Impacts on Shrimp Yields of the 1981 Fishery Conservation Zone Closure off Texas

SCOTT NICHOLS

ABSTRACT — A yield-per-recruit analysis and a simulation model of shrimp fishing show that an increase in brown shrimp yield was realized from closure of the Fishery Conservation Zone (FCZ) off Texas during May-July 1981. Yields were 11.7 million pounds greater (29 percent) than would have been expected with the FCZ open during May-August 1981. Some of the increase in yield was made at the expense of standing stock. Projections over the fishable lifespan of the shrimp indicate that yields will be increased 4 million pounds (7 percent) due to the FCZ closure.

Introduction

Between 22 May and 15 July 1981, trawl fishing was prohibited in the 200-mile Fishery Conservation Zone (FCZ) off the Texas coast. The FCZ was closed to implement part of the "Fishery Management Plan for the Shrimp Fishery in the Gulf of Mexico," developed by the Gulf of Mexico Fishery Management Council. The main purpose of the regulation was to improve yields by allowing newly recruited brown shrimp, *Penaeus aztecus* (Ives) to grow larger before harvesting.

Since 1959, Texas state waters (the Territorial Sea, 0-9 n.mi. from the coast) have been closed 45-60 days every year during the May-July period. In 1981, the FCZ off Texas was closed for the first time. In this paper I examine the effects of the Texas FCZ closure on yields of brown shrimp from the Texas FCZ area and on yields in offshore waters from the Gulfwide brown shrimp stock. The analytical facets presented are:

1) The size structure of the population in the FCZ, as deduced from a research cruise by the *Oregon II*,

2) A yield-per-recruit analysis for the Texas FCZ area, using population-structure data from the *Oregon II* cruise, and growth and mortality information derived by Parrack[1],

3) A virtual population analysis of the brown shrimp stock for May-August 1981, and

4) A simulation of Gulfwide fishing patterns and resulting yields that would have been expected in 1981 had the FCZ been open.

Additionally, descriptions of patterns of fishing effort, catch per unit effort (CPUE), and CPUE-derived estimates of stock distribution are presented in a discussion relating FCZ closure and Gulfwide yields.

Size Structure in the FCZ

The *Oregon II* conducted a trawl survey off the Texas coast, from 6 June until 2 July 1981, to estimate the size composition of the shrimp population in the FCZ. Data from cruises by the *Gus III* during the 1960's were used to identify major sources of variation for shrimp abundance and size composition. Knowledge of the variations allowed the development of a sampling strategy to maximize the precision of the estimates of the population's size composition. The *Gus III* data showed a strong relationship between shrimp mean size and depth, with a weaker relationship between CPUE and depth. Day/night differences in CPUE were indicated. Large variations in CPUE alongshore were observed, but no variations useful to sampling design was detected. Variations in CPUE and size with calendar time were confounded with alongshore, depth, and time-of-day variations in the complete data set. Examination of subsets of the data suggested that any relationships between average size or CPUE and calendar time were weak and probably varied from year to year.

The strategy employed was to sample in detail along the depth gradient. Sampling would be conducted as close to the end of the closure period as possible and be restricted to less than 3 weeks duration to minimize calendar time effects. All sampling would be done at night. One hundred samples were believed possible with these restrictions. Variations alongshore were assumed to be random. Economy of operation required that samples be taken in nonrandom order, eliminating any possibility of isolating calendar time effects and time × alongshore interactions. Operation of the *Oregon II* is limited to depths exceeding 5 fathoms (fm).

The Texas coast was stratified by 1-fm increments (except for two deeper strata of 30-35 and 35-50 fm). The number of samples in each stratum

[1]Parrack, M. L. Some aspects of brown shrimp exploitation in the northern Gulf of Mexico. Presented at the Workshop on Scientific Basis for the Management of Penaeid Shrimp. Key West, Fla., November 1981. Southeast Fisheries Center, National Marine Fisheries Service, NOAA, Miami, FL 33149.

Scott Nichols is with the Miami Laboratory, Southeast Fisheries Center, National Marine Fisheries Service, NOAA, 75 Virginia Beach Drive, Miami, FL 33149.

was allocated based on variances of CPUE from the *Gus III* data and spatial area in each stratum. Each sample was taken by trawling across the entire width of its stratum in the direction of maximum depth gradient (40-foot shrimp trawl, 8-foot by 40-inch wood door). To avoid overloading the net and reducing CPUE, trawls were raised after 30 minutes, emptied, and trawling resumed for those samples where stratum "width" exceeded 30-minutes trawling time.

Sampling for the size distribution study took place between 6 June and 28 June. Problems in operations prevented sampling the 35-50 fm strata as designed. Three nonrandom, nighttime samples taken for other purposes (two on 1 July) were available and were treated as if they were random samples. Apparent low abundances outside 35 fm probably minimize negative impacts from this substitution. Because shrimp CPUE's proved to be high, haphazard subsampling of trawl hauls was instituted during operations.

All shrimp caught were counted by species. Subsampled shrimp were sexed and measured for total length, and total lengths were converted to tail lengths using Brunenmeister's (1980) conversions.

The fraction of the population in any sex and size category was estimated using a ratio estimator:

$$P_i = \frac{\sum_{k=1}^{K} \left(\frac{A_k}{\sum_{j=1}^{J_k} a_{jk}} \right) \left(\sum_{j=1}^{J_k} n_{ijk} \right)}{\sum_{k=1}^{K} \left(\frac{A_k}{\sum_{j=1}^{J_k} a_{jk}} \right) \left(\sum_{j=1}^{J_k} N_{jk} \right)}$$

where P_i = fraction of the population in the *i*th sex and size class,

K = number of depth strata,

J_k = number of samples in the *k*th stratum,

A_k = fractional area of the *k*th stratum,

a_{jk} = length of the *j*th trawl in the *k*th stratum (a random variable in this formulation),

n_{ijk} = number of shrimp in size class *i* in the *j*th trawl in the *k*th stratum, and

N_{jk} = number of shrimp in all sex and size classes in the *i*th trawl in the *k*th stratum.

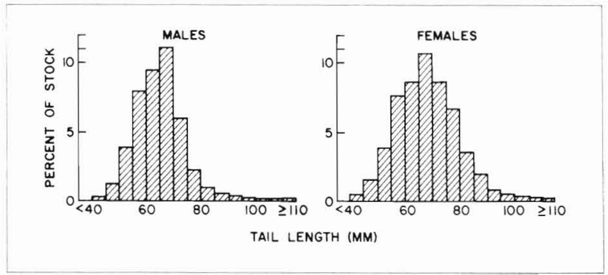

Figure 1.—Population size and sex structure of brown shrimp in the Texas FCZ, 6-28 June 1981.

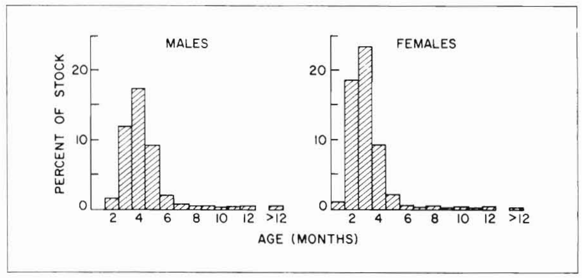

Figure 2.—Projected age and sex structure of brown shrimp in the Texas FCZ, 22 May 1981.

Estimated size and sex composition in the FCZ, treating the cruise as if it were synoptic, is shown in Figure 1. Using these data, the age composition of the population at the beginning of the closure period was estimated. By assuming that the mortality rate and growth rates derived by Parrack (footnote 1) hold, and ignoring migration, the population structure in the FCZ was projected back to 22 May 1981 (Fig. 2).

Yield-Per-Recruit Analysis for the Texas FCZ

Effects within the FCZ of allowing fishing vs. closure in the Texas FCZ were examined using a yield-per-recruit type model, substituting the population structure of 22 May for "recruitment." Effects of growth, natural mortality, and fishing mortality were simulated using a weekly time step. Reliable, age-specific estimates of fishing mortality rate (*F*) for the Texas FCZ alone are not available, so results are presented as a function of *F*. (An approximate value of *F* for the entire Texas area will be derived in a succeeding section and its implications discussed at that point.) Migration across the boundaries of the Texas FCZ was assumed to be zero during the closed period. As a practical matter, this implies that all shrimp detected in the

FCZ during the cruise were present throughout the closed period and that no shrimp entered the Texas FCZ after the cruise. I believe the effects of this simplification are minor, causing if anything an overestimate of any gain due to closure.

The simulation showed that the standing stock (by weight) in the Texas FCZ should have increased 78 percent during the closed period. Translating the stock increase into yield depends on the intensity of fishing. Closure of the Texas FCZ will produce increased yield at all but exceedingly low *F*'s (Fig. 3). Assuming that closing the FCZ only delayed fishing, and that fishing intensity would be the same whenever the area opened, the gain in potential yield from the FCZ can be estimated as a function of *F* (Fig. 4). Empirical evidence presented in the next section actually indicates that *F* following closure exceeded the level expected had the FCZ been open. Thus, if *F* following closure exceeded about 0.6, then the expected gain in yield per recruit would be less than is shown in Figure 4.

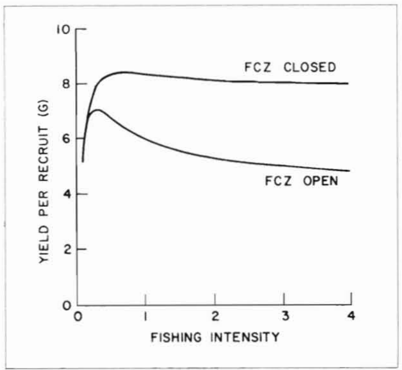

Figure 3.—Estimated yield of brown shrimp per recruit from the Texas FCZ.

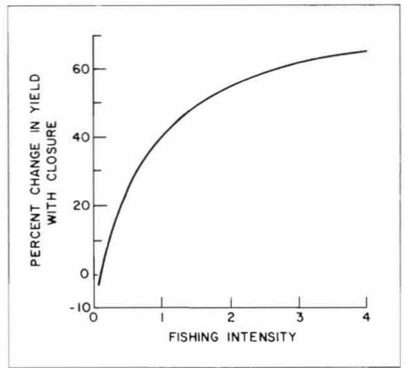

Figure 4.—Estimated percent gain in yield of brown shrimp per recruit from the Texas FCZ with closure.

Table 1.—Estimated catch of brown shrimp (in thousands) by age, May-August 1981.

Age (mo)	Month of capture			
	May	June	July	August
3	90,611.4	84,313.3	46,352.0	21,796.3
4	173,120.0	236,579.8	255,452.5	169,250.8
5	116,955.1	171,197.7	249,326.9	197,776.7
6	18,466.8	68,552.2	158,533.1	134,647.5
7	7,799.5	24,614.0	80,989.0	83,684.6
8	3,941.3	10,957.5	44,385.2	53,248.4
9	1,913.4	5,301.6	22,137.9	26,965.1
10	921.0	2,611.5	11,951.7	14,961.8
11	594.5	1,653.2	7.650.5	9,861.3
12	349.4	741.7	3,990.0	7,112.5
13	272.7	553.6	2,828.2	4,784.9
14	202.2	401.9	2,006.6	3,324.9
15	148.5	295.0	1,471.7	2,438.7
16	108.1	216.5	1,086.4	1,799.3
17	78.5	157.2	788.3	1,305.6
18	60.2	122.1	618.4	1,023.3
19	44.8	90.9	460.2	761.5
20	34.2	68.1	340.0	563.3
21	25.1	52.2	268.8	444.1
22	21.2	42.4	213.2	353.1
23	14.7	29.8	150.8	249.6
24	10.3	22.1	116.0	191.3
25	8.3	17.2	88.7	146.6
26	8.3	17.2	88.6	146.4
27	4.4	7.7	34.4	57.6

Table 2.—Estimated stock size of brown shrimp (in thousands) for May-August 1981.

Age (mo)	Month			
	May	June	July	August
3	1,194,219.0	928,643.7	489,185.3	257,554.0
4	936,692.7	939,069.7	717,460.0	376,152.4
5	538,154.7	642,605.0	586,402.6	379,731.8
6	251,825.4	353,128.8	392,749.2	273,487.4
7	152,505,8	198,612.8	239,239.5	190,852.6
8	102,823.2	123,402.9	147,381.4	130,446.9
9	77,896.2	84,417.6	95,567.0	85,391.2
10	45,843.7	64,943.2	67,399.7	61,453.8
11	29,955.0	38,410.1	53,205.4	46,702.9
12	20,905.5	25,104.5	31,367.5	38,508.3
13	15,039.5	17,580.8	20,814.5	23,181.9
14	10,967.2	12,628.1	14,545.0	15,216.5
15	8,367.6	9,205.6	10,443.5	10,605.2
16	6,319.7	7,028.9	7,611.3	7.586.2
17	4,673.6	5,312.4	5,819.6	5,516.2
18	3,753.4	3,930.0	4,404.4	4,256.6
19	2,704.9	3,158.9	3,252.8	3,201.5
20	2,072.3	2,275.0	2,621.3	2,361.3
21	1,620.3	1,743.1	1,885.5	1,931.2
22	1,189.3	1,364.4	1,444.6	1,366.8
23	750.8	998.9	1,129.3	1,040.4
24	377.1	629.4	828.0	828.0
25	164.9	313.5	518.6	602.1
26	78.3	133.6	252.6	362.4
27	42.1	59.4	98.5	134.9

Virtual Population Analysis of the Offshore Brown Shrimp Stock

Estimates of brown shrimp landings by market size category for the U.S. Gulf of Mexico from January through August 1981 were obtained through the statistical collection program of the Southeast Fisheries Center's Technical and Information Management Service. The procedures used in Parrack's analysis (footnote 2) of the brown shrimp fishery for 1960-79 were followed to determine brown shrimp effort and to estimate the age composition of the landings from market-size categories. Estimates of landings by age for May-August 1981 are presented in Table 1.

A virtual population analysis (VPA) of the landings was performed using the age data in Table 1 (see Ricker, 1975, for a general description of the method). VPA requires that the catch-by-age table be complete and accurate, that the natural mortaility rate *(M)* be known, and that the fishing mortality rate *(F)* be known for at least one time period in the life of each cohort. Although discarding and unreported landings are certain to have occurred, Table 1 is treated as if it were complete. The possible effects of unreported catches are considered in the discussion. Parrack's estimate (footnote 1) of $M = 0.155$ per month was used. Estimates of age-specific *F*'s were made for August based on August fishing effort, the distribution of the stock in August as inferred from CPUE, and past observed relationships between *F*, fishing effort, and CPUE-derived stock distribution patterns from Parrack's work.

Stock size estimates for the May-August period are presented in Table 2; fishing mortality rate estimates are given in Table 3. Compared with Parrack's stock size estimates for previous years, 1981 appears to be a particularly strong year. Abundances of shrimp recruited during the spring and early summer of 1981 are roughly on a par

Table 3.—Estimated brown shrimp *F* values for May-August 1981.

Age (mo)	Month			
	May	June	July	August
3	0.08536	0.10301	0.10775	0.09568
4	0.22182	0.31588	0.48125	0.65712
5	0.26631	0.33736	0.60775	0.81294
6	0.08238	0.23437	0.56667	0.74746
7	0.05675	0.14333	0.45150	0.63396
8	0.04224	0.10063	0.39078	0.57522
9	0.02686	0.07014	0.28654	0.41412
10	0.02192	0.04435	0.21183	0.30353
11	0.02165	0.04755	0.16829	0.25771
12	0.01820	0.03240	0.14740	0.22166
13	0.01976	0.03456	0.15827	0.25115
14	0.02009	0.03495	0.16090	0.26797
15	0.01934	0.03519	0.16464	0.28412
16	0.01864	0.03381	0.16695	0.29447
17	0.01829	0.03244	0.15774	0.29376
18	0.01746	0.03411	0.16398	0.29909
19	0.01805	0.03155	0.16533	0.29544
20	0.01797	0.03282	0.15051	0.29642
21	0.01689	0.03288	0.16671	0.28415
22	0.01938	0.03414	0.17315	0.32535
23	0.02138	0.03274	0.15537	0.29842
24	0.02978	0.03854	0.16358	0.28566
25	0.05583	0.06115	0.20352	0.30350
26	0.12118	0.14957	0.47211	0.56721
27	0.12000	0.15000	0.47000	0.61180

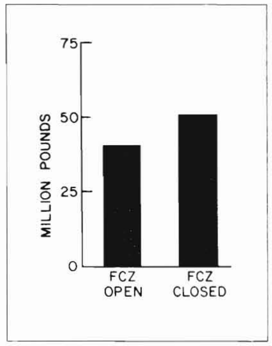

Figure 5.—Comparison of Gulfwide May-August 1981 yields of brown shrimp: FCZ open vs. FCZ closed.

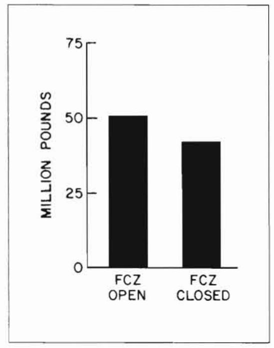

Figure 6.—Comparison of Gulfwide August 1981 standing stock of brown shrimp; FCZ open vs. FCZ closed.

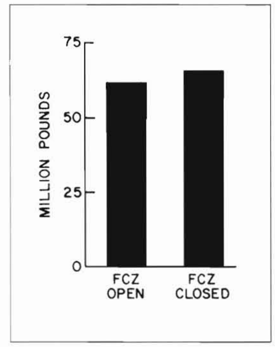

Figure 7.—Comparison of Gulfwide brown shrimp yields over the fishable lifetime of the "protected" shrimp: FCZ open vs. FCZ closed.

with 1978 levels. Abundances of older shrimp also appear to be high, as was the case in 1977. Fishing mortality rates for 1981 appear to be similar to 1977-78 levels.

Yields, Had the FCZ Been Open

Probably the most reasonable prediction of what fishing mortality rate would have been had the FCZ been open can be derived from age-specific *F*'s in recent years when the FCZ was open. I generated fishing mortality rate estimates using the average 1977-78 *F*'s calculated by Parrack (footnote 1) as a baseline fishing pattern. Data for these years are the most recent available and both represent "good years" for brown shrimp landings. To set the magnitude of the *F*'s for 1981, I assumed that effort expended in August indexed effort "available" for 1981, which was 62.3 percent of the average effort for 1977-78 in August. Fishing mortalities for May-August 1981, had the FCZ been open, were estimated to be 0.623 multiplied by the 1977-78 average levels.

Simulated fishing of the May-August period, using the May stock size estimates and May-July recruitment generated from the VPA analysis, provides estimates of Gulfwide yields obtainable had the FCZ been open. To project through the fishable lifespan of the shrimp present during the closure period, the 1977-78 rates multiplied by the August effort ratio were extended through December. The January-April fishery had changed radically in 1981 compared with 1977-78, in that effort was only 22 percent of the 1977-78 level. Assuming this represents a change in fuel price economics that will continue, winter fishing was simulated by multiplying the 1977-78 *F* level by 0.22. Because small contributions to yields can be expected for a second year, the *F*'s just described were repeated for a second year (May through April).

Closing the Texas FCZ appears to have increased Gulfwide yields in weight by 29 percent (11.7 million pounds of tails) during the May-August period (Fig. 5). Some increase was registered during the closure, not just after. Part of the short-term increased yields were achieved at the expense of the standing stock on the grounds. Existing Gulfwide biomass on 1 August was estimated to be 20 percent lower than predicted with the FCZ open (Fig. 6). Over the fishable lifespan of the shrimp present or recruited during closure, the gain in yield estimated from closing the Texas FCZ was 7 percent, about 4.1 million pounds Gulfwide (Fig. 7).

Discussion

The changes in yield estimated with the Gulfwide analysis can be reconciled very well with the predicted local changes in yield from the Texas FCZ. Examination of the expected gain stockwide and the patterns of fishing effort will indicate both an effect due to protection of a portion of the stock and an effect due to an alteration in fishing pattern. Some components of the effort pattern alteration can be clearly attributed to the closure.

Assuming there had been no changes in effort patterns, the maximum effect of closure on Gulfwide yields can be approximated. An estimation of *F* off Texas in August was made via Baranov's catch equation (Baranov, 1918, cited in Ricker, 1975) using the reported catch off Texas, and an estimate of the average August stock size off Texas. August stock size off Texas was estimated as the fractional amount of the stock off Texas determined from August CPUE data multiplied by the average Gulfwide stock size determined from the VPA

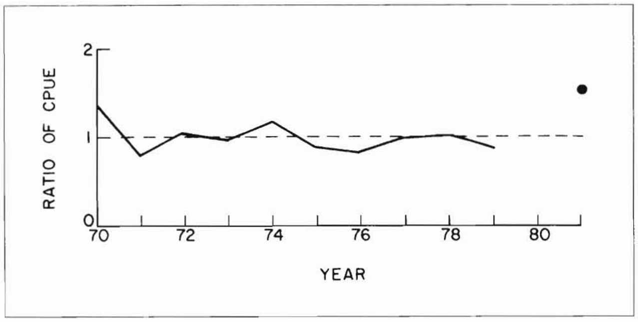

Figure 8.—Ratio of brown shrimp CPUE off Texas to CPUE elsewhere in the Gulf in August. Dashed line indicates the average value for 1970-79; dot is the 1981 value.

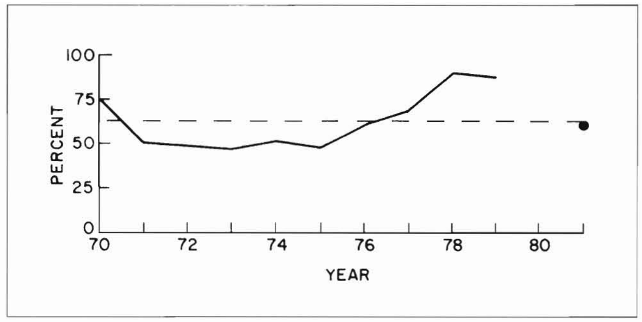

Figure 9.—Ratio of (brown shrimp directed) fishing effort in June vs. August, Gulfwide. Dashed line indicates the average value for 1970-79; dot is the 1981 value.

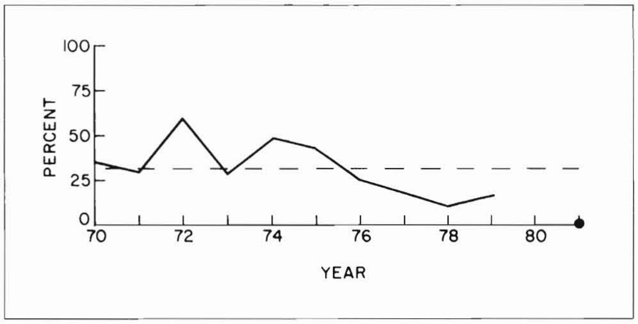

Figure 10.—Fraction of brown shrimp fishing effort off Texas in June. Dashed line indicates the average value for 1970-79; dot is the 1981 value.

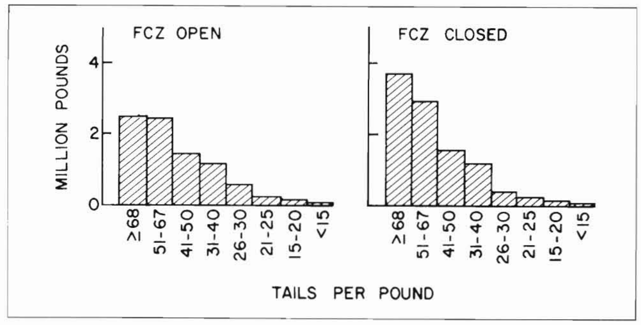

Figure 11.—Comparison of observed landings of brown shrimp by market size category in June 1981 (FCZ closed) with predicted landings (FCZ open).

analysis. Averaged over age, *F* off Texas was estimated to be 1.06 per month. Assuming this rate held for the Texas FCZ, the maximum gain from the FCZ is about 40 percent (from Figure 4). Projecting stock size estimates for Texas (using a "Texas only" VPA) to May, and calculating the percent of the stock off Texas actually in the FCZ from the *Oregon II* results, suggest that 29 percent of the Gulf stock was in the Texas FCZ at the time of closure. Enhancing yields from 29 percent of the stock by 40 percent implies that yields from the entire stock would be enhanced about 12 percent.

The high catch rates off Texas in 1981 relative to the rest of the Gulf apparently are due to the closure of the FCZ more than any unusual differences in recruitment between Texas and "elsewhere." Shown in Figure 8 are the ratios of CPUE off Texas vs. elsewhere, since 1970. The ratio averages about 1:1, with only 1970 even remotely approaching the ratio observed in 1981. If the ratio for 1981 had been 1:1 without closure, enhancement of the biomass in the FCZ by the predicted 78 percent would result in a ratio of catch rates of about 1.62:1 upon opening. This ratio agrees very closely with the 1.54:1 ratio observed in August.

Empirical comparisons of fishing effort patterns in 1981 with those of past years are inconclusive regarding a possible shift in effort from the Texas FCZ to other areas during the closed period. Shown in Figure 9 are the ratios of June effort to August effort, Gulfwide, for 1970-79 and 1981. The 1981 June:August effort ratio (61 percent) is very close to the 1970-79 average (63 percent). This suggests that almost all the effort traditionally exerted off Texas was relocated to other areas in the Gulf during the closure. On the other hand, the fraction of June effort off Texas had been declining in the late 1970's (Fig. 10), and the June:August ratio (Gulfwide, Fig. 9) had been rising. The average June: August ratio for the baseline years used in the yield simulation was 81 percent. The observed 1981 ratio of 61 percent suggests that more than the 15 percent Texas share of the effort for 1977-78 simply dropped out.

Comparison of the observed landings by size category in June 1981 with the size composition predicted for fishing with the FCZ open shows an increase in the smallest size categories and a slight decrease in larger sizes with FCZ closure (Fig. 11). A movement of effort from the more offshore areas of Texas to nearshore areas else-

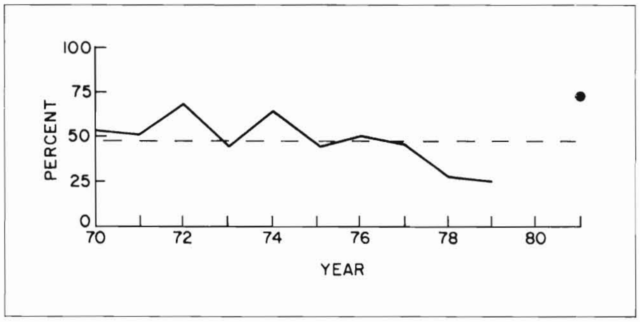

Figure 12.—Fraction of brown shrimp fishing effort off Texas in August. Dashed line indicates the average value for 1970-79; dot is the 1981 value.

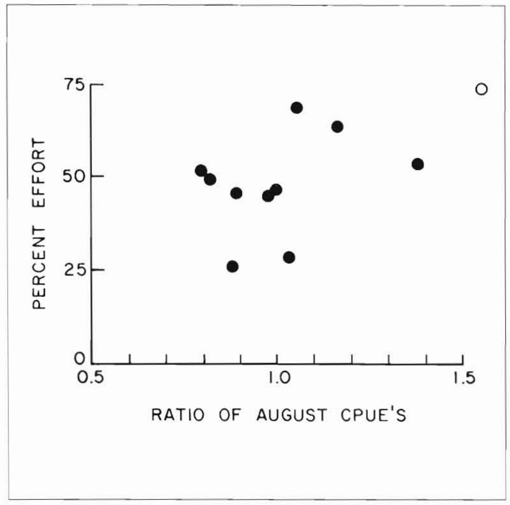

Figure 13.—Percent of Gulfwide brown shrimp fishing effort off Texas in August vs. ratio of August CPUE off Texas: August CPUE elsewhere in the Gulf, 1970-81. (Data unavailable for 1980.)

Table 4.—August catch per unit effort for brown shrimp off Texas and elsewhere in the Gulf, 1970-79 and 1981.

	Pounds of tails per 24-hours of fishing time[1]	
Year	Off Texas	Elsewhere
1970	1,041	757
1971	844	1,070
1972	933	891
1973	357	367
1974	685	591
1975	582	657
1976	648	797
1977	904	914
1978	747	727
1979	502	571
1981	1,289	832

[1]Brown shrimp directed.

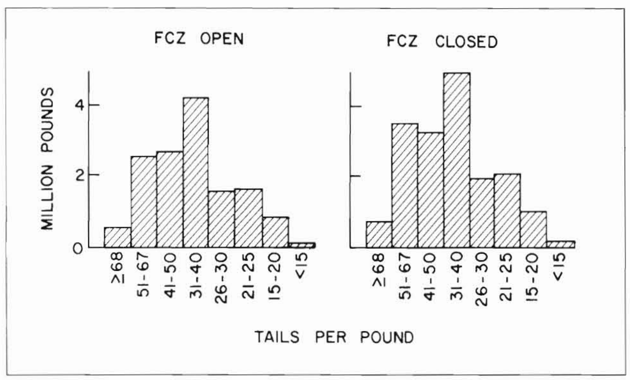

Figure 14.—Comparison of observed landings of brown shrimp by market size category in August 1981 (FCZ closed) with predicted landings (FCZ open).

where could help produce such a shift in size distribution of the catch, but because the existence of such an effort movement is uncertain, the existence fishing on smaller shrimp in June may not be directly related to the closure.

Whatever the extent of any effort movement during closure, there was apparently no large-scale depletion of the stock elsewhere in the Gulf. August CPUE for areas other than Texas are higher than all but three of the ten years, 1970-79 (Table 4). The approximate agreement between the observed ratio of August CPUE for Texas vs. elsewhere, and the ratio predicted simply from changes within the Texas FCZ, also suggest that no major depletion took place elsewhere.

Fishing effort comparisons do indicate a definite increase in effort off Texas relative to (and probably at the expense of) the rest of the Gulf after the closure ended. The fraction of August effort exerted off Texas since 1970 is shown in Fig. 12. The fraction for 1981 exceeds all previous years. The high catch rates off Texas undoubtedly attracted the large relative effort, although relative effort has been only weakly predictable from relative catch rates in the past (Fig. 13). Because most of the imbalance in catch rates appears to be due to the FCZ closure, the high relative effort off Texas can be directly attributed to the closure.

Comparisons of the catch by market size categories in August for the observed (FCZ closed) and simulated (FCZ open) conditions show an increase in all size categories, with virtually no change in average size landed (Fig. 14). The lack of change in average size indicates that the change in fishing effort pattern in August in 1981 did not produce much change in the distribution of F among ages.

Sensitivity Considerations

I believe that there are three areas where consequences of particular assumptions and specific parameter estimates are potentially severe enough to require expanded discussion: 1) The natural mortality rate *(M)* estimate, 2) the "August multiplier" assumption for determining F had the FCZ been open, and 3) the effects of discarded or otherwise unreported catch.

Results of yield-per-recruit models are notoriously sensitive to departures of estimated M from the true value. If M is underestimated, the gains predicted for the FCZ could be overestimated. However, the predicted distribution of relative CPUE (Texas vs. elsewhere) was close to that observed. The predicted differences were based on the yield-per-recruit model, so any serious error in M is unlikely.

Establishing the magnitude of fishing mortality rates from the ratio of August effort in 1981 to the average effort in 1977-78 was chosen as the most straightforward procedure available. However, there is reason for concern in that the magnitude of the reduction in effort in 1981 relative to 1977-78 (62 percent) is not reflected in the fishing mortality rates for August. I believe this represents a real change in fishing patterns between 1977, 1978, and 1981. Much of the effort that dropped out may have been essentially "peripheral," in part perhaps the effort of less-efficient fishermen, but also due to reductions of effort in areas of relatively low stock densities. This change in fishing pattern calls into question the low multiplier, in that the effort, had the FCZ been open, might have been more "efficient" also. If fishing effort in 1981 was truly more "efficient," simulated F's might be too low, and that gain due to closure might be overestimated.

Any error caused by underestimating the value of F, had the FCZ been open, will overestimate the amount of yield gained due to closure, but there are three reasons why I believe the conclusion that there was some gain with closure is unaffected:

1) Some of the cause of the observed "high" F in August is legitimately due to intense fishing in areas of high stock densities, densities generated in part by the FCZ closure.

2) The F estimates for June on large shrimp are not out of line with the effort multiplier without postulating a change in "efficiency." (Smaller shrimp appear to have been exploited more "efficiently," however.)

3) The magnitude of the error in estimated F (had the FCZ been open) required to reverse the conclusion is rather high. F's with the FCZ open must be one-third higher than calculated to eliminate a predicted gain from closure. If F's were two-thirds higher, a net loss of less than 5 percent would have been predicted.

If discarding was a constant fraction of the landings for the FCZ, both open and closed, the effects of ignoring discards here would probably be minimal. The extent of discarding probably varies in a complex manner in response to relative abundances of small and large shrimp, total catch rates, and prices. I concluded that I could not predict changes in discarding practices and must ignore any effects. Qualitatively, the FCZ closure might be expected to reduce discarding, thus the gain from closure estimated here may be underestimated.

Conclusions

Closure of the Texas FCZ appears to have ample potential for increasing yields from the Texas FCZ, as indicated by the yield-per-recruit analysis. The empirical estimation of changes in Gulfwide yields indicated a gain slightly below that predicted simply from enhancement of Texas FCZ yields. Dilution of some of the gain would be expected if fishing effort patterns shifted out of the Texas FCZ during closure and into the FCZ after closure. A definite shift of effort to the Texas FCZ after opening is evident in the data. Evidence concerning possible shifts to other areas of the Gulf during closure is equivocal. Apparently, the closure did not cause any major depletion of brown shrimp throughout the rest of the Gulf.

The effects of the closure are superimposed on a fishery that has changed noticeably since the late 1970's, presumably in response to the economics of the times. The changes include a severe reduction of the winter brown shrimp fishery and an overall reduction in fishing effort, preferentially in areas of lower stock densities. Preferential reduction of effort in more marginal areas appears to have made the fishery more "efficient." Under 1981 conditions, potential gains from the closure were exploited more quickly than they would have been under late 1970's conditions, probably at some expense to yield benefits yet to be realized.

Literature Cited

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