Shark/snapper/grouper Longline surveys

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Introduction and Survey Design

The Southeast Fisheries Science Center (SEFSC) Mississippi Laboratories has conducted standardized bottom longline surveys in the Gulf of Mexico, Caribbean, and Southern North Atlantic since 1995 (Figure 1). The objective of this shark/snapper/grouper longline survey is to provide fisheries independent data for stock assessment purposes for as many species as possible, and this survey, conducted annually in U.S. waters of the Gulf of Mexico (Table 1), provides an important source of fisheries independent information on Gulf of Mexico red snapper.

The primary objective of the initial surveys was assessment of the distribution and abundance of large and small coastal sharks across their known or suspected ranges. The fishing depths were selected based on commercial shark fishing log summaries, which indicated that the primary depths of effort were 18-73m (10 to 40 fm). A random stratified sampling design with three depth strata; 18-36m (10-20 fm), 36-55mm (20-30 fm) and 55-73 (30-40 fm) was used and uniform effort across contiguous 60 nm sampling zones was achieved. Results of the first two years of the survey, including a detailed description of the protocol and gear, are summarized by Grace and Henwood (1997).

Based on analysis of the first two survey years, the 1997 survey was modified by eliminating depth stratification and changing the survey depths to 10-55m (5-30 fm). The depth reduction was at the request of SEFSC to ensure that the full range of several coastal sharks was encompassed by the survey. Elimination of depth stratification was to avoid over-sampling strata which represented the least available habitat (the 30-40 fm strata represented very little of the available bottom, but was receiving 33% of the effort). During 1997, the survey was expanded into Mexican waters in an attempt to cover the full geographic range of some of the more important commercial shark species.

In 1998, the survey was conducted in Mexican waters of the Gulf of Mexico, the circumference of Cuba and the circumference of Navassa Island. Station selection based upon proportional allocation was implemented to ensure that the most abundant habitat received the highest levels of effort. Proportional allocation worked well in Mexican waters, but proved difficult in Cuba due to the narrowness of the continental shelf around most of the island. In many areas finding bottom for a one mile set was a challenge, limiting that set to certain depths was impossible.

A significant event in the evolution of our longline surveys occurred in 1999 when we were requested to implement a longline survey targeting red snapper (*Lutjanus campechanus).* At the time, red snapper were not specifically targeted as part of the shark surveys; a different hook type (circle hook) was used, and different depth strata were sampled. The snapper work was conducted between 64-146m (35-80 fm) in an area from east of the Mississippi River to south of

Perdido Key, Florida. Random sampling without proportional allocation was used and sampling units were 10 n. mi. blocks given the small geographical area to be covered.

The 1999 shark survey was impacted by the unavailability of the Oregon II. Lack of a larger vessel capable of Gulfwide surveys led to substitution of the 55 ft. shrimp trawler RV Caretta as our survey vessel. The Caretta did not have the range, endurance or capability for 24-hr operations, and it was evident that a full shark survey was not possible. Given the logistical constraints posed by the Caretta, we contracted the survey to an area from the Texas-Louisiana border to Panama City, Florida. By doing this we were able to double and sometimes triple the effort within our 60 nm sampling units (shrimp statistical zones), and to test for optimal sampling levels by species and area. The survey used proportional allocation based on the amount of bottom within each unit. A hook experiment using 25% circle hooks and 75% J hooks was included to allow comparison of catches between the red snapper surveys and the shark surveys.

The year 2000 saw the second red snapper pilot survey conducted off Texas. Stations were randomly selected within 20 nm contiguous sampling blocks in depths of 64-146m (35-80 fm). The hook comparison study was continued with 75% circle hooks and 25% J hooks.

As a result of the two red snapper surveys and the encountering of many important commercial shark species in deeper waters, the 2000 annual shark survey in the Gulf of Mexico was expanded to a depth range of 9-183m (5-100 fms). Proportional allocation was used and the hook comparison study was continued with 75% J hook sets and 25% circle hook sets. A similar survey was conducted in the Atlantic over the same depth ranges and using the same percentages of circle and J hook sets.

In 2001, the shark and red snapper surveys were combined into a single annual survey of the U.S. Gulf of Mexico. Proportional allocation based on shelf width within statistical zones was adopted and the survey was stratified by depth with 50% allocation in 9-55m, 40% allocation from 55-183m and 10% allocation from 188-366m. This allocation provided effort in the 9-55m strata comparable to that achieved in previous shark surveys, thereby preserving the time series back to 1995. The major change in the shark surveys was adoption of the Circle hook as the standard for these surveys. The Gulfwide survey has been completed during FY01, FY02 and FY03 with no further changes in sampling methodologies.

Prior to combining the red snapper and shark surveys, we conducted hook comparison studies, sampling density experiments and estimated relative abundance trends for sharks. The following text describes these experiments from a shark stock assessment standpoint, but these approaches also work for red snapper. What did not work particularly well was assessing relative abundance trends for red snapper using the early shark data because very few red snapper were caught in the early surveys.

Sampling Density Experiment

During the first 4 years of survey activities (1995 - 1998), survey effort was allocated based on logistics (time available and coverage area). Often the coverage areas were extensive (i.e., the U.S. Gulf of Mexico and Atlantic seaboard, Grace [2]) and allocation of longline sets was determined by available sea days. However, during the 1999 survey vessel constraints prevented a geographically broad-based survey and the survey area was restricted to the north-central U.S. Gulf of Mexico. Based on the allocation of sea days, bottom longline effort within some of the 60-nautical mile statistical zones was increased 2 fold over previous years. This sampling increase allowed statistical analysis useful for determining adequate sampling levels for several important shark management species without having to account for annual variability. The survey area for the 1999 survey extended from south of western Louisiana to south of Cape San Blas of the Florida panhandle (Figure 1). During the 1995 - 1998 surveys this area produced the highest and most species diverse shark catches as compared with other areas.

The coefficient of variation on mean CPUE per species was evaluated at different sample sizes. This was accomplished by first assuming the mean CPUE for each species and its variance was accurate for each population in the sample area. This assumption was considered valid due to the high concentration of sampling effort within the survey area. Due to the zero inflated highly skewed nature of the data, unbiased estimates of mean CPUE and variance were computed using the delta method (Pennington, 1983, 1996). From these statistics, percent standard error (PSE) was calculated for each species for simulated sample sizes ranging from 1 - 200. Line plots were constructed representing the change in PSE with increasing sample size. Sharks encountered during the surveys were not normally distributed and fit the description of low density populations when sampling with passive gear (Murphy and Willis, 1996). The PSE plots (Fig. 2) exhibit a general trend for decreasing PSE with an increase in sampling size; this emulates the slope of the plot presented by Murphy and Willis (1996) for low-density distributions that are not normally distributed (frequency of capture plotted against the number of organisms captured by set with passive gear). Employing the delta method (Pennington, 1983 and 1996) for determining adequate sampling sizes facilitated a more useful and accurate analysis than analytical methods that assume normal distributions.

For the purposes of the sampling density experiment, a sample size that yielded a PSE < 50.0% was considered to have adequate precision for providing reliable statistical information. Based on a PSE of 50.0%, it was possible to determine adequate sampling levels for several important shark management species (e.g., blacknose, blacktip, Atlantic sharpnose, spinner, sandbar, tiger, scalloped hammerhead and finetooth; Fig. 2). The sharks presented are grouped according to their sample size ranges to facilitate graphic representation. For all sharks collectively, a PSE of 50% is achieved with 10 longline sets. For the finetooth shark, the least frequently encountered shark, just under 160 longline sets are required to achieve a PSE of 50%. The PSE values are synoptic within the time frame and survey area for survey CARETTA 99-01.

An associated result to the analysis for the sampling density experiment is the rank in ascending PSE values by species; all sharks combined, blacknose, sharpnose, blacktip, tiger, spinner, scalloped hammerhead, sandbar and finetooth . The PSE ranking closely follows the order for percent composition by species for all surveys combined; the exceptions are the Atlantic sharpnose shark that constitutes a higher percent catch composition than the blacknose shark and the absence of smooth dogfish that are distributed deeper than the depth range for the data set used for the sampling density experiment. This parallel between the 2 rankings may be an indication that the survey area assessed during CARETTA 99-01 (the north-central Gulf of Mexico) may be a unique assessment window representative of shark populations in a broad geographical sense.

The results of the sampling density experiment are important to survey objectives in that it is possible to determine effort levels necessary to sufficiently document species distributions. This can be of particular importance for not only assessing the effectiveness of a survey, but also for designing surveys targeting a specific species. If annual abundance variability is considered not to be a potential source of bias when allocating effort, it is possible to establish adequate sampling levels (based on a past survey or collection of past surveys) for species within specific areas or for broad-based surveys. This is a useful tool for examining not only the more abundant species, but also for assessing cryptic species; surveys can be tailored with effort allocation by area to suit research or management objectives. For some of the rarely captured species achieving adequate sampling would require an unrealistic and logistically challenging amount of effort to gain reliable statistical information on CPUE data.

For the red snapper SEDAR we performed the above analysis using pilot study data from Texas (where C-hooks were employed) and Mississippi (where J-hooks were employed) (1999-2000). We found that relatively few samples (stations) are needed off Texas to develop a reasonably precise estimate for red snapper CPUE using C-hooks. Off Mississippi, sample sizes needed for precise estimates cannot be achieved using J-hooks (Figure 3).

Hook Comparison Study

For statistical analyses comparing differences between the use of C hook and J hooks, species specific CPUE, mean total length (TL) per hook type, and diversity of catch was compared between hook types for the four cruises during where both hook types were used [i.e., CARETTA 99-01; GU-00-03 (8); OT-00-04 (241); FE-00-12 (2)]. Due to the zero inflated highly skewed nature of the CPUE data, traditional parametric tests (e.g., *t*-tests) were not appropriate to discern differences in CPUE between hook types for each species. Therefore, a two-group comparison randomization technique was used to test the null hypothesis of no difference in mean CPUE between red snapper captured with C hooks and those with J hooks. This technique was first established by Fisher (1935, 1936) and has recently been updated by Manly (1997). To accomplish this technique, the species specific arithmetic mean difference in CPUE was calculated between C hooks and J hooks (d_{sp}). Next, under the null hypothesis that there is no difference in CPUE between hook types (i.e., the distribution of CPUE data is the same for each hook type), any one of the observed values $c_1, c_2, \ldots, c_m$ and $j_1, j_2, \ldots, j_n$ could equally have occurred in either of the samples. Therefore, a new sample 1 was chosen by randomly selecting m values out of the full set of $m + n$ values, with the remaining n values providing the new sample 2. The mean difference was then calculated for this randomized set of data. This step was repeated 1000 times for a total of 1000 randomized mean differences. These differences were arranged in order from smallest to largest. If the null hypothesis was true, then d_{sp} should tend toward zero, which would be the center of the list of the set of 1000 differences. However, if there was a difference in the distributions of CPUE between C hooks and J hooks, then d_{sp} would tend to be at either end of the list depending on whether the difference is negative or positive. For a positive difference, d_{sp} was said to be sufficiently large ($\alpha = 0.05$) if it occurred among the top 95% of the values in the list. For a negative difference, d_{sp} was said to be significant ($\alpha = 0.05$) if it occurred among the bottom 5% of the values in the list. This type of randomization test has many advantages. First, the test is exact and secondly, it is not necessary to assume any particular type of distribution such as a normal distribution for each sample for a *t*-test. In addition, unlike a non-parametric test such as the Mann-Whitney U-test, it allows the original data to be used rather than just the ranks of the data.

When examining the comparison data stratified by depths 9 m - 55 m (5 fm - 30 fm), there was a significant difference for CPUE between hook types with the C hook having significantly higher

CPUEs for all sharks collectively, blacknose, finetooth, blacktip and Atlantic sharpnose sharks (Table 2). When data from all depth strata are assessed, the only significantly higher shark CPUE is for all sharks collectively (Table 3) and for all telelosts, red snappers and groupers (Table 4).

To test for differences in mean TL per species per hook type, *t*-tests were employed due to the approximate normality of the data. First, however, equality of variances was tested ($a = 0.05$) per species between hook types using the Folded F method (Steel and Torrie, 1980). If the variances between hook-types were different then a *t*-test for unequal variances was conducted using the Satterthwaite method (1946), and if variances were not significantly different then a *t*-test for equal variances was conducted using the pooled method (Devore and Peck, 1994). Results are shown in Table 5.

To compare species diversity between hook sizes, the diversity of fish communities sampled by each hook size was indexed using the Shannon-Wiener method (Shannon, 1948); data analysis from surveys where both hook sizes were used [i.e., CARETTA 99-01; GU-00-03 (8); OT-00-04 (241); FE-00-12 (2)]. To compare indices from each hook size, a modified *t*-test was used based on methods established by Basharin (1959) and Hutcheson (1970). The results were; $H'_C = 1.41$, $S_{H'C} = 0.068$, and $H'_J = 1.34$, $S_{H'J} = 0.074$, where H'_C and H'_J are the Shannon-Wiener diversity indices for C hooks and J hooks respectively, and $S_{H'C}$ and $S_{H'J}$ are standard deviations of those index values. The *t*-value was 0.703 and the *p*-value for difference in diversity was $p > 0.25$. Therefore, the analysis establishes there was no significant difference in species diversity between hook types (totals; 32 species for C hooks, 28 species for J hooks).

There are several important implications from the hook comparison study; most notably is hook type can affect CPUE. Improving survey efficiency by using a more effective C hook results in catches with generally higher CPUE values. This is an important consideration for better utilization of survey opportunities (getting the most return for survey effort), controlling gear-related biases, and for expanding survey objectives to target a variety of important management species (e.g., red snapper and yellowedge grouper).

Recommended uses of longline data for the current SEDAR

While the shark longline surveys date back to 1995, the early data were not particularly useful in terms of red snapper distribution and abundance estimates due to the depths covered by the surveys and the use of J hooks instead of C hooks. Data from the red snapper pilot studies and from the last three years of the combined survey indicated that snapper vulnerable to this gear are most abundant in depths of 20-70 fathoms (37-146 m), with peak abundance in the 30-60 fathom (55-110 m) range. Thus, the 10-55 m depth range of the 97-99 surveys was outside of the peak distributional range of the species of interest. This, coupled with the fact that the J hook was found to be significantly less efficient in capture of red snappers, led to conclusions that little useful information could be gleaned from the shallow water shark surveys using the J hook.

For the present SEDAR, we suggest that the only fishery independent longline data that should be used is that in which a C hook was employed and the survey covered depths out to at least 165m. The two red snapper pilot surveys used the correct hook type in the correct depth ranges but were isolated temporally and spatially, and Gulfwide extrapolations from localized data are not recommended. We suggest that the best data are FY01, FY02 and FY03 surveys where C hooks were used and the survey design remained unchanged. We recognize the limitations of a three year time series, but the strength of the longline data is the ability to characterize a portion of the population that was previously not sampled.

Before any statistics were employed, the occurrence of stations and stations where red snapper were caught were plotted by year and all years combined (Figures 4 – 7). These visual presentations indicated that the majority of the snapper catches occurred off Louisiana and Texas, with relatively low catch rates east of the Mississippi River. The plots also indicate that numerous stations occurred inshore and offshore of stations where snapper were caught suggesting a strong depth affinity for snapper vulnerable to this gear. It can be noted from the plots that the FY01 and FY02 surveys were not fully completed (avoiding hurricanes) and that the data should be adjusted accordingly. FY03 was the only survey in which all scheduled stations were completed.

Red snapper CPUE was plotted on depth of capture to examine its depth distribution in the Gulf (Figure 8). The survey places 50% of the effort in the 9-55m depths, 40% of the effort in depths of 55-183m, and 10% in the 183-366m depth strata. CPUEs were then calculated based on effort and catches within each of the depth strata. Due to a lack of occurrence of red snapper in the deepest stratum, this stratum was dropped from further analyses.

A modeling approach was used to develop annual abundance indices based on CPUE (number/100 hook hour) of red snapper for the three survey years (i.e., 2001, 2002, 2003). We used MIXED procedure in SAS as described in (Patetta, 2002) to estimate both mean annual frequency of occurrence (i.e., based on presence/absence) and mean annual CPUE. Abundance indices were developed not only for the overall US GOM, but separate indices were developed for red snapper collected both east and west of the Mississippi River Delta as well. A mixed logistic regression model was employed to estimate mean annual frequency of occurrence of red snapper. The parameter included in all models was year, and separate covariance structures were developed for each survey year within the mixed models. The LSMEANS statement in the MIXED procedure was use estimate the mean annual frequency of occurrence and test for differences between means. Methods for developing an index of mean annual CPUE were the same as those of the aforementioned mixed logistic regression. However, we assumed an overdispersed Poisson distribution for the CPUE data, and used a mixed loglinear model. Presently, all current models have insignificant lack-of-fit ($p > 0.25$ for all models), and indices resulting from these models are shown in Table 6. CPUE was found to be significantly different between the eastern and western Gulf, but between-year differences in the two regions were not noted.

We next constructed age frequency histograms for red snapper collected east and west of the Mississippi River (Figure 9). West of the River, the population has an age structure similar to what might be expected in an unfished situation with full recruitment at age 8, representation of all age classes through the mid 20s, and one individual reaching the age of 53. East of the River, fish are younger with a few older fish and a maximum age of 19. Using only the data from west of the Mississippi River, we calculated instantaneous mortality for this segment of the population to be $Z = 0.1289$. Assuming that very little fishing pressure is being exerted on these older, offshore fish, we suggest that Z may be a reasonable indicator of M (natural mortality) for these segments of the red snapper population.

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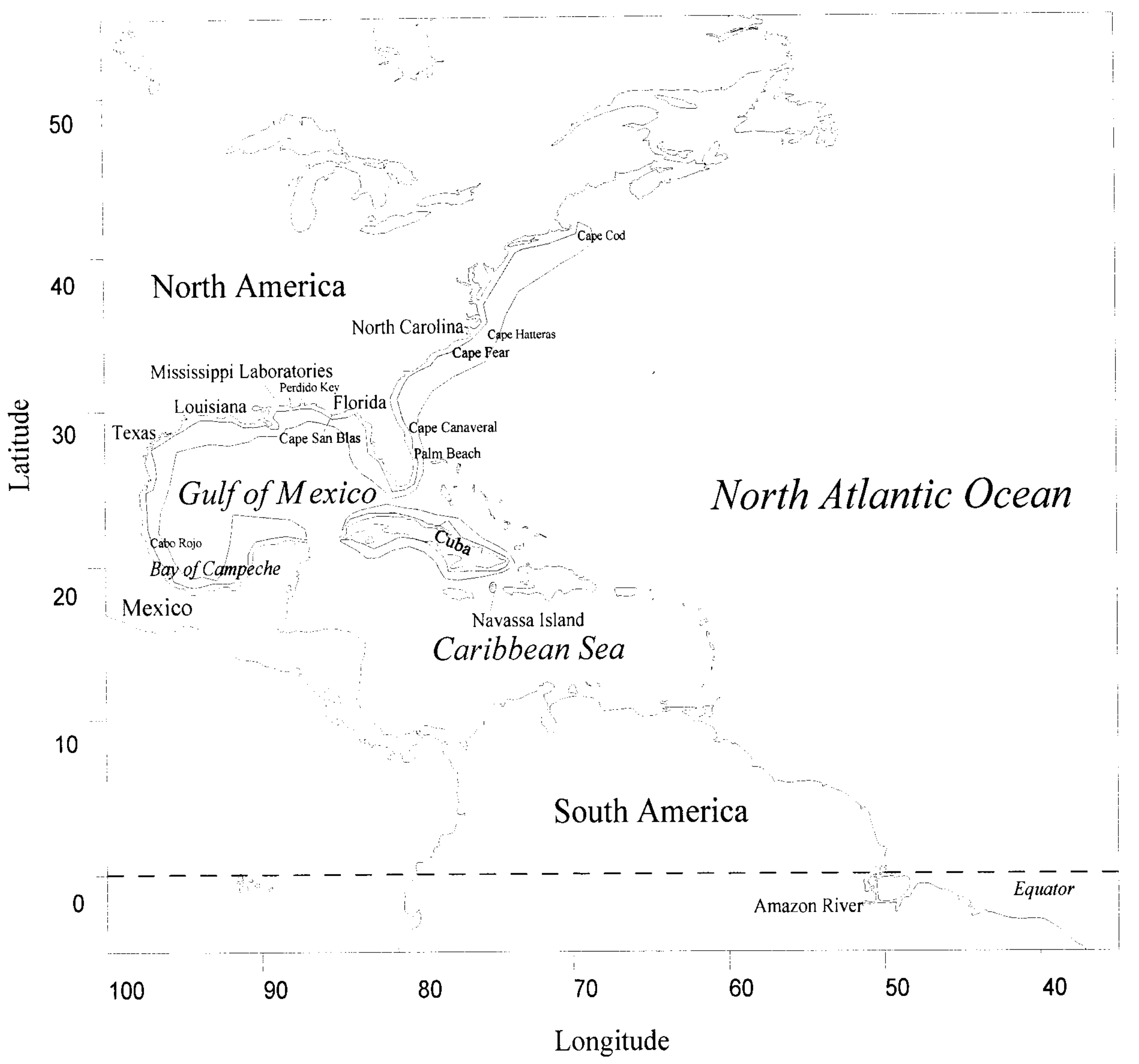

Figure 1. Survey areas for NMFS MS Laboratories longline projects (1995-2001) in the western North Atlantic Ocean.

Table 1. NMFS MS Laboratory longline projects, 1995 - 2003.

Survey	Date	Location	Depth range (m)	Effort (# sets)	Random station selection description.
OT-95-04 (218)	7/23 - 8/17/95	GOM[1]	18 m - 73 m	82	Stations depth stratified and equally allocated within statistical zones; depth strata 18 m - 37 m, 37 m - 55 m, 55 m - 73 m; J hooks.
RS-95-03 (2)	8/10 - 8/24/95	Atlantic[2]	18 m - 73 m	45	Stations depth stratified and equally allocated within statistical zones; depth strata 18 m - 37 m, 37 m - 55 m, 55 m - 73 m; J hooks.
OT-96-04 (222)	7/31 - 9/13/96	GOM and Atlantic	18 m - 73 m	151	Stations depth stratified and equally allocated within statistical zones; depth strata 18 m - 37 m, 37 m - 55 m, 55 m - 73 m; J hooks.
OT-97-04 (227)	7/25 - 9/24/97	Mexican GOM, GOM and Atlantic	9 m - 55 m	259	Stations not depth stratified but equally allocated within 60 linear n. mile zones or statistical zones; J hooks.
OT-98-02 (231)	7/24 - 9/22/98	Mexican GOM, Cuba [3], GOM	9 m - 413 m	216	Stations not depth stratified but equally allocated within 60 linear n. mile zones or statistical zones; J hooks.
OT-99-02 (233)	2/16 - 3/2/99	Atlantic	9 m - 55 m	29	Stations not depth stratified but equally allocated within statistical zones; J hooks.
FE-99-10 SEF	5/6 - 5/19/99	GOM	64 m - 146 m	60	Station coordinates by random longitude and random depth and equally allocated within 10 linear n. mile contiguous sampling blocks; circle hooks.
CARETTA 99-01	8/4 - 9/28/99	GOM	9 m - 55 m	161	Proportional allocation based on continental shelf width within statistical zones; sampling density experiment; hook comparison experiment with 75% J hooks, 25% circle hooks.
GU-00-03 (8)	6/6 - 6/19/00	GOM	64 m - 146 m	59	Station coordinates by random longitude and random depth and equally allocated within 20 linear n. mile contiguous sampling blocks; hook comparison experiment with 75% circle hooks, 25% J hooks.
OT-00-04 (241)	8/3 - 8/28/00	GOM	9 m - 183 m	137	Proportional allocation based on continental shelf width within statistical zones; sampling density experiment; hook comparison experiment with 75% J hooks, 25% circle hooks.
FE-00-12 (2)	9/6 - 10/16/00	Atlantic	9 m - 183 m	105	Proportional allocation based on continental shelf width within statistical zones; sampling density experiment; hook comparison experiment with 75% J hooks, 25% circle hooks.
OT-00-08 (244)	12/6 - 12/12/00	GOM	55 m - 366 m	41	Station coordinates by random longitude and random depth and equally allocated within 10 linear n. mile contiguous sampling blocks; stations depth stratified with 4 stations each block 55 m - 183 m, 2 stations each block 183 m - 366 m; hook comparison experiment with 75% circle hooks, 25% J hooks.
ONJUKU-01	6/1 - 6/20/01	Mexican GOM[4]	9 m - 50 m	38	Proportional allocation based on continental shelf width within 60 linear n. mile sampling zones; circle hooks, Atlantic bonito for bait.
OT-01-04 (247)	7/31 - 9/30/01	GOM	9 m - 366 m	277	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
ONJUKU-01	6/28 - 7/5/02	Mexican GOM[4]	18 m - 217 m	30	Proportional allocation based on continental shelf width within 60 linear n. mile sampling zones; circle hooks, Atlantic bonito for bait
OT-02-04 (251)	7/31 - 9/21/02	GOM	9 m - 366 m	212	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
OT-03-04 (255)	7/29 - 9/29/03	GOM	9 m - 366 m	280	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.

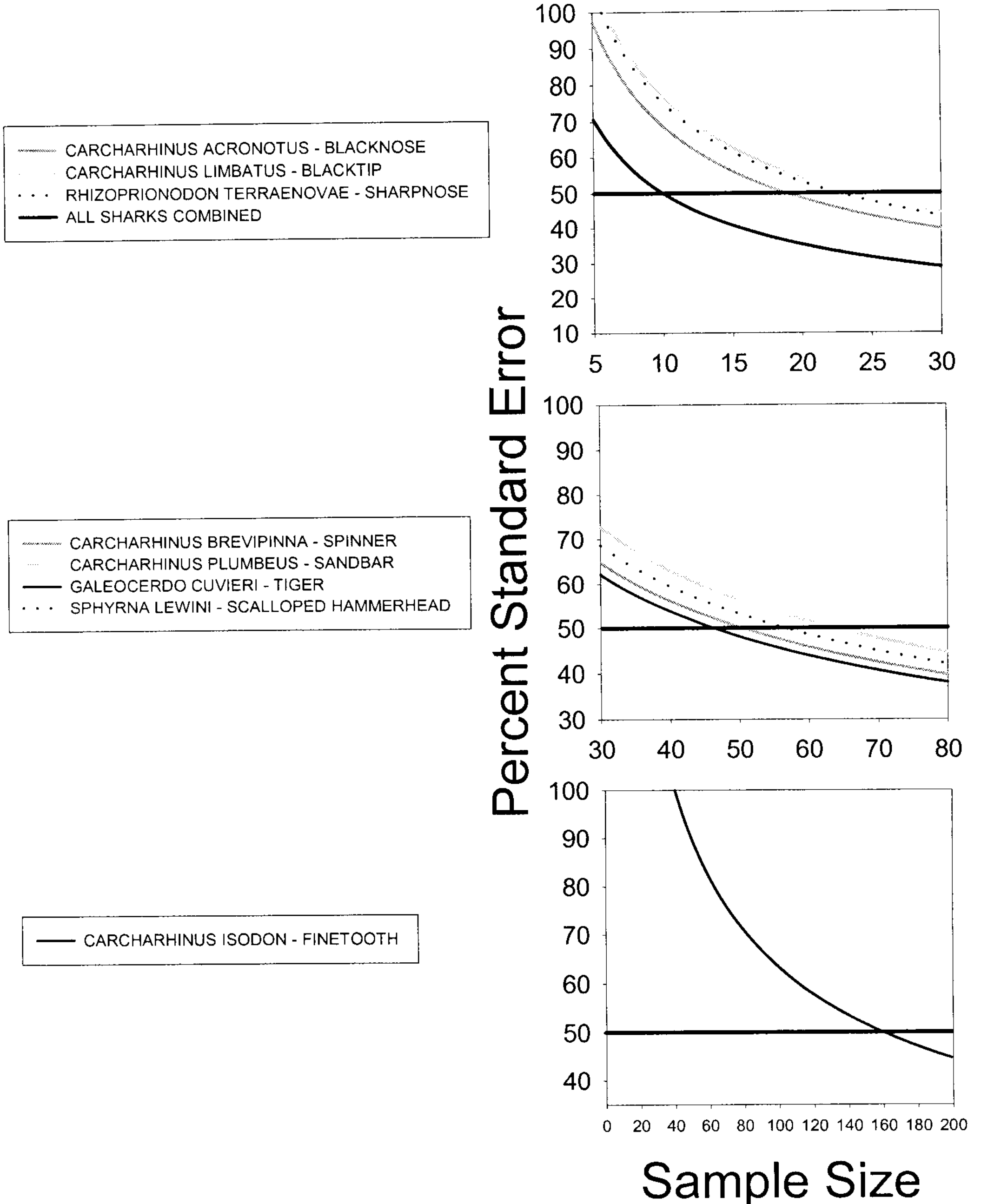

Figure 2. Percent standard error (i.e., coefficient of variation of the mean) shown as a function of sample size for selected species sharks and for all species combined. Dark horizontal line in each graph represents the 50% threshold.

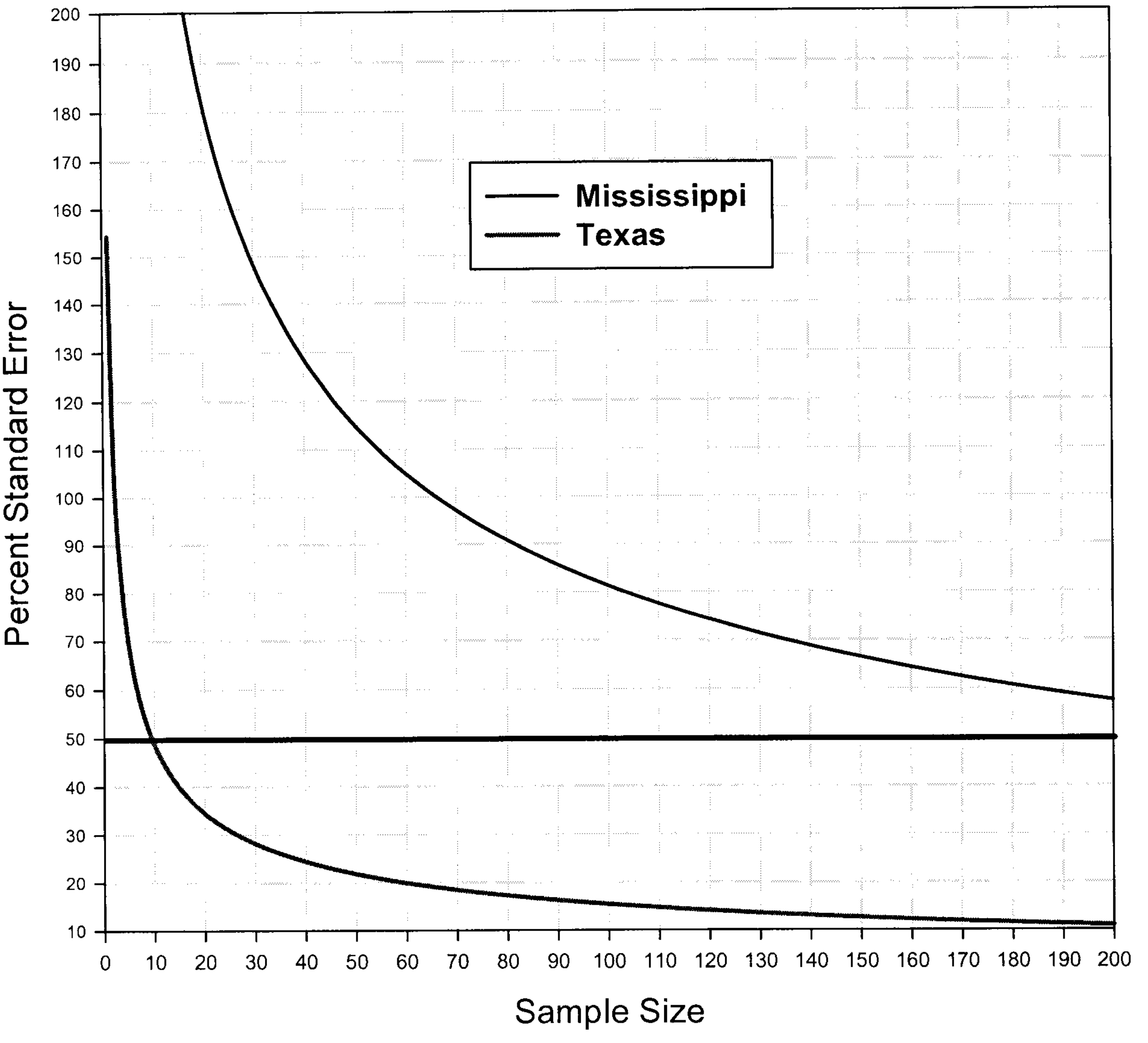

Figure 3. Percent standard error (i.e., coefficient of variation of the mean) shown as a function of sample size for red snapper collected in cruises off Texas and Mississippi. Dark horizontal line represents the 50% threshold.

Table 2. Mean differences between CPUE of sharks captured with c-hooks ($n_c = 99$) and those captured with j-hooks ($n_j = 274$; $n_{total} = 373$) between 5 and 30 fathoms.

Species	**Occurrences**	**Total number of individuals**	**Mean CPUE, c-hooks**	**Mean CPUE, j-hooks**	**Mean difference**	**p-value**
All Sharks	301	2237	9.38	4.77	4.61	>0.0001**
Carcharhinus acronotus, blacknose	86	178	0.84	0.35	0.49	0.005**
Carcharhinus brevipinna, spinner	29	90	0.41	0.18	0.23	0.123
Carcharhinus falciformis, silky	12	13	0.060	0.026	0.034	0.127
Carcharhinus isodon, finetooth	6	29	0.273	0.007	0.266	0.008**
Carcharhinus limbatus, blacktip	70	156	0.69	0.32	0.37	0.032**
Carcharhinus luecus, bull	14	30	0.0808	0.0803	0.0005	0.464
Carcharhinus plumbeus, sandbar	25	34	0.101	0.088	0.003	0.417
Galeocerdo cuvieri, tiger	77	116	0.39	0.28	0.11	0.183
Rhizoprionodon terraenovae, sharpnose	211	1558	6.44	3.36	3.08	0.001**
Sphyrna lewini, scalloped hammerhead	22	25	0.061	0.069	-0.008	0.492
Sphyrna mokarran, great hammerhead	3	3	0.010	0.007	0.003	0.443

**Significant at $\alpha > 0.05$. *Marginally significant at $\alpha > 0.1$.

(04-241, 55-991, 63-003, 64-012, 04-244) depth 5-30 fathoms

Table 3. Mean differences between CPUE (# per 10,000 hook hours) of sharks captured with c-hooks ($n_c = 166$) and those captured with j-hooks ($n_j = 336$; $n_{total} = 502$).

Species	Total occurrences	Total number of individuals	Mean CPUE, c-hooks	Mean CPUE, j-hooks	Mean difference	p-value
All Sharks	411	3319	836	575	261	0.002**
Carcharhinus acronotus, blacknose	88	182	52	28	24	0.093*
Carcharhinus brevipinna, spinner	39	130	25.90	25.89	0.01	0.479
Carcharhinus falciformis, silky	31	37	12	5	7	0.067*
Carcharhinus isodon, finetooth	6	29	16	1	15	0.414
Carcharhinus limbatus, blacktip	82	217	45	43	2	0.405
Carcharhinus luecus, bull	20	40	7	9	-2	0.411
Carcharhinus plumbeus, sandbar	49	65	14	12	2	0.379
Centrophorus granulose, slimy	4	86	51.2	0.3	50.9	0.062*
Galeocerdo cuvieri, tiger	79	118	23.49	23.51	-0.02	0.513
Ginglymostoma cirratum, nurse	19	25	8	4	4	0.091*
Isurus oxyrinchus, shortfin mako	3	3	60.2	59.5	0.7	0.499
Mustelus canis, smooth dogfish	67	281	84	42	42	0.074*
Mustelus norrisi, Florida smoothhound	8	14	4	2	2	0.255
Rhizoprionodon terraenovae, sharpnose	251	2015	473	366	107	0.141
Sphyrna lewini, scalloped hammerhead	52	65	16	12	4	0.245
Sphyrna mokarran, great hammerhead	3	3	0.602	0.595	0.007	0.504

**Significant at $\alpha > 0.05$. *Marginally significant at $\alpha > 0.1$.

(04-241, 55-991, 63-003, 64-012, 04-244) no depth limits

Table 4. Mean differences between CPUE of groupers and snappers captured with c-hooks ($n_c = 166$) and those captured with j-hooks ($n_j = 336$; $n_{total} = 502$).
*Significant at $\alpha > 0.05$.

Species	Total occurrences	Total number of individuals	Mean CPUE, c-hooks	Mean CPUE, j-hooks	Mean difference	p-value
All Groupers and Snappers	58	174	94	5	89	> 0.0001*
Epinephelus flavolimbatus, yellowedge grouper	20	34	18	1	17	> 0.0001*
Epinephelus morio, red grouper	7	27	15	1	14	0.018*
Epinephelus nigritus, warsaw grouper	3	4	2	0	2	0.036*
Lutjanus campechanus, red snapper	32	101	54	3	51	> 0.0001*
Mycteroperca phenax, scamp	2	3	2	0	2	0.104
Rhomboplites aurorubens, vermilion snapper	3	3	2	0	2	0.034*

(04-241, 55-991, 63-003, 64-012, 04-244) no depth limits

Table 5. Mean differences between total lengths of sharks, groupers and snappers captured with c-hooks and those captured with j-hooks.
**Significant at $\alpha > 0.05$. *Marginally significant at $\alpha > 0.1$.

Species	Sample size, c-hooks	Sample size, j-hooks	p-value for equal variances	Mean total length, c-hooks (mm)	Mean total length, j-hooks (mm)	Mean difference (mm)	t-value	p-value
All Sharks	1747	1376	<0.0001**	989	1058	-69	-6.14	<0.0001**
Carcharhinus acronotus, blacknose	84	88	0.0123**	1047	1076	-29	-1.40	0.1631
Carcharhinus brevipinna, spinner	77	52	0.3654	1154	1185	-31	-0.90	0.3681
Carcharhinus falciformis, silky	21	16	0.0966*	1094	1259	-166	-1.66	0.1136
Carcharhinus isodon, finetooth	27	2	0.9999	1191	1073	119	1.31	0.2023
Carcharhinus leucus, bull	14	26	0.4077	1918	2326	-408	-2.64	0.0119**
Carcharhinus limbatus, blacktip	114	102	0.0912*	1184	1309	-125	-4.27	<0.0001*
Carcharhinus plumbeus, sandbar	26	36	0.5767	1499	1614	-114	-1.54	0.1297
Galeocerdo cuvieri, tiger	39	78	0.2954	1164	1336	-173	-2.20	0.0301**
Mustelus canis, smooth dogfish	212	64	0.2398	1050	1129	-79	-3.38	0.0008**
Rhizoprionodon terraenovae, sharpnose	971	872	0.0036**	872	894	-22	-3.96	<0.0001**
Sphyrna lewini, scalloped hammerhead	31	33	0.4217	1695	1751	-56	-0.45	0.6516
Epinephelus flavolimbatus, yellowedge grouper	30	2	0.9968	754	949	-195	-1.83	0.0777*
Epinephelus morio, red grouper	24	2	0.3358	528	550	-22	-0.21	0.8340
Lutjanus campechanus, red snapper	88	11	0.5635	756	842	-86	-2.97	0.0037**

(04-241, 55-991, 63-003, 64-012, 04-244) no depth limits, estimated lengths included, total lengths

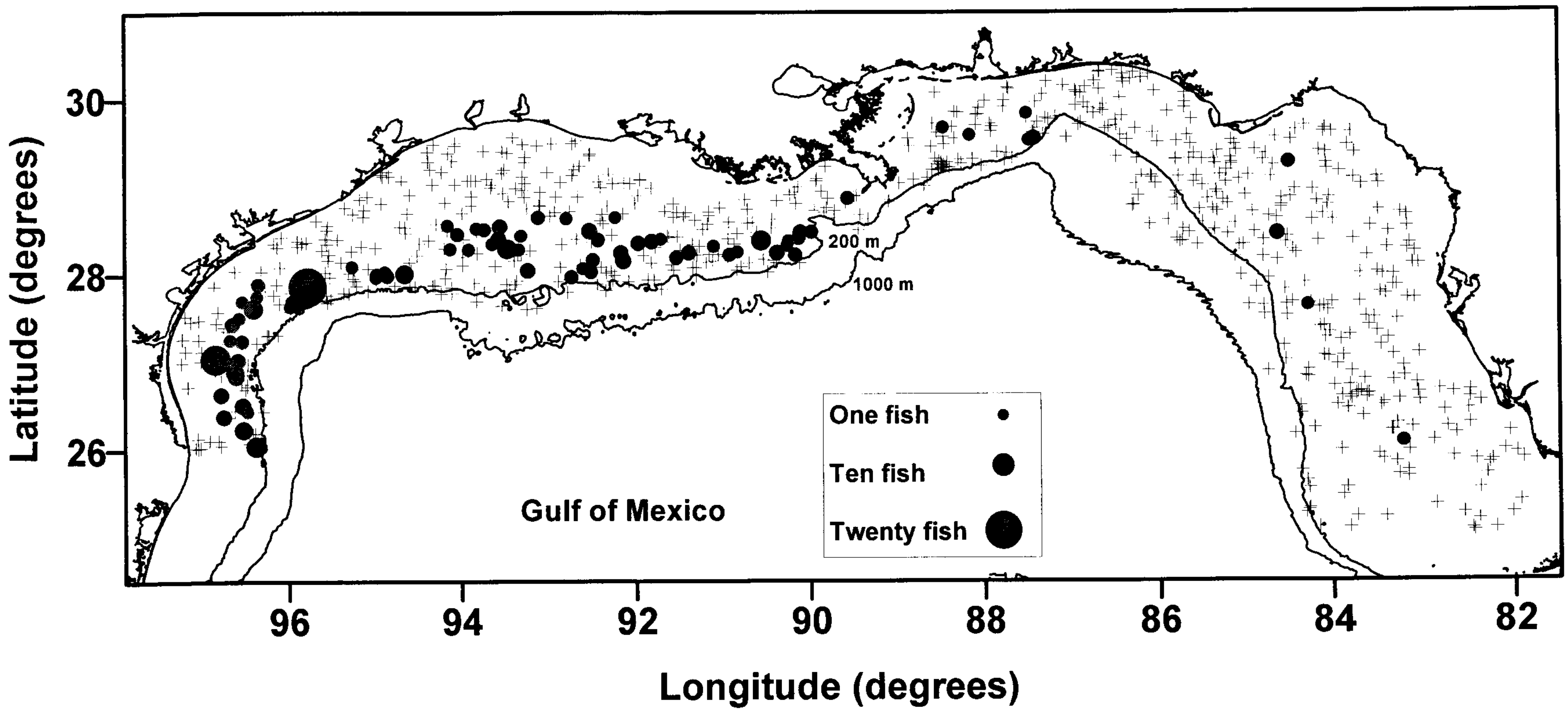

Figure 4. Chart of red snapper catch in Gulf longline surveys from 2001 to 2003.

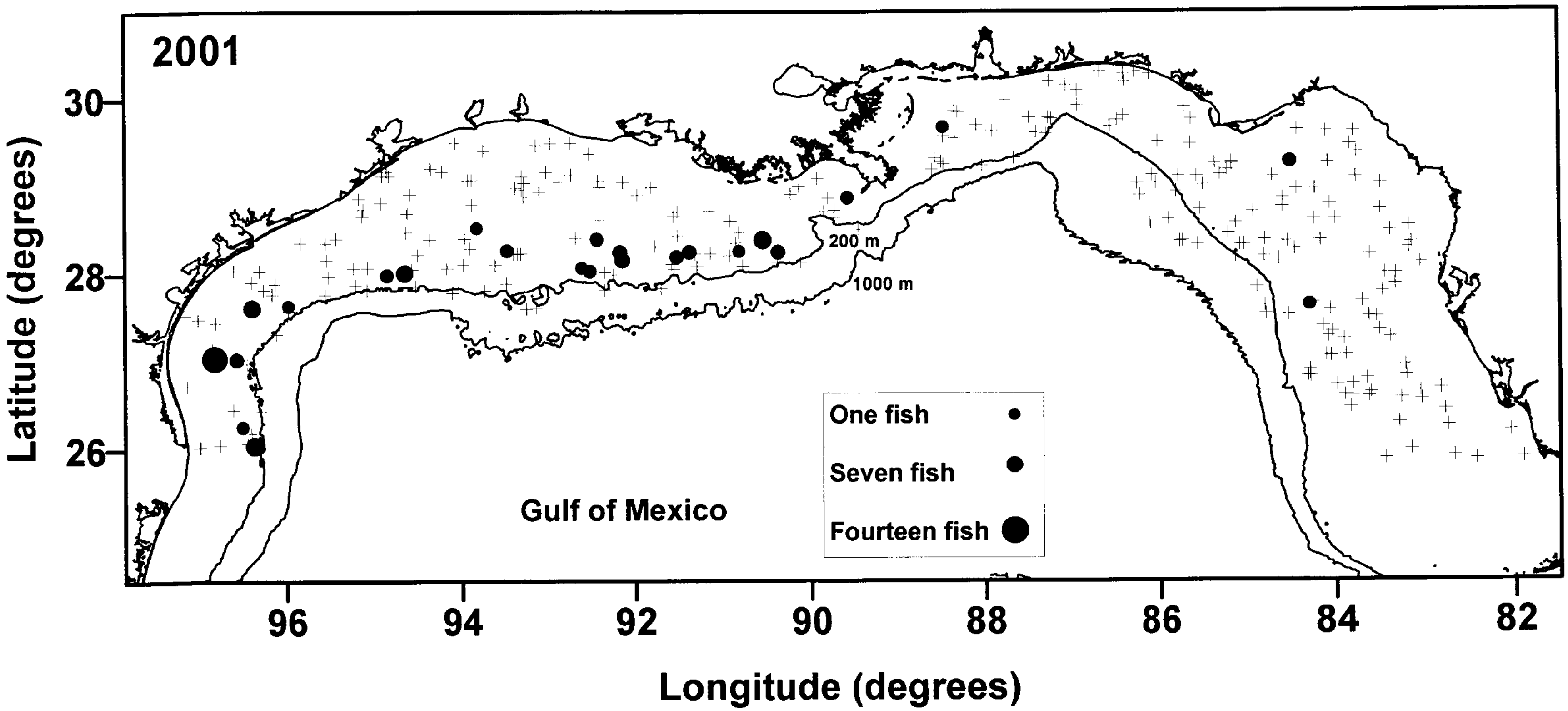

Figure 5. Chart of red snapper catch in Gulf longline surveys from 2001.

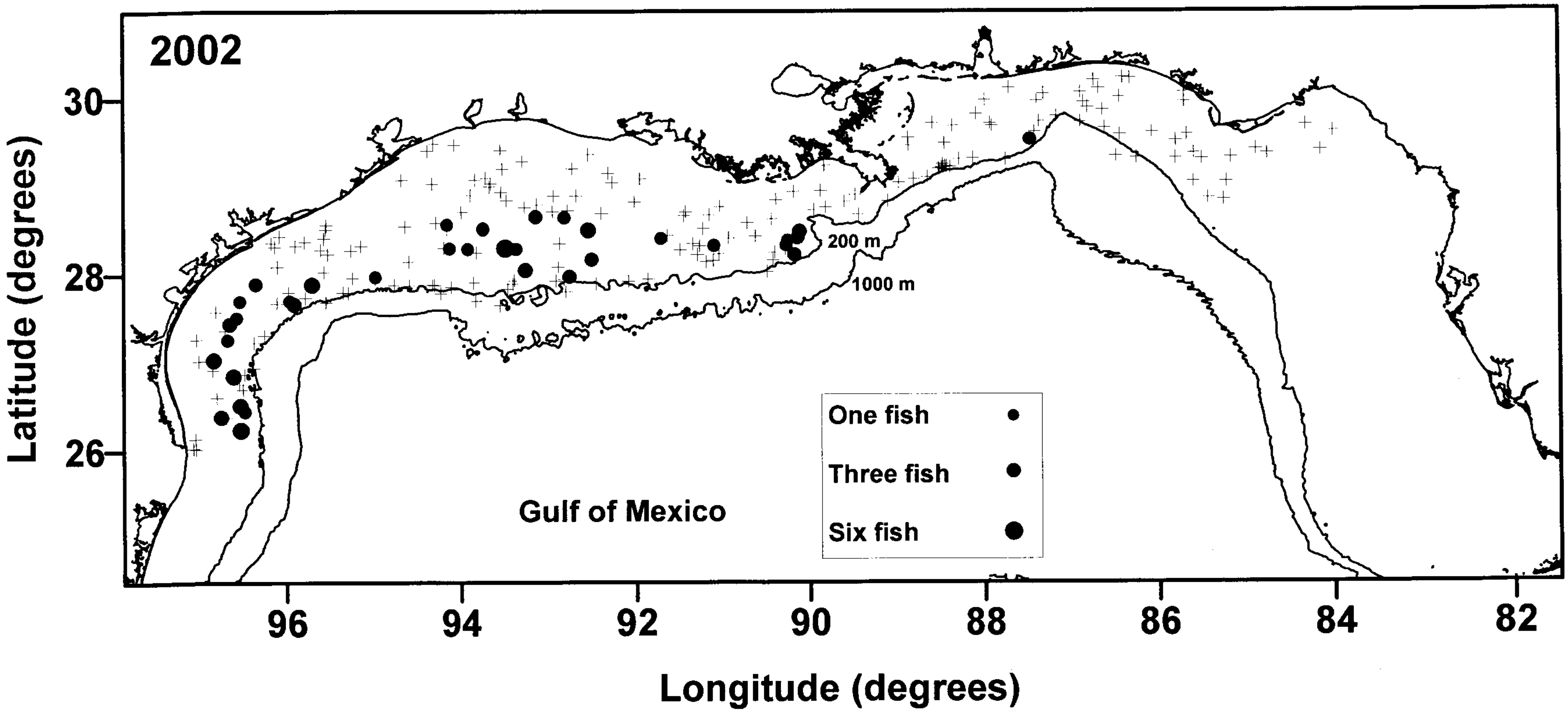

Figure 6. Chart of red snapper catch in Gulf longline surveys from 2002.

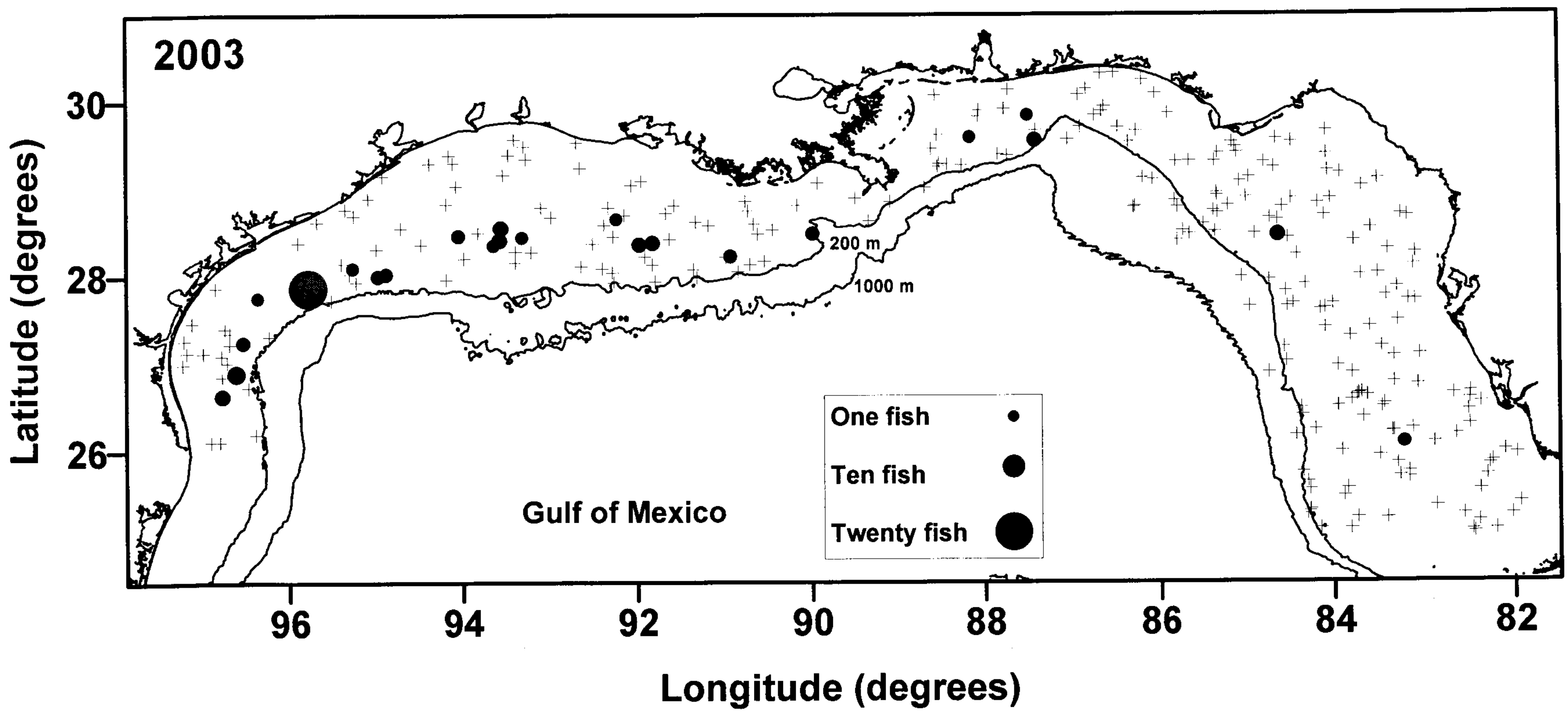

Figure 7. Chart of red snapper catch in Gulf longline surveys from 2003.

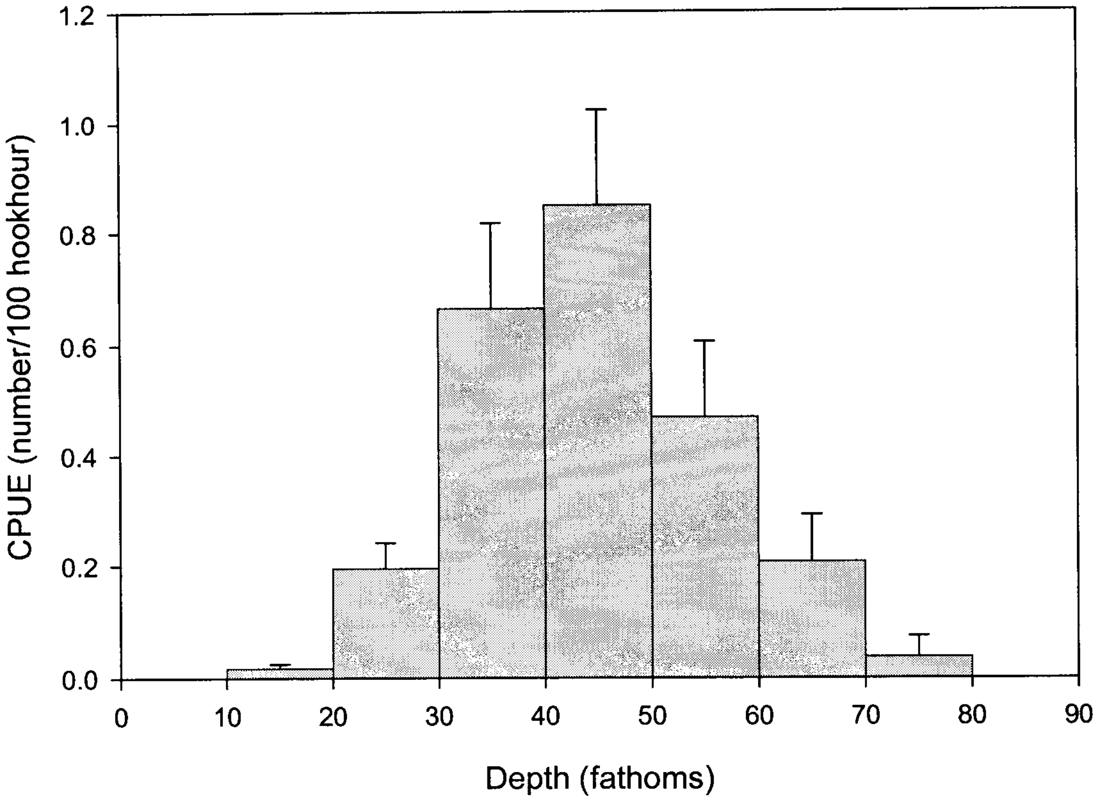

Figure 8. Depth distribution of CPUE (number/100 hookhour) of red snapper collected during NMFS research longline surveys from 1999-2003 in depths of 3-245 fathoms (error bars represent one stadard error).

Table 6. Annual indices of frequency of occurrence and CPUE (number per 100 hookhours) of red snapper in the Gulf of Mexico. Indices were derived for those red snapper collected between 5 – 100 fathoms and those collected between 30 – 100 fathoms (number of stations from which data was used in analyses are listed). The Gulfwide demarcation indicates indices were calculated over the entire U.S. Gulf of Mexico, while West and East refer to indices derived for red snapper collected west and east of the Mississippi River Delta. Letters associated with certain index values indicate a significant difference ($\alpha = 0.05$) between those values. Absence of letters indicates no significant difference between annual index values.

5 – 100 fathoms (number of stations used: Gulfwide = 699, West = 374, East = 325)

Year	Frequency of Occurrence, Gulfwide		Frequency of Occurrence, West		Frequency of Occurrence, East	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
2001	0.1029 a	0.0212	0.1774	0.0371	0.0252	0.0192
2002	0.1739 b	0.0280	0.2333	0.0364	0.0175	0.0295
2003	0.0924 a	0.0201	0.1900	0.0426	0.0268	0.0170

Year	CPUE, Gulfwide		CPUE, West		CPUE, East	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
2001	0.3098	0.0953	0.5755	0.1824	0.0329	0.0276
2002	0.3632	0.0738	0.4951	0.0990	0.0162	0.0278
2003	0.2657	0.1120	0.6056	0.2754	0.0375	0.0283

30 – 100 fathoms (number of stations used: Gulfwide = 307, West = 169, East = 138)

Year	Frequency of Occurrence, Gulfwide		Frequency of Occurrence, West		Frequency of Occurrence, East	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
2001	0.2059 abc	0.0431	0.3448	0.0654	0.0227	0.0380
2002	0.2755 ab	0.0476	0.3768	0.0603	0.0345	0.0569
2003	0.1215 ac	0.0355	0.2857	0.0754	0.0154	0.0260

Year	CPUE, Gulfwide		CPUE, West		CPUE, East	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
2001	0.6369	0.2108	1.1031	0.3538	0.0224	0.0384
2002	0.6000	0.1382	0.8388	0.1864	0.0318	0.0547
2003	0.4596	0.2651	1.1069	0.6594	0.0413	0.0710

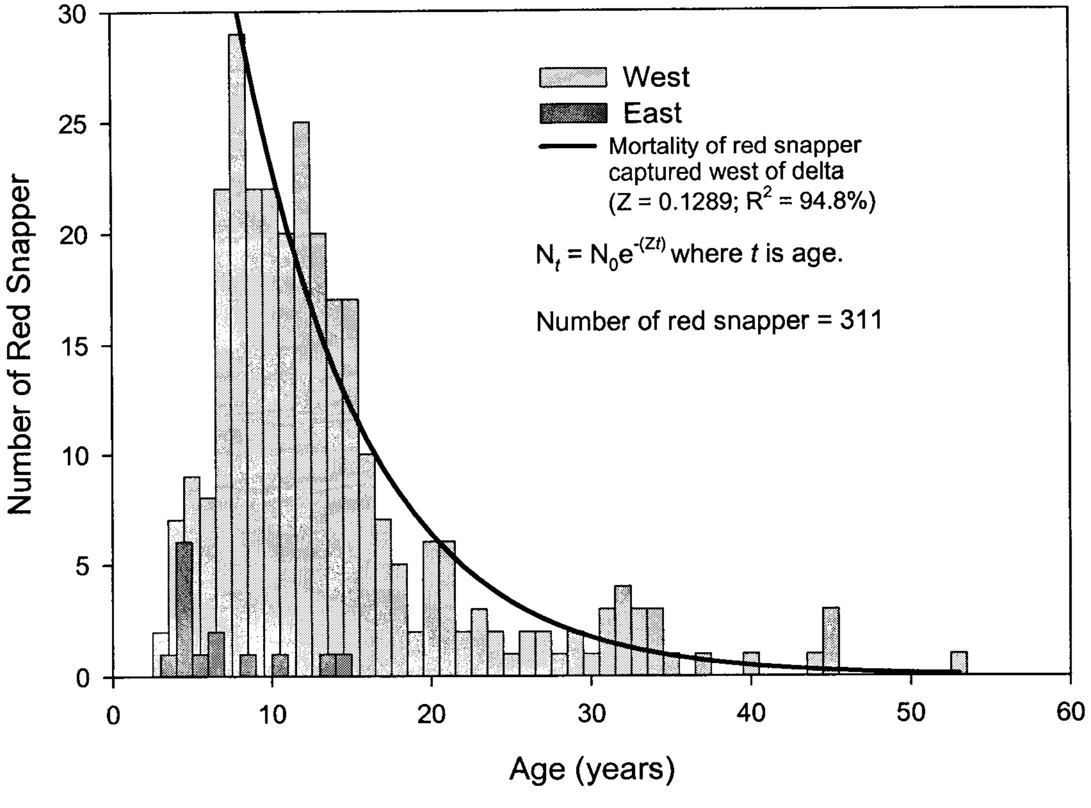

Figure 9. Age frequency histograms for red snapper collected east and west of the Mississippi River Delta, and mortality for those collected west of the delta (survey years 2000 - 2003).