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Abstract.—Bycatch reduction devices (BRDs) have been mandated for use in the U.S. Gulf of Mexico shrimp fishery to reduce shrimp trawl mortality of juvenile red snapper *Lutjanus campechanus.* Conditional survival of juvenile red snapper from shrimp trawl bycatch has been estimated to be on the order of 12%. The BRDs have been estimated to reduce shrimp trawl bycatch mortality by more than the 50% reduction that has been estimated as necessary to rebuild the stock by the target date of 2019. Results from analyses in this study that used observer data collected during 1992–1996 do not support this contention. A low fraction of the annual bycatch occurs during times of the year when BRDs effectively exclude juvenile red snapper at the sizes encountered. Maximum potential exclusion of juvenile red snapper with the use of BRDs is only about 25–27%, not 59% as has been previously estimated. If rebuilding requires a 50% reduction in age-0 and age-1 red snapper bycatch mortality to achieve the stock recovery targets, this study's results clearly demonstrate that the BRD by itself will not produce the mortality reductions necessary to meet this objective.

The stock of red snapper *Lutjanus campechanus* in the western Gulf of Mexico was recognized by the Gulf of Mexico Fisheries Management Council (GMFMC) as being severely overfished more than a decade ago. The GMFMC implemented management measures beginning in the mid 1980s (Goodyear 1995). The initial action set a 12-in size limit for the recreational fishery but still allowed the retention of five undersized fish per fisher. The GMFMC took more restrictive actions in 1990. The size limit was increased to 13 in; a recreational bag limit of seven fish was imposed; quotas were established for the commercial fisheries; and an emerging nearshore longline fishery, which was taking substantial numbers of large red snapper, was prohibited. Also in 1990, the offshore shrimp fishery began widespread compliance with the turtle excluder device (TED) regulations that had been implemented to protect sea turtles. These devices may have caused an associated reduction in shrimp catch (Renaud et al. 1993) and fish catch, including red snapper (LGL Ecological Research Associates 1997).

These and continued management actions appear to have benefited the affected fish stocks. For example, the recruitment index (catch per unit effort, CPUE, of age-1 red snapper in summer; Goodyear 1995; Schirripa and Legault 1997) has steadily increased since the mid 1980s (Figure 1). As of 1996 (the 1995 year-class), recruitment approached a level last seen in the 1970s and early 1980s (Schirripa and Legault 1997). One exception occurred in 1990, which reflected the exceptional abundance of the 1989 year-class (Goodyear 1995; Schirripa and Legault 1997). When the annual commercial quotas were first set in the range of 2–3 million pounds in the mid 1980s, they were not filled. In recent years, total allowable catch (TAC) has been set at 9.12 million pounds. The commercial allocation (4.65 million pounds) has been reached within a matter of weeks, and the fishery was subsequently closed (Figure 2). Frequently, the recreational allocation (4.47 million pounds) has been exceeded in these same years, but closures have not occurred because of the time required to estimate recreational landings. In 1997, the National Marine Fisheries Service (NMFS), for the first time ever, closed the recreational fishery before the end of the year. Estimates of stock level by year and age (Schirripa and Legault 1997) showed substantial increases in recent years, especially the portion of the stock 14 years of age and older (Figure 1). Age 14, assuming an instantaneous natural mortality rate of 0.10, is the age that red snapper reach maximum reproductive potential (Goodyear 1995).

Despite the apparent positive effects of management actions, the unweighted transitional spawning potential ratio (SPR; Goodyear 1993, 1995) has remained lower (1–10%, depending on the assumptions used in the estimate) than the 20% overfishing threshold adopted by the GMFMC. Be-

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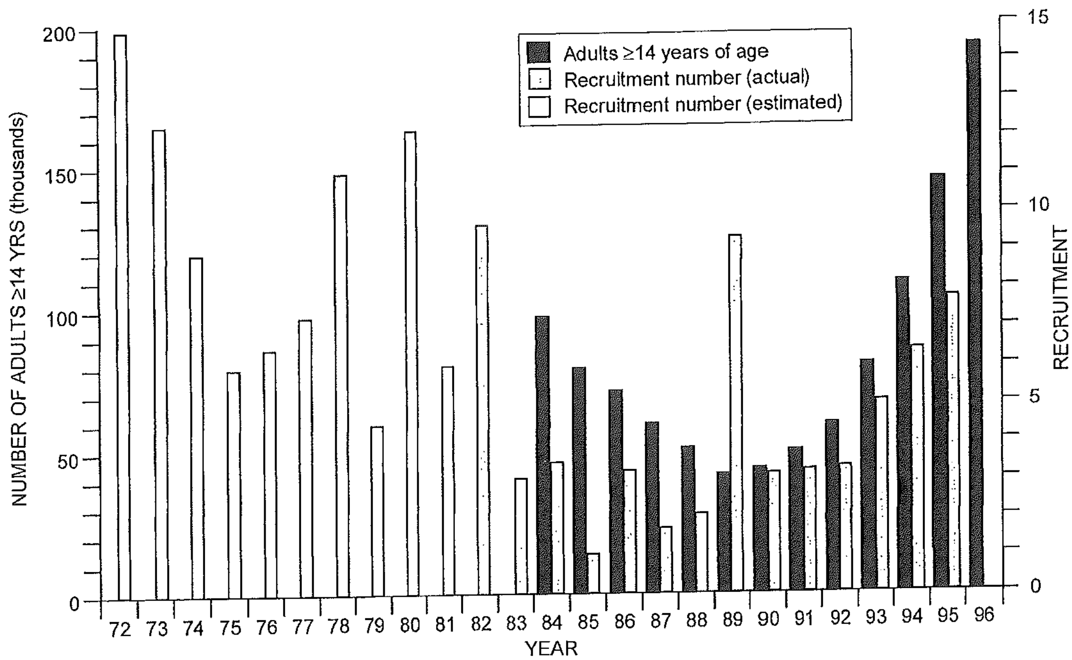

FIGURE 1.—Annual estimates of spawning stock that are age 14 or older (Schirripa and Legault 1997), the relative values of the summer age-1 recruitment index (Schirripa and Legault 1997), and historical estimates (Goodyear 1995). The age-1 recruitment index is shown by year-class.

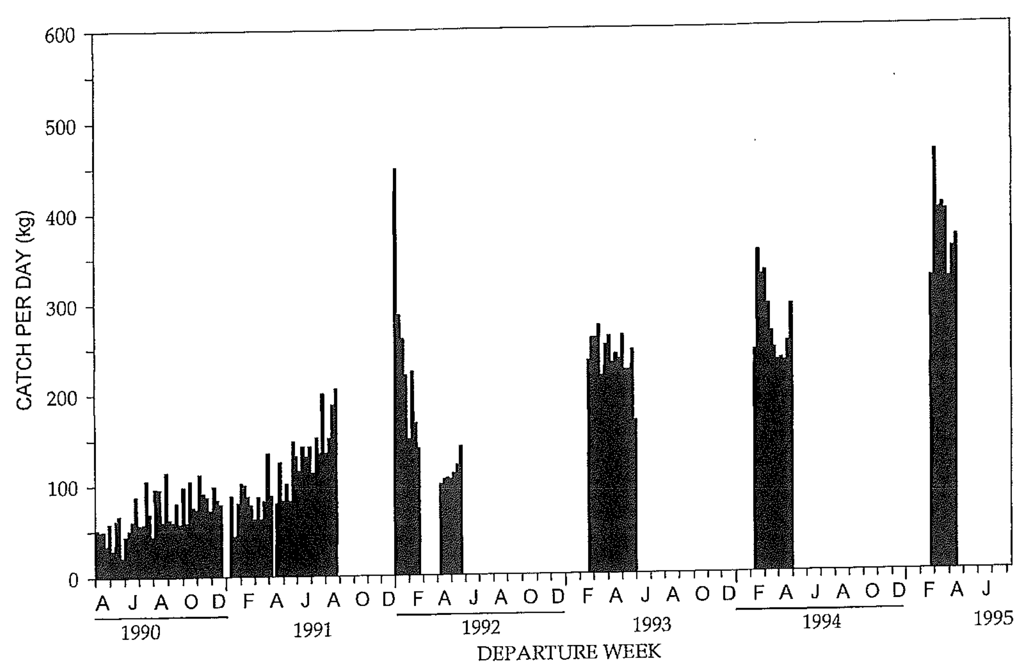

FIGURE 2.—Commercial fishery catch per unit effort and the time required to harvest the commercial fraction of the total allowable catch, 1990–1995 (from Goodyear 1995).

cause of the longevity of red snapper (>50 years; Goodyear 1995), many years will be required before the effects of past fishing mortality pass through the stock and allow SPR to increase. Further, fishing mortality has remained above levels estimated as necessary for rebuilding the stock, especially juvenile mortality from shrimp trawl bycatch. In Amendment 9 to the Shrimp Fishery Management Plan, the GMFMC determined that shrimp trawl bycatch mortality must be reduced by 50% to achieve the 20% SPR goal by the target date of 2019 (GMFMC 1996).

The GMFMC (1996) determined that the use of bycatch reduction devices (BRDs) would reduce the catch of juvenile (age-0 and age-1) red snapper taken as bycatch in the shrimp fishery by the required amount. Results of shrimp trawl bycatch studies conducted during 1990–1996 by the National Marine Fisheries Service (NMFS) Southeast Region in conjunction with the Gulf and South Atlantic Fisheries Development Foundation, Inc. (NMFS 1997a; Branstetter 1997), experimentally tested 145 BRD designs. Of these, 21 were promising enough to be evaluated on commercial shrimp vessels (Watson et al. 1997b). Results of analysis reported in Watson et al. (1997a, 1997b) showed that one of these designs (the so-called midsized fisheye situated in the first one-third of the cod end of the trawl or "EE-Fisheye BRD") met the GMFMC's red snapper bycatch reduction criteria. The NMFS mandated this BRD for use in the western Gulf of Mexico shrimp fishery beginning in May 1998 (U. S. Office of the Federal Register 63:71[April 14, 1998]:18139–18147).

Our objective was to reestimate the juvenile red snapper bycatch reduction from an EE-Fisheye BRD using a different approach from that used by Watson et al. (1997a, 1997b). First, the length frequency data reported by Branstetter (1997) from all paired tows with nets equipped with EE-Fisheye BRDs and control nets were used to determine an exclusion-size threshold (EST) for each month. Next, we estimated the fraction of the total annual bycatch that is associated with each month (and the size distribution associated with that month's catch) and two regional strata. Spatial stratification was required to incorporate seasonal–spatial patterns of shrimp fishing effort, juvenile red snapper abundance, and associated differences in size frequency of juvenile red snapper in the bycatch. The EST and percent bycatch per month were then combined to derive the proportion of the annual bycatch that exists above the threshold point, thereby deriving the net gain in survivorship. Specifically, the proportions of the monthly fractions of the total annual bycatch that were above the exclusion-size threshold were calculated for each region and then summed to provide an overall estimate of the bycatch reduction that would occur with an EE-Fisheye BRD.

The Watson et al. (1997b) analysis included data from 50 shrimp trawl tows. They compared catches in a BRD-equipped trawl on one side of a vessel with catches in a trawl without a BRD on the other side of the vessel during the same tow. Catches of juvenile red snapper in the BRD nets were 59% lower than in the control nets. The corresponding reduction in fishing mortality was estimated to be 59–60% (Watson et al. 1997b).

Of the 50 tows included in the Watson et al. (1997b) analysis, 26 were made in July and 10 in August, months in which the shrimp trawl bycatch is dominated by age-1 red snapper (Goodyear 1995; Gallaway et al. 1998). All of these samples were taken off the Texas coast between Galveston and Brownsville. The samples analyzed by Watson et al. (1997b) were also restricted to only one (the 30-mesh position) of the several locations included in the EE-Fisheye category. In fall, the abundance of juvenile red snapper in the region studied increases dramatically due to young-of-the-year recruitment, which greatly increases the bycatch rates compared with summer. Only 6 of the 50 selected samples were taken in fall, five tows in October and one tow in November. All of these samples were obtained off of the Louisiana coast. The mean catch rates of the fall tows (0.2–0.8 red snapper/h in the control nets) were lower than those obtained in the 36 summer samples (0.8–1.6 red snapper/h in the control nets). Eight tows used in the analysis were taken off the Louisiana coast in December when the CPUE in the control net was 0.2 red snapper/h. These observations led us to question the representativeness of the 50 samples used in the analysis.

Methods

Our analyses used the 1992–1996 shrimp trawl observer data obtained from NMFS. The 1992–1996 observer program was conducted as a result of a 1990 amendment to the Magnuson Fishery Conservation and Management Act (NMFS 1995, 1997a; Branstetter 1997) and had two primary goals. The first goal was to estimate and characterize the size composition of shrimp trawl bycatch. Observers aboard voluntarily participating shrimp trawlers logged the distribution of effort, shrimp catch, and bycatch. The second goal was

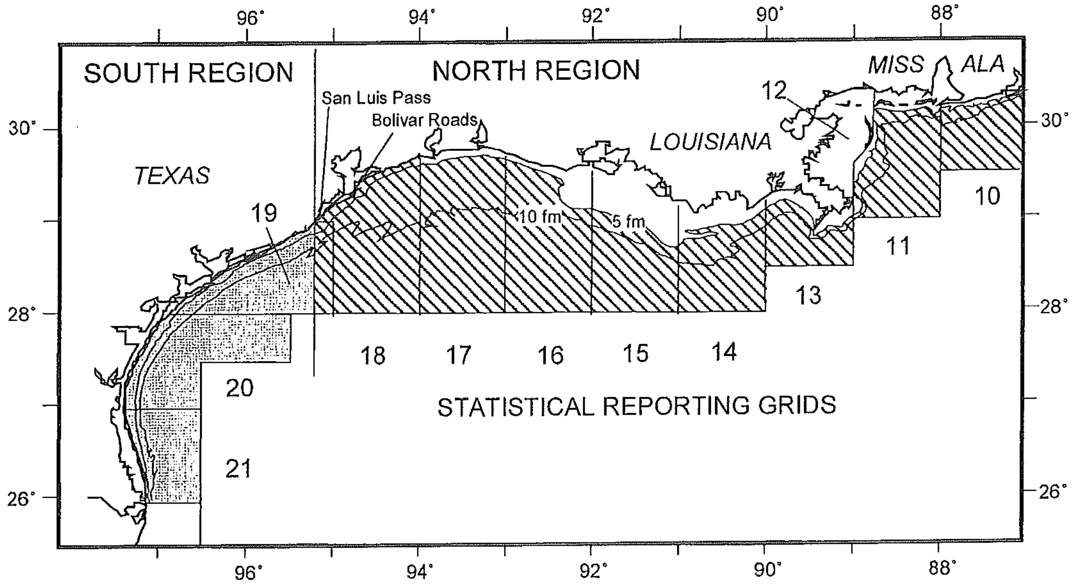

FIGURE 3.—Map of the western Gulf of Mexico showing the statistical reporting grids and geographic strata used to calculate bycatch estimates (from Gallaway et al. 1998).

to determine bycatch reduction attributes of various BRD designs. Observers aboard voluntarily participating shrimp trawlers logged the catches and size distribution of bycatch taken in paired tows of BRD-equipped and control nets. Details of the program can be found in Branstetter (1997) and NMFS (1995, 1997a). The database from this program is housed in the Galveston Laboratory of NMFS and is the best available data for estimating monthly patterns of red snapper bycatch in the Gulf of Mexico shrimp fishery in recent years.

Exclusion-Size Thresholds

Exclusion-size thresholds were determined by overlaying quarterly length frequency distributions of juvenile red snapper obtained in nets equipped with an EE-Fisheye BRD (regardless of location within the first one-third of the cod end of the net) on the length frequency distributions of juvenile fish taken on the same tows in a control net without the BRD (Branstetter 1997). The exclusion-size threshold was defined as being the size interval at which the length frequency of the fish in a BRD net decreased and remained lower than the frequency of fish at the same sizes taken in the control net. The size at this inflection point was defined as the exclusion-size threshold. It was assumed that fish smaller than the EST would not be effectively excluded, but that all larger fish would be excluded.

The paired length frequency data we used in this analysis (Branstetter 1997) were compiled on a quarterly basis, in which the winter quarter included length frequency data from January–February; the spring data were from April–May; the summer data were from July–August; and the fall data represented October–November collections. We assumed the winter EST values were also representative for March, that the spring value was representative for June, and that the fall value was also representative for September and December.

Estimation of Monthly Bycatch and Size Fractions

Regional stratification.—Calculation of the mean monthly bycatch and size composition of the bycatch from the observer data were based on the same regional strata and depth zones defined by Gallaway et al. (1998). These spatial divisions were justified by Gallaway et al. (1998) based on biological, oceanographic, and climatological differences. The North Region extends from 87°W longitude to 95°13′W longitude, and the South Region extends from 95°13′W longitude to the Texas–Mexico border (Figure 3). The nearshore areas of the North Region in statistical reporting grids 10–17 are greatly influenced by the discharges of the Mississippi and Atchafalaya rivers. Low-salinity waters occur throughout the water column to depths of about 5 fathoms and, at the surface, even further offshore (Goodyear 1995; Gallaway and Cole 1997). Red snapper are generally absent at depths of 5 fathoms or less in this region (Gallaway and Cole 1997). Following Gallaway et al. (1998), this depth zone in this region was, therefore, excluded from our analysis. Nearshore areas inside the 5-fathom contour were retained in the remainder of the North Region and in the South Region because red snapper were commonly caught at these depths, at least in the South Region (Goodyear 1995; Branstetter 1997; Gallaway and Cole 1997; Gallaway et al. 1998).

The NMFS statistical reporting grids used to estimate shrimp landings and shrimp fishing effort correspond to our two geographic regions (Figure 3). The boundaries between grids occur at intervals of 1° longitude, except for the boundary between grids 18 and 19. Here the 95°W longitude boundary beginning at about the intersection with the 5-fathom depth contour has been extended by NMFS west to longitude 95°13W. This dogleg adjustment to the nearshore boundary between grids 18 and 19 allows for the west opening of the Galveston Bay system (San Luis Pass) to be in the same statistical grid as the east opening (Bolivar Roads) to the system. For consistency between nearshore and offshore waters, we also included offshore waters between longitudes 95°W and 95°13W as part of statistical grid 18. This necessitated adjustments to the reported fishing effort data for depths greater than 5 fathoms, which were made as described below.

Total fishing effort.—The NMFS shrimp fishing effort data are reported in monthly values of days fished in each of 11 depth zones and 21 statistical areas. Effort for the North Region was calculated from (1) the sum of the 1992–1996 effort for all offshore depth zones greater than 5 fathoms in statistical grids 10 through 17 (longitude 87°W to 94°W), (2) the sum of all offshore effort (including areas inside the 5-fathom contour) for statistical grid 18 (longitude 94°W to 95°W), and (3) 19.89% of the total offshore effort for statistical grid 19 (allocated based on surface area fraction to account for the modified North Region boundary of 95°13W). Offshore effort in the South Region included effort summed across all depth zones in statistical grids 20 and 21 and the remaining 80.11% of statistical grid 19.

The mean shrimp fishing effort $\bar{X}$ by month (m) and region (r) was calculated as

$$\bar{X}_{m,r} = \frac{1}{5}\sum_{\text{year}=1992}^{1996} X_{y,m,r}$$

where $X_{y,m,r}$ is the total effort in a month and region for a given year (y). Taking one-fifth the sum gives the average over 5 years. Two standard errors of the mean are used to depict the annual variation in total fishing effort.

Observer catch rates.—Catch and effort data for the vessels sampled by observers during 1992–1996 for characterizing shrimp trawl bycatch (NMFS 1997a) were used to develop an effort-weighted estimate of monthly catch per hour (catch per unit effort, CPUE) for each region:

$$\text{CPUE}_{m,r} = \frac{\sum_{\substack{\text{all tows}\\ 1992\text{–}1996}} \text{catch}_{m,r,t}}{\sum_{\substack{\text{all tows}\\ 1992\text{–}1996}} \text{effort}_{m,r,t}},$$

where t = tow.

The standard error for this estimate is calculated as

$$\text{SE}(\text{CPUE}_{m,r}) = \sqrt{\sum_{\substack{\text{all tows}\\ 1992\text{–}1996}} [W^2_{m,r,t}][\text{var}(\text{CPUE}_{m,r,t})]},$$

where $W_{m,r,t}$ is the proportion of the total month and region effort represented by an individual tow; and the variance (var) is:

$$\text{var}(\text{CPUE}_{m,r,t}) = \frac{1}{N-1}\cdot\sum_{\substack{\text{all tows}\\ 1992\text{–}1996}} [\text{CPUE}_{m,r,t} - \text{CPUE}_{m,r}]^2,$$

where N is the total number of tows for a given month and region combination.

The monthly CPUE for the North Region included data from all tows taken between 87°W and 94°W longitude at depths greater than 5 fathoms and for the subregion greater than or equal to 94°W but less than 95°13′W longitude, all tows taken at all offshore depths. The South Region monthly CPUE calculations included all data collected west of or equal to 95°13′W longitude at any depth.

The CPUE data analyzed were also restricted to those obtained from good tows; if the net was indicated to have been fouled or otherwise impaired during a tow, this information was noted by the observer and such data were not used to calculate CPUE. Catch values were adjusted following Branstetter (1997) to reflect the total catch in a net in instances where subsampling of nets occurred. The CPUE values for the months of March (52 observed tows yielded no red snapper) and December (not sampled during any year) in the South

TABLE 1.—Monthly and regional distribution of observed shrimp trawl tows during 1992–1996 and the corresponding number of tows with red snapper bycatch.

	Number of observed tows						Observed tows with red snapper					
Month	1992	1993	1994	1995	1996	Total	1992	1993	1994	1995	1996	Total
North Region												
Jan		69	15		1	85		44	9		1	54
Feb		114	34	48		196		50	23	43		116
Mar		7	18	36	14	75			12	24	14	50
Apr	17	25	18		5	65	1	2	9		3	15
May	4	6	16		11	37	2	3	5		3	13
Jun		95	26		1	122		2	12		1	15
Jul	7	72	100	42	15	236	2	16	83	18	15	134
Aug	50	33	54	29	5	171	29	3	29	9	3	73
Sep	36	18	40	51		145	21	1	33	42		97
Oct	46	39	49	66		200	28	28	46	46		148
Nov	32	8	58	90		188	27	8	49	76		160
Dec	17	43	22	24		106	12	25	19	21		77
Total	209	529	450	386	52	1626	122	182	329	279	40	952
South Region												
Jan		6		2		8		6		2		8
Feb	9	4		5		18		4		2		6
Mar	38	14				52						0
Apr	29	42	6		2	79		23	5		2	30
May	12	21	9			42		10	7			17
Jun						0						0
Jul	78	81	82	21	10	272	19	30	34	18	7	108
Aug	31	40	24		11	106	27	22	11		10	70
Sep	2	48			11	61	1	27			11	39
Oct	17	45		33	5	100	17	45		33		95
Nov	6	34	2			42	6	32	1			39
Dec						0						0
Total	222	335	123	61	39	780	70	199	58	55	30	412

Region were calculated as the average of the CPUEs for the preceding and following months.

Bycatch estimates.—Total bycatch was calculated for each month in each region as follows:

$$\text{regional monthly bycatch} = (\text{day fished} \cdot 24\ \text{h} \cdot \text{d}^{-1})\ (\text{catch} \cdot \text{h}^{-1} \cdot \text{net}^{-1})\ (2\ \text{nets}).$$

The average of two nets fished is an assumed value following Nichols et al. (1987, 1990), Nichols (1990), Nichols and Pellegrin (1992), Nichols (1996), and Gallaway et al. (1998). The 24 monthly values (12 months × 2 regions) were summed as an estimate of total bycatch, which was used to determine the relative monthly fractions taken in each region. The standard error of the bycatch estimate was calculated incorporating both the standard error of CPUE and the standard error of effort.

Age composition of the bycatch was estimated for each month in each region from the size data collected as part of the observer characterization program. Bycatch in both regions between the months of January and June was allocated to age-1 red snapper because (1) by convention, the summer–fall recruits of the previous year are assigned a birth date in January and (2) new recruits do not begin to enter the shrimp fishery until July. The age-1 proportion of the bycatch during the months of July and August was estimated based on an observed bimodal size distribution. Fish less than 90 mm fork length (FL) were considered to be age 0, and larger fish were considered to be age 1. In September–December, the proportion of age-1 fish was estimated from the percent of the catches larger than 150 mm FL. In this arbitrary use of a single dividing line between age-0 and age-1 fish during fall; age-0 fish late in the season would be classified as age 1. For December in the South Region, where no observer fishing was done, and no measurement data exist, the proportion of age-1 fish was estimated from the overall fraction of fish larger than 150 mm FL that was observed for September–November.

Results

In all, 1,626 tows were observed in the North Region during 1992–1996 as compared with 780 tows in the South Region over the same period (Table 1). The last year of the program (1996) was

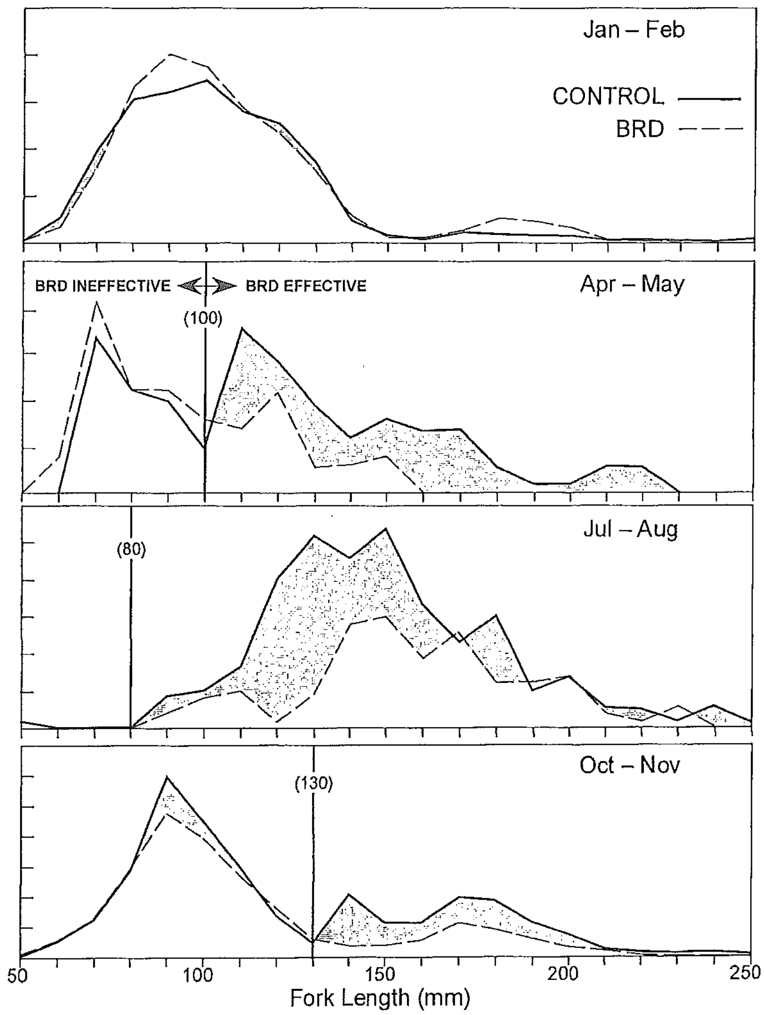

FIGURE 4.—Quarterly total length frequencies of Gulf of Mexico red snapper taken in a control (without a BRD) net compared with those taken in nets equipped with a 5-in × 12-in fisheye BRD situated in the first one-third of the cod end of shrimp trawls used in the Gulf of Mexico shrimp fishery. Vertical lines are the exclusion-size thresholds (100, 80, and 130 mm FL) for the spring, summer, and fall months. Data from Branstetter (1997). The frequency scale was not shown in the source document.

characterized by the lowest number of annual tows in both regions. July was the only month in which samples were obtained in all years in both regions. August samples were obtained in all years in the North Region and in 4 of the 5 years in the South Region (Table 1). In contrast, no tows were obtained in any year in June or December in the South Region. In June, the South Region is closed to shrimping; but, in December, the region is open. In all, 58% of the tows observed in the North Region collected red snapper, compared with 53% in the South Region.

Exclusion-Size Thresholds

The quarterly size frequency data compiled by Branstetter (1997) are shown in Figure 4. There were no consistent differences in catch by size between control and BRD-equipped nets during the winter season, which indicated that BRDs were not effective for any size of juvenile red snapper taken in the bycatch during that time of year. We assigned ESTs of 100, 80, and 130 mm FL for the spring, summer, and fall months, respectively (Figure 4). Later in the paper we will assume that all fish above these threshold sizes that were taken in the bycatch characterization studies would have been excluded had an EE-Fisheye BRD been in place in the nets.

Monthly Size Fractions of the Bycatch

Juvenile red snapper taken in shrimp trawls during January–April were mostly less than 170 mm FL in both the North and South regions (Figure 5). During May–August, juvenile red snapper in the South Region bycatch were scarce in May and June, most were greater than 110 mm in July, and two size-groups were represented in August. The modal length of the smaller fish was centered around 50 mm FL, and the larger fish ranged between 130 and 170 mm FL (Figure 5). Most of the juvenile red snapper in the North Region during May–August ranged between 110 and 200 mm FL; newly recruited age-0 fish appeared at about 50 mm FL in July and August (Figure 5).

The size distribution differed between regions during September–December (Figure 5). In the South Region, red snapper catches were dominated by age-0 fish, virtually all less than 150 mm FL each month (September–November). Although age-0 red snapper dominated in the North Region during fall, substantial numbers of fish greater than 150 mm FL were also taken each month (Figure 5).

Monthly Fishing Effort Patterns

Patterns of total shrimp fishing effort differed by region and month (Figure 6). Monthly effort levels were lowest during January–April in each region, with the 5-year average being below 4,000 nominal days fished in each region during each month (Figure 6). From this point, the patterns of mean monthly total effort diverged between the regions. The average monthly effort in the North Region peaked in June at nearly 11,000 nominal days fished (Figure 6). We believe this represents a shift in the fishery to Louisiana and more easterly regions that occurs when both state and federal waters off the Texas coast are closed to shrimp fishing. A decline to about 9,000–10,000 d occurred in July to October, which was followed by a decrease to about 8,000 d in December (Figure 6).

In the South Region, the average May level of effort remained below 4,000 nominal days fished, which then decreased to about 113 d fished in June, a result of the entire region being within the boundary of the "Texas closure" for the entire month. Effort then jumped to greater than 5,290 d fished in July, corresponding with the midmonth Texas opening, and reached an annual peak in August at about 7,000 mean days fished. After August, mean effort in the South Region exhibited a steady decline to about 4,200 d fished in December.

Monthly Patterns for Catch per Unit Effort

The CPUE of juvenile red snapper in the North Region was relatively low (≤1.6 fish/h) during January–August, except for January and July (Figure 6). The January high (5.0 fish/h) reflects continued abundance of small fish from the previous fall. Although technically defined as age 1, most of these fish are smaller than 160 mm FL (Figure 5). The increased CPUE in July in the North Region (4.3 fish/h) corresponds to a shift in effort from Louisiana offshore waters to the upper-Texas coast portion of the North Region that is coincident with the Texas opening in July. This shift results in more effort in areas of higher abundance of red snapper. The elevated CPUEs (to 9 fish/h) that occur in the North Region in the fall reflect recruitment of age-0 fish, especially in November (Figures 5, 6). However, age-1 fish make up a moderate to small fraction of the catch during each of these months (Figure 6).

In the South Region, a peak of juvenile red snapper CPUE of 12.8 fish/h occurred in October, and CPUE levels remained above 6.7 fish/h from October through February of the following year (Figure 6). These periods of elevated CPUE are clearly the result of age-0 fish recruitment in fall. Age-1 fish made up 17, 1, 2, and 3% of the September–December catches in the South Region during fall (Figures 5, 6). This contrasts with the pattern in the North Region where the corresponding age-1 fractions were 27, 46, 16, and 12%, respectively (Figure 6). Abundance of small age-1 fish in the South Region declined from 7.0 fish/h in February to 0.9 fish/h in April, and CPUE ranged from 1.2 to 2.2 fish/h during May–September (Figure 6).

Monthly Bycatch Patterns

Total monthly bycatch for 1992–1996 was estimated to range between 3.2 and 6.1 million red snapper during September–December, with peak levels occurring in October (6.1 million) and November (5.5 million). Most of the bycatch during fall was made up of age-0 fish (Figure 6). With the exception of July (2.2 million fish), the average 1992–1996 bycatch of juvenile red snapper during the other 8 months of the year (ranging from 0.2 to 1.4 million fish) was markedly smaller than the levels observed during fall months. The elevated July bycatch was mostly (~85%) age-1 fish. The

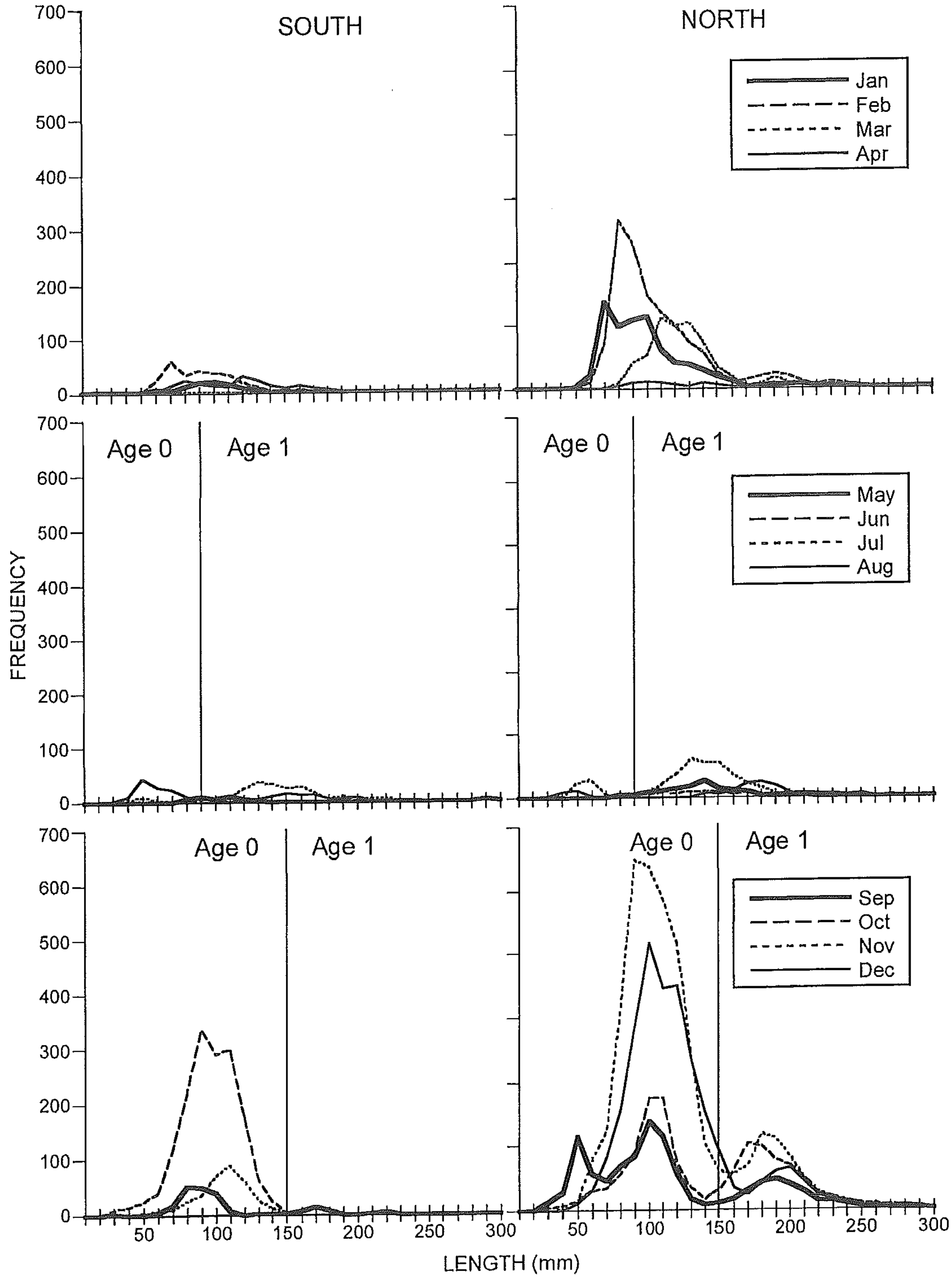

FIGURE 5.—Monthly length frequency distributions for juvenile red snapper taken in shrimp trawl bycatch by geographic region and month.

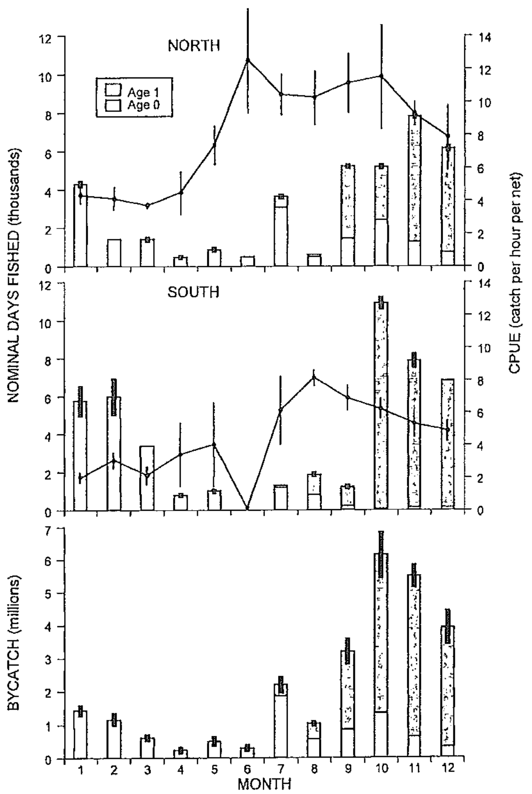

FIGURE 6.—Monthly estimates of juvenile red snapper catch per unit effort (CPUE) and total fishing effort for the North Region, South Region, and the total monthly bycatch estimates. Error bars represent two standard errors of the mean.

higher July catches appeared to come mainly from waters off the upper Texas coast immediately following the opening of these waters after the closure. The Texas opening occurs during the period from early to mid-July, depending on the size of shrimp.

An estimated 60% of the mean annual shrimp trawl bycatch of juvenile red snapper during 1992–1996 occurred in the North Region, as compared with 40% in the South Region (Table 2). In the North Region, the monthly fraction exceeded 10% of the total mean annual bycatch in September, October, and November; in the South Region only the October fraction exceeded 10%. Considering both regions, more than 71% of the mean annual bycatch of juvenile red snapper occurred in fall (September–December).

EE-Fisheye BRD Efficiency

Based on the mean bycatch estimates, the proportion of the monthly fraction of the annual bycatch represented by juvenile red snapper above the EST ranged from 0 to 86.2% in the North Region and from 0 to 91.9% in the South Region (Table 2). More than 80% of the bycatch in the North Region exceeded the EST in May–August; July was the only month in the South Region where as much as 80% of the catch exceeded the EST.

Considering monthly fractions of the total bycatch taken in each region in conjunction with the fraction of the monthly catch at or above the EST, the total annual reduction in bycatch from an EE-Fisheye BRD would be on the order of 26%, with

TABLE 2.—Derivation of the mean annual monthly fractions (1992–1996) of red snapper bycatch in shrimp trawls subject to exclusion by the EE-Fisheye BRD considering regional and seasonal size factors that influence catch reduction performance. The annual bycatch fraction multiplied by the proportion above the exclusion-size threshold (EST) equals the bycatch reduction by region and month, which are then summed to obtain the monthly total. The sum of the monthly totals provides an estimate of the total annual reduction.

	Annual bycatch fraction (%)		Proportion above EST (%)		Bycatch reduction (%)		
Month	North	South	North	South	North	South	Total
Jan	3.380	2.091	0.000	0.000	0.000	0.000	0.000
Feb	1.045	3.411	0.000	0.000	0.000	0.000	0.000
Mar	0.950	1.366	0.000	0.000	0.000	0.000	0.000
Apr	0.403	0.503	63.333	64.641	0.255	0.325	0.580
May	1.162	0.761	86.207	50.000	1.002	0.380	1.382
Jun	1.154	0.000	85.714	44.512	0.989	0.000	0.989
Jul	6.944	1.475	83.956	91.915	5.830	1.356	7.186
Aug	1.116	2.830	84.049	44.390	0.938	1.256	2.195
Sep	10.619	1.554	27.419	17.727	2.912	0.275	3.187
Oct	10.929	12.412	46.123	2.199	5.041	0.273	5.314
Nov	13.238	7.679	20.824	5.785	2.757	0.444	3.201
Dec	8.881	6.096	22.723	2.893	2.018	0.176	2.194
Total	59.821	40.179			21.742	4.485	26.228

22% occurring in the North Region and 4% occurring in the South Region (Table 2). More than one-half of this reduction (14%) occurs during the last 4 months of the year, with most occurring in the North Region. These reductions assume that all fish above the EST are excluded and survive. Clearly, not all are excluded (see Figure 4), and it is doubtful that all excluded fish survive.

We conducted the same analyses presented in Table 2 using the upper and lower bounds of the monthly bycatch estimates (±2 SE) instead of the mean as the starting point for evaluating BRD efficacy. Using the lower bounds of the estimates, there was a net reduction of 25%, with 21% occurring in the North Region and 4% occurring in the South Region. Using the upper bound, bycatch reduction attributable to the EE-Fisheye BRD was 27% overall, 22% in the North and 5% in the South. Use of the upper and lower bounds of the monthly estimates did not greatly alter the pattern of the monthly fractions from that produced with the mean estimate. Next, we arbitrarily assigned the upper bound of the monthly bycatch estimates to months which had greater than 25% of the catches consisting of fish larger than the EST, and the lower bound of the estimates were assigned to months where the fraction of the catch larger than the EST was less than 25%. The purpose of this selection was to maximize the reduction efficacy by using the upper bound of the bycatch estimates for months characterized by high BRD reductions and the lower bounds of the estimates for months when the BRD was not as efficient in excluding juvenile red snapper due to their small size. Under this scenario, the overall reduction attributable to use of the EE-Fisheye BRD was 27%, with 21% occurring in the North Region and 6% occurring in the South Region.

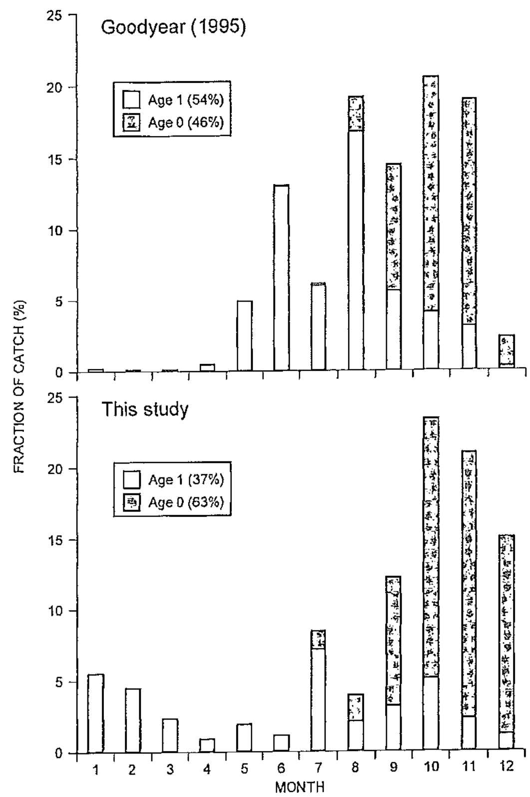

FIGURE 7.—Annual mean monthly age-0 and age-1 red snapper shrimp trawl bycatch from Goodyear (1995) and the 1992–1996 observer program (this study).

Discussion

The monthly fractions and age composition of the shrimp trawl bycatch shown by our analysis differ substantially from the patterns depicted in the red snapper stock assessment (Figure 7). The monthly fractions used in the Goodyear (1995) stock assessment were derived by Nichols and Pellegrin (1992) from historical observer data gathered mainly during the mid to late 1970s. These observations suggest bycatch during those years was lowest during January–April but increased markedly during May–August. The vast majority of these fish were age 1, and peak bycatch levels for age-1 fish were estimated to occur in June and August (Figure 7). Bycatch was estimated to remain high in September–November, mainly due to recruitment of age-0 fish (Figure 6). The December bycatch estimates were small, and age-1 fish were scarce (Goodyear 1995; Figure 7). Overall, age-1 fish were estimated to constitute 54% of the total bycatch.

The results of our analyses, using more contemporary data, suggest that bycatch is higher in spring, lower in summer, and higher in December, compared with the results of Goodyear (1995) (Figure 7). The total age-1 fraction was only 37%, 13% of which was taken during January–April, a period when BRD efficiency is low. Goodyear (1995) estimated a January–April value of 0.72%. The modern observer data reflect that June was characterized by the lowest average level (1.2%) of red snapper bycatch of any summer month (not one of the highest). The highest summer bycatch level occurred in July (8.4% of the annual total). Our results show that about 4% of the annual total bycatch was taken during August (Figure 7), compared with 19% for August in Goodyear (1995).

Our results come closest to agreement during the fall. The major difference during this season is that we show a relatively high bycatch for December (15%), whereas Goodyear (1995) suggested only about 2% of the average annual bycatch occurred in December (Figure 7).

The Goodyear (1995) monthly bycatch patterns were derived by means of a general linear model (GLM) analysis conducted by NMFS that incorporated historical observer data for 1972–1982 and resource trawl data for 1972 to the 1990s (e.g., Nichols 1990; Nichols et al. 1990; Nichols and Pellegrin 1992). The relationship between observer data and resource survey trawl data are used to predict shrimp trawl bycatch for times and places where no observer data are available (e.g., 1982–1992). The number of resource survey tows outnumber the observer tows on the order of 25 to 1. Both data sets are strongly unbalanced in years before 1982, especially the resource survey trawl data which were restricted to the fall season and the region around the mouth of the Mississippi River. The stratification employed in these analyses included four regions, two depth zones, and three seasons for the period 1972–1992 (21 years). This yields more than 1,512 time–space cells, many of which were not sampled during a given year. As much as 70% of the CPUE values in the historical data were zeros, which further complicated the analysis. Once the estimates were obtained, the size–age distribution of the catch was assigned, based on a composite of all available length frequency data (Goodyear 1995).

Gallaway et al. (1998) conducted an alternative GLM analysis of the same data. First, the historical and recent data were separated into two epochs (1972–1984 and 1985–1996) to guard against nonstationarity. Second, fewer and larger time–space cells were used, and third, catch and effort data were pooled on a week-within-trip basis to reduce the number of zeros in the analysis. Lastly, size distributions were calculated for each region and season separately, rather than using a composite of length frequency applied to all regions. The results of this analysis showed good agreement with the NMFS estimates for the early epoch but markedly lower total estimates and a different size–age structure of the bycatch for the recent epoch. The similarity of the respective estimates for the early epoch in combination with the divergence of the two estimates when the historical data were not included in the analysis suggests that the present-day estimates of monthly bycatch reflect a real change in the fishing rather than being a result of a stratification artifact.

We believe that the results of the 1992–1996 observer bycatch studies provide the best data for estimating the monthly fractions of red snapper bycatch for recent years. We suggest that these results also provide the best estimates for the relative monthly levels and size compositions of juvenile red snapper in the catch for the period dating back to 1990, and perhaps back to 1980. Of the 966 tows in the 1972–1982 observer database, 647 (67%) were taken between 1972 and 1979. The year 1980 marks the date at which (1) the relative fishing power of craft fishing in the Gulf of Mexico shrimp fishery peaked (123% of the 1965 level) and then subsequently stabilized between 1981 and 1993 at about 112–122% of the 1965 level (Griffin et al. 1997) and (2) the Texas closure (part of May, all of June, and part of July) was extended from state waters (9 mi) to include the entire 200-mi U.S. Exclusive Economic Zone (NMFS 1997b). Although the Texas closure area was reduced to 15 mi offshore during 1986–1989, it was increased to 200 mi in 1990 and all years since (NMFS 1997b). Further, in all years from 1972 to 1989, shrimping was allowed from 0 to 4 fathoms during the closure. Red snapper are taken as bycatch at these depths along the lower Texas coast in the area we have defined as the South Region (Branstetter 1997; NMFS 1997a; Gallaway et al. 1998). This exception was eliminated in 1990 and all years since. We conclude that (1) the Texas closure since 1980 has greatly influenced the distribution of offshore fishing effort and (2) data from before 1980 are not representative of today's conditions.

From this analysis of red snapper bycatch, it seems evident that differences in BRD efficiency among sizes, months, and regions must be taken into account when estimating the reduction in shrimp trawl bycatch mortality that will result from BRD use. When these factors are considered, the EE-Fisheye BRD is unlikely to reduce shrimp trawl bycatch by more than 25–27% (Table 2). Although a high (>80%) proportion of the catch would be subject to exclusion during summer months in the North Region and during July in the South Region, the fraction of the bycatch taken during these months is relatively small, except for July in the North Region (Table 2). In contrast, during the fall months when bycatch levels are high, the proportion of the catch at a size subject to exclusion is lower (2–46%; Table 1) than during summer (>80%; Table 2). Overall, the implication from our analysis is that the certified EE-Fisheye

BRD cannot achieve more than a 25–27% reduction in bycatch in the current fishery, and this assumes that 100% of the bycatch subject to exclusion would not only be excluded but would survive at the same rates as untrawled fish.

The results presented in this paper assume that the BRD is 100% effective for excluding red snapper above the EST. In practice, however, larger fish are not completely excluded by the BRD (Branstetter 1997). Although some red snapper that are less than the EST are potentially excluded, our 25–27% mortality reduction estimates may be higher than what actually occurs. This study, however, illustrates that the timing of red snapper bycatch and the shrimp fishing effort reduce the effectiveness of the BRD to rates that are well below the GMFMC targets to rebuild spawning stock biomass.

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References

Branstetter, S. 1997. Bycatch and its reduction in the Gulf of Mexico and south Atlantic shrimp fisheries. Report of Gulf and South Atlantic Fisheries Development Foundation, Inc., to National Oceanic and Atmospheric Administration, Award NA57FF0285, Tampa, Florida.

Gallaway, B. J., and J. G. Cole. 1997. Cumulative ecological significance of oil and gas structures in the Gulf of Mexico: a Gulf of Mexico fisheries habitat suitability model—phase II model description. U.S. Geological Survey, Biological Resources Division, USGS/BRD/CR-1997-0009, and Minerals Management Service, Gulf of Mexico OCS Region, OCS Study MMS 97-0044, New Orleans, Louisiana.

Gallaway, B. J., M. Longnecker, J. C. Cole, and B. Meyer. 1998. Estimates of shrimp trawl bycatch of red snapper (*Lutjanus campechanus*) in the Gulf of Mexico. Pages 817–839 *in* F. Funk and seven coeditors. Fishery stock assessment models. Alaska Sea Grant College Program, Fairbanks.

Goodyear, C. P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. Canadian Special Publication of Fisheries and Aquatic Sciences 120:67–81.

Goodyear, C. P. 1995. Red snapper in U.S. waters of the Gulf of Mexico. Southeast Fisheries Science Center, Miami Laboratory, Coastal Resources Division, Contribution MIA-95/96-05, Miami.

Griffin, W. L., A. K. Shah, and J. M. Nance. 1997. Estimation of standardized effort in the heterogeneous Gulf of Mexico shrimp fleet. U.S. Marine Fisheries Service Marine Fisheries Review 59(3):23–33.

GMFMC (Gulf of Mexico Fisheries Management Council). 1996. Amendment number 9 to fishery management plan for the shrimp fishery of the Gulf of Mexico, U.S. waters with supplemental environmental impact statement, regulatory impact review, initial regulatory flexibility analysis and social impact assessment. GMFMC, Tampa, Florida.

LGL Ecological Research Associates. 1997. Summary updates regarding bycatch issues in the Gulf of Mexico. Report to Texas Shrimp Association, Aransas Pass, Texas.

NMFS (National Marine Fisheries Service). 1995. Cooperative research program addressing finfish bycatch in the Gulf of Mexico and south Atlantic shrimp fisheries: a report to Congress. NMFS, Washington, D.C.

NMFS (National Marine Fisheries Service). 1995a. Bycatch in the southeastern shrimp trawl fishery: a data summary report. NMFS, Sustainable Fisheries Act Task N-10.03, Miami.

NMFS (National Marine Fisheries Service). 1995b. Biological review of the 1997 Texas Closure. Gulf of Mexico Fishery Management Council, Southeast Fisheries Science Center, Galveston Laboratory, Galveston, Texas.

Nichols, S. 1990. The spatial and temporal distribution of the bycatch of red snapper by the shrimp fishery in the offshore waters of the U.S. Gulf of Mexico. National Marine Fisheries Service, Mississippi Laboratories, Pascagoula, Mississippi.

Nichols, S. 1996. An update on some issues relating to the distribution of red snapper bycatch. National Marine Fisheries Service, Southeast Fisheries Center, Mississippi Laboratories, Pascagoula, Mississippi.

Nichols, S., and G. Pellegrin, Jr. 1992. Revision and update of estimates of shrimp fleet bycatch 1972–1991. National Marine Fisheries Service, Southeast Fisheries Center, Mississippi Laboratories, Pascagoula, Mississippi.

Nichols, S., A. Shah, G. Pellegrin, Jr., and K. Mullin. 1987. Estimates of annual shrimp fleet bycatch for thirteen finfish species in the offshore waters of the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Center, Mississippi Laboratories, Pascagoula, Mississippi.

Nichols, S., A. Shah, G. J. Pellegrin, Jr., and K. Mullin. 1990. Updated estimates of shrimp fleet bycatch in the offshore waters of the U.S. Gulf of Mexico 1972–1989. National Marine Fisheries Service, Mississippi Laboratories, Pascagoula, Mississippi.

Renaud, M., and five coauthors. 1993. Loss of shrimp by turtle excluder devices (TEDs) in coastal waters of the United States, North Carolina to Texas: March 1988–August 1990. Fishery Bulletin 91:129–137.

Schirripa, M. J., and C. M. Legault. 1997. Status of the red snapper in U.S. waters of the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Contribution MIA-97/98-05, Miami.

Watson, J., A. Shah, and D. G. Foster. 1997a. Bycatch reduction device summary. Section 3 *in* Bycatch in the southeast shrimp trawl fishery, a data summary report. National Marine Fisheries Service, Sustainable Fisheries Act Task N-10.03, Miami.

Watson, J., A. Shah, S. Nichols, and D. Foster. 1997b. Bycatch reduction estimates for selected species in the Gulf of Mexico for bycatch reduction devices evaluated under the regional bycatch program. National Marine Fisheries Service, Southeast Fisheries Science Center, Mississippi Laboratories, Pascagoula, Mississippi.