. The fish density at GI94 and ST54, sites on the continental shelf, was fairly uniform throughout the water column, although significantly ($P < 0.05$) higher densities were found immediately adjacent to the surface and the bottom (Fig. 5). However, at GC18 we observed a dramatic decrease in fish density with depth, and below 100 m fish density was essentially zero (Fig. 6). The vast number of fishes were found in the upper water column at GC18; 88% of the fishes were found from 0 to 60 m. Densities varied with position on the continental shelf; sites on the shelf (GI94 and ST54) had observed densities that were four to eight times higher than in the upper 60 m of water at GC18, which is on the continental slope (Figs. 5–6).

Because the near-field area of influence was

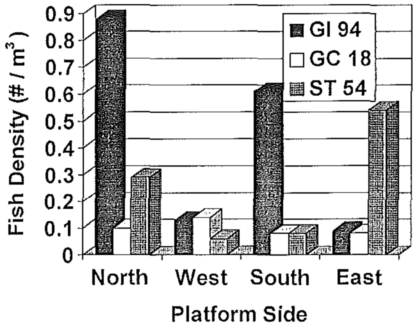

Fig. 4. Mean fish density by platform side at petroleum platforms Grand Isle 94 (GI 94), South Timbalier 54 (ST54), and Green Canyon 18 (GC18).

defined and densities were known throughout the water column, the total abundance of fishes associated with each platform could be estimated. Average estimated abundance (with 95% CI) at each side over the study period was 26,347 (± 3,636) at GI94, 13,444 (± 4,578) at ST54, and 11,224 (± 2,618) at GC18.

Discussion

This study continues to demonstrate the utility of hydroacoustic survey techniques to study the assemblage of fishes associated with petroleum platforms, with potential use at natural and other artificial reefs. This methodology allows for the measurement of the area of influence of these de facto artificial reefs, estimates of abundance throughout the water column, and over long time periods, the determination of the fisheries value of these structures.

Our results support the variability in the abundance of fishes associated with petroleum platforms and artificial reefs observed in earlier studies. Similarities with previous research from artificial and natural reefs in shallow water include density changes with depth (Chang 1985; Shinn and Wicklund 1989; Rooker et al., 1997), however, no research has examined the density of fishes at deepwater natural or artificial reefs. The results from GC18, a site on the continental slope with a water depth of 219 m, revealed extremely low fish densities below 100 m. These findings have serious implications for artificial reef programs, especially in the Gulf of Mexico, because if habitat is not maintained in the upper water column, a platform's function as an artificial reef is questionable. In support of our conclusions, previous research has shown that species richness in the Pacific is negatively related to depth (Stevens 1996), and bottom trawl data from the shelf break in the Gulf of Mexico (water depth > 110 m) documented the presence of 69 species; however, low abundances of all species were commonly found and few reef-dependent species were captured (Chittenden and Moore, 1977). This effect of depth on fish density demonstrated by this research has implications on the use of retired platforms sited as deepwater artificial reefs. Current regulations in the Texas and Louisiana artificial reef programs (Wilson et al., 1987; Stephan et al., 1990) call

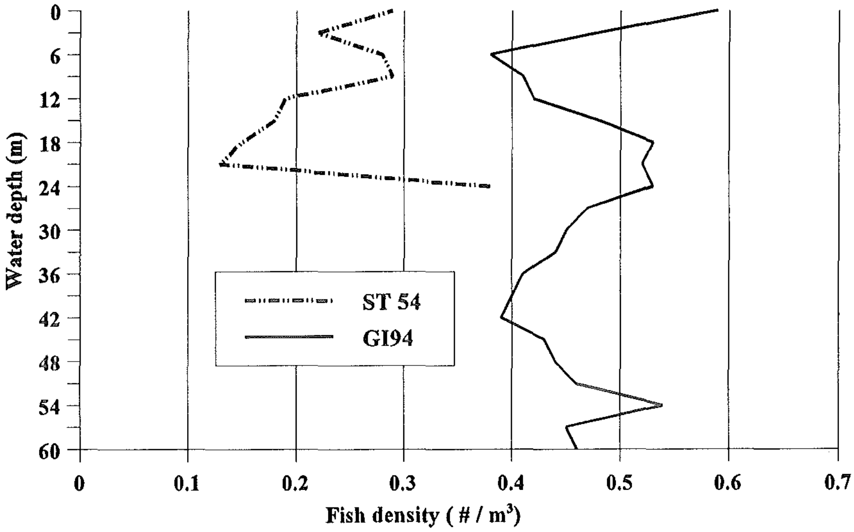

Fig. 5. Mean fish density by depth at petroleum platforms Grand Isle 94 (GI 94) and South Timbalier 54 (ST54).

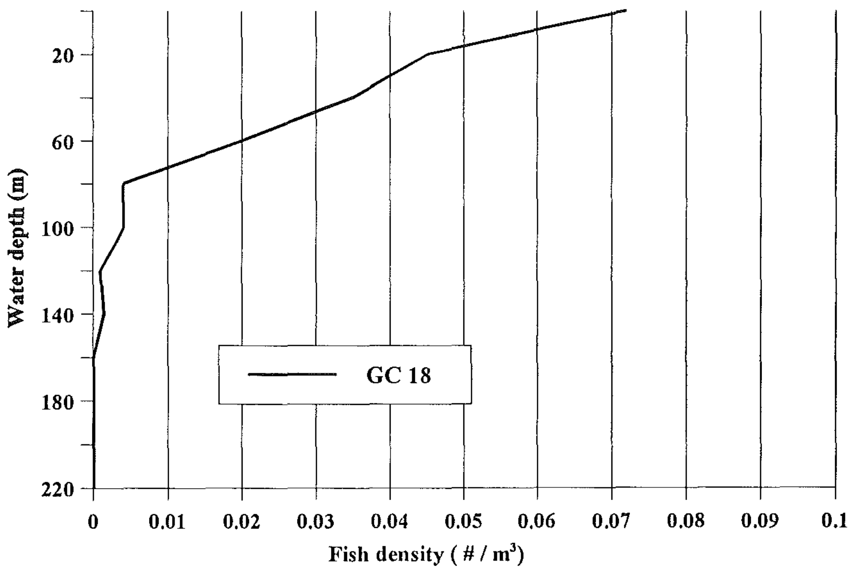

Fig. 6. Mean fish density by depth at the petroleum platform Green Canyon 18 (GC 18).

for the toppling of retired platforms, with few exceptions, when they are sited as artificial reefs. However, if this approach is utilized in a deepwater environment, it is apparent that the structure in the upper water column will be lost. As an option, the National Research Council (NRC, 1996) has recommended that the siting of deepwater platforms (water depth > 90 m) as artificial reefs be changed to allow for the removal of the upper 27 m of the structure with the remainder left standing. Our results support this recommendation. As an example, if GC18 was conventionally sited as an artificial reef, with the top of the reef approximately 150 m below the surface (i.e., toppled in place after explosive cutting of legs), its effectiveness as an artificial reef would be greatly diminished, based on our results that few fishes would be associated with the structure.

Our results also support previous research, which observed variability in the abundance of fishes associated with petroleum platforms. Previous researchers have demonstrated that variability in fish density was found over various time scales from month to seasons at sites on the continental shelf (Continental Shelf Associates, 1982; Gallaway and Lewbel, 1982; Putt, 1982; Scarborough-Bull and Kendall, 1987; Stanley and Wilson, 1990, 1991, 1996, 1997). Platform side continued to affect fish density (Wilson and Stanley, 1991; Stanley and Wilson, 1996, 1997), demonstrating the importance of thorough sampling at a site to obtain accurate information on the overall abundance of fishes. Structure size has also been shown to affect fish density, and we observed the highest density at the mid-sized platform, which is consistent with results from our earlier research (Stanley and Wilson 1991). Previous studies have shown fish abundance is directly correlated with reef size to a maximum reef volume of 4,000 m^3 (Ogawa et al., 1977). The size of the platform with the highest density and abundance in this study, while larger in reef volume than the optima due to the open construction of platforms, is comparable to the optimal surface area reported by Ogawa et al. (1977). The largest platform in this study (GC18), although three to 10 times larger than the others in this project, had the lowest observed densities, an anomaly likely due to the location and water depth of the site.

Hydroacoustics again illustrated its effectiveness in relating the area of influence of a platform the size of an artificial reef to its fish assemblage. As we defined it, the area of influence extended 10–18 m horizontally beyond the physical size of the platform, varying with site. This is consistent with earlier research by Stanley and Wilson (1996, 1997) and Gerlotto et al. (1989). Additionally, it would appear that the effect of platforms on fish abundance is localized. After a distance of 30–50 m, fish density decreased to levels found in the open waters of the northern Gulf of Mexico by Morgan (1996).

This research confirms the variability of fish assemblages associated with petroleum platforms and reinforces the need to sample on each side and throughout the water column to obtain an accurate estimate of fish abundance. It also demonstrates the importance of petroleum platforms to the marine environment of the northern Gulf of Mexico, as illustrated by the high abundance of fishes found at the sites. Despite the variance observed among sites, 10,000 to 30,000 fishes were found at each site at any one time. Because more than 1,500 platforms are found in similar water depths, it is clear that these structures have an effect on the fisheries of the region.

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