Estimation of Fisheries Impacts Due to Underwater Explosives Used to Sever and Salvage Oil and Gas Platforms in the U.S . Gulf of Mexico

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Prepared under MMS Interagency Agreement 17912
by
National Marine Fisheries Service
Southeast Fisheries Science Center
Miami, Florida 33149

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Final Report

U.S. Department of the Interior
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PREFACE

The title of this study, "Estimation of Fisheries Impacts Due to Underwater Explosives Used to Sever and Salvage Oil and Gas Platforms in the U.S. Gulf of Mexico," is somewhat of a misnomer. There are a wide variety of oil and gas structures in addition to platforms. Data analysis included extrapolation of results to other structure types in addition to those commonly referred to as platforms. A detailed explanation appears in the report. Also, no distinction was made between petroleum and gas structures.

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Gregg R. Gitschlag, Michael J. Schirripa, Joseph E. Powers

Executive Summary

According to data from the National Marine Fisheries Service (NMFS) Platform Removal Observer Program which includes removals in both federal and state waters, from 1989-98 a total of 958 structures were salvaged using explosives for an annual average of roughly 96 structures. One obvious consequence of using explosives is a negative impact on fish. There has previously been no attempt to quantify the impacts of explosive platform removal on fish populations. Of special concern is the commercially and recreationally important red snapper (*Lutjanus campechanus*) which occurs at many of these structures. The red snapper continues to be the subject of intense government regulation as this species is severely overfished and there are significant problems in the long-term viability of the stock (Goodyear and Phares 1990; Goodyear 1996; Cowan 1998; Schirripa, 1998).

Fishery managers attempt to track the size and status of stocks using mathematical equations which include variables relating to recruitment and mortality. The results of such stock assessment analyses provide managers with critical information needed to manage fisheries. This study quantifies the mortality of fish species resulting from explosive platform removals. For the first time, mortality estimates from platform removals were used in stock assessment analyses to determine the relative importance of this mortality compared with other sources of mortality such as commercial and recreational fishing, trawl bycatch, and discards. As a result, stock assessments may be improved through addition of this new parameter into stock assessment equations.

The most severely impacted fish species at explosive structure removals in order of abundance were Atlantic spadefish (*Chaetodipterus faber*), blue runner (*Caranx crysos*), red snapper (*Lutjanus campechanus*), and sheepshead (*Archosargus probatocephalus*). These four species accounted for 86% of estimated mortality. Numbers of all other impacted species were far below those of the top four. Of the species encountered in these field studies, only red snapper, gag and red drum have stock assessments conducted on them by the National Marine Fisheries Service. For red snapper, even when the mortality estimate was doubled, impacts were estimated to be small, well within the variation of our current assessments, and would not alter current determinations of status or current management recovery strategies. Similarly, current methods of assessment would not detect the even smaller changes in magnitude of gag and red drum. Results indicated no significant difference in estimated mortality of red snapper by depth, longitude, platform

age, season, surface salinity, and surface temperature in the study area (14-32 m)during May to September. These analyses suggest no appropriate strata for expansion of mortality data to the greater Gulf of Mexico and indicate that platforms in the water depths studied can be included in a single group for the purpose of estimating fish mortality due to explosive platform removals. Although the effects of structure complexity on fish abundance was not an objective of this study, unpublished data from the National Marine Fisheries Service indicated structure complexity may directly influence observed mortality. This parameter was integrated into the sensitivity analysis for stock assessment. A significant difference in red snapper length at removals in 20-30 m water depths vs those at shallower and deeper depths was also incorporated into the analysis.

Future impacts to the red snapper stock were predicted based on forecasts of future structure removals reported by Pulsipher et al. (in press). Estimates of future mortality were higher than current estimates but less than the doubled value of current red snapper mortality which was used in these stock assessment analyses. Consequently, future red snapper mortality estimates at explosive structure removals fall within the variation of our current assessments. Given the assumptions used in these forecasts, predicted future mortality would not alter current determinations of stock status or current management recovery strategies for red snapper. However, should future facts alter the validity of these assumptions, then these predictions should be revised accordingly.

Three important caveats should be remembered when interpreting these results. First, species composition and abundance can change in water depths deeper than those encountered during this study. Second, sample size was small, only nine platforms out of more than 4,000 structures present in the U.S. Gulf of Mexico. Finally, all sampling was conducted during the months of May through September.

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1.0 INTRODUCTION

The first offshore energy platform in the Gulf of Mexico was built in 1942 (Pulsipher et al, in press). As of January 31, 2000 there were 3,967 oil and gas structures[1] present in federal waters of the Gulf of Mexico. Federal regulations require removal of these structures within one year of lease termination. According to data from the National Marine Fisheries Service (NMFS) Platform Removal Observer Program which includes removals in both federal and state waters, from 1989-98 a total of 958 structures were salvaged using explosives for an annual average of roughly 96 structures. For the same period, MMS data for federal waters indicate underwater explosives were used in 64% of all removals (submerged wells not included in these data). In the most common explosive removal method, 40-50 lb charges are detonated inside the pilings and well conductors at a minimum depth of 5 m below the sea floor (MMS requirement). Consequently, hundreds of pounds of explosives, primarily Comp-B and C-4, are used at most offshore platform removals.

Offshore platforms function as artificial reefs attracting a wide variety of marine life as well as an abundance of anglers (Hastings et al. 1976; Sonnier et al. 1976; Dugas et al. 1979; Gallaway 1980; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Gallaway and Martin 1980; Ditton and Auyong 1984; Witzig 1986; Reggio 1987; Stanley and Wilson 1989; Scarborough-Bull and Kendall 1990; Stanley and Wilson 1990; Rooker et al. 1997). One obvious consequence of using explosives to remove offshore structures is a negative impact on fish. Although offshore platforms have been the subject of much scientific study over the years, there has previously been no attempt to quantify the impacts of explosive platform removal on fish populations. Of special concern is the commercially and recreationally important red snapper (*Lutjanus campechanus*) which occurs at many of these structures. The red snapper continues to be the subject of intense government regulation as this species is severely overfished and there are significant problems in the long-term viability of the stock (Goodyear and Phares 1990; Goodyear 1996; Cowan 1998; Schirripa, 1998).

Fishery managers attempt to track the size and status of stocks using mathematical equations which include variables relating to recruitment and mortality. The results of such stock assessment analyses provide managers with critical information needed to manage fisheries. This study attempts to quantify the mortality of fish by species resulting from explosive platform

[1]Michelle Morin, Minerals Management Service, 1201 Elmwood Park Boulevard, New Orleans, LA 70123. Personal communication.

removals. For the first time, mortality estimates from platform removals were used in stock assessment analyses to determine the relative importance of this mortality compared with other sources of mortality such as natural and fishing mortality. As a result, stock assessments may be improved through addition of this new parameter into stock assessment equations.

2.0 STUDY SITE SELECTION

Although this study was intended to sample a total of 10 platforms, sufficient data to estimate fish mortality were collected at 9 of 10 study sites off the Louisiana and Texas coasts in water depths ranging from 14-32 m (Table 1, Figure 1). Field work spanned seven sampling seasons from 1993-1999 primarily due to restrictions relating to structure type, water depth, season, and cooperation from platform owners. Structures in very shallow water were thought to lack key species of interest, particularly red snapper. Intensive underwater sampling required substantial amounts of bottom time. This limited study depths to a maximum of approximately 36 m. Also, best results were obtained when sampling was conducted as soon as possible after explosives were detonated. This minimized fish loss from the sea floor due to predation and allowed samples to be collected before decomposition of dead fish resulted in subsequent bloating and floating of carcasses to the surface that could occur within 24 h of detonation. Loss of dead fish from the sea floor could cause gross underestimates of fish mortality. Due to safety considerations platform salvage work halted while research divers collected samples in close proximity to the platform. Despite a dive contingent which usually numbered a dozen or more, this generally meant that the platform owner would incur additional costs of thousands or tens of thousands of dollars for a 5 h work delay. To accommodate diving operations and reduce cost overruns, removals occurring during the winter weather season from December through April were not targeted for inclusion in the study. For these reasons, selection of the ten study sites is best characterized as opportunistic rather than random.

3.0 MATERIALS AND METHODS

3.1 Sampling

Although sampling techniques were refined during the study, basic sampling design is summarized in Figure 2. After detonation of explosives, dead fish either floated to the surface or sank to the sea floor. To assess the impact on fish populations, field personnel operating from inflatable boats used dip nets to

Table 1. Characteristics of platforms studied.

Platform ID	SMI 23	WD 30	ST 146	SS 158	WC 172	WC 173	WC 181	SS 209	GA 288	SS 214[1]
Depth (m)	25	13.7	28	16.8	14.6	14.6	17.6	32	22.9	36
Depth (ft)	82	45	92	55	48	48	58	105	75	118
Platform age (yr)	33	39	16	12	23	19	17	37	31	24
Longitude (°W)	91.88	89.62	90.5	91.03	93.23	93.18	93.2	90.87	94.7	90.86
Surface temperature (°C)	29	30	26	30.5	30.5	29	32.1	31	28	29
Surface salinity (ppt)	33		26	18	23	25	24	28.8	28.5	30
Month of removal	8	7	5	7	8	9	7	7	5	6
Year removed	94	94	95	93	95	95	97	98	99	97
Volume (m^3)	7050	9809	6860	3310	1037	1927	1408	5696	2290	29860

[1] Mortality was not estimated at this location because only surface fish collections were conducted.

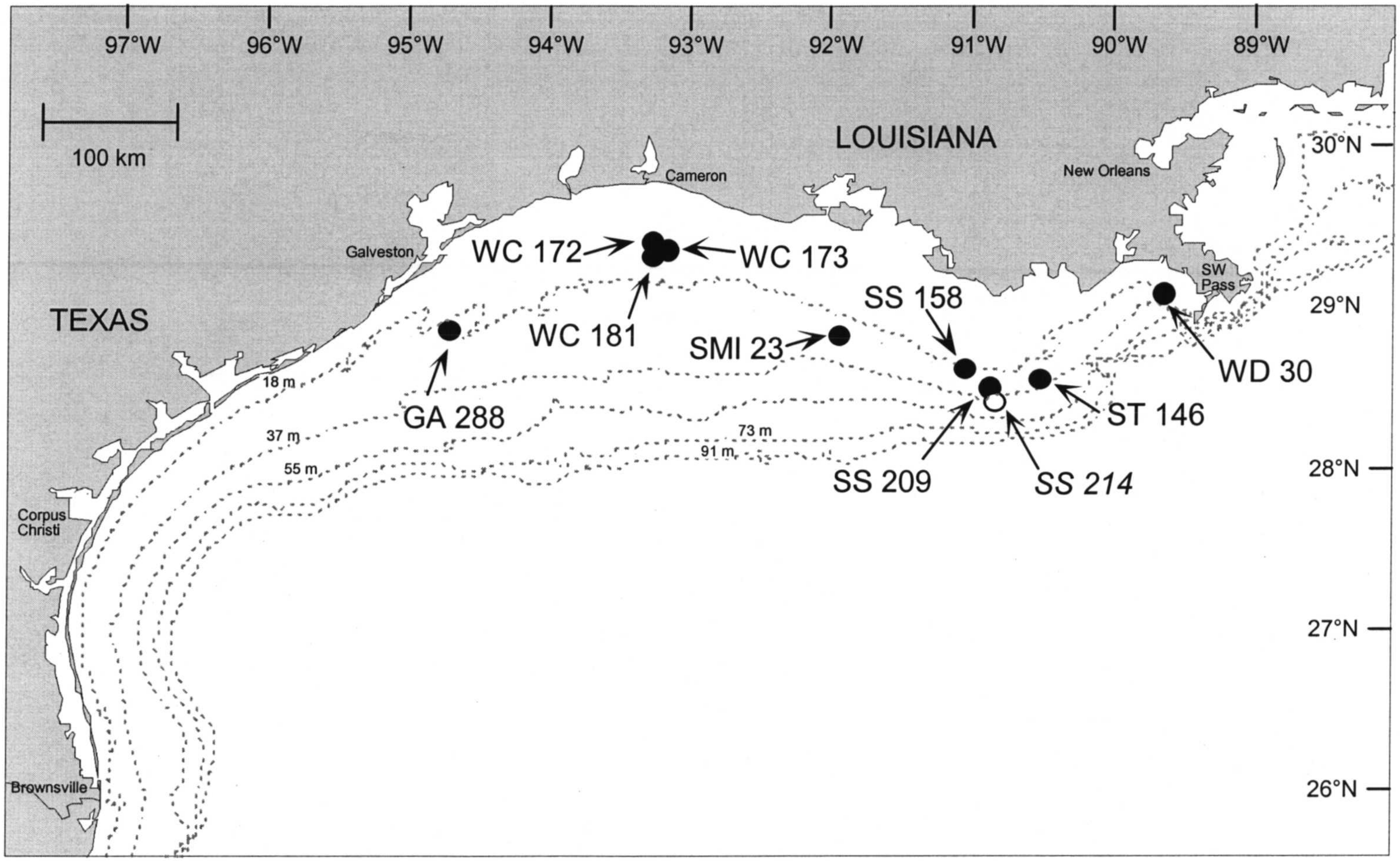

Figure 1. Map of study sites. Dark circles represent platforms where fish mortality was estimated from samples collected at the sea surface and bottom. The white circle represents a platform where only sea surface sampling was conducted.

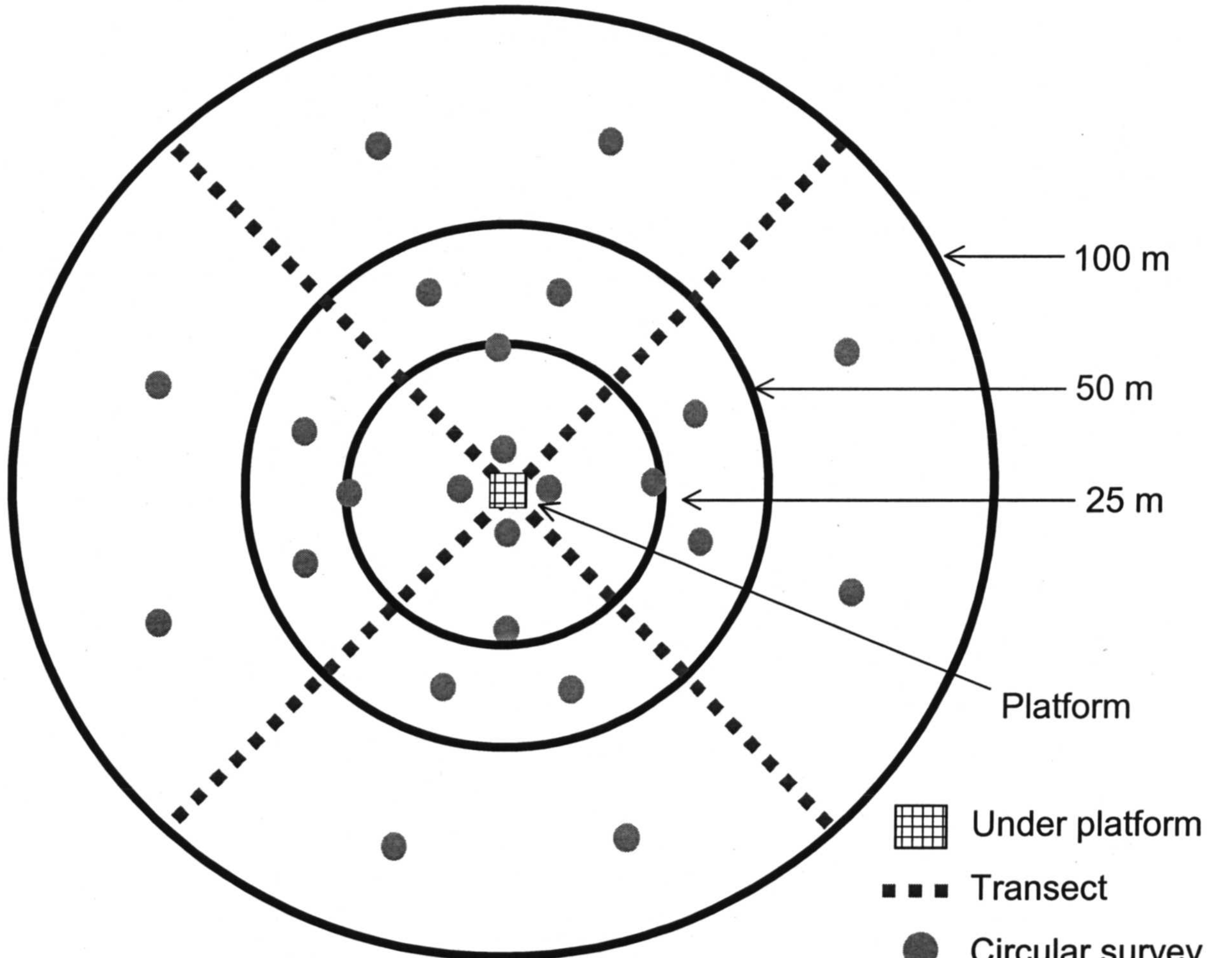

Figure 2. Schematic of sampling design showing transect lines, circular surveys, and sampling area under platform.

collect all dead fish that floated to the surface while divers manually sampled dead fish that sank to the sea floor. Dives were delayed a minimum of 30 minutes after detonation to allow fish to die and sink to the bottom. Three techniques were employed to sample dead fish from the sea floor beneath and around the platform: transect lines, circular surveys, and sampling frames. One hundred meter transect lines radiating out from the base of the platform were sampled by divers. Two hundred meter transects were surveyed at one platform. Transect width varied with underwater visibility but was either 2 or 4 m. Two person dive teams were always used during collections. Divers lined up on opposite sides at one end of a transect line. Each diver grasped the transect line in one hand and used their outstretched arms to estimate a transect width of either 1 or 2 m on each side of the line. At the first study site divers used mesh bags to collect discrete samples of dead fish in 5 m increments along the 100 m transect line. This proved to be too time consuming so 25 m increments were sampled at all but the final study site where the 25 m area nearest the platform was divided into two 12.5 m segments (Figure 3).

A second technique was used to assess fish mortality around the platform. At the first study site, 44 square frame nets measuring 13.4 m^2 each were deployed on the sea floor around the platform within a radius of 100 m. A buoyed line attached to the frames allowed easy retrieval from a vessel after explosives were detonated. At subsequent platform removals these nets were replaced with circular surveys performed by divers. One end of a 3.35 m long PVC pipe was staked to the sea floor. Using the pipe as a distance gauge, divers collected dead fish as they swam the pipe in a circle using the staked end of the pipe as a pivot point. Twenty-four circular surveys measuring 6.7 m in diameter and 35.3 m^2 were sampled within 100 m of the structure. Samples within 25 m (Figure 4) of the structure were collected along guidelines secured to the base of the platform to insure there was no overlap between circular and transect surveys. Beyond 25 m there was little chance of overlap, and a compass and range finder were generally used to locate sampling sites within selected quadrants around the platform (Figure 5).

Dead fish which fell to the sea floor beneath the platform were collected using rectangular sampling frames of various designs and dimensions (Figure 6). One inch galvanized pipe frames measuring 3 x 3 m were initially used to accommodate potentially large fish kills beneath the platform. These frames featured mesh that could be pursed with a draw string to prevent fish loss during retrieval to the surface with lift bags. When large fish kills were not encountered, these heavy, cumbersome frames were replaced with lightweight PVC frames without mesh. Divers manually placed fish from the sampling frame into mesh

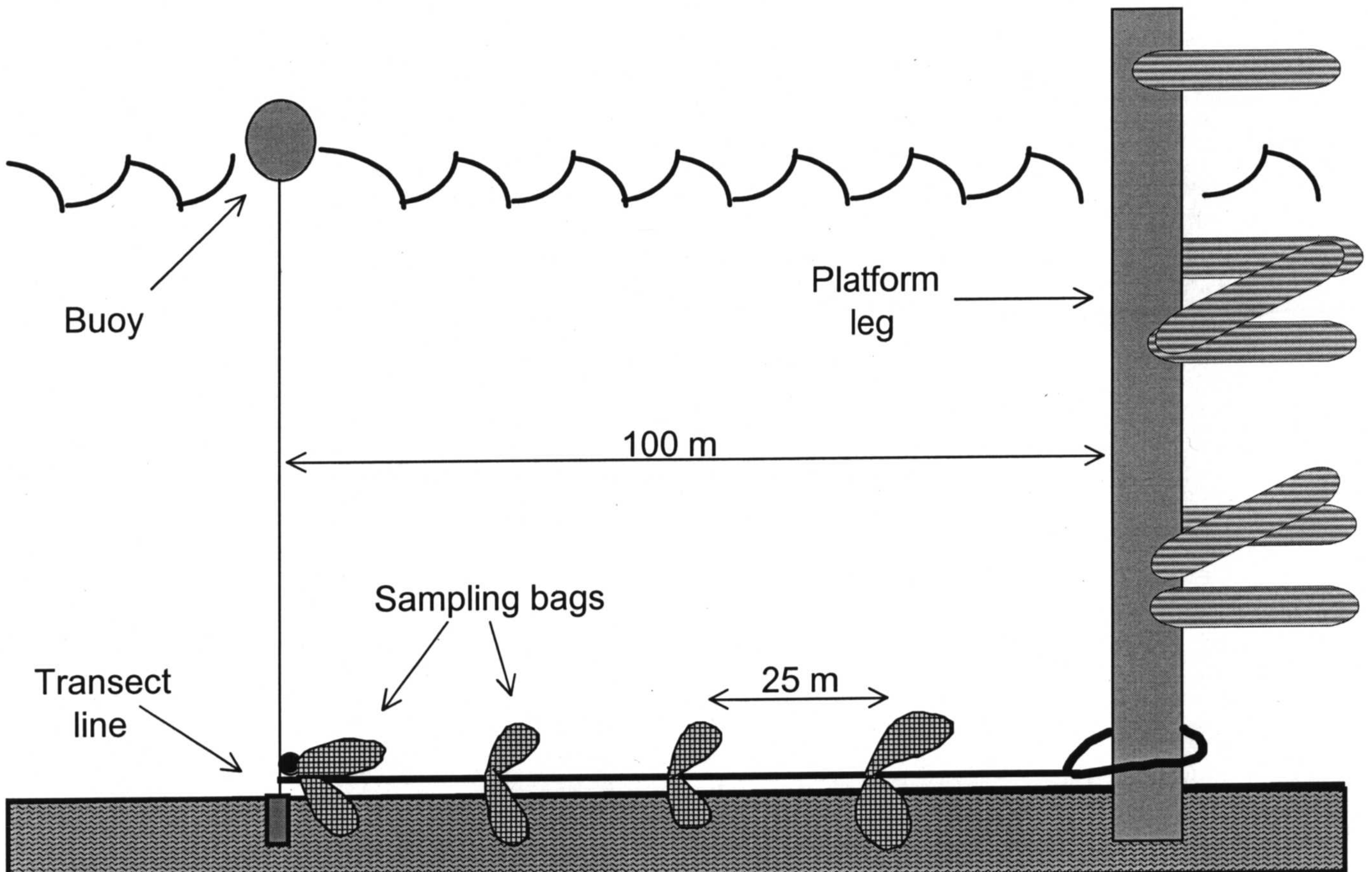

Figure 3. Schematic of transect line sampling showing 100 m line secured to the platform at one end and weighted and staked to the sea floor at the other. Divers deployed from an inflatable boat and followed the buoy line down to the transect line. Divers collected all dead fish within a predetermined sampling width, either 1 or 2 m, on each side of the transect. Fish samples were generally bagged in 25 m increments which allowed calculation of fish estimates at different distances around the platform. Bags with fish were clipped back onto the transect line and empty bags were used for collections along the next section until the entire line was sampled.

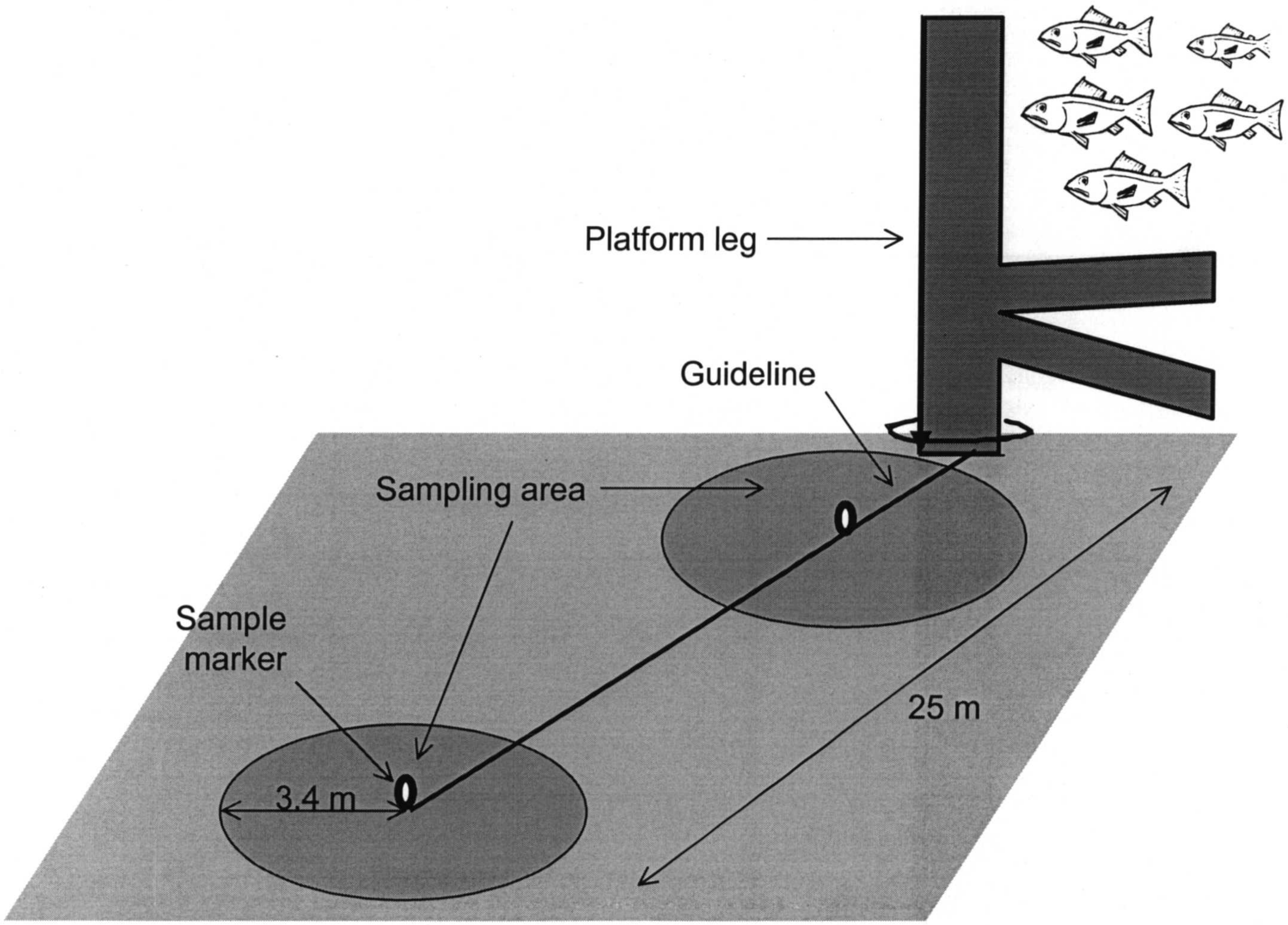

Figure 4. Schematic of circular surveys within 25 m of platform. To prevent overlap with transect line sampling, a guideline was used to mark locations of circular surveys adjacent to the platform. Divers descended along the platform leg and followed the guideline to the marker to begin sampling.

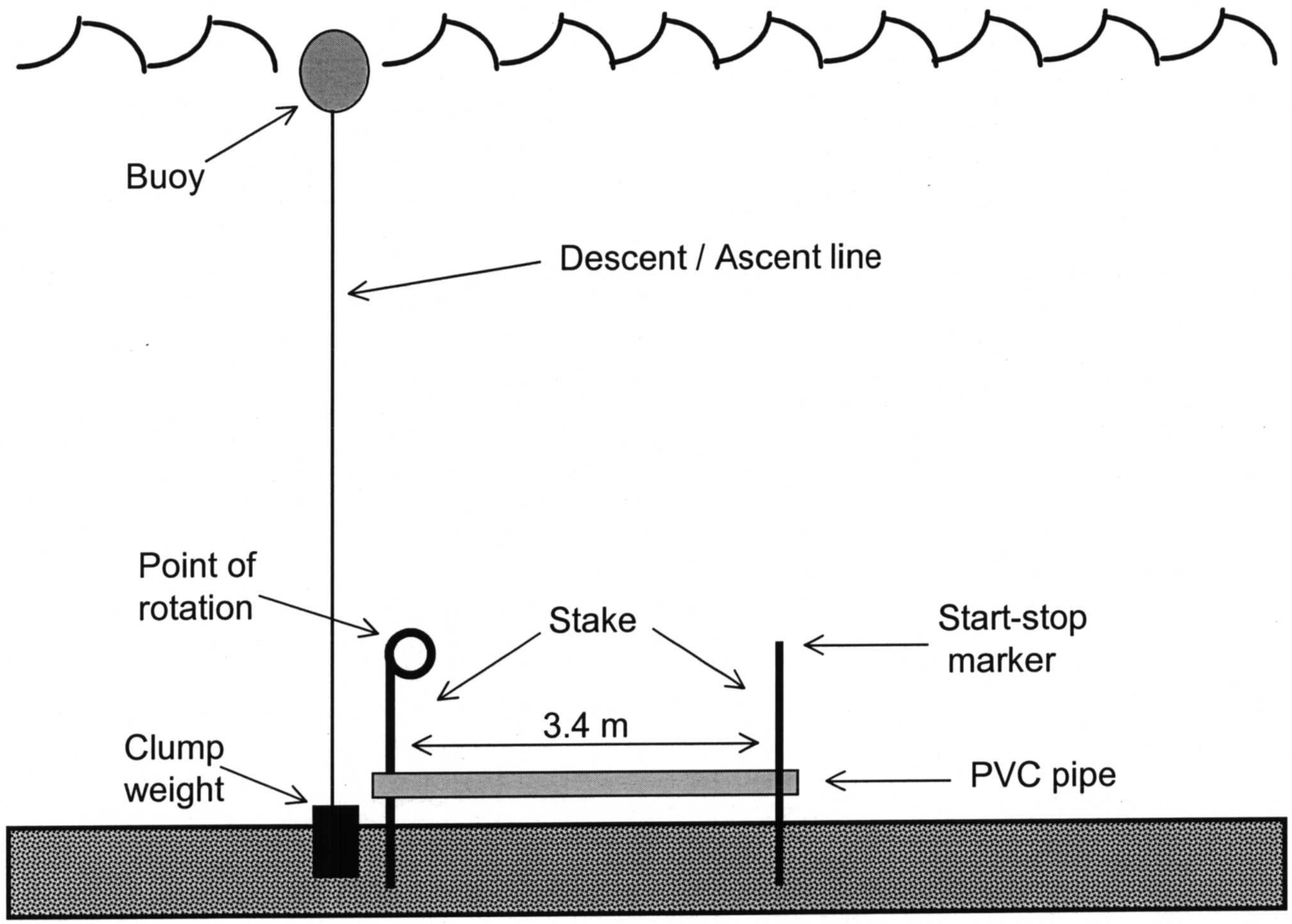

Figure 5. Schematic of circular surveys at distances greater than 25 m from platform. Buoys were set using a compass and range finder to mark sampling locations. Using the staked end of a 3.4 m long PVC pipe as a pivot point, divers collected fish in sampling bags as they swam a circle. When underwater visibility was low, a marker stuck in the sea floor was used to indicate the start-stop point of the survey.

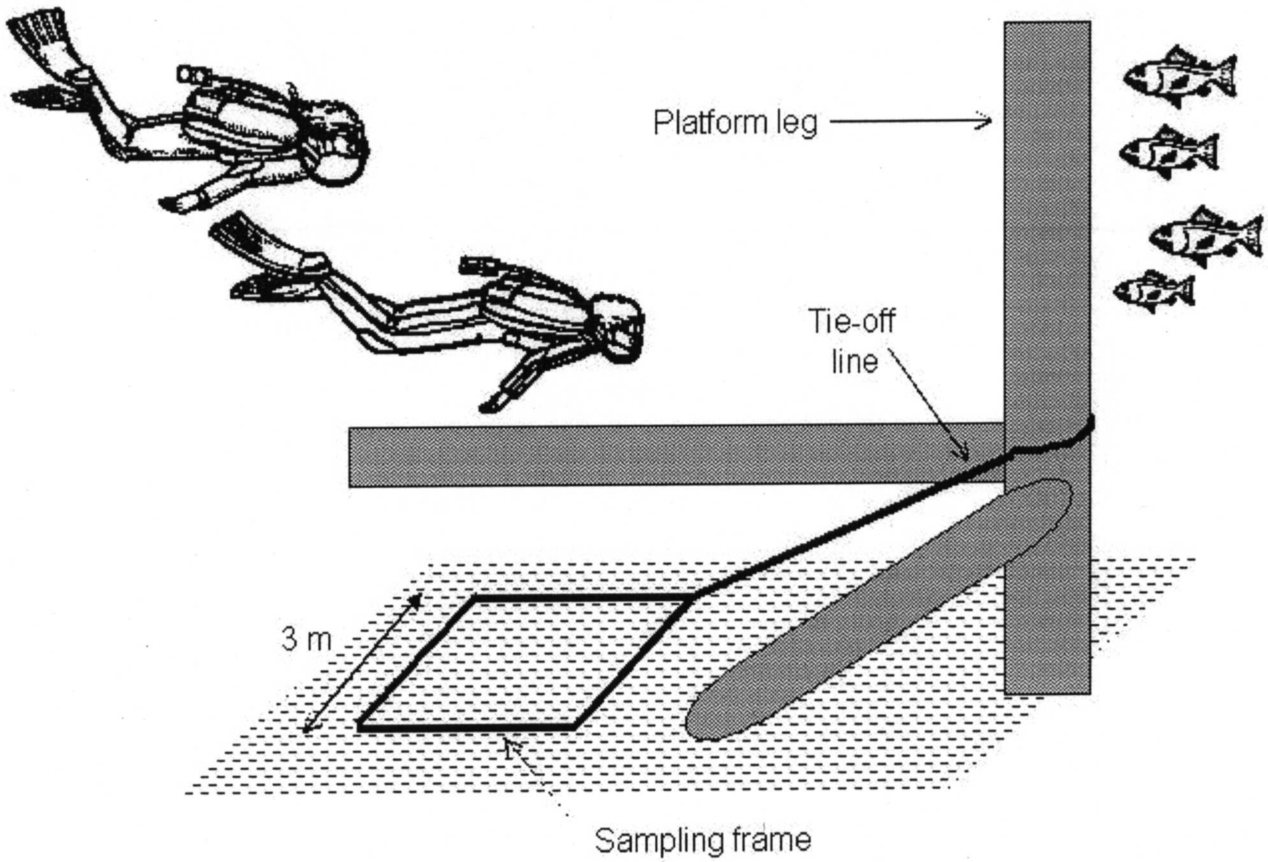

Figure 6. Schematic of sampling under a platform. Sampling frames constructed of PVC pipe were placed beneath the platform. Lines securing the frames to the platform served as rope highways during night dives and when visibility was poor. Divers manually collected all fish that fell within the borders of the sampling frame.

bags. At the large platform at West Delta Block 30, structural members were also used to delineate sampling areas on the sea floor. For further information about diving operations, diver training, and sampling at offshore platforms consult Gitschlag (1995).

3.2 Fish Tagging Study

To estimate fish population size prior to detonation of explosives, a fish mark recapture study was conducted. Fish were captured on rod and reel using assorted hook sizes. Traps were occasionally used to supplement catches. Total length and species were recorded for each fish landed. Fish were tagged with plastic t-bar tags using tagging guns. Only fish that were alive and in good condition were released.

3.3 Analysis

3.3.1 Mortality Estimates

Data recorded for dead fish collected after the explosion included species identification, total length, weight, and tag presence or absence. Unless otherwise stated, all results refer to fish greater than or equal to 8 cm total length since this was the minimum size consistently collected by hand by divers. Sea-floor surface areas were calculated for each region surrounding the platform in 25 m increments out to 100 m. Fish density was determined for each 25 m band around the platform. The ratio of total area to sample area within each band was calculated and multiplied by fish density to determine estimated fish mortality for that region. Mortality estimates for each region were summed to provide a total estimate of fish mortality from the sea floor surrounding the platform. The area immediately under the platform, called the footprint, was determined mathematically after subtracting areas where well conductors penetrated the sea floor. Samples from the footprint area were pooled and fish mortality was estimated as described above. Finally, the estimate from the 100 m area surrounding the platform was combined with that of the footprint and added to the surface mortalities to provide a total mortality estimate for each platform.

3.3.2 Statistical Analysis

Mortality estimates at each platform by species and for all species combined were partitioned into a series of two sample tests to analyze various factor effects. Prior to analysis, data were tested for normality using the Kolmogorov-Smirnov test and for equality of variance using the F-test. When no significant differences were found at $P<=0.05$, single factor ANOVA was used. When either test showed rejection of the null hypothesis, data were transformed using square root and re-tested. In one case where data passed the normality test but transformation did not reduce variance, ANOVA was used when variance was somewhat heteroscedastic ($P=0.03$ for red snapper analysis by longitude).

Due to unequal sample sizes, GLM (general linear model) was used for multivariate analysis for both mortality and length data. Due to the large sample size of length measurements for each of the top five impacted species except mangrove snapper, length data were not subjected to the same rigorous testing for normality and homogeneity of variance prior to GLM analysis in keeping with the Central Limit Theorem. After GLM analysis, plots of means by standard deviations were reviewed to assess patterns indicative of unequal variance. None were observed. When significant differences were found with GLM, main effects were further analyzed using Tukey-Kramer studentized range test for paired comparisons. For analysis of length of positively (floating) and negatively buoyant (sinking) red snapper at each platform, data were not normally distributed and the nonparametric Mann-Whitney test was used. Data at two platforms were log transformed to reduce heteroscedasticity (F-test $P=0.02$ for Block 23 and $P=0.04$ for Block 181).

For mangrove snapper length, sample size was small in some depth-longitude cells so normality and variance testing was performed. Although mangrove snapper length by depth zone was not normally distributed, variance was equal and Mann-Whitney test was used for paired comparisons of three depth zones (<20 m vs 20-30 m, <20 m vs >30 m, and 20-30 m vs >30 m). Mangrove snapper lengths were log transformed to equalize variance for comparison of two depth zones (<20 m vs > 20 m).

Estimated mortality by year and platform volume were analyzed using the Spearman rank correlation coefficient (Glantz 1992). Volume was calculated by multiplying the footprint area of the platform by water depth. This provided an overestimate of platform volume because, except in shallow water, the footprint area on the sea floor is larger than the deck area at the sea surface.

Analysis of fish density around platforms used actual, not estimated, numbers of fish. To approximate the normal distribution, transect data were transformed by log(density + 1). All species were grouped together and analyzed using a two sample t-test assuming unequal variance. According to the Central Limit Theorem, confidence in the results of this procedure increases with increasing sample size because the distribution of the sample mean approaches a normal distribution. Similar procedures were used for analysis of circular survey data.

3.3.3 Population Estimates and Mortality Rates

Estimates of pre-detonation fish populations were calculated using the ratios of tagged to untagged fish as follows:

$$N_b = N_a \times N_{tb}/N_{ta}$$

where Nb is the number of live fish present before blasting, N_a is the number of dead fish collected after blasting, N_{tb} is the number of fish tagged and released before blasting, and N_{ta} is the number of dead tagged fish collected after blasting. This equation was used to estimate pre-detonation population sizes by species. A total fish population estimate was not calculated because species composition of fish tagged prior to detonations differed from that of dead fish collected after detonations. This was a consequence of selectivity of fishing gear used to catch live fish for pre-detonation tagging.

Mortality rates were calculated for species at platforms where both pre-detonation population estimates and post-detonation mortality estimates were determined. Dividing the mortality estimate by the population estimate yielded the mortality rate.

3.3.4 Quantitative Impact on Selected Fish Stocks

The inherent uncertainty in expanding red snapper mortality from "per platform" estimates to annual estimates was acknowledged and accounted for in the evaluation of impacts by including three different versions of the estimate for recent mortality and two versions for future mortality:

Data Set A: Low estimate of annual red snapper mortality based on structure removal data from 1989-98: estimated annual mortality of 29,046 fish.

Data Set B: Moderate to high estimate of annual red snapper mortality based on structure removal data from 1989-98: estimated annual mortality of 41,200 fish.

Data Set C: Low estimate of future annual red snapper mortality based on forecasts of annual structure removals for 1999-2023: estimated annual mortality of 43,157 fish.

Data Set D: High estimate of annual red snapper mortality based on forecasts of annual structure removals for 1999-2023: estimated annual mortality of

66,435 fish.

Data Set E: This data set represents an arbitrary doubling of Data Set B to establish some limits on possible impacts given uncertainties in estimation of platform mortality: estimated annual mortality of 82,400 fish.

Low (Data Set A), moderate to high (Data Set B), and double the moderate to high estimates (Data Set E) of annual red snapper mortality at explosive platform removals were calculated based on information obtained from this and other studies from 1989-98 (see Discussion for details). Similar procedures were used to develop Data Sets C and D to assess future impacts on red snapper based on a forecast of future platform removals (Pulsipher et al., in press).

3.3.4.1 Red Snapper Stock Assessment Methodology

Length frequencies of red snapper were converted to age frequencies using Table 1 of Schirripa and Legault (1999), the most recent red snapper stock assessment analyses. The resulting age-frequency (Figure 7) and platform mortality at age (for each year class, Table 2) indicate that age two was the modal age of platform mortality. Stock assessment analysis was performed on the doubled data set to establish bounds on the purported impact. The additional mortality at age (1989-98) implied by the doubled estimate was added to each year of the annual fishing induced mortality at age estimated from other sources: commercial, recreational, discard mortality and bycatch (Table 3). The stock assessment analysis in Schirripa and Legault (1999) was then repeated using the mortality at age *including* Data Set E for each year, 1989-98.

Note that the assessment analyses in Schirripa and Legault (1999) have evolved in their complexity from earlier work (Goodyear and Phares 1990, Goodyear 1989). The current methods use the same population model; however, improvements in statistical fitting algorithms have allowed the relaxation of assumptions used previously. These improvements have included: 1) mortality at age is not assumed to be known with certainty and statistical variation in mortality is accounted for in the fitting; 2) selectivity at age from each fishery is estimated through the fitting procedure, rather than being imposed through an external assumption; and 3) the stock recruitment model (needed for calculating management benchmarks) is fit simultaneously with other variables rather than being fit after the fact. Details of these modifications are given in Schirripa and Legault (1999).

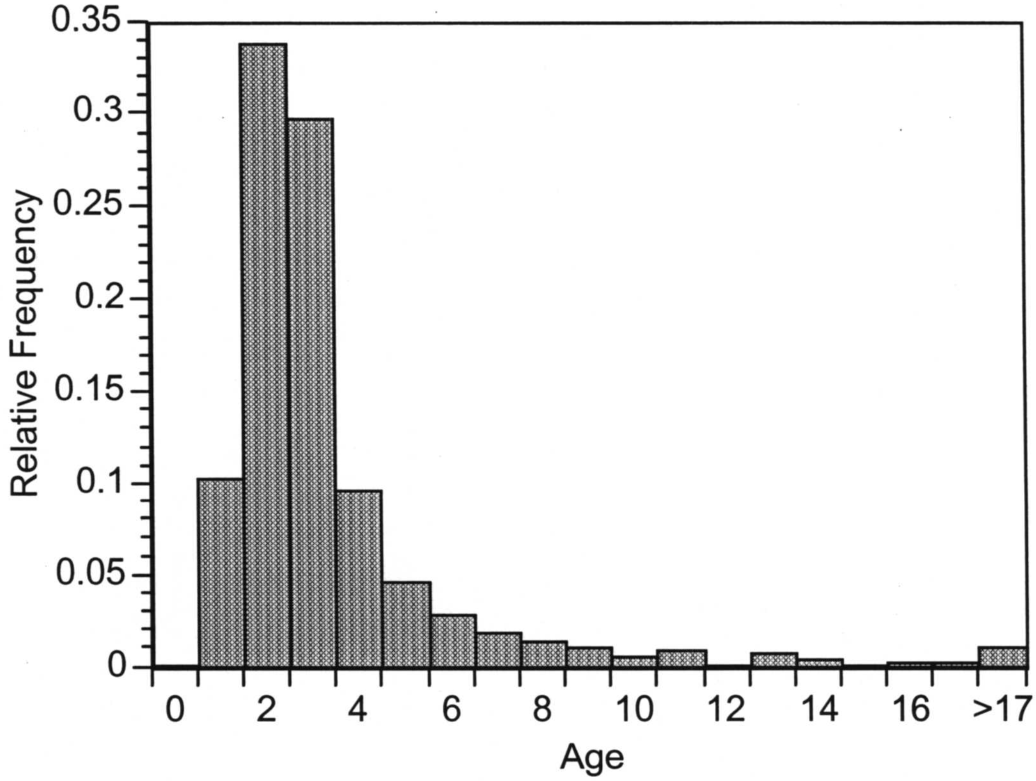

Figure 7. Estimated age frequency of annual platform mortality of red snapper.

Table 2. Estimated platform mortality at age (numbers of red snapper) for each mortality estimate (Data Sets A - E).

Age	Data A	Data B	Data C	Data D	Data E
0	27	39	42	65	80
1	2935	4148	4423	6809	8445
2	9784	13923	14599	22473	27874
3	8704	12327	12860	19796	24554
4	2809	3985	4149	6387	7922
5	1334	1896	1971	3034	3763
6	843	1185	1237	1904	2362
7	550	788	820	1262	1566
8	427	602	629	968	1201
9	321	451	474	730	905
10	186	264	279	429	533
11	283	398	420	647	802
12	36	52	54	83	103
13	211	300	318	490	607
14	111	154	160	246	305
15	14	26	28	43	53
16	72	99	105	162	200
17	84	117	123	189	235
>17	315	446	466	717	890
Total	29046	41200	43157	66435	82400

Data Set A: Low estimate of annual red snapper mortality based on structure removal data from 1989-98.

Data Set B: Moderate to high estimate of annual red snapper mortality based on structure removal data from 1989-98.

Data Set C: Low estimate of future annual red snapper mortality based on forecasts of annual structure removals for 1999-2023.

Data Set D: High estimate of annual red snapper mortality based on forecasts of annual structure removals for 1999-2023.

Data Set E: This data set represents an arbitrary doubling of Data Set B to establish some limits on possible impacts given uncertainties in estimation of platform mortality.

Table 3. A. Mortality at age of red snapper including directed fisheries mortality (including release mortality) and bycatch (from Schiripa and Legault 1999). B. Proportion of additional mortality from platform removals using Data Set E (double the moderate to high estimate of annual red snapper mortality at platform removals based on 1989-98 data).

A.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15+
1984	8045789	7302444	506023	864375	540476	270269	127047	30311	39326	24281	14530	15416	20249	15126	12203	60674
1985	5070414	12371844	432742	339458	302873	260491	152088	73475	19594	29908	21538	14256	16145	21952	16571	77366
1986	10842855	7392935	595474	723587	120196	205164	203251	100490	44564	12127	19847	15603	11092	13487	19531	91445
1987	8827322	14100342	324418	979206	273198	44206	101539	126078	64519	25668	6331	9900	7740	5499	6776	59906
1988	10246806	11636915	672163	536294	599219	144512	27728	78146	111708	61296	24391	5918	9177	7203	5132	61561
1989	16479304	10180341	444697	1049868	135491	236220	69519	15217	49015	76716	44447	17890	4311	6572	5050	41309
1990	15994584	35611302	286573	613345	393603	31700	67176	25476	6541	23053	37293	21861	8782	2127	3290	25304
1991	20893292	24191064	639866	609185	284748	225460	19545	42668	17351	4826	18569	32722	20762	8850	2241	30905
1992	16086854	12985745	299222	1996646	225908	143947	157250	16675	41639	18803	5657	22958	41467	26483	11163	38440
1993	18256121	14202511	362664	1183261	1508757	60209	49074	91187	14434	46772	24905	8234	35108	64271	40825	65438
1994	19752131	21180642	311503	885412	702375	718076	18205	13368	29594	5920	23644	15015	5707	27407	55113	112695
1995	19966959	23153641	188159	797526	461400	244759	300186	7043	4858	11564	2632	11964	8500	3521	18116	120108
1996	13140123	22019964	232382	806827	783925	259742	175625	239360	5020	3127	7215	1671	7897	5886	2554	115397
1997	15104940	24125247	333637	1153038	885121	356024	127735	108431	178746	4235	2816	6716	1592	7680	5851	123459
1998	16526770	9469581	218530	803275	1125239	452510	152838	55392	52581	97317	2511	1778	4464	1106	5544	104431

B.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15+
1989	0.001	0.003	0.055	0.008	0.028	0.010	0.023	0.079	0.018	0.007	0.018	0.006	0.141	0.046	0.010	0.038
1990	0.001	0.001	0.086	0.013	0.010	0.075	0.023	0.047	0.138	0.023	0.022	0.005	0.069	0.143	0.016	0.062
1991	0.000	0.001	0.038	0.013	0.013	0.010	0.080	0.028	0.052	0.110	0.043	0.003	0.029	0.034	0.024	0.051
1992	0.001	0.002	0.082	0.004	0.017	0.016	0.010	0.072	0.022	0.028	0.142	0.004	0.015	0.012	0.005	0.041
1993	0.000	0.002	0.068	0.007	0.002	0.039	0.032	0.013	0.063	0.011	0.032	0.013	0.017	0.005	0.001	0.024
1994	0.000	0.001	0.079	0.009	0.005	0.003	0.086	0.090	0.031	0.090	0.034	0.007	0.106	0.011	0.001	0.014
1995	0.000	0.001	0.130	0.010	0.008	0.010	0.005	0.171	0.186	0.046	0.305	0.009	0.071	0.087	0.003	0.013
1996	0.001	0.001	0.106	0.010	0.005	0.009	0.009	0.005	0.180	0.170	0.111	0.062	0.077	0.052	0.021	0.014
1997	0.001	0.001	0.074	0.007	0.004	0.007	0.012	0.011	0.005	0.126	0.285	0.015	0.381	0.040	0.009	0.013
1998	0.001	0.003	0.112	0.010	0.003	0.005	0.010	0.022	0.017	0.005	0.319	0.058	0.136	0.276	0.010	0.015
Avg.	0.001	0.002	0.083	0.009	0.010	0.018	0.029	0.054	0.071	0.062	0.131	0.018	0.104	0.071	0.010	0.029

In conjunction with the red snapper stock assessment analysis using the additional mortality from Data Set E, management benchmarks and population characteristics were recalculated. These included: fishing mortality rate at which the slope of the yield-per-recruit curve is one tenth of what it is at the origin (F0.1); the fishing mortality rate that maximizes yield-per-recruit (Fmax); the fishing mortality rate which reduces spawning potential ratio to 20%, 30%, and 40% of what it would be with no fishing (F20%SPR, F20%SPR, F40%SPR); the fishing mortality rate that would eventually produce maximum sustainable yield (FMSY); and the most recent estimate of fishing mortality rate (for 1998, F1998). Additionally, Maximum Sustainable Yield (MSY), the biomass that would support the taking of MSY (BMSY), and the spawning stock in number of eggs that would support MSY (SSMSY) were also calculated. The results were compared to results from the base case stock assessment (Schirripa and Legault 1999).

3.3.4.2 Gag (*Mycteroperca microlepis*) Stock Assessment Methodology

Gag, a popular recreational and commercial grouper, were present in the platform removal samples (Table 4). The mean number of gag killed per platform (only 1.6) was expanded to an annual estimate equivalent to the ratio of red snapper in Data Set E relative to the mean kill per platform removal (82,400/514.7). This yielded an annual platform removal kill of 256 gag per year (under Data Set E assumptions). This value was compared to the results of the most recent gag stock assessment (Schirripa and Legault 1997) which are reproduced in Table 5.

3.3.4.3 Red Drum (*Sciaenops ocellatus*) Stock Assessment Methodology

Red drum were also present in low numbers in the platform removal samples (Table 4). The mean number of red drum killed per platform removal (6.0) was expanded to an annual estimate equivalent to the ratio of red snapper in Data Set E relative to the mean kill per platform (82,400/514.7). This yielded an annual platform removal kill of 961 red drum per year (under Data Set E assumptions). This value was compared to the results of the most recent red drum stock assessment (Porch 2000) which are reproduced here in Table 6.

Table 4. Estimated mortality and descriptive statistics by species and platform.

SPECIES	SMI 23	WD 30	ST 146	SS 158	WC 172	WC 173	WC 181	SS 209	GA 288	Total	Mean	Std error	Std dev	Var	95% confidence level
Almaco jack	29	0	1	0	0	0	0	0	0	30	3	3	10	92	7
Atlantic bumper	0	0	0	0	46	201	0	0	0	247	27	22	67	4471	51
Atlantic croaker	0	0	0	0	0	7	0	0	0	7	1	1	2	5	2
Atlantic spadefish	2069	631	698	1689	911	1068	2401	633	2774	12875	1431	275	824	679238	634
Atlantic thread herring	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Belted sand bass	11	0	0	0	1	0	17	0	0	29	3	2	6	40	5
Bermuda chub	0	0	0	0	0	0	43	0	0	43	5	5	14	204	11
Black drum	0	19	6	0	2	14	0	0	3	44	5	2	7	48	5
Blue runner	611	33	1592	1069	219	0	684	13	646	4867	541	181	542	294154	417
Bluespotted searobin	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
Chub mackerel	0	0	0	0	0	0	0	0	4	4	0	0	1	2	1
Cocoa damselfish	0	0	0	0	0	0	4	0	0	4	0	0	1	2	1
Crevalle jack	0	0	0	0	5	0	0	0	0	5	1	1	2	2	1
Cubbyu	0	0	0	0	0	0	0	0	66	66	7	7	22	487	17
Gag	6	6	2	0	0	0	0	0	0	14	2	1	3	7	2
Gray triggerfish	144	1	16	116	13	0	22	43	44	399	44	17	52	2685	40
Great barracuda	5	0	0	0	0	0	0	0	0	5	1	1	2	2	1
Guaguanche	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Gulf toadfish	0	0	0	0	0	0	0	0	24	24	3	3	8	63	6
Hardhead catfish	0	6	0	0	4	397	0	0	0	407	45	44	132	17466	101
Harvest fish	0	0	0	0	0	5	0	00	0	5	1	1	2	2	1
Ladyfish	0	3	0	0	0	0	0	0	0	3	0	0	1	1	1
Lane snapper	34	0	60	0	1	0	0	193	82	371	41	22	65	4197	50
Leopard toadfish	53	0	0	0	0	0	0	0	0	53	6	6	18	317	14
Lookdown	0	3	0	0	0	0	0	0	0	3	0	0	1	1	1
Mangrove snapper	63	364	240	44	1	1	0	324	64	1100	122	49	146	21322	112
Molly miller	0	0	0	0	0	0	4	0	0	4	0	0	1	2	1
Mullet	0	22	0	0	0	0	0	0	0	22	2	2	7	54	6
Ocean triggerfish	0	0	2	0	0	0	0	0	0	2	0	0	1	0	1
Pigfish	23	0	0	0	3	0	0	0	31	57	6	4	12	141	9
Pinfish	0	0	0	0	0	3	0	0	17	20	2	2	6	33	4
Planehead filefish	44	0	0	0	0	0	0	0	0	44	5	5	15	213	11
Red drum	0	0	0	35	0	0	0	0	19	54	6	4	12	156	10
Red snapper	1193	24	298	296	498	709	709	418	487	4632	515	111	332	110174	255
Remora	0	0	0	0	13	0	0	0	0	13	1	1	4	19	3
Rock hind	0	0	9	0	0	0	7	0	5	22	2	1	4	14	3
Scaled sardine	0	0	0	0	8	0	0	0	0	8	1	1	3	7	2
Scamp	3	0	0	0	0	0	0	0	0	3	0	0	1	1	1
Schoolmaster	9	0	0	0	0	0	0	0	0	9	1	1	3	9	2
Scrawled filefish	0	0	0	0	0	0	4	0	0	4	0	0	1	2	1
Sergeant major	0	0	0	0	5	16	0	0	0	21	2	2	5	30	4
Sharksucker	0	0	0	0	0	3	0	0	0	3	0	0	1	1	1
Sheepshead	330	1007	120	395	457	386	968	61	370	4094	455	110	329	108436	253
Silk snapper	0	0	0	39	0	0	0	0	0	39	4	4	13	166	10
Silver trout	0	0	140	0	1	0	0	0	0	141	16	16	47	2173	36
Spanish sardine	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Speckled trout	0	3	0	0	0	0	0	0	0	3	0	0	1	1	1
Tomtate	0	0	0	0	0	0	0	0	464	464	52	52	155	23929	119
Unknown damselfish	0	0	0	0	0	0	0	0	16	16	2	2	5	30	4
Unknown eel	0	0	0	0	0	0	0	27	0	27	3	3	9	81	7
Unknown soapfish	0	0	1	0	0	0	0	0	38	39	4	4	13	161	10
Unknown	0	6	0	0	0	0	0	46	0	52	6	5	15	231	12
Whitespotted soapfish	23	0	3	0	4	0	10	5	53	97	11	6	17	302	13
Yellow chub	1	0	0	0	0	0	0	2	5	8	1	1	2	3	1
Yellowtail snapper	6	0	0	0	0	0	0	0	0	6	1	1	2	4	2
Total	4657	2128	3188	3682	2193	2812	4874	1765	5216	30513	3390	429	1288	1658640	990

Table 5. A. Gulf of Mexico gag catch at age (without platform removal estimates). B. Estimated number at age. C. Estimated fishing mortality rate at age. All tables are from most recent assessment (Schirripa & Legault 1990).

A. Catch at age

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
0	59221	17064	21342	14255	1068	119235	4402	64897	858	5892	6184
1	150908	72295	73647	93977	44157	6239	186202	20761	293570	4570	40385
2	187199	141039	153511	134722	64317	95021	9592	383520	38167	579451	12745
3	137228	130462	157149	111652	68312	90321	100872	8076	360526	35789	499217
4	121975	107169	116331	87660	70015	82589	78855	73083	1981	224942	15467
5	92876	71323	77917	62485	48354	60262	59415	64918	11315	699	88126
6	55241	38484	45741	38867	32296	32872	37890	47029	13893	3108	325
7	26739	18265	23514	20851	20965	18430	19099	26062	14064	4192	1717
8	12104	8837	10046	9442	12559	9747	10293	11592	9326	5081	2513
9	4594	3756	4262	3100	6513	4842	5265	5790	4495	3901	3114
10	1605	1480	1268	1046	2365	2147	2664	2740	2336	2065	2398
11	976	1055	585	274	1212	945	1805	2345	1918	2099	2552
Total	850666	611229	685313	578331	372133	522650	516354	710813	752449	871789	674743

Annual Ave of Total = 649679.1

B. Number at age

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
0	1094081	931874	756028	564509	43760	2441090	218696	3297382	85338	976042	252318
1	1006385	886835	786259	630946	472669	36675	1990625	184154	2777948	72656	834626
2	807251	726637	696374	608568	456145	365956	25798	1540989	139291	2119309	58303
3	552892	521915	495078	457567	399351	333116	227266	13370	972240	84666	1289343
4	371871	349175	328764	281211	290735	280568	203357	102856	4116	504744	39947
5	222007	207623	201698	175782	161201	185584	165298	102426	21916	1723	227606
6	109492	105629	112972	101860	93725	94144	104175	87534	28804	8478	839
7	50693	43525	55464	55137	51881	50906	50739	54759	32205	12029	4435
8	20248	19099	20658	26106	28254	25358	26837	26082	23186	14785	6490
9	7443	6347	8317	8553	13771	12771	12851	13621	11790	11373	8043
10	2844	2203	2023	3246	4505	5869	6533	6216	6397	6009	6193
11	1729	1570	934	850	2309	2583	4426	5320	5252	6108	6591
Total	4246936	3802432	3464569	2914335	2018306	3834620	3036601	5434709	4108483	3817922	2734734

C. Fishing mortality rate at age

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
0	0.06	0.0199	0.0309	0.0276	0.0266	0.054	0.0219	0.0214	0.0109	0.0065	0.0267
1	0.1757	0.0918	0.1062	0.1744	0.1059	0.2018	0.106	0.1292	0.1206	0.0701	0.0535
2	0.2861	0.2337	0.27	0.2713	0.1643	0.3264	0.5073	0.3106	0.3479	0.347	0.2674
3	0.3096	0.3122	0.4156	0.3035	0.203	0.3435	0.6428	1.0282	0.5056	0.6012	0.5348
4	0.4328	0.3988	0.4761	0.4065	0.2989	0.3791	0.5358	1.3961	0.721	0.6464	0.5348
5	0.5928	0.4586	0.5332	0.4789	0.3878	0.4274	0.4857	1.1186	0.7997	0.569	0.5348
6	0.7725	0.4942	0.5673	0.5247	0.4604	0.4681	0.4931	0.8499	0.7232	0.4981	0.5348
7	0.8261	0.5953	0.6036	0.5186	0.5658	0.4902	0.5154	0.7094	0.6285	0.467	0.5348
8	1.0101	0.6814	0.7318	0.4896	0.6441	0.5297	0.5282	0.644	0.5623	0.4588	0.5348
9	1.0674	0.9932	0.7908	0.4909	0.703	0.5203	0.5764	0.6058	0.5241	0.4577	0.5348
10	0.9188	1.2468	1.0962	0.4234	0.82	0.4968	0.5728	0.6367	0.4957	0.4588	0.5348
11	0.9188	1.2468	1.0962	0.4234	0.82	0.4968	0.5728	0.6367	0.4957	0.4588	0.5348
Ages 3-20	0.8399	0.9805	0.8987	0.4372	0.6824	0.4791	0.5599	0.742	0.551	0.4858	0.5348
Ages 3-15	0.8095	0.878	0.8227	0.4425	0.6295	0.4722	0.5549	0.7825	0.5722	0.4962	0.5348
Ages 6-15	0.9189	1.0245	0.9271	0.4564	0.7293	0.4989	0.555	0.6629	0.5412	0.4634	0.5348

Table 6. Catch at age of red drum (without platform removal mortality) from most recent assessment (Porch 2000).

Year	Age 0	1	2	3	4	5	6	7	8	9	10+	Total
1979	1223084	4684690	709840	92050	97256	135919	178673	121113	141873	72783	431952	7889233
1980	663585	3694230	1262266	120094	69124	72896	172633	221795	150351	176186	626671	7229831
1981	981272	1994110	1081798	442832	99963	53528	78330	171767	220642	149507	798426	6072175
1982	1755830	3308810	832672	308113	170404	72370	60050	80289	176060	226106	971668	7962371
1983	475074	3881589	1845374	310492	206858	173902	98398	74226	99249	217539	1480621	8863322
1984	426804	2390703	1660383	452747	380959	270300	306508	162009	122186	163367	2795218	9131183
1985	510186	3709014	2176560	815334	417795	484652	478113	532728	281456	212304	5141256	14759398
1986	614832	3646962	1866425	252018	110609	41997	53657	52648	58655	30993	589525	7318320
1987	648498	2095886	1384156	151684	41402	25393	14012	17177	16848	18771	198592	4612420
1988	440500	1062259	931303	145979	29404	1960	5151	2751	3373	3309	42687	2668676
1989	368500	460121	857058	138123	50965	5416	6037	5295	2829	3467	47287	1945097
1990	574500	396099	535085	117468	22372	829	4902	3127	2742	1465	26287	1684877
1991	970500	2319526	654009	99601	53300	1414	13382	6196	3952	3466	35078	4160424
1992	759800	1578037	1667890	60833	24962	3269	10685	7954	3683	2349	22908	4142370
1993	876400	1217060	1590896	233959	17041	1863	15513	9538	7099	3287	22543	3995199
1994	914900	1884994	1290323	228481	84922	1056	8233	14131	8686	6465	23527	4465720
1995	817500	2127316	1812427	192410	101655	6929	7458	8579	14723	9050	31251	5129299
1996	677300	1232365	1253477	121355	52221	12543	36396	6347	7302	12532	34302	3446139
											Mean 1989-96 =	**3621141**

4.0 RESULTS

4.1 Fish < 8 cm TL (Total Length)

With the exception of this section, results describe only fish greater than or equal to 8 cm in total length. This appeared to be the minimum size which divers routinely collected by hand. At one site where a large number of very small fish were observed, all fish no matter what size were painstakingly collected within a single 1.5 X 1.5 m frame on the sea floor beneath the platform. Specimens included 117 vermilion snapper (*Rhomboplites aurorubens*), 6 round scad (*Decapterus punctatus*), 2 lane snapper (*Lutjanus synagris*), and 2 scaled sardine (*Harengula pensacolae*). Mortality of small vermilion snapper measuring < 8 cm TL within the footprint area of this platform was estimated at approximately 5,900. Estimated mortality of all small fish in the footprint area alone exceeded 6,200 compared with a total estimated mortality (footprint area plus 100 m radius) of approximately 4,900 for fish measuring >8 cm.

4.2 Estimated Mortality

4.2.1 Overview

Total estimated mortality per platform ranged from 1,765-5,216 with a mean of 3,390, standard error 429, and 95% confidence level of 990. Four species including Atlantic spadefish (*Chaetodipterus faber*), blue runner (*Caranx crysos*), red snapper, and sheepshead (*Archosargus probatocephalus*) accounted for 86% of the total estimated mortality. Inclusion of mangrove snapper (*Lutjanus griseus*), the species with the next highest estimated mortality, raised this value to 90% (Table 7). Descriptive statistics for all species collected are presented in Table 4. Although gray triggerfish ranked only eighth in mean estimated mortality it was noteworthy because it was the only species outside of the top five that was collected at eight of nine platforms studied. Mean estimated mortality per platform was 1,431 for Atlantic spadefish, 541 for blue runner, 515 for red snapper, 455 for sheepshead, 122 for mangrove snapper, and 44 for gray triggerfish. Range in estimated mortality by platform was 631-2,774 for Atlantic spadefish, 0-1,592 for blue runner, 24-1,193 for red snapper, 61-1,007 for sheepshead, 0-364 for mangrove snapper, and 0-144 for gray triggerfish. Standard error was 275 for Atlantic spadefish, 181 for blue runner, 111 for red snapper, 110 for sheepshead, 49 for mangrove snapper, and 17 for gray triggerfish. For other species, estimated mortality per platform exceeded 200 only once out of nine platforms studied. These species included Atlantic bumper (*Chloroscombrus chrysurus*,

Table 7. Estimated mortality of the five most impacted species.

Species	Total estimated mortality	% of total estimated mortality
Atlantic spadefish	12875	42
Blue runner	4867	16
Red snapper	4632	15
Sheepshead	4094	13
Mangrove snapper	1100	4
Total	27568	90

201), hardhead catfish (*Arius felis*, 397), and tomtate (*Haemulon aurolineatum*, 464).

Atlantic spadefish occurred in large, tightly knit schools that remained in close contact with the structure, usually within roughly 20-40 m. Blue runner were found at platforms in both large and small schools. Blue runner ranged more widely around platforms than did Atlantic spadefish, sometimes on the order of several hundred meters, and may escape serious impact from explosives if they are further from the platform at the instant charges are detonated. Red snapper occurred at all platforms studied. Estimated mortality ranged from the low hundreds to over a thousand except at the shallowest structure where mortality was 24. Sheepshead also occurred at all study sites. This species was found right at the structure rather than ranging at some distance. Estimated mortality was generally in the low to mid hundreds but exceeded one thousand at one platform. Mangrove snapper were numerous at two-thirds of the study sites and were much less abundant than red snapper. Gray triggerfish were found at all but one platform studied but always in modest numbers (usually less than 100) compared with the more abundant schooling species such as Atlantic spadefish and red snapper. Tomtate were only found at one structure (Galveston Area Block 288) where they were abundant. Hardhead catfish were found at three platforms. Nearly 400 hardhead catfish were estimated at one platform although estimated mortality at two other structures was four and six. Atlantic bumper were only reported at two platforms with values estimated at 46 and 201. Mean mortality per platform for other species of interest including gag grouper, lane snapper, and red drum was 2, 41, and 6, respectively.

Fish mortality resulting from the use of underwater explosives may be affected by many factors including but not limited to water depth, platform location, platform age, platform size and complexity, salinity, temperature, weight of explosives used in structure removal, and seasonal and annual variations. A series of graphs plotting estimated mortality by each of these parameters appears in Figures 8-14.

4.2.2 Mortality by Depth and Longitude

Estimated mortality by depth was plotted for each species and for all species combined (Figure 8). The graph for all species combined was very similar to that for Atlantic spadefish which accounted for 42% of total estimated mortality. Mortality plots for all species combined showed a steady increase with water depth from 14 m to a maximum at 23 m followed by a continuous decline with further increase in depth. Estimated mortality at the maximum study depth (32 m) was nearly the same as that at the shallowest study depth (14 m). Estimated mortality

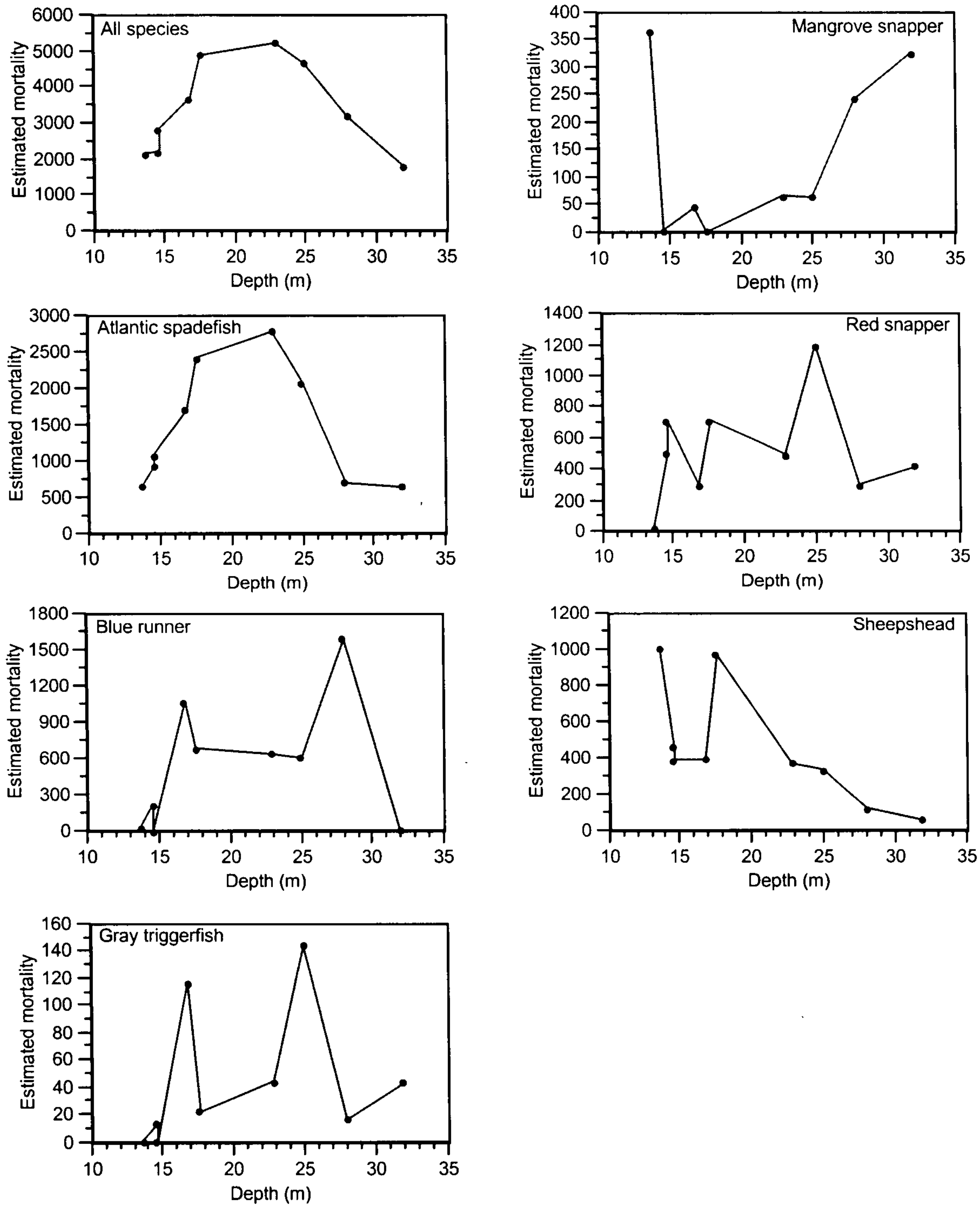

Figure 8. Estimated mortality at platforms by water depth and species.

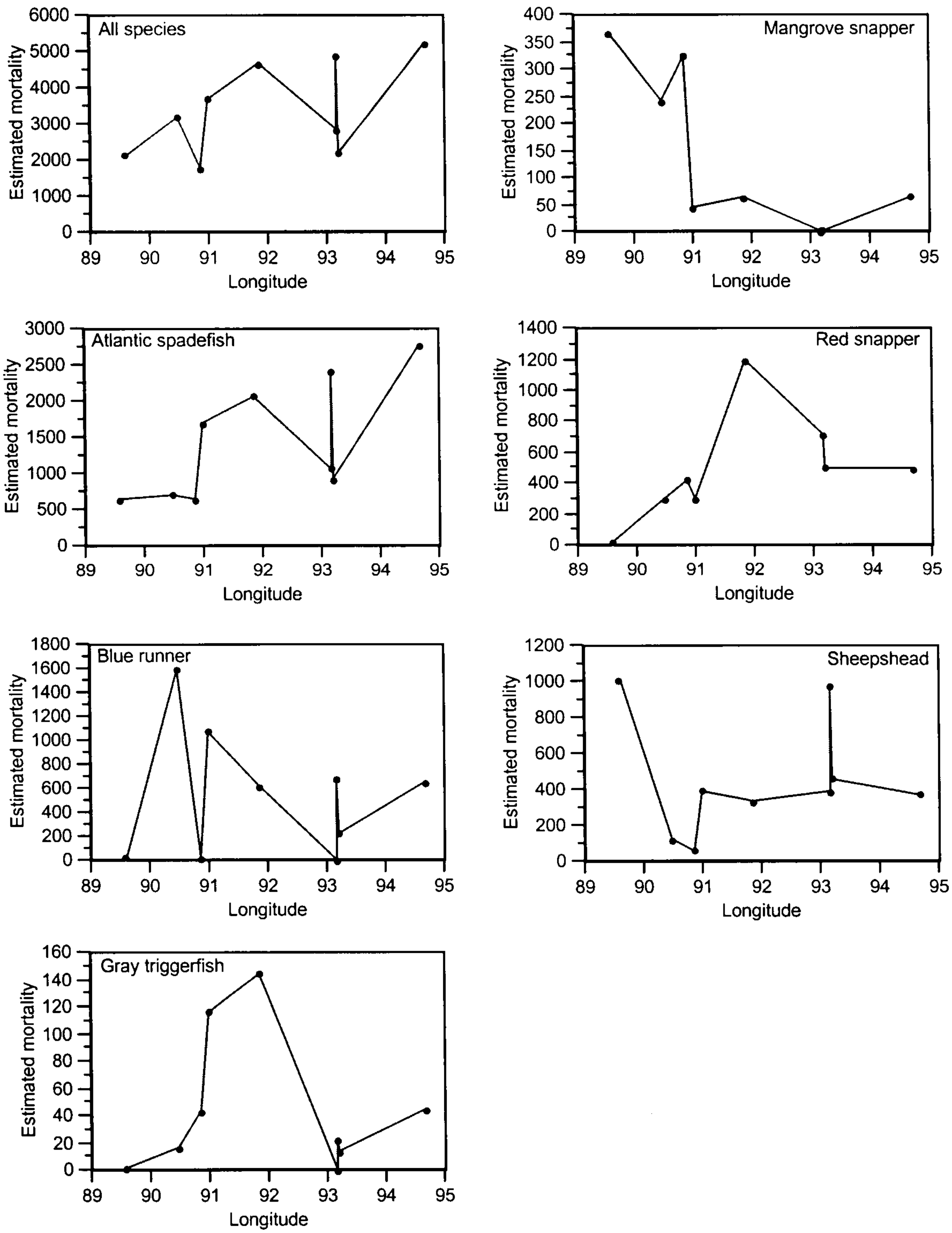

Figure 9. Estimated mortality at platforms by longitude and species.

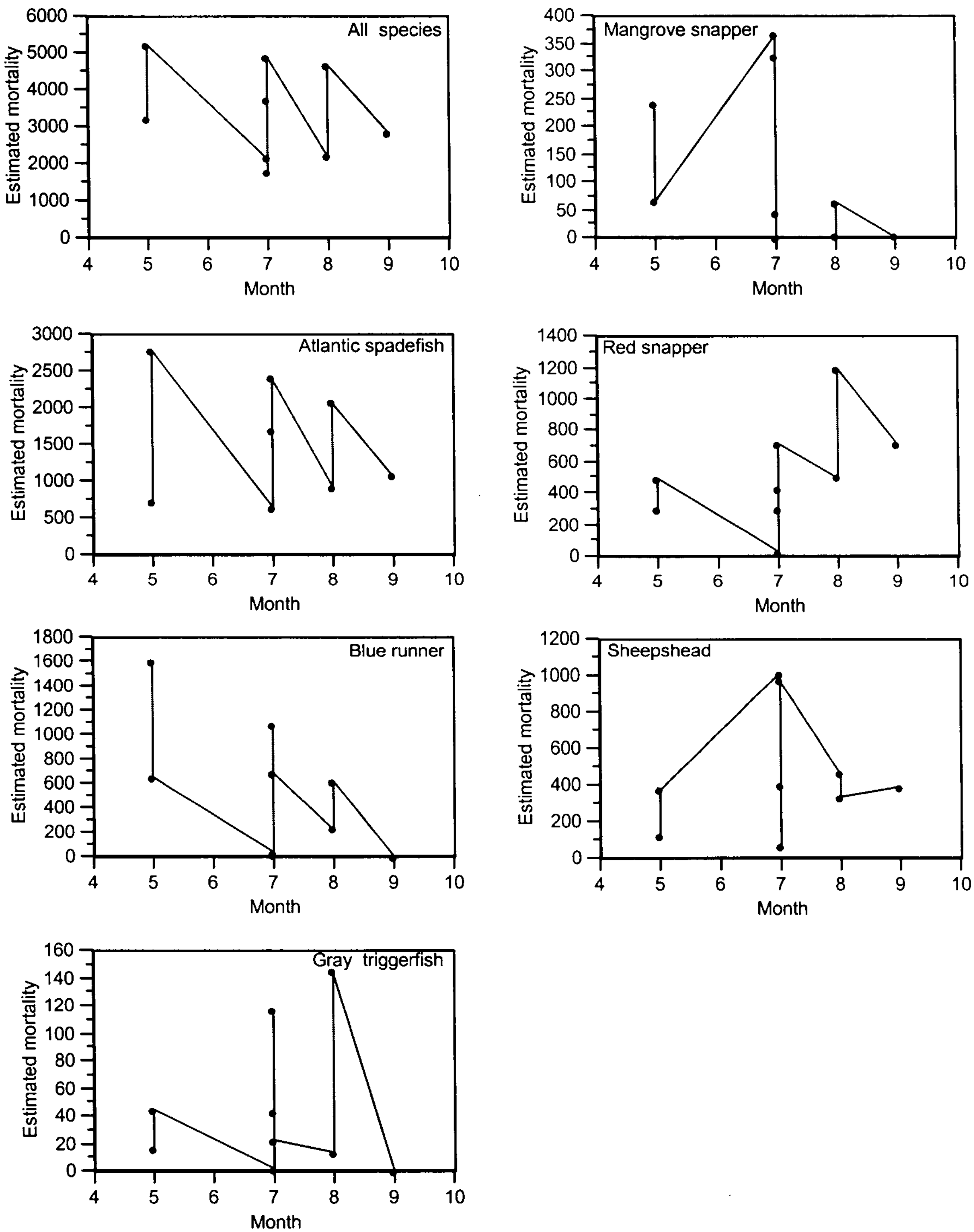

Figure 10. Estimated mortality at platforms by month and species.

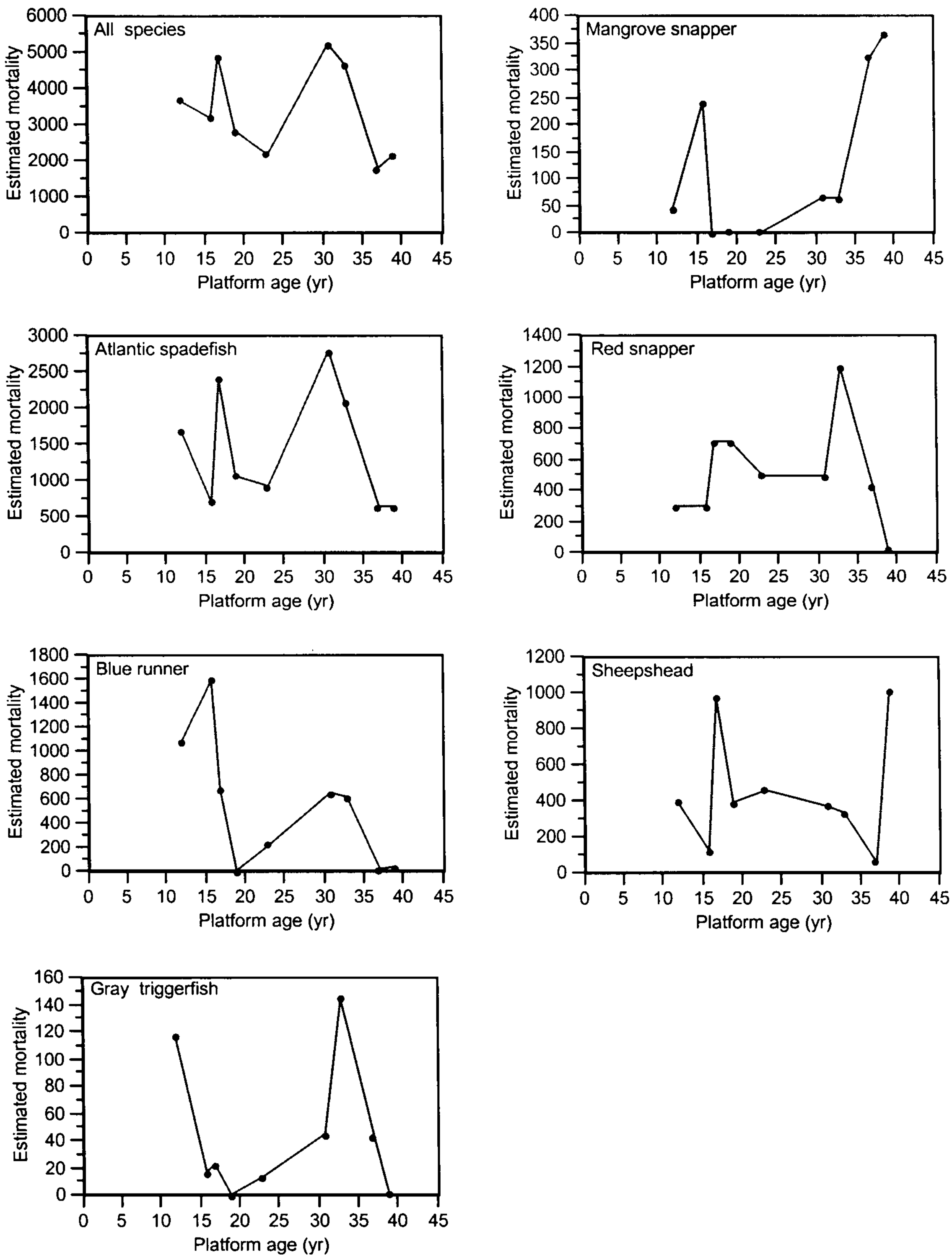

Figure 11. Estimated mortality at platforms by platform age and species.

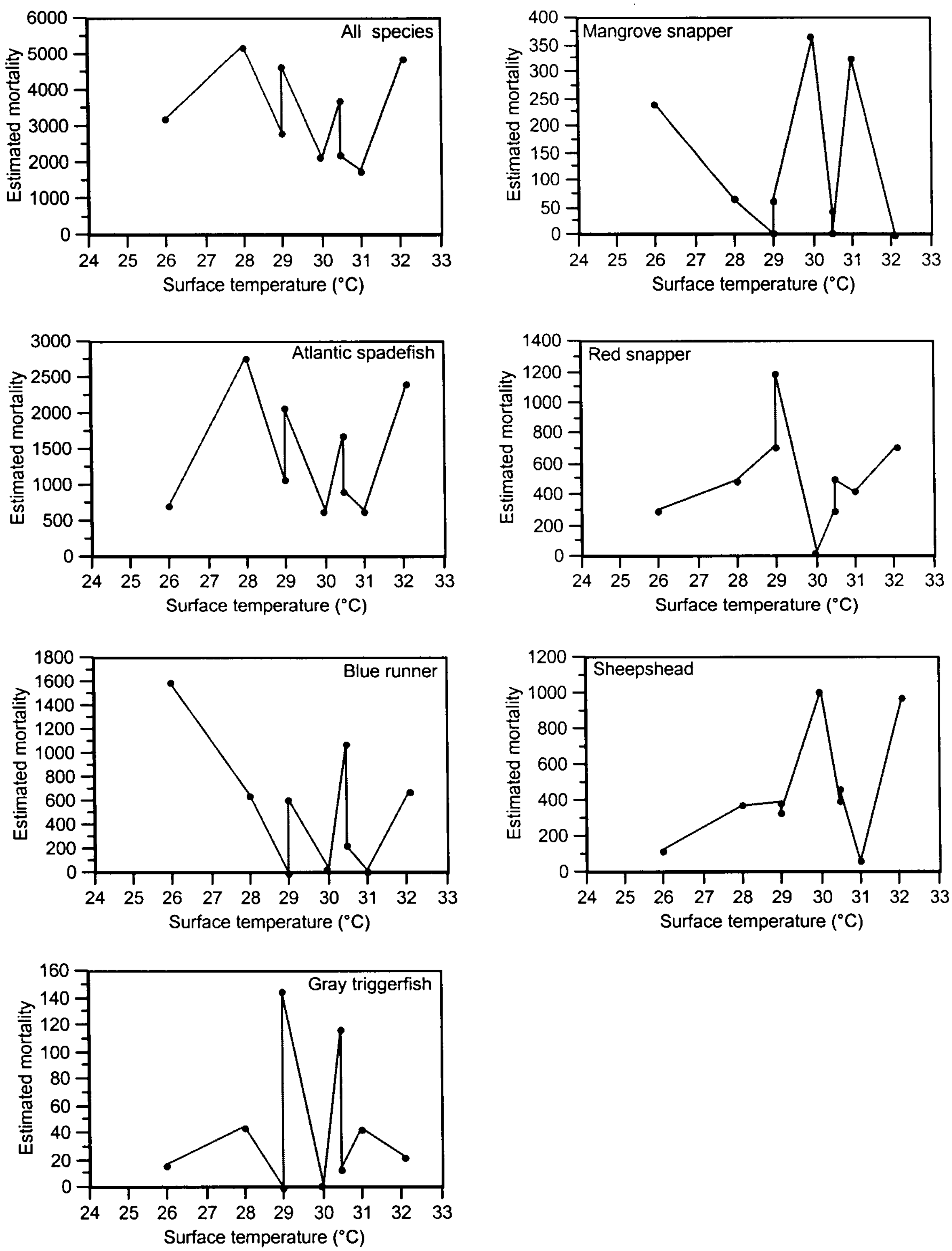

Figure 12. Estimated mortality at platforms by surface water temperature and species.

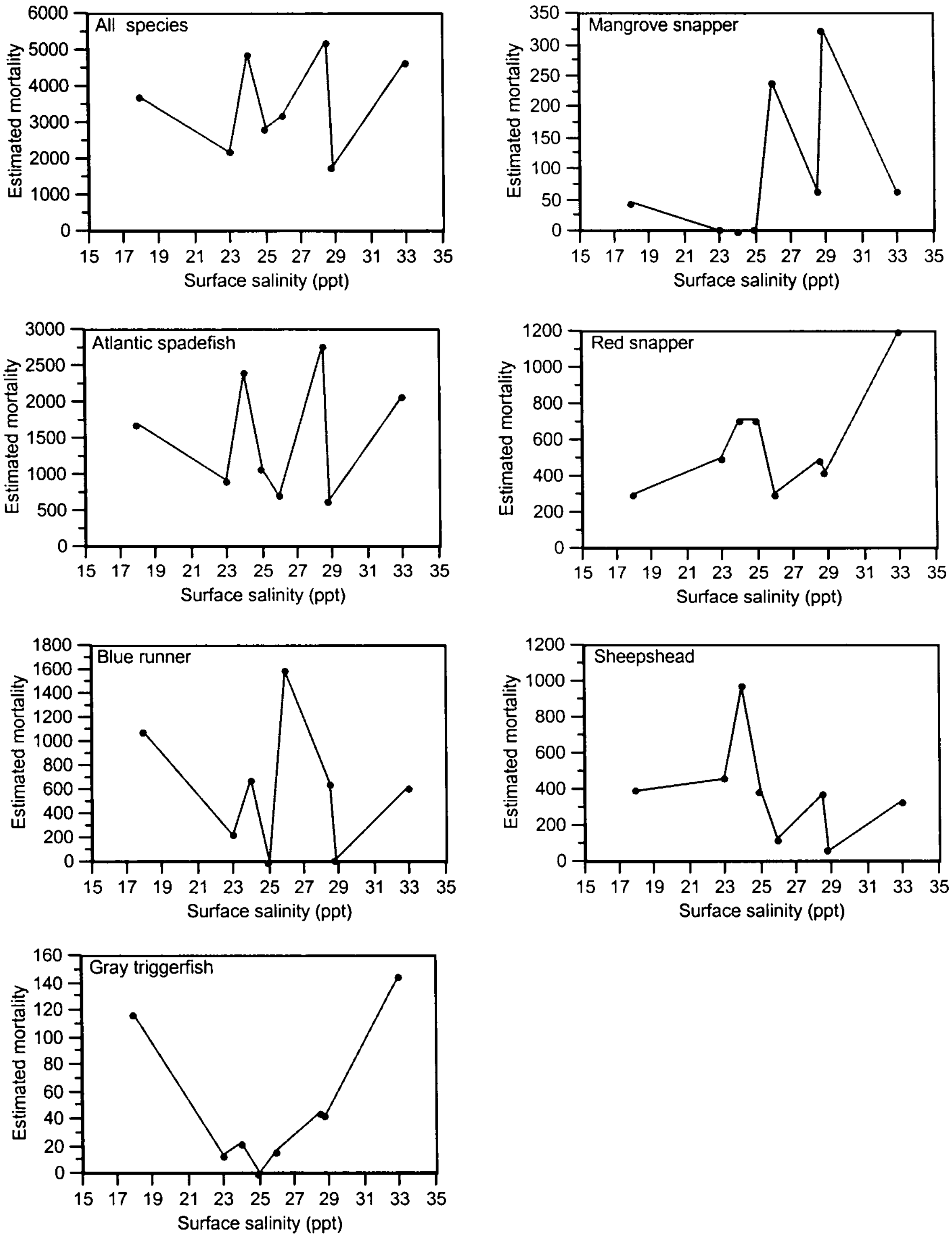

Figure 13. Estimated mortality at platforms by surface water salinity and species.

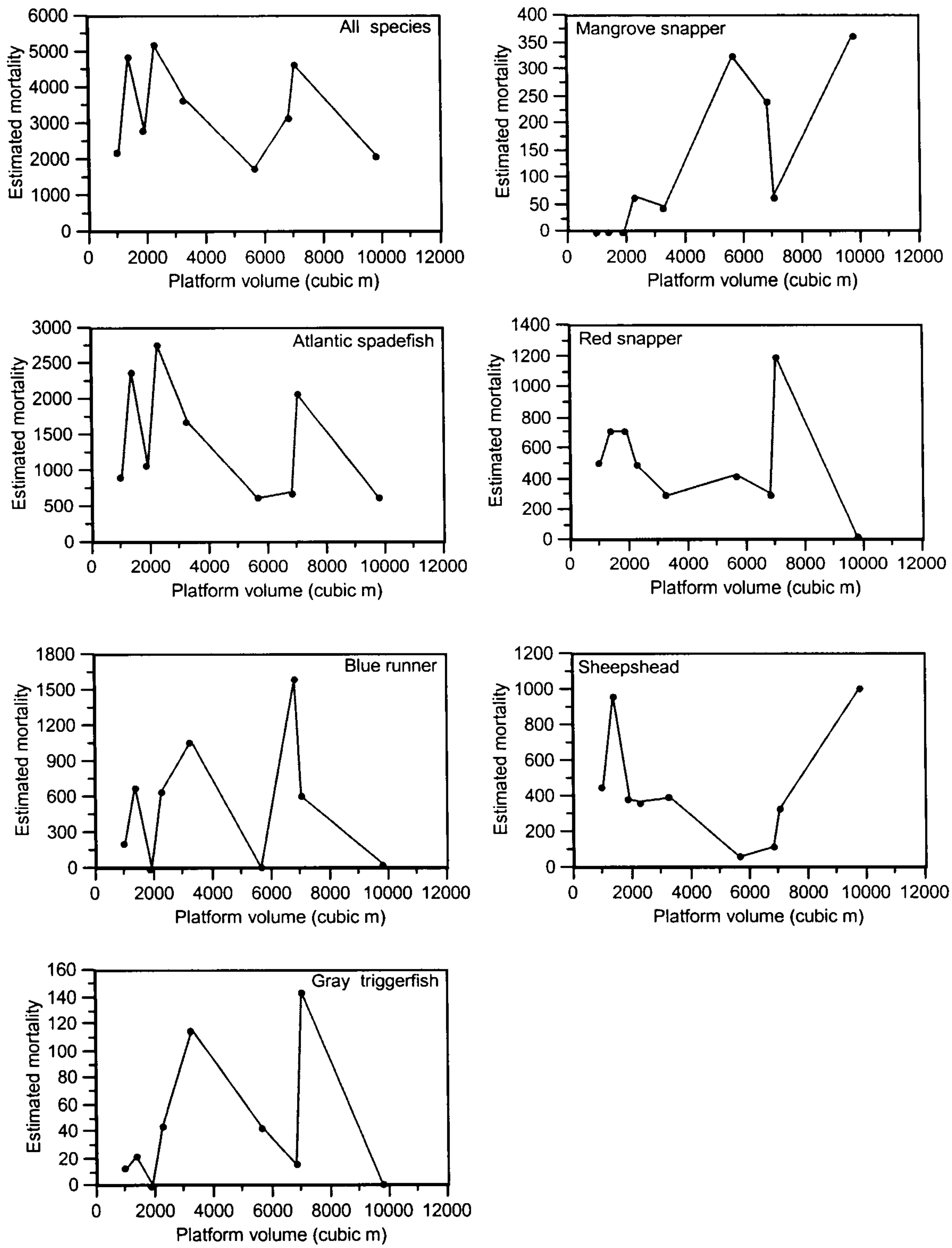

Figure 14. Estimated mortality at platforms by platform size and species.

of blue runner varied widely from 0-1592. Plots showed highest values at depths between 17-28 m. Estimated mortality of gray triggerfish at three platforms in depths less than 15 m was low, 13 or less. At greater depths values ranged from 16-144. Mortality of mangrove snapper was highest at the shallowest platform, 14 m, located off the Mississippi delta in an area at least occasionally influenced by lenses of clearer, offshore water. At platforms deeper than 20 m mangrove snapper mortality estimates displayed a general increase with depth. In contrast, mortality estimates for red snapper were lowest at the shallowest study site but were relatively high and quite variable (296-1193) at increased depths. Mortality estimates for sheepshead were highly variable at depths below 20 m but continuously decreased at greater depths.

Estimated mortality for each species and all species combined was compared for water depths <20 m versus >20 m using ANOVA (Table 8). Despite general trends described above, a significant difference (P=0.05) was found only for sheepshead with estimated mortality continuously decreasing at depths greater than 20 m.

Longitude was used as an indication of platform location along the east-west axis through the study area. Graphs of estimated mortality by longitude showed a high degree of variability for Atlantic spadefish, blue runner, sheepshead, and all species combined (Figure 9). Peaks in estimated mortality for gray triggerfish occurred at mid-longitudes while other values were much lower. For mangrove snapper highest mortality occurred east of 91°. This contrasted with red snapper where highest values were observed at higher longitudes to the west.

Estimated mortality for each species and all species combined was compared for longitude <92° versus >92° (longitude of Lafayette, Louisiana is 92°) using ANOVA (Table 8). There was no significant difference (P>0.05) for any species except mangrove snapper (P=0.01).

To further focus on platform location as a factor in determining the extent of impacts due to underwater explosives, GLM two factor analysis with interaction for 3 depths (<20 m, 20-30 m, >30 m) by 2 longitudes was used to analyze differences in estimated mortality. No significant difference (P>0.05) was found for depth and longitude interaction for Atlantic spadefish, blue runner, gray triggerfish, mangrove snapper, red snapper, sheepshead, and all species combined.

4.2.3 Mortality by Season

Mortality assessments at explosive platform removals were conducted during May, July, August, and September. Time frame of the study spanned late spring through summer. Graphs of estimated

Table 8. ANOVAs for estimated mortality by test parameter for the six most impacted species and all species combined.

	Blue runner	Gray triggerfish	Mangrove snapper	Red snapper	Sheeps-head	Spade-fish	All
Depth <20m vs >20m	0.42	0.25	0.19	0.53	0.05	0.74	0.55
Longitude <=92 and >92	0.49	0.27	0.01	0.52	0.37	0.27	0.46
Platform age <25yr. vs >25yr.	0.32	0.51	0.09	0.91	0.93	0.78	0.92
Season Spring (May) vs Summer (Jul, Aug, Sep)	0.09	0.68	0.53	0.59	0.34	0.59	0.35
Surface temperature <30°C vs >=30°C	0.43	0.75	0.61	0.23	0.34	0.51	0.25
Surface salinity <=26ppt vs >26ppt	0.51	0.21	0.21	0.40	0.33	0.47	0.61

mortality by month indicated extreme month to month variability (Figure 10). Estimated mortality for each species and all species combined was compared for spring (May) versus summer (July-September) using ANOVA (Table 8). There was no significant difference (P>0.05) for Atlantic spadefish, blue runner, gray triggerfish, mangrove snapper, red snapper, sheepshead, or all species combined.

4.2.4 Mortality by Platform Age

Graphs of estimated mortality by platform age indicated great variability (Figure 11). Estimated mortality for each species and all species combined was compared for platform age <25 yr vs >25 yr using ANOVA (Table 8). No significant difference (P>0.05) was found for Atlantic spadefish, blue runner, gray triggerfish, mangrove snapper, red snapper, sheepshead, or all species combined.

4.2.5 Mortality by Surface Temperature and Salinity

Surface temperature ranged from 26-32°C with a mean of 30°C while surface salinity ranged from 18-33 ppt with a mean of 26 ppt. Separate graphs of estimated mortality by temperature and salinity showed high variability for Atlantic spadefish, blue runner, gray triggerfish, mangrove snapper, red snapper, sheepshead, and all species combined (Figures 12 and 13). No significant difference (P>0.05) in estimated mortality was found for surface water temperature (<30°C vs >=30°C) or salinity (<=26 vs >26 ppt; Table 8).

4.2.6 Estimated Mortality by Platform Size

The volume of water enclosed within the boundary of the platform served as an index of platform size. Plots of estimated mortality by platform size are shown in Figure 14. Estimated mortality by platform size was analyzed using Spearman rank correlation coefficients. P values ranged from >0.2 to >0.5 for Atlantic spadefish, blue runner, gray triggerfish, red snapper, sheepshead, and all species combined, but was <0.02 for mangrove snapper. This indicated no correlation between estimated mortality and platform volume for any species except mangrove snapper.

4.3 Length-Frequency

Although a sufficient number of transect, circular, and frame samples were collected from the sea floor to estimate total mortality at nine of ten platforms studied, sampling of dead fish floating on the surface was completed at all ten locations. Graphs of total length by species and platform appear in Figures 15-20. GLM was used to analyze length by depth, longitude, and their interaction for surface and bottom fish collections at all platforms combined. Depth zones were defined as <20 m and >20 m and longitude was partitioned into groups <92° and >92°. Significant differences in total length ($P<=0.003$) were found for all three parameters for blue runner, red snapper, Atlantic spadefish, sheepshead, and all species combined (Table 9). Mangrove snapper lengths also varied significantly ($P<0.03$) with depth, but longitude was not tested due to small sample size at longitudes above 92°. Mean lengths of blue runner (36.3 vs 30.6 cm), mangrove snapper (48.5 vs 34.9 cm), and sheepshead (40.9 vs 34.6 cm) were greater in deeper water while red snapper (36.0 vs 37.3 cm) and Atlantic spadefish (27.8 vs 31.1 cm) were smaller (Table 10). Larger fish were found east of 92° for blue runner (35.7 vs 30.6 cm) and red snapper (36.7 vs 35.8) but not for Atlantic spadefish (28.0 vs 31.0 cm) and sheepshead (33.3 vs 38.7 cm).

4.4 Population Estimates and Mortality Rates

Pre-detonation population estimates were calculated whenever tag/recapture studies provided sufficient data. In most tag/recapture experiments using conventional techniques, recapture rates of 2-5 % are anticipated. Recovery rates as high as 73% (Table 11) attest to the effectiveness of sampling with explosives. Red snapper estimates at 7 platforms ranged from 503-1943 with a mean of 905 and standard error of 196 (Table 12). Atlantic spadefish population estimates at three platforms ranged from 1432-1782 with a mean of 1564 and standard error of 110. At four platforms gray triggerfish were estimated to number 63-131 with a mean of 104 and standard error of 16. The blue runner population was estimated at 558 at one platform while almaco jack (*Seriola rivoliana*) numbered only 28 at another platform.

Mortality rates were determined for species and platforms where pre-detonation population estimates were calculated (Table 13). Mortality rate is the estimated mortality divided by population estimate. Rates for red snapper varied from 59-88% with a mean of 71% and standard error of 4. Atlantic spadefish rates ranged from 72-135% with a mean of 108 and standard error of 19. Mortality rates for gray triggerfish varied from 68-125% with a mean of 81 and standard error of 30. Mortality rates for blue runner and almaco jack were 123% and 104%, respectively.

Table 9. GLM analysis of total length by depth (<20m vs >20m) and longitude (<92° vs >92°) for most impacted species.

	P values			
	Depth	**Longitude**	**Interaction**	**N**
Atlantic spadefish	0.000	0.000	0.000	4020
Blue runner	0.000	0.000	0.000	845
Mangrove snapper	0.027	-	-	562
Red snapper	0.000	0.003	0.000	2983
Sheepshead	0.000	0.000	0.000	1993
All species	0.000	0.000	0.000	11964

Table 10. Mean total length by depth (<20m vs >20m) for the most impacted species and all species combined.

	<20m	**n**	**>20m**	**n**
Atlantic spadefish	31.1	2271	27.8	1749
Blue runner	30.6	342	36.3	503
Mangrove snapper	34.9	245	48.5	317
Red snapper	37.3	904	36.0	2079
Sheepshead	34.6	1591	40.9	402
All species	33.0		33.9	

Table 11. Recapture rates (100 x number of tags recovered / number of tags released) for tag-recapture study.

	Platform							
Species	**SMI 23**	**ST 146**	**SS 158**	**WC 172**	**WC 173**	**WC 181**	**SS 209**	**GA 288**
Almaco jack	25							
Atlantic spadefish			13		72	34		
Blue runner						29		
Gray triggerfish	24		13				30	
Red snapper	41	49		73	19	20	62	44

Table 12. Population estimates by species and platform.

Species	SMI 23	ST 146	SS 158	WC 172	WC 173	WC 181	SS 209	GA 288	Mean	Std error	Std dev	Var	95% confidence level
	Platform												
Almaco jack	28								28	0			
Atlantic spadefish			1432		1477	1782			1564	110	190	36258	473
Blue runner						558			558				
Gray triggerfish	129		93				63		95	19	33	1092	82
Red snapper	1943	503		597	1091	1048	601	553	905	196	517	26754	478

Table 13. Mortality rates (100 x estimated mortality / population estimate) by species and platform.

Species	SMI 23	ST 146	SS 158	WC 172	WC 173	WC 181	SS 209	GA 288	Mean	Std error	Std dev	Var	95% confidence level
	Platform												
Almaco jack	104								104	0			
Atlantic spadefish			118		72	135			108	19	32	1044	80
Blue runner						123			123				
Gray triggerfish	112		125				68		102	17	30	874	73
Red snapper	61	59		83	65	68	70	88	71	4	11	121	10

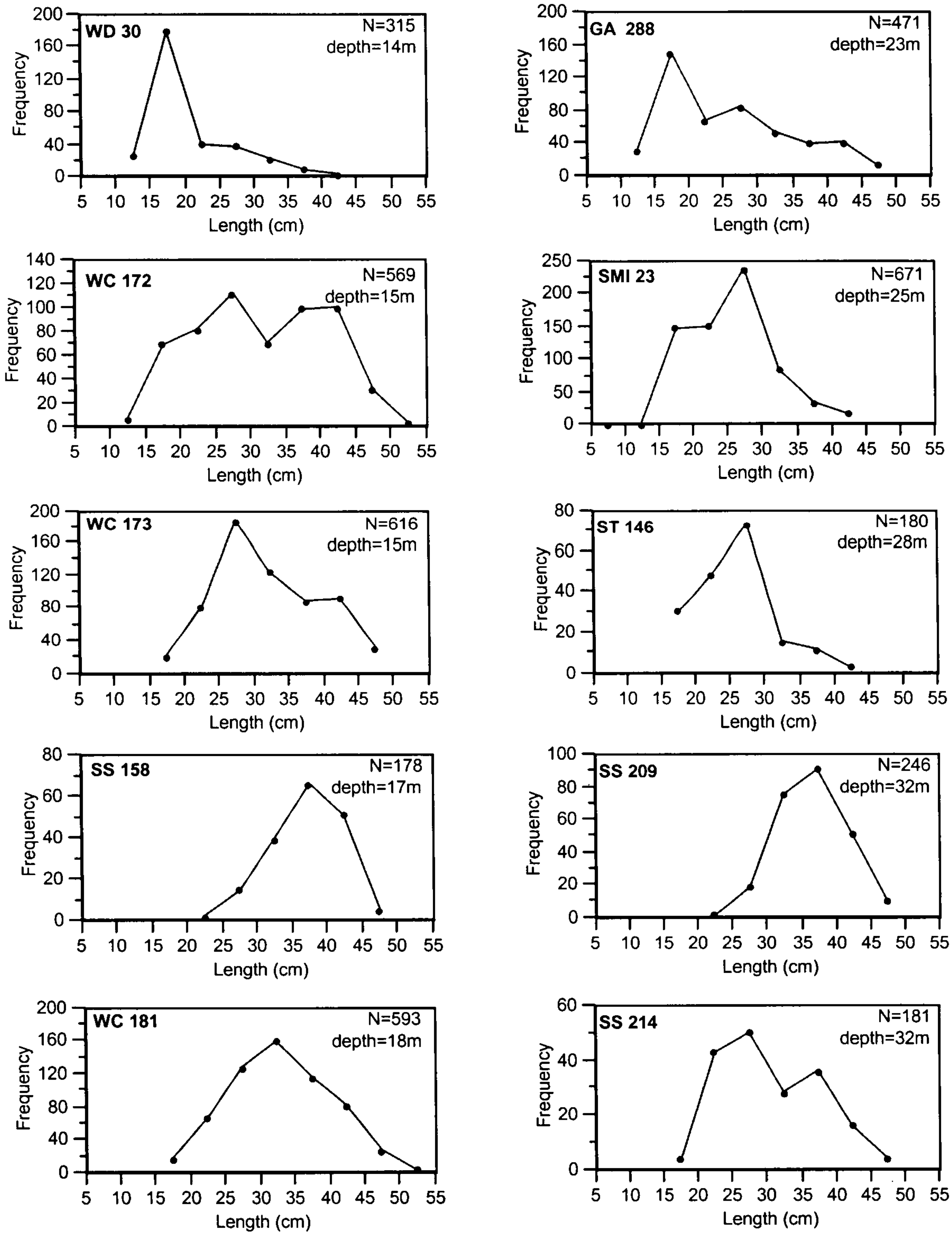

Figure 15. Length-frequency (TL in cm) of Atlantic spadefish by platform.

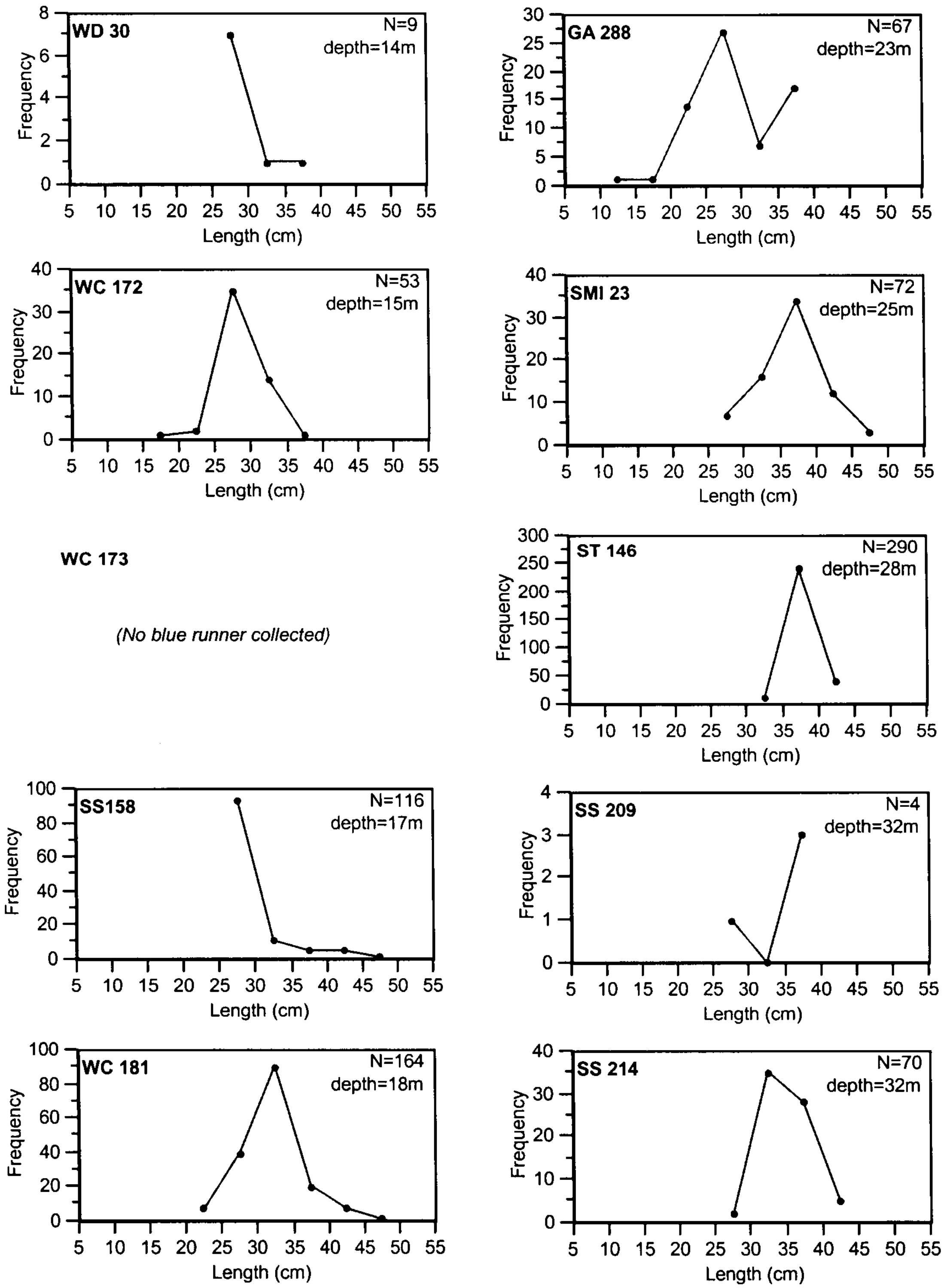

Figure 16. Length-frequency (TL in cm) of blue runner by platform.

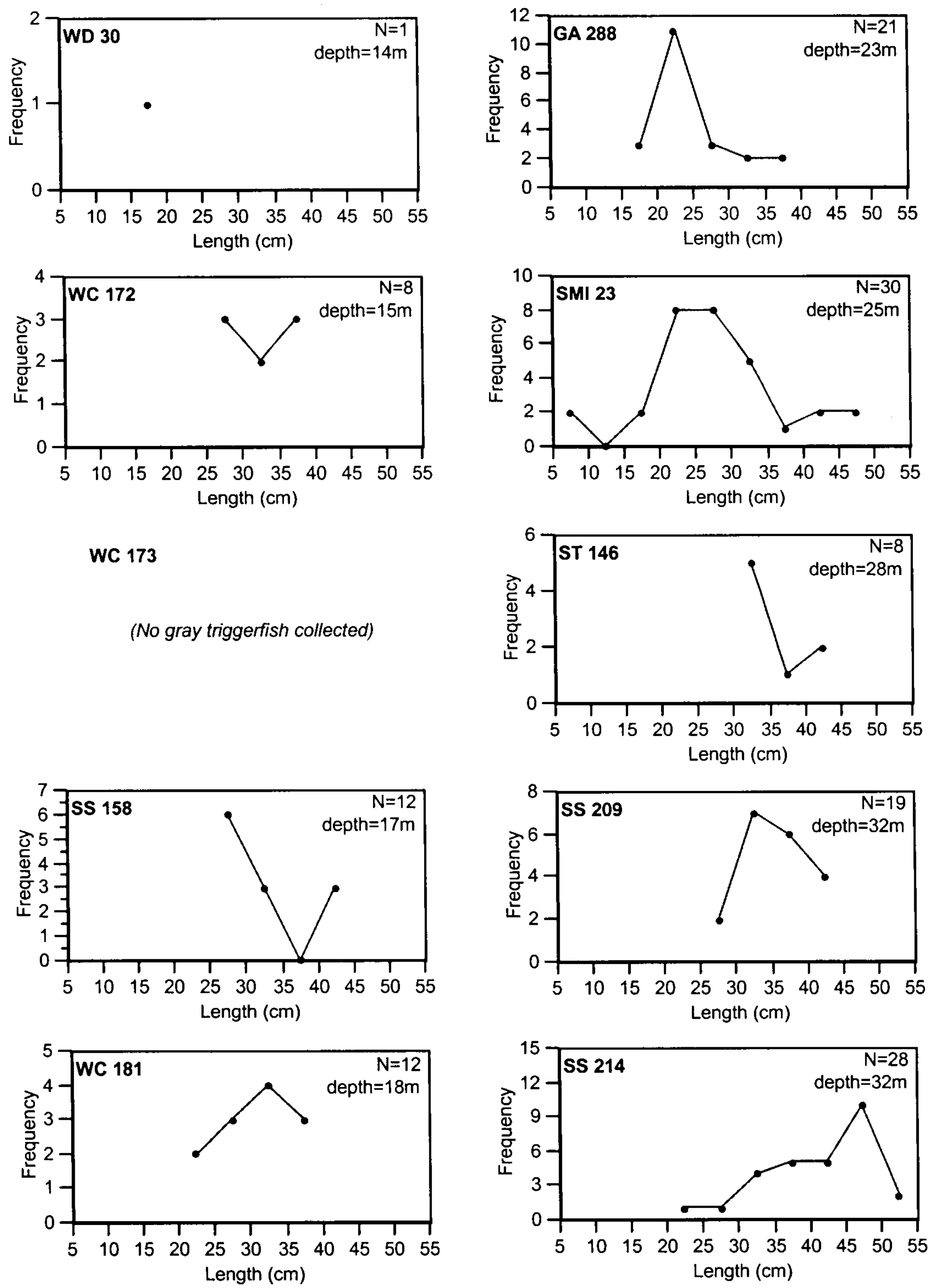

Figure 17. Length-frequency (TL in cm) of gray triggerfish by platform

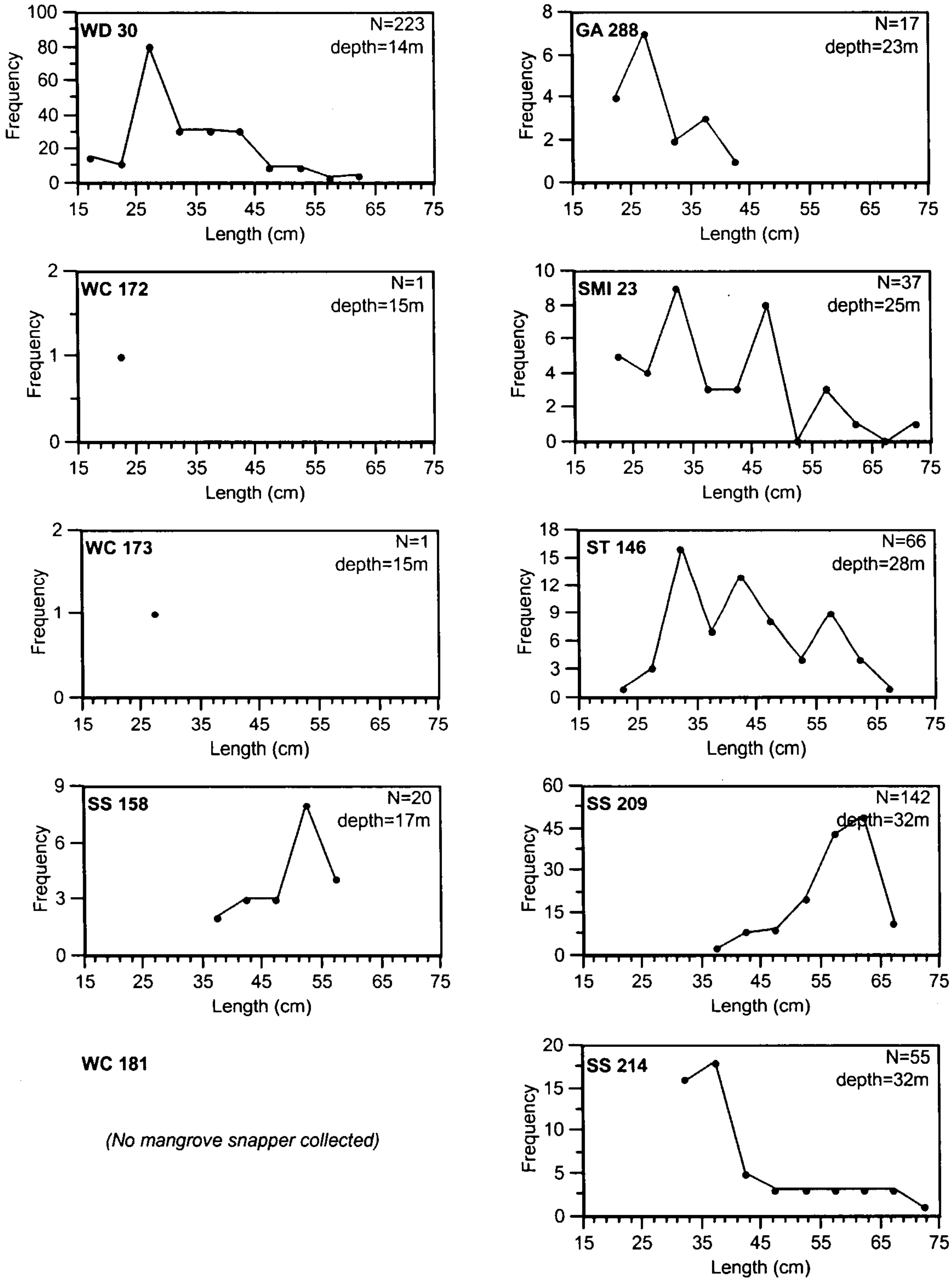

Figure 18. Length-frequency (TL in cm) of mangrove snapper by platform.

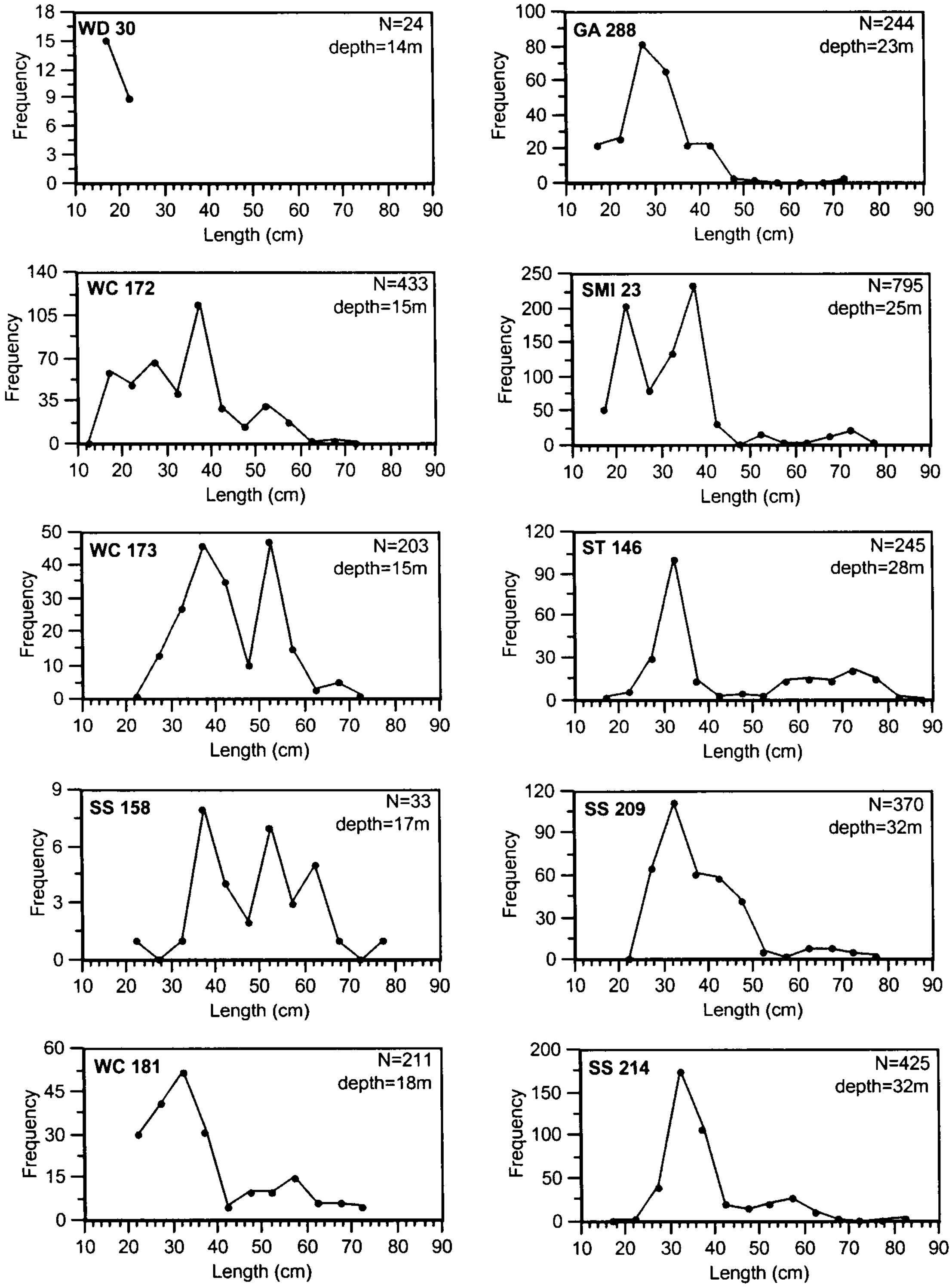

Figure 19. Length-frequency (TL in cm) of red snapper by platform.

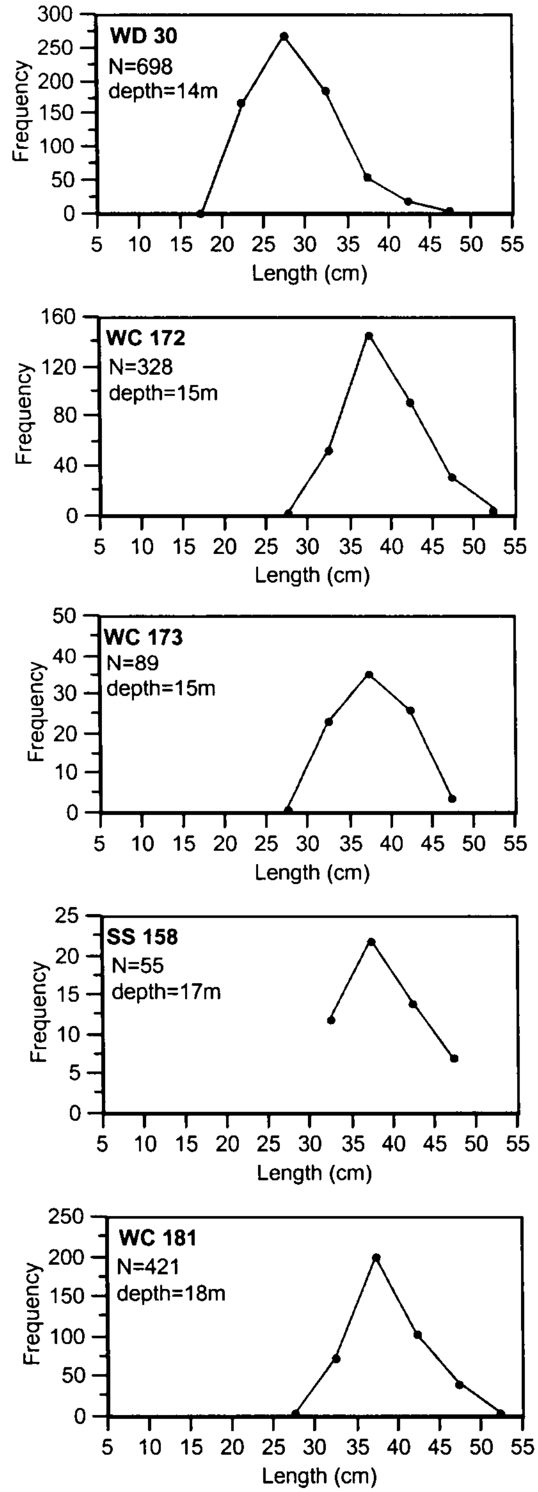

Figure 20. Length-frequency (TL in cm) of sheepshead by platform.

4.5 Fish Density Around Platforms

A summary of the locations of all underwater fish collections appears in Figure 21. Numbers of fish collected along transect line surveys from eight platforms were analyzed using the two sample t-test. There was a significant difference ($P<0.001$) in fish density (log(density + 1) transformed) for samples collected at 0-25 m (0.027 fish/m^3) and 25-50 m (0.002 fish/m^3) distances from platforms along transect lines. Using data from circular surveys collected at 0-6.7 m and 18.3-25.0 m from the platform, two sample t-test indicated a significant difference ($P=0.003$) between samples. Fish density was higher closer to the platform (0.051 fish/m^3 vs 0.007 fish/m^3). Fish density for transect data collected between 50-75 m and 75-100 m from platforms averaged 0.001 and 0.000 fish/m^3.

4.6 Comparison of Estimated Mortality and Size of Positively and Negatively Buoyant Fish

Table 14 shows no consistent relationship between the number of red snapper carcasses collected at the surface and the estimated number of red snapper which sank to the sea floor after detonations. Results for all fish species combined were also highly variable. Paired t-test of log transformed ratios of positively (floating) to negatively buoyant (sinking) fish showed a significant difference between red snapper and all species combined. More red snapper floated to the surface than sank at 4 of 8 study sites compared with only 2 of 9 study sites for all fish species combined. Ratios of floating to sinking red snapper ranged from 0.03-6.74 per platform while the range for all species combined was 0.03-1.47. At the upper end of the range, more red snapper floated than sank by a factor of 6.74. Extremely low values indicate that few fish floated to the surface. A ratio of 0.03 means that an estimated 33 times more fish sank to the sea floor than floated to the surface. Results for all species combined indicate that more fish generally sink than float and that actual total fish mortality may be considerably more than what is observed at the surface.

GLM analysis of red snapper length by factors of platform and buoyancy showed a significant difference ($P<0.01$) for both factors and interaction. Mann-Whitney tests used to compare length of floating vs sinking red snapper at each platform showed mixed results. A significant difference ($P<0.05$) in total length of positively vs negatively buoyant fish was found at four platforms, but no difference was apparent at four other platforms (Table 15). Mean total length was larger for positively buoyant fish at all platforms except one in 15 m of water where negatively buoyant fish were significantly larger. Difference

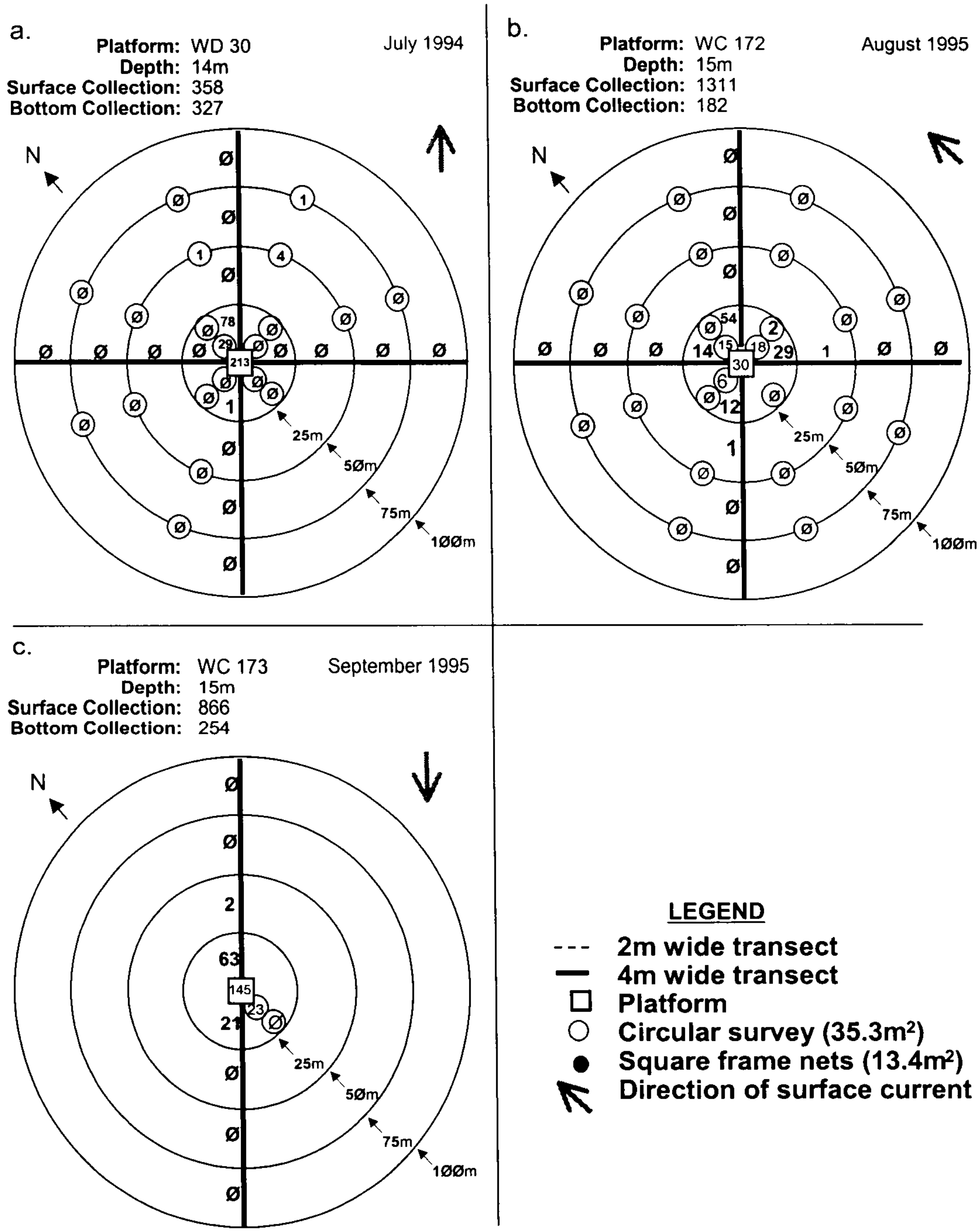

Figure 21. Summary of fish collections by platform. Number of fish collected by divers is shown in the schematics. The number inside the square at the center represents fish sampled beneath the platform. Circled values indicate circular surveys. Numbers adjacent to vertical and horizontal lines are transect line samples.

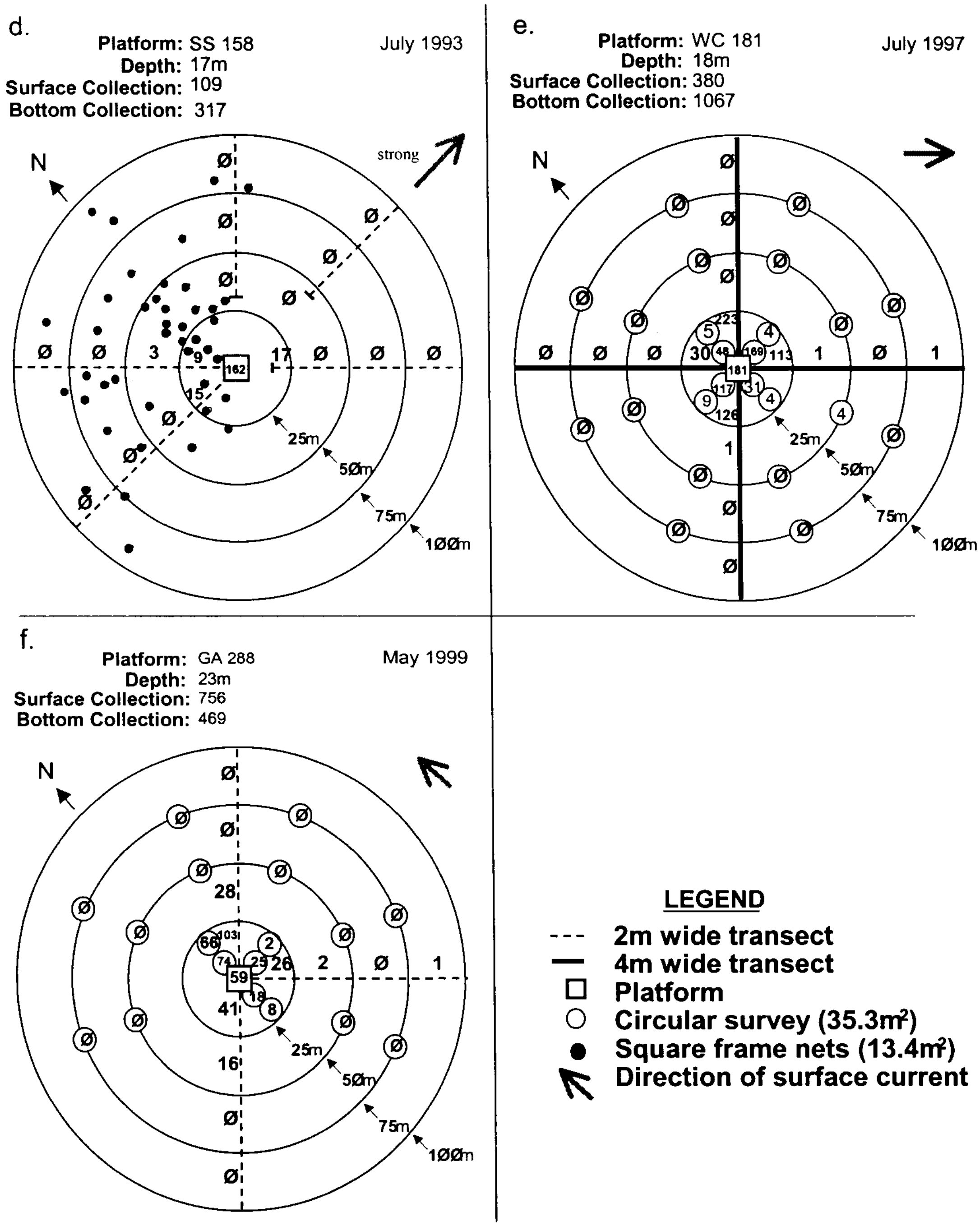

Figure 21 Cont. Summary of fish collections by platform. Number of fish collected by divers is shown in the schematics. The number inside the square at the center represents fish sampled beneath the platform. Circled values indicate circular surveys. Numbers adjacent to vertical and horizontal lines are transect line samples.

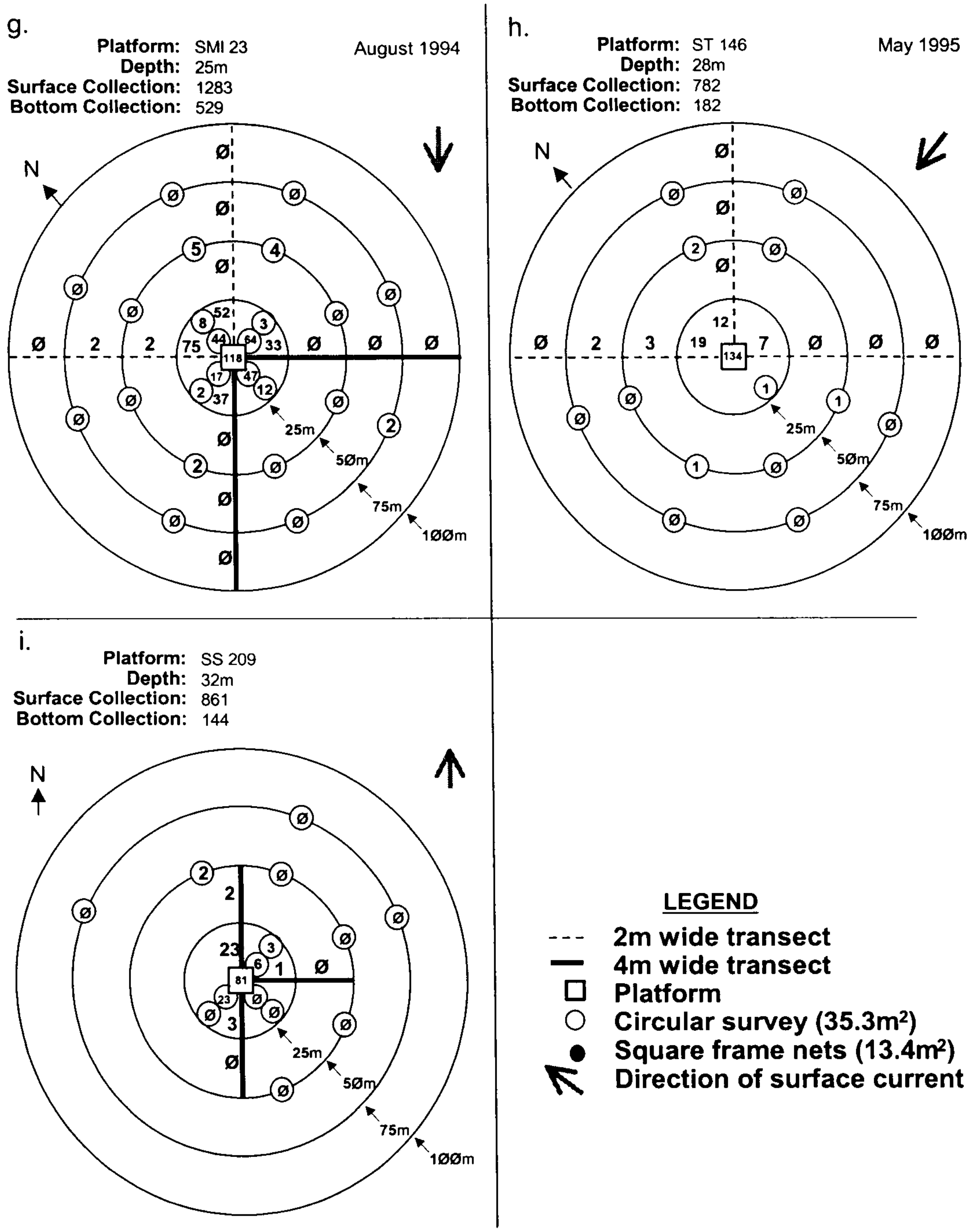

Figure 21 Cont. Summary of fish collections by platform. Number of fish collected by divers is shown in the schematics. The number inside the square at the center represents fish sampled beneath the platform. Circled values indicate circular surveys. Numbers adjacent to vertical and horizontal lines are transect line samples.

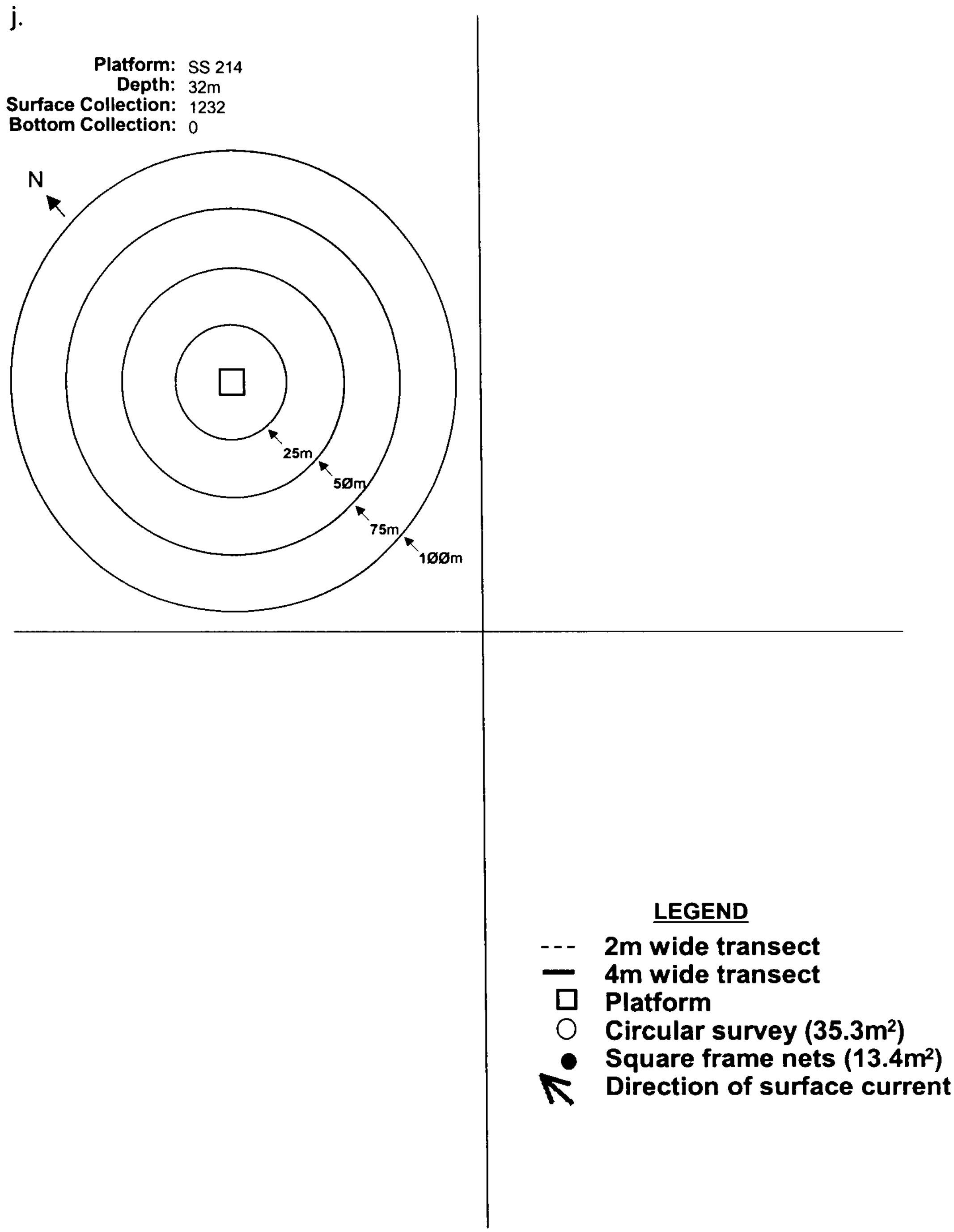

Figure 21 Cont. Summary of fish collections by platform. Number of fish collected by divers is shown in the schematics. The number inside the square at the center represents fish sampled beneath the platform. Circled values indicate circular surveys. Numbers adjacent to vertical and horizontal lines are transect line samples.

Table 14. Comparison of red snapper mortalities collected at the surface (floaters) with estimated mortality from the sea floor (sinkers).

Platform	Floaters	Sinkers	Total	Ratio floater/sink	Percent floater/total	Depth (m)
WC 172	417	81	498	5.15	84	15
WC 173	120	589	709	0.20	17	15
SS 158	10	286	296	0.03	3	17
WC 181	73	636	709	0.11	10	18
GA 288	202	285	487	0.71	41	23
SMI 23	714	479	1193	1.49	60	25
ST 146	238	58	296	4.10	80	28
SS 209	364	54	418	6.74	87	32
Total	2138	2468	4606		46	

Table 15. Comparison of total length of positively (floater) and negatively (sinker) buoyant red snapper by platform.

Platform	Mean TL floaters	N floater	Mean TL sinker	N sinker	Mann-Whitney P	Depth (m)
WC 172	34.1	416	40.1	17	0.06	15
WC 173	44.4	120	43.1	83	0.45	15
SS 158	56.8	10	45.7	23	0.01	17
WC 181	49.6	73	30.9	138	0	18
GA 288	31.5	202	25.1	42	0	23
SMI 23	33.1	714	29.3	81	0.01	25
ST 146	44.7	238	40.2	5	0.4	28
SS 209	38.5	361	38	9	0.68	32

between mean lengths of positively and negatively buoyant red snapper ranged from -6.0 to 18.7 cm. These two platforms were in depths of 15 and 18 m, respectively. Combining all positively buoyant fish yielded a mean of 36.7 cm while the mean for all negatively buoyant fish combined was 34.1 cm. The difference between these means was 2.6 cm. Since results did not show a consistently significant difference between length of positively and negatively buoyant fish at individual platforms and since the overall difference in mean length of positively and negatively buoyant fish was small, it should be acceptable to utilize historical data from the NMFS Platform Removal Observer Program, which is only available for positively buoyant fish, to enhance the present data set with additional red snapper lengths.

4.7 Assessing Impacts (1989-98)

4.7.1 Impacts on Red Snapper (1989-98)

Red snapper stock assessment analysis including mortality from explosive structure removals was conducted using the Data Set E structure removal estimate (arbitrary doubling of the moderate to high estimate to provide an upper limit of mortality). Results were compared to the base case assessment from Schirripa and Legault (1999; Figure 22). Benchmark comparisons appear in Table 16. The impact of including platform removal Data Set E was that abundance estimates were almost indistinguishable from the original assessment (Figure 22). The differences were well within the statistical estimation variances for the original assessment.

The additional mortality from explosive removals (Data Set E) altered management benchmarks, as well, (Table 16) with the fishing mortality and MSY benchmarks decreasing 3% or less and stock size benchmarks increasing less than 1%. The present management strategy of the Gulf Council is robust to these changes in benchmarks, i.e. the recovery strategy would function approximately the same with or without the platform removal inclusion. Again, note that these changes are well within the original estimation variation. Finally, note that these results are designed to evaluate bounds on the purported impacts by using Data Set E. Actual impacts are likely to be less.

Red snapper mortality from explosive structure removals was compared to other sources of mortality. The doubled red snapper mortality estimate resulting from explosive structure removals was divided by the combined mortality from commercial and recreational fishing, release mortality, and bycatch for each age class and year (Table 3B). When tabled values of these

Table 16. Changes in red snapper management benchmarks from base case assessment when refitting estimation models using platform removal Data Set E (double the moderate to high estimate of annual red snapper mortality at platform removals based on 1989-98 data).

	Base	Platform	% Change (P-B)/B
F0.1	0.096	0.093	-3.04%
Fmax	0.125	0.121	-3.03%
F20%SPR	0.169	0.165	-2.78%
F30%SPR	0.126	0.122	-2.80%
F40%SPR	0.095	0.093	-2.83%
Fmsy	0.118	0.115	-2.99%
Fcurrent	0.474	0.444	-6.32%
MSY (million pounds)	107.995	106.146	-1.71%
Bmsy (million pounds)	3930.31	3940.31	0.25%
SSmsy (million eggs)	7.76E+09	7.78E+09	0.22%

F0.1	Fishing mortality rate at which the slope of the yield-per-recruit curve is one tenth of what it is at the origin.
Fmax	Fishing mortality rate that maximizes yield-per-recruit.
F20%SPR	Fishing mortality rate which reduces spawning potential ratio to 20% of what it would be with no fishing
F30%SPR	Fishing mortality rate which reduces spawning potential ratio to 30% of what it would be with no fishing
F40%SPR	Fishing mortality rate which reduces spawning potential ratio to 40% of what it would be with no fishing
Fmsy	Fishing mortality rate that would eventually produce maximum sustainable yield
Fcurrent	Most recent estimate of fishing mortality rate (for 1998, F1998)
MSY	Maximum sustainable yield
Bmsy	Biomass that would support the taking of MSY
Ssmsy	Spawning stock in number of eggs that would support MSY

Table 17. Estimated number of dead fish floating at the surface after detonations during 1986-98 (data provided by NMFS Platform Removal Observer Program).

Structure type	Number of structures	Average number of floating fish per structure	Total estimated number of floating fish	Minimum value estimated per structure	Maximum value estimated per structure
Platform	742	567	420932	0	8875
Submerged well	57	133	7554	0	1105
Caisson	252	109	27372	0	2738
Flare pile	7	41	285	0	200

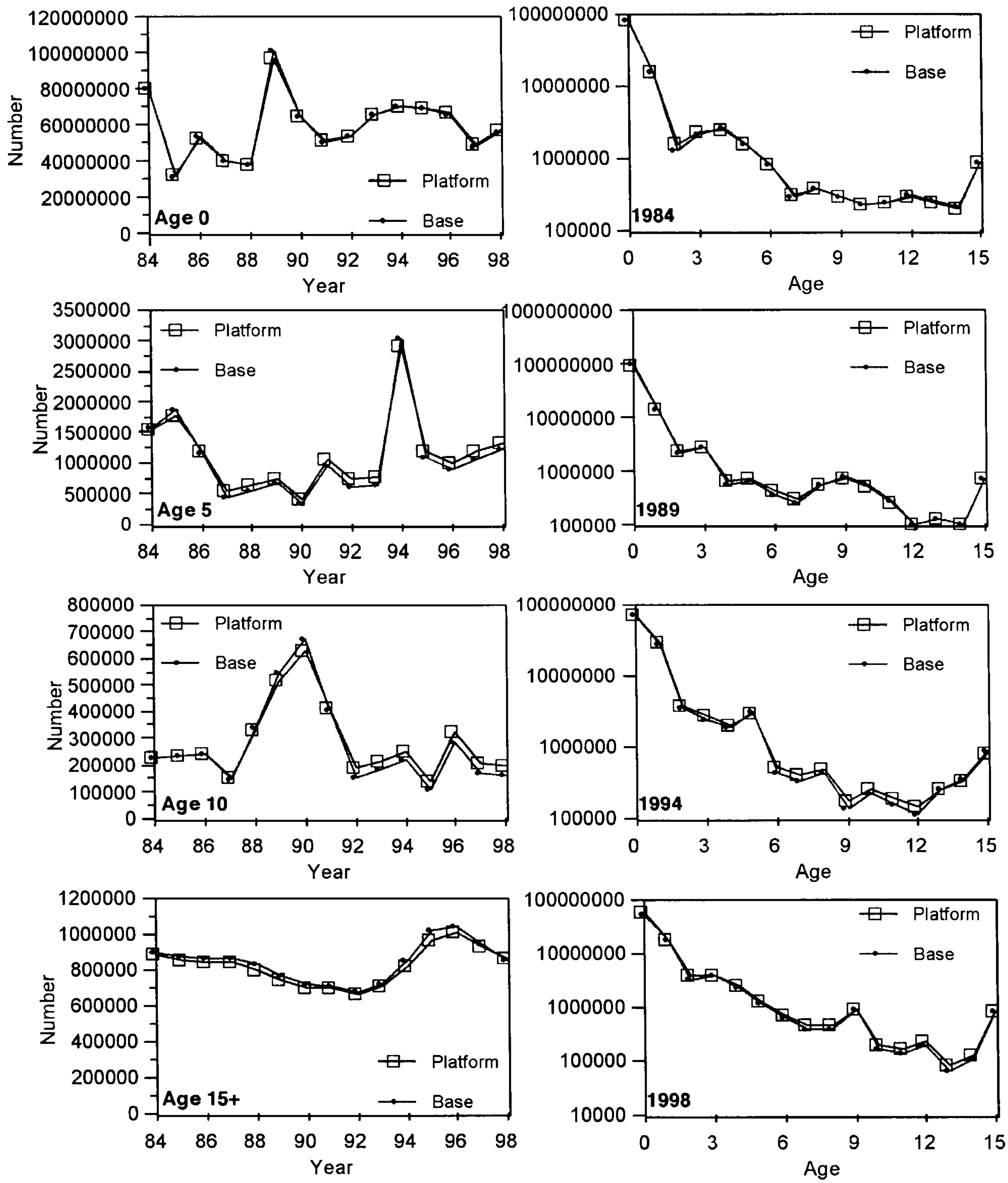

Figure 22. Red snapper assessment results including platform removals using Data Set E (represents arbitrary doubling of moderate to high estimate of red snapper mortality at platforms) compared to base case assessment (base).

proportions were averaged by age class, results showed that mortality from explosive structure removals represented the following percentage of other combined mortality: 1% or less for ages 0, 1, 3, 4, and 14; 1-5% for ages 5, 6, 11, and 15+; 5-10% for ages 2, 7, 8, 9, and 13; and 10-13% for ages 10 and 12. Note that these calculations were based on the doubled estimate of red snapper mortality at explosive structure removals to provide a boundary for purported impacts.

4.7.2 Impacts on Gag (1989-98)

Annual estimated mortality of gag at explosive platform removals (under Data Set E assumptions; see Discussion) is 256 fish per year. Comparison with results from the most recent gag stock assessment (Table 5) indicates this represents 0.04% of the average annual mortality from other sources. Current methods of assessment would not detect such small changes in magnitude.

4.7.3 Impacts on Red Drum (1989-98)

The annual estimated mortality of red drum at explosive structure removals (under Data Set E assumptions) is 961 fish per year. Comparison with results from the most recent red drum stock assessment (Table 6) shows this is 0.03% of the average annual mortality from other sources. Such a small change is indistinguishable using current methods of assessment.

4.8 Assessing Future Impacts on Red Snapper (1999-2023)

The procedures described above provide an analysis for the period 1989-98 and can be used to assess the present status of the red snapper stock. During this ten year period, a total of 958 structures were removed from federal and state waters of the Gulf of Mexico using explosives for an annual average of about 96. However, a recent forecast for 1999-2023 estimates the number of annual structure removals (both mechanical and explosive) in federal waters to increase to 186 (Pulsipher et al, in press). This value was adjusted (see Section 5.11.5) to yield an estimated annual average of 129 explosive structure removals in both state and federal waters for 1999-2023. The high estimate of mortality (assuming equal red snapper mortality at all structure types) based on these increased removals yields a projected annual mortality at explosive structure removals of 66,435 red snapper for 1999-2023. Although this is more than the 41,200 annual estimate for 1989-1998, it is still considerably less than the 82,400 value used in the 1989-98 stock assessment analysis which represents double the annual 1989-98 estimate. Consequently, the impact of a projected increase in average annual explosive structure removals is not expected to be distinguishable from benchmarks assuming other influencing factors remain constant and removal forecasts are accurate.

Another consideration in assessing future red snapper stocks relates to habitat. Various estimates place the increase in Gulf of Mexico reef habitat due to offshore platforms at 10-25%. Pulsipher et al. (in press) predict the number of platforms in federal waters will decrease from 3,687 in 1999 to 2,612 in the year 2023, a reduction of 1,075 platforms or about 29%. This is certainly a substantial loss of habitat. The question of whether offshore platforms represent critical habitat that increases fish numbers rather than simply redistributing individuals has long been debated. If offshore oil and gas structures prove to be critical habitat, then a reduction in stock size may accompany the large reduction in structure numbers from the Gulf of Mexico.

5.0 DISCUSSION

5.1 Overview

One obvious finding from this study is the lack of significant differences in estimated mortality as a function of test parameters including depth, longitude, surface temperature and salinity. This was due to a variation in fish abundance between platforms, small sample size in some cells, and a generally limited range over which variables were tested. For example, there was general consistency in platform complexity and a fairly narrow range in depth, surface salinity and surface temperature. Estimated mortality of fish at a given platform within study depths from 14-28 m ranged from approximately 2,000-5,000 for fish measuring greater than 8 cm TL. Depending on one's perspective, it appears that platforms with similar characteristics may have quite different numbers of fish impacted by explosives since mortality differed by more than a factor of two for the highest and lowest estimates. Conversely, a range of 2,000-5,000 may be considered fairly narrow considering the difficulty and complexity involved in field sampling, the many variables that can affect fish distribution at platforms, and wide ranges in fish populations reported from month to month by other researchers (Putt 1982; Stanley and Wilson 1996a; Stanley and Wilson 1997).

To understand fish mortality we must first understand fish distribution at offshore structures. Any factor affecting fish distribution at platforms may affect mortality. For example, at West Delta Block 30, the easternmost platform studied in 14 m of water, 493 Atlantic spadefish and little else were tagged in May. When explosives were finally detonated about 30 days later, only 9 of 315 spadefish collected had tags. Although no snapper of any species were captured during pre-detonation tagging operations at this site, 220 mangrove snapper were collected dead after detonations with a total estimated mortality of 364. Fish distribution at West Delta Block 30 was influenced by a lens of clear water that moved into the area during the 30 day period between tagging and blasting. In areas such as this where more than a hundred structures can be viewed with the naked eye from atop the removal platform, movement of fish between structures is not surprising. It is clear that fish populations at platforms are dynamic and fish are not as habitat faithful as once thought.

In general, failure to detect a significant difference in various parameters tested in this study does not indicate that these factors may not affect fish distribution. It does indicate that parameter values encountered during the study were not dissimilar enough to cause differences in fish distribution given the small number of platforms studied. For at least some parameters, when a sufficient change occurs in values beyond the ranges found in this study, fish assemblages and resulting fishery impacts will undoubtedly change. For example, species distribution in general has been reported to change as fish move from shallower to deeper water in relation to changing seasons and temperatures (Bradley and Bryan 1974; Hastings et al. 1976)

5.2 Depth and Longitude

Attempts have been made to characterize fish assemblages at platforms by depth (Gallaway and Lewbel 1982; Stanley and Wilson in press). Based on observations at some 20 platforms off Louisiana and 18 off Texas, Gallaway and Lewbel (1982) suggested three depth zones of fish assemblages at platforms: the coastal zone ranged from 0-30 m, the offshore zone from 30-60 m, and the bluewater zone deeper than 60 m. These depth ranges are, of course, general in nature and gradual rather than acute changes in fish assemblages can be expected in transitional depths. Gallaway and Lewbel (1982) observed variation between the coastal and offshore zones in general abundance of certain species.

Using estimated mortality as an indication of abundance permits comparison with these earlier studies. The only platform we investigated in the offshore zone was at 32 m which could be considered a transitional location between zones. Consequently, it was not surprising to see both similarities and differences in our results and those reported by Gallaway and Lewbel. These authors reported sheepshead and gray triggerfish were present but not abundant in the offshore zone which corresponded with our results. We observed tomtate at only one structure but they were abundant. This is noteworthy because Gallaway and Lewbel (1982) described a high abundance of tomtate in this same field nearly 20 years ago. They also reported the absence of large schools of tomtate at Louisiana structures. Although these authors observed high numbers of Atlantic spadefish at intermediate depth zones eventually decreasing with increasing depth in the bluewater zone, we found a decreasing, but insignificant, trend in abundance to 32 m. In contrast to their finding of large schools of lookdown at coastal Louisiana platforms, we estimated mortality for all nine platforms combined at only three individuals. Gallaway and Lewbel (1982) reported smaller schools of red snapper in 0-30 m depths, but, again, our results showed no statistical difference in estimated red snapper mortality by depth. However, anecdotal reports describe thousands of dead red snapper floating to the surface after explosives were detonated at platforms in deeper water.

Red snapper mortality at explosive structure removals may increase in the offshore and bluewater zones. During 1989-98 an annual average of 5 platforms and 3 submerged wells were removed with explosives in the bluewater zone (NMFS Platform Removal Observer Program unpublished data). Although bluewater platforms will have to be removed at some time in the future, they currently represent a minor portion of explosive removals.

Results for major impacted species corresponded with those of Stanley and Wilson (in press). At their 20 m study site, the most abundant species included Atlantic spadefish, red snapper, blue runner, and sheepshead in that order. While our study ranked blue runner slightly ahead of red snapper, red snapper was only one percentage point ahead of blue runner in Stanley and Wilson's results.

Although some differences between Louisiana and Texas platforms were noted by Gallaway and Lewbel (1982), only one Texas platform was included in the present study. Consequently, it is not surprising that results from our analysis of estimated mortality and fish length by longitude did not parallel those of this earlier work.

5.3 Season

This study was not designed to address seasonal and annual variations in fish mortality at platforms. Studies of blasting impacts were only conducted during May, July, August and September which encompasses late spring and summer. The number of platforms studied annually was one in 1993, two in 1994, three in 1995, and one each in 1997, 1998, and 1999. Since it was impossible to sample any platform more than once (platforms were removed), it is not surprising that graphs of estimated mortality by year also showed great variability. Lack of significant differences in mortality during these few months does not mean that seasonality plays no important role in fish distribution and abundance at offshore platforms. Seasonal changes in fish abundance are well documented for the Gulf of Mexico (Gallaway 1980; Gallaway et al. 1981; Mosley 1966; Bradley and Bryan 1975; Lukens 1981; Fable et al. 1981; Reagan 1985; Sutter and McIlwain 1987). Large differences can occur not only between seasons but also on a monthly basis. Fish population size was observed to vary by a factor of two to five from month to month (Putt 1982; Stanley 1994). Heavy fishing pressure on red snapper may contribute to seasonal lows in summer abundance at some platforms (Gallaway 1980). Given the small sample size and large monthly variation found in our study, it is clear that these results should not be used as an indicator of trends in seasonal or annual fish mortality at individual platform removals.

Unpublished data collected by one of the authors (G. Gitschlag) from 1987-98 documents explosive removals in the U.S. Gulf of Mexico. Fifty-nine percent of explosive removals at structures classified as platforms by the NMFS Platform Removal Observer Program occurred from May through September and 84% from May through December. Relatively few removals occur during winter months when costs escalate due to severe weather. For structures of all types, 61% of removals occurred during May-September and 85% from May-December. Consequently, distribution of fish during winter months is not a major factor affecting mortality related to explosive removals because few removals occur during this period.

5.4 Platform Age

Platform age less than 25 yr vs greater than 25 yr was not a significant factor affecting fish mortality at platforms. Age of structures studied was from 12-39 years while 4 of 9 platforms exceeded 30 years. Based on this platform age structure, fish communities had ample time for development at all study sites. One noteworthy platform was South Marsh Island Block 23, a 33 year old structure located in 25 m of water at longitude 91.88°. This platform had previously been part of a larger three structure complex interconnected by above water bridges. The other two platforms, a 4 pile and a 6 pile structure, were removed 11 months earlier using over 318 kg (700 lb) of explosives. Since these explosions may have decimated the fish population at all three structures, the remaining platform offers insight into the extent of recolonization achieved by fish species during this 11 month period. Apparently, this was ample time to achieve repopulation. Total estimated mortality at this platform ranked second out of the nine platforms studied while red snapper mortality ranked first exceeding the second ranked platform by 68%.

Colonization of newly installed platforms occurs quite rapidly and mature fish assemblages can be anticipated at all but the very youngest platforms. Lukens (1981) reported full colonization of Gulf of Mexico artificial reefs can occur within 15 months. Stanley and Wilson (1991) also found structure age was not a significant factor in explaining fish abundance at platforms. Generally, it is the older platforms that are removed. Relatively few very young platforms are salvaged. Thus platform age does not appear to be an important parameter affecting mortality of fish at explosive platform removals.

5.5 Surface Temperature and Salinity

Surface temperature ranged from 26-32°C. No significant difference in estimated mortality was found at water temperatures < 30°C vs >=30°C. Bottom temperature ranged from 22-27°C. Although fish distribution is certainly affected by extreme salinity and temperature, these were not encountered during the study. Although low salinities may be encountered near areas affected by large freshwater outflow from rivers, this study was not designed to assess this influence. Red snapper have been collected at temperatures ranging from 13-28 C° (Rivas 1970, Roe 1976) and have survived repetitive 20 min laboratory exposure to about 45 ppt (Huff and Burns 1981). In general, during seasons when most platform removals occur, natural fluctuations in salinity and temperature are not expected to be an important factor affecting fish distribution at offshore platforms.

Surface salinity ranged from 18-33 ppt with an average of 26 ppt. Variation in surface salinity (<=26 vs >26 ppt) did not have a significant effect on mortality estimates. Fish appeared to be unaffected by fluctuations within this range. Bottom salinity was less variable (25-33 ppt).

5.6 Platform Size

Gallaway and Lewbel (1982) reported that abundance of Atlantic spadefish was directly proportional to platform size. Stanley and Wilson (1991, in press) reported structure size affected fish density with higher density at mid-size platforms. Ogawa et al. (1977) and Rousenfell (1972) also found fish abundance was directly correlated with reef size. In contrast, anecdotal information provided to the author by a professional snapper fisherman indicated that one of his largest catches occurred on a submerged structure about the size of a barrel. We found no significant difference in estimated fish mortality resulting from explosive platform removals as a function of platform size. Perhaps size alone does not determine fish abundance at offshore platforms.

5.7 Length-Frequency

Analysis of length-frequency data provided an opportunistic glimpse of possible relationships between fish size, water depth and geographic location (longitude) of platforms. For a thorough investigation, a much larger sample of platforms is obviously required. Results for the five major species impacted at explosive structure removals did not indicate a general trend of larger fish being taken in deeper water. Three species (blue runner, sheepshead, and mangrove snapper) exhibited larger mean lengths at depths greater than 20 m while two others (Atlantic spadefish and red snapper) did not. Further analysis of red snapper data indicated significantly smaller fish at 20-30 m platform depths than at shallower and deeper depths. Combining additional red snapper data from the NMFS Platform Removal Observer Program provided similar results. It is recommended that additional data from other sources be combined for further testing which should consider more depth zones as well as capture seasons. This is necessary to account for migration across depth zones at various times of the year.

Although fish length varied significantly by longitude for each species tested, no general trend in size was observed for platforms east of 92° vs west of 92°. Size and growth are complex variables and are affected by many parameters. The significant interaction effect may serve as an indicator of the importance of multiple parameters in determining fish size.

5.8 Population Estimates and Mortality Rates

Fishing equipment used in tag and release experiments did not collect representative samples of all species. Population estimates were only calculated when sufficient data were obtained. Consequently, estimated mortality for all species combined provided the only index of total fish abundance. Average total estimated mortality (3390) was about four times lower than the estimated abundance (13,444) reported by Stanley and Wilson (in press) at a single platform in 22 m of water. This difference may be partially due to differences in methodology. Acoustic sampling of live fish used by Stanley and Wilson reportedly had a minimum target size of 2.5 cm total length (Love 1971) which was considerably smaller than the 8 cm minimum used in the present study. Large numbers of fish less than 8 cm were collected at only one structure where estimated mortality of these small fish exceeded 6200 in the area immediately under the platform.

Population estimates based on tag/recapture studies assume that 100% of tagged fish survive and mix with the population. Great care was taken to release only fish that appeared to be in good condition. However, external inspection may not always provide a good index of internal trauma (Gitschlag and Renaud, 1994) and some fish may succumb after release. Survival depends on many factors including where the fish was hooked, handling of fish, depth of capture (especially for physoclistic species), and abundance of predators in the area. When fish with gas bladders are retrieved rapidly to the surface during capture, the gas within the bladder can expand and cause serious internal damage. If survival of tagged and released fish is less than 100% then population estimates will be higher than actual and estimated mortality due to explosives will be low. This may in part account for some of the low mortality estimates found for red snapper. When estimated mortality in this study exceeds population estimates, estimated mortality is recommended as a superior indicator of population size.

However, some low rates were real and not artifacts. On the rare occasions when divers encountered good visibility during post-detonation dives, considerable variation was observed. In 14 m of water at the largest platform studied, dives made within hours of the detonation showed a wide variety of fish species swimming beneath the platform. At another removal at 18 m depth, divers observed nearly complete mortality with the water column essentially devoid of any swimming fish.

5.9 Fish Density At Platforms

While it is widely known that fish congregate at platforms and other offshore structures, data which quantitatively describe this phenomenon are limited (Gallaway et al. 1981, Gallaway and Lewbel 1982; Continental Shelf Associates 1982; Putt 1982; Stanley 1994; Stanley and Wilson 1996a; Stanley and Wilson 1996b; Stanley and Wilson 1997; Stanley and Wilson in press). Dead fish that sink to the sea floor may provide an index of pre-detonation fish density at various distances around platforms. However, when fish swimming in the water column are killed by explosives, they may not fall directly to the sea floor. Currents may move carcasses laterally during descent. Also, hydrodynamic characteristics of the carcass may cause lateral movement during descent even in the absence of current. In this study a moderately strong current was only present at one platform in 18 m of water in Ship Shoal Block 158. Data from this platform were not included in the analysis of fish density.

For platforms at depths of 14-32 m, results from the present study showed fish density decreased dramatically beyond 18 m. This compared well with results from Stanley and Wilson (in press) who found an area of influence of 18 m around two platforms in depths of 22 m and 60 m. Stanley and Wilson (1996b; 1997) also reported a near field area of influence of 16 m on the continental shelf where water depth was 25 m. Gerlotto et al.

(1989) reported fish densities adjacent to a platform were 5 to 50 times greater than 50 m away. Stanley and Wilson's highest mean densities were roughly an order of magnitude larger than those in the present study. This difference may in part be related to methodology. Recall that Stanley and Wilson's technique detected fish with a minimum size of 2.5 cm in contrast to an 8 cm minimum in the present study.

5.10 Comparison of Positively and Negatively Buoyant Fish

When fish are killed by explosives some sink to the sea floor while others float to the surface. Extensive efforts were made to collect all dead fish which floated to the sea surface after explosives were detonated. In contrast, a sample was taken of dead fish which sank to the sea floor and an estimate of mortality was calculated mathematically. If a consistent mathematical relationship exists between the number of fish which float and the number which sink, then we need only to sample carcasses at the surface to obtain reliable estimates of total mortality. This would be extremely economical compared to the cost of fielding a team of divers to collect samples from the sea floor. Unfortunately, the ratio between positively and negatively buoyant fish varied widely with more fish floating to the surface at some explosive platform removals and more sinking to the sea floor at others.

5.11 Estimating Red Snapper Impacts across the U.S. Gulf of Mexico Using Stock Assessment Techniques

Key information required in stock assessment includes the number and size of fish killed each year. In order to estimate total annual mortality associated with explosive structure removals in the U.S. Gulf of Mexico, we must first consider two important factors that may affect fish distribution: structure complexity and water depth. Size of fish mortalities must also be determined.

5.11.1 Structure Complexity and Red Snapper Mortality

There is a wide variety of oil and gas structures in the Gulf of Mexico including but not limited to platforms. The NMFS Platform Removal Observer Program collects data at all explosive structure removals in both state and federal waters of the U.S. Gulf of Mexico and its embayments. Data files maintained by this program define a platform as a multi-pile structure, a caisson as a single pile structure which is generally freestanding but occasionally connected to a platform, a flare pile as a single pile structure usually associated with a platform, and a submerged well as a single pile extending some distance above the sea floor but not approaching the sea surface. The platform category includes a wide range of structures, some quite large with dozens of pilings. In many cases several platforms are placed close together in complexes connected above water via walkways. NMFS data for 1989-98 showed that 70% of all explosive structure removals were platforms, 23% were caissons, 6% were submerged wells, and 1% were flare piles. Platform removals exceeded caisson removals by a factor of three and were justifiably the focus of the present study.

Data from the NMFS Platform Observer Program include visual estimates of dead, floating fish made opportunistically after explosives are detonated. These estimates can be extremely crude for large fish kills that are difficult to count accurately. They can also provide very accurate information in cases where few fish float to the surface as might be anticipated at single pile structures if they do not attract large numbers of fish. Data collected from 1989-98 show the average number of floating fish per structure was approximately 567 for platforms, 109 for caissons, 41 for flare piles, and 133 for submerged wells (Table 17). We cannot conclude that fish mortality at caissons was less than half that observed at platforms because the present study showed no consistent relationship between observed surface mortality and total mortality. Nevertheless, the data clearly indicate that fish mortality at caissons was not trivial despite the disparity in complexity between platforms and caissons.

In addition to the volume of water encompassed within the boundary of the platform, the number of pilings at a platform can serve as an indication of structure complexity. Structure complexity was fairly consistent in the present study. Eight of the nine platforms studied were small, four pile structures ranging in depth from 15-32 m. One larger, 24 pile structure was located in 14 m of water where total estimated fish mortality was second lowest and red snapper mortality was nearly zero. This provides strong evidence that, contrary to popular belief, structure size alone may not be the most important factor in determining fish population size.

5.11.2 Water Depth and Structure Removal

Although no significant difference in estimated mortality by water depth was found in this study, on a larger scale, water depth does affect fish distribution and should be considered a potential factor affecting the calculation of total annual fish mortality at explosive structure removals. Depths of platforms used in the study can be compared with historical data from the NMFS Platform Removal Observer Program. From 1989-98, 33% (319) of explosive structure removals occurred in 14-32 m, while 43% (420) were in shallower water and 24% (228) in deeper water.

After more of the older structures in shallow water are removed, removal depth should increase over time as deeper water structures increase in number and age. Maximum depth for a platform removal was 114 m. Only eight structures, all submerged wells, were removed at greater depths with a maximum of 394 m. Caisson removals rarely exceeded 30 m in depth.

5.11.3 Red Snapper Length by Water Depth

As discussed earlier, total length of red snapper varied significantly by depth zone although the mean difference was small. A significant difference ($P<0.001$) was found for depths <20 m vs >20 m. Further analysis indicated a difference for red snapper lengths taken from 20-30 m vs those from shallower (<20 m) and deeper (20-30 m) depths. This did not follow the intuitive expectation of larger fish occurring in deeper water. Also, it posed a problem in determining how to expand these results to structure removals outside the depth range of the study.

To further investigate the relationship between red snapper length and water depth, additional sources of data were explored. Lengths for red snapper collected from both sea surface and sea floor in the present study were combined with length data for floating red snapper collected opportunistically by personnel from the NMFS Platform Removal Observer program at various explosive structure removals from 1987-1998. This contributed an additional 13,527 red snapper lengths for a total of 16,510 collected at 116 explosive structure removals. Pooling of these data was justified for several reasons. Since the objective is to assess red snapper mortality at all explosive structure removals, it is advisable to utilize the largest possible data set representing as many of these removals as possible from all depth zones where red snapper were collected. In the present study, only 4 of 8 platforms showed a significant difference between length of red snapper collected at the surface and those collected at the sea floor. The overall mean length of positively buoyant fish was only 2.6 cm more than that of negatively buoyant fish. Analysis of the combined data set using GLM single factor analysis and Tukey-Kramer studentized range test for paired comparisons yielded results similar to the previous findings. There was a statistical difference in red snapper length due to depth ($P<0.00$) and the difference was in the 20-30 m strata.

5.11.4 Assessment of Impacts on Red Snapper (1989-98)

Ideally, mortality estimates for additional depth strata and structure type would provide information for the missing cells of the study prior to developing an estimate for total fish

Table 18. Description of data used in stock assessment sensitivity analysis for red snapper mortality at explosive structure removals in >7 m depths.

Data Set	Estimate	Period	Annual number of explosive structure removals	Structure types included	Estimated red snapper mortality per structure	Annual estimated RS mortality at explosive structure removals
A	Low	1989-98	56.4	Platforms & well jackets	515	29,046
B	Mod-High	1989-98	80	All[1]	515	41,200
C	Low	1999-2023	83.8	Platforms & well jackets	515	43,157
D	Mod	1999-2023	129	All[1]	515	66,435
E	2xB	1989-98	160	All[1]	515	82,400

[1]"All" includes platforms, well jackets, caissons, flare piles, and submerged wells.

mortality in the U.S. Gulf of Mexico. Since these data are not now and may never become available, another strategy was implemented. A sensitivity analysis provided a reasonable index to make this assessment.

Low, moderately high, and very high estimates of red snapper mortality were determined (Table 18). Estimates of total mortality were based on structure type while size composition was weighted by water depth. To provide a low estimate of mortality due to explosives we assumed no red snapper were killed at caissons and flare piles while mortality at other structure types was the same as that obtained in the present study. For the moderately high estimate, we assumed mortality was the same at all structure types including caissons and flare piles. Finally, we doubled the moderately high value to obtain a very high estimate of red snapper impacts.

Information collected by the NMFS Platform Removal Observer Program was used to further refine the analysis. The depth range at which red snapper were collected was 7-114 m (22-375 ft). Consequently, structures in water depths less than 7 m were not included in the red snapper analysis. Rivas (1970) and Moseley (1966) reported red snapper taken as shallow as 9 m and 14 m, respectively while Bradley and Bryan (1975) collected snapper as shallow as 5.5 m in trawls. Although dead, floating fish were not collected at every structure removal monitored by NMFS observers from 1987-98, observers did perform fish collections at 321 structures at depths from 7-114 m and 22 structures at shallower depths to a minimum of 2 m.

Red snapper length records from the present study were combined with those from the NMFS Platform Removal Observer Program as described above. Although no significant difference in estimated mortality was detected at depths <20 m vs >30 m, there was a significant difference in red snapper length at depths from 20-30 m. Consequently, all length records were sorted into two depth zones (7-20 m and >30 m vs 20-30 m) as were counts of explosive structure removals. Estimated annual red snapper mortality per structure (515) was multiplied by the ten year (1989-98) average annual number of explosive structure removals in each depth zone (from NMFS Platform Removal Observer Program data) to yield an estimate of red snapper mortality for each depth zone. Red snapper lengths in each depth zone were expanded by replication to equal these estimates.

These expanded data sets were used in stock assessment analysis to determine the effect of mortality due to explosive structure removal on the overall stock. Despite natural variation in the data and possibly higher mortality at depths greater than study depths, doubling the moderately high estimate is expected to provide a value that far exceeds the actual mortality.

Of the species encountered in these field studies, only three have stock assessments conducted on them: red snapper, gag and red drum. Of these, estimated mortality of red snapper at platform removals was 331 times that for gag and 86 times that for red drum. Yet even when the estimate of red snapper mortality was doubled, the impacts were estimated to be small, well within the variation of our current assessments, and would not alter current determinations of status or current management recovery strategies. Therefore, it is not scientifically meaningful to develop quantitative mitigation strategies for platform removal based on these results. However, there are several general points about mitigation that may be made. Results indicated that smaller (younger pre-spawning) fish are likely to be the most affected age-groups in platform removal for nearly all species. Thus, a goal of any mitigation strategy would be to reduce the mortality overall and reduce it on young (small) fish disproportionately. If particular times or areas can be defined in which overall abundance on platforms or abundance of small fish on platforms is likely to be reduced, then platform removals could be focused in those times and areas. Unfortunately, the data from the nine platform removals do not provide consistent advice in this regard. Knowledge of the biology of the species involved would be more useful than quantitative analysis that might be done with the existing data. In general, water depths where red snapper occur are also characterized by platforms. One exception is movement of fish out of shallow water during winter with decreasing water temperature. Thus, explosive removal of platforms in shallow water during winter might be expected to reduce impacts on red snapper and other fish species.

Sampling strategies to improve the precision of the determinations of impact and mitigation options should take two forms: 1) increase precision of the "per platform" mortality estimates by increasing the number of platforms sampled; and 2) detect the effect of other factors on mortality by stratifying the platform sampling. Of these two, stratified sampling will likely be of the greatest benefit in reducing uncertainty. Factors that are likely to have an effect are depth, geographical area and season. These effects are likely to be different between species. With the present sample of nine platforms, the data are not sufficient to design stratified sampling regimes. Thus, generally increasing the number of platforms sampled would be useful in both reducing variation in the mean kill per platform estimate, but more importantly it would provide further guidance as to the important factors for more detailed sampling designs. Of course, the cost of increased sampling would have to be evaluated in light of the expected impacts of platform removals on the stocks discussed above.

5.11.5 Assessing Future Impacts on Red Snapper (1999-2023)

This analysis utilized data from NMFS, MMS, and Pulsipher et al. (in press). Unlike data from the NMFS Platform Removal Observer Program, the MMS data set did not include subsea wells, flare piles or any removals that occurred in state waters. These two data sets were used together in conjunction with Pulsipher's forecast of future platform removals to assess future impacts on red snapper. If explosives continue to be used at approximately 64% of all removals[1], then fish populations at 119 platforms and caissons (0.64 x 186 predicted annual platform removals) will be impacted annually. Using MMS data, this represents an increase of 59% ((119-75)/75) over the 1989-1998 period. As of January 31, 2000, 8.8% (351 of 3967) of structures present in the Gulf of Mexico were in depths less than about 7 m. Reducing the 119 predicted explosive removals by this factor yields 109. From 1989-98 NMFS recorded an additional 126 removals in depths >7 m including submerged wells and flare piles in federal waters and structures of all types in state waters. This represents 10.8% (126/1172) of all removals (explosive and non-explosive) in the 1989-98 MMS data base. Assuming this ratio remains constant in the future, the total number of explosive structure removals predicted annually will increase by an additional 20 (0.108 x 186) to provide a total of 129 (109 + 20) annual explosive structure removals in depths >7 m[1]. This is a moderately high estimate based on all structure types having the same mortality of red snapper. A low estimate of 83.8 structures per year was obtained by deleting caissons, flare piles, and submerged wells from the NMFS data along with similar structure designations in the MMS data set.

5.12 Sources of Error

Transect lines provided continuous sampling from the platform out to a distance of 100 m while circular surveys provided discrete, discontinuous samples. Circular surveys and sampling frames provided more accurate information than transect lines where transect widths (thus sampling area) were approximated, not measured. Transect width was designed to be either 1 or 2 m depending on underwater visibility. Distance was estimated using the armspread of divers to approximate 2 m. Divers with both longer and shorter armspreads were used during the study. Whenever possible, transect and circular survey data were combined to estimate total mortality so any small discrepancy would be even further diluted. Sampling of dead fish under the platform was highly accurate. Percent coverage of the footprint area under the platform by sampling frames ranged from 12-83% with an average of 28%. Similarly, virtually every dead fish observed at the surface was collected.

Mortality estimates for certain platforms were probably slightly low for several reasons. Divers could not collect more fish than were present but they could fail to collect all fish due to poor visibility. At Ship Shoal Block 158, the only site where there was a substantial current, sample bags for the downcurrent transect line were lost during retrieval. Divers who collected the samples reported large numbers of fish which was anticipated due to the strongly directional current moving fish carcasses as they sank to the sea floor.

If the assumption of decreasing mortality with increasing distance from platform is true, then other factors tended to slightly overestimate mortality. This is due to a continuous decrease in the ratio of sampling to total area as one proceeds away from the platform. This would tend to slightly overestimate mortality based on transect line and circular survey data. For example, the total area of the 12.5-25 m band around a platform is larger than the 0-12.5 m band, but the sampling area was constant throughout the entire 0-25 m region along the transect line. Similar reasoning holds for pooling of the two innermost circular surveys (0-6.7 m and 18.3-25 m). Thus samples taken closer to the platform had a somewhat higher weighting in the overall average.

Exceptions could occur in the case of schooling species such as blue runner which were often observed at greater distances. Mortality then becomes a matter of chance depending on where a school is at the instant explosives are detonated. Another exception was identified at a platform in 18 m of water. No fish were collected in 7 of 8 circular surveys conducted at a distance of 50 m. Four fish including 3 red snapper and a sheepshead were collected in a sample which happened to be located adjacent to a large debris pile. It appears that fish were attracted to the debris on the otherwise barren sea bottom. Presence of structure around platforms probably affects fish distribution and hence mortality resulting from explosive platform removal.

In general, positive and negative sources of error probably cancel each other out or result in slightly low estimates. Exceptions include cases when samples with large numbers of fish were lost. Overall, final estimates appear to be accurate and variance in estimated mortality by species indicates real differences between platforms.

Data analysis indicated that future estimates can be improved somewhat by partitioning the area within 25 m of the platform into more than one sampling region. While increments of 5 m proved to be too time-consuming given most logistical situations, partitioning of the 0-25 m area around the platform into two sampling regions, as was done at the last study site, Galveston Block 288, worked well.

6.0 SUMMARY

1. The most severely impacted fish species in order of abundance were Atlantic spadefish, blue runner, red snapper, and sheepshead. These five species accounted for 86% of estimated mortality. Numbers of all other impacted species were far below those of the top four.

2. Of the fish species encountered in these field studies, only three have stock assessments conducted on them: red snapper, gag and red drum. For red snapper, even when the mortality estimate was doubled, impacts were estimated to be small, well within the variation of our current assessments, and would not alter current determinations of status or current management recovery strategies. Similarly, current methods of assessment would not detect the even smaller changes in magnitude of gag and red drum.

3. In general, results indicated no significant difference in estimated mortality of red snapper by depth, longitude, platform age, season, surface salinity, and surface temperature in the study area (14-32 m) during May to September.

4. These analyses suggested no appropriate strata for expansion of mortality data to the greater Gulf of Mexico. Consequently, platforms in the water depths studied can be included in a single group for the purpose of estimating fish mortality due to explosive platform removals.

5. Although the effects of structure complexity on fish abundance was not an objective of this study, unpublished data from the National Marine Fisheries Service indicated structure complexity may directly influence observed mortality. This parameter was integrated into the sensitivity analysis for stock assessment.

6. A significant difference in red snapper length at removals in 20-30 m water depths vs those at shallower and deeper depths was also incorporated into the analysis.

7. Future impacts to the red snapper stock were predicted based on forecasts of future structure removals reported by Pulsipher et al. (in press). Although estimates of future mortality were higher than current estimates, they were still within the variation of our current assessments. Given the assumptions used in these forecasts, predicted future mortality would not alter current determinations of the status of the red snapper stock or current management recovery strategies.

8. Two important caveats should be remembered when interpreting these results. First, species composition and abundance can change in water depths deeper than those encountered during this study. Second, sample size was small. Only nine to ten platforms were sampled out of more than 4,000 structures present in the U.S. Gulf of Mexico.

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Appendix I

Pre-detonation Visual Fish Surveys

Minerals Management Service requested performance of visual fish surveys to be patterned after Bohnsack and Bannerot (1986). These researchers described the use of stationary visual census techniques for use on coral reefs. In general, protocols included divers listing all fish species observed in 5 min within an imaginary cylinder with a 7.5 m radius extending from sea surface to bottom. With the exception of schooling fish which were counted as soon as they were observed, divers counted the number of individuals observed for each species recorded during a second 5 minute session performed immediately after the first. The authors reported underwater visibility generally exceeded 12 m.

Key differences in the environmental conditions encountered during our study in the northern Gulf of Mexico and Bohnsack & Bannerot's study in the Florida Keys prevented duplication of their protocols. Underwater visibility in our study was as low as 2 m or less and never allowed divers to visually sample the entire water column. Although visual surveys were conducted using a reduced survey radius appropriate to the visibility encountered, it was determined that using these values to calculate fish densities and generate fish population estimates would result in severe errors. It was impossible to determine when the same individuals made multiple passes through a given survey area. On many occasions it was obvious that fish were swimming through multiple survey areas and being counted by more than one diver during the same 5 minute survey period, yet it was impossible to document how often this occurred. Reduced survey distance in our study may have affected which species were observed since some species approach divers much more closely than others. By the end of our study it became clear that the procedures described by Bohnsack and Bannerot were not directly applicable to our study sites. Consequently, fish survey data were not used to estimate fish population size.

Appendix II

Common and Scientific Names of Collected Fish

Common name	Scientific name
Almaco jack	*Seriola rivoliana*
Atlantic bumper	*Chloroscombrus chrysurus*
Atlantic croaker	*Micropogonias undulatus*
Atlantic spadefish	*Chaetodipterus faber*
Atlantic thread herring	*Opisthonema oglinum*
Belted sand bass	*Serranus subligarius*
Bermuda chub	*Kyphosus sectatrix*
Black drum	*Pogonias chromis*
Blue runner	*Caranx crysos*
Bluespotted searobin	*Prionotus roseus*
Chub mackerel	*Scomber japonicus*
Cocoa damselfish	*Pomacentrus variabilis*
Crevalle jack	*Caranx hippos*
Cubbyu	*Equetus umbrosus*
Gag	*Mycteroperca microlepis*
Gray triggerfish	*Balistes capriscus*
Great barracuda	*Sphyraena barracuda*
Guaguanche	*Sphyraena guachancho*
Gulf toadfish	*Opsanus beta*
Hardhead catfish	*Arius felis*
Ladyfish	*Peprilus paru*
Lane snapper	*Lutjanus synagris*
Leopard toadfish	*Opsanus tau*
Lookdown	*Selene vomer*
Mangrove snapper	*Lutjanus griseus*
Molly miller	*Blennius cristatus*
Mullet	*Mugil* (sp.)
Ocean triggerfish	*Canthidermis sufflamen*
Pigfish	*Orthopristis chrysoptera*
Pinfish	*Lagodon rhomboides*
Planehead filefish	*Monocanthus hispidus*
Red drum	*Sciaenops ocellatus*
Red snapper	*Lutjanus campechanus*
Remora	*Remora remora*
Rock hind	*Epinephelus adscensionis*
Scaled sardine	*Harengula pensacolae*
Scamp	*Mycteroperca phenax*
Schoolmaster	*Lutjanus apodus*
Scrawled filefish	*Aluterus scriptus*
Sergeant major	*Abudefduf saxatilis*
Sharksucker	*Echeneis naucrates*

Sheepshead	*Archosargus probatocephalus*
Silk snapper	*Lutjanus vivanus*
Silver trout	*Cynoscion nothus*
Spanish sardine	*Sardinella anchovia*
Speckled trout	*Cynoscion nebulosus*
Tomtate	*Haemulon aurolineatum*
Whitespotted soapfish	*Rypticus maculatus*
Yellow chub	*Kyphosus incisor*
Yellowtail snapper	*Ocyurus chrysurus*

The Department of the Interior Mission

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

The Minerals Management Service Mission

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

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

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