Simulated and Actual Effects of the Brown Shrimp, *Penaeus aztecus*, Closure in Mexico

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Introduction

One of Mexico's major shrimp fisheries is located in the northwestern Gulf of Mexico off the States of Tamaulipas and Veracruz (Fig. 1). Catch is mainly brown shrimp, *Penaeus aztecus*, which can be as high as 90% of total landings (Castro et al., 1982). Pink shrimp, *Penaeus duorarum*, is also found in the catch, but usually it is not clearly separated from brown shrimp in processing plants. Pink shrimp and white shrimp, *Penaeus setiferus*, make up only 10% of catch in this area.

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ABSTRACT—Simulations based on a yield-per-recruit model were performed to analyze the impact of growth overfishing on brown shrimp, Penaeus aztecus, *and to assess the effects of a closed season inshore and offshore of the Mexican States of Tamaulipas and Veracruz. Closure of both the inshore and offshore fisheries could enhance cohort yield by more than 300%. Cohort yield enhancement would be only about 60–80% if only the offshore season were closed. The closed season of 1993 gave better results as it covered a larger part of the brown shrimp peak recruitment period. Catch per unit of effort (CPUE) after closure in 1993, compared with 1994, was 2.4 times higher than the mean CPUE of the month. Total annual offshore yield increased 72% in 1993 (3,800 metric tons (t)) and 10% in 1994 (506 t) with respect to the mean annual offshore catch during the 10-year period prior to the 1993 closure. Simulation results could help identify alternatives that permit the coexistence of the inshore and offshore fisheries while maintaining high profitability of the brown shrimp fishery.*

Shrimp stocks have supported both inshore and offshore fisheries since the 1950's. Shrimp exploitation increased to maximum levels of around 13,000 metric tons (t) whole weight with an average production of about 10,000 t during 1987–92. Almost half was produced by the artisanal inshore fishery. The shrimp fishery in this area was considered stable after reaching the 10,000 t average production level in 1978 (Arreguín-Sánchez et al., In press) as it has not shown marked declines observed in other shrimp stocks in the Campeche Bank (Gracia, 1989a, In press). However, the steady increase in the artisanal inshore fishing effort has led to growth overfishing of the stock. Additionally, the increase in artisanal fishing effort, along with the offshore commercial fishing pressure, may eventually reduce shrimp biomass.

To protect brown shrimp juveniles from growth overfishing, a closed season was proposed and implemented by the Fisheries Secretariat of the Mexican Government in 1993. This regulation was imposed to improve yield and value of shrimp by allowing brown shrimp recruits to grow to a larger and more optimal size.

A fishing closure during the main recruitment period is a common method used for protecting and enhancing shrimp stocks (García, 1989). The antecedent of this type of regulation for

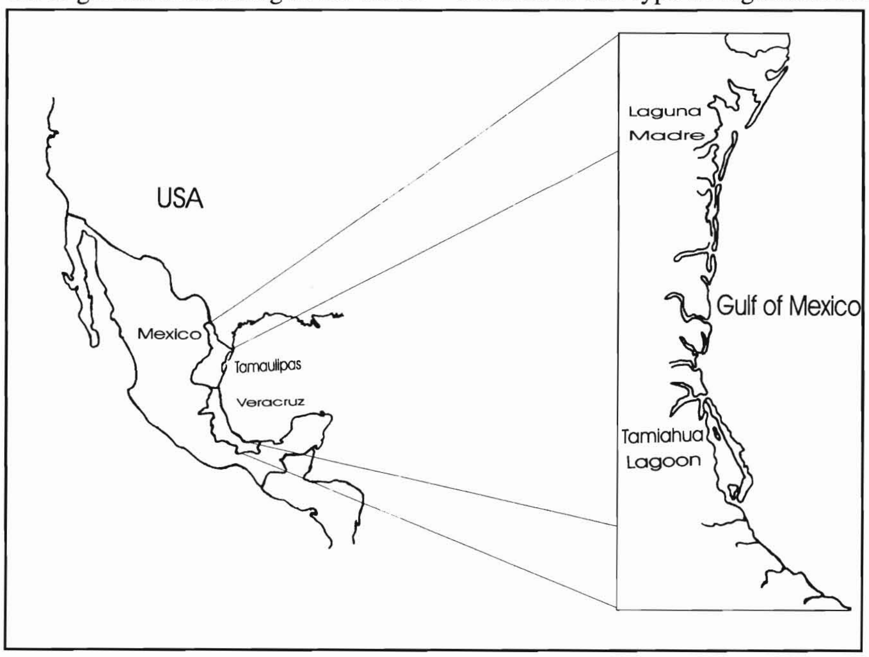

Figure 1.—The brown shrimp fishery area in the States of Tamaulipas and Veracruz, México.

brown shrimp can be found in Texas where a closed season was established in the Territorial Sea for 45–60 days during the May–July period every year since 1959; in 1981 the closure was extended to the 200-mile Fishery Conservation Zone (Klima, 1989). The most recent example in Tamaulipas coastal waters occurred in 1974 when an experimental closure was set from 15 June to 31 July (Castro and Villalobos, 1976). In 1993, a formal closure was established for brown shrimp in the States of Tamaulipas and Veracruz from 30 May to 15 July. The closure was repeated in 1994 from 15 June to 1 August.

In this paper I analyze the biological basis for this regulation, optimum closure periods, and the effects of the 1993 and 1994 closures on brown shrimp yields.

Basis of the Analysis

Fishery exploitation and the interactions of sequential fisheries were examined using a yield-per-recruit type of model. Fishery and populations parameters were obtained from the literature when available, and others were estimated from fishery statistical data. Natural mortality parameters were estimated through approximate methods following Gracia (1989b) and compared with those available in the literature. Age-specific fishing mortality patterns were derived through a pseudo cohort analysis (Mesnil, 1988) using estimates of brown shrimp age compositions from landings during the most important recruitment period (June–September) in the year (Table 1).

Table 1.—Brown shrimp monthly fishery parameters used for simulations.

Growth parameters	L_∞ = 204 mm	
	W_∞ = 72.1 g	
	K = 0.2115	
	t_0 = 0.2914	
Estuarine natural mortality (ages 1, 2)	0.8	
Marine natural mortality	0.2, 0.3, 0.56	
Estuarine fishing mortality	0.11 to 0.65	
Marine fishing mortality	Age	F
	3	0.002
	4	0.022
	5	0.051
	6	0.093
	7	0.105
	8	0.225
	9	0.322
	10	0.388
	11	0.393
	12	0.455
	13	0.474
	14	0.311
	15	0.386
	16	0.330

The monthly recruitment pattern was estimated by analyzing fishery data of Laguna Madre and offshore landings. Brown shrimp, like other tropical penaeids, are reproductively active all year, but exhibit a peak during February–March. Following this pattern, the main recruitment in the Laguna Madre begins in April, peaks in May, and then decreases to minimum values in September. Field sampling during the main fishery period (May–July) was carried out in Laguna Madre to estimate the size structure of the artisanal catch. Fishery data were obtained through the statistical collections of the Delegación de Secretaría de Pesca in Tamaulipas. It was assumed that brown shrimp have a mean life expectancy of 16 months. Effects of natural mortality, fishing mortality, and growth were simulated using a 15-day time step.

Results

Artisanal fishing for brown shrimp in Laguna Madre, Mexico, is conducted year round. However, the main fishing period runs from April to August (Fig. 2). A large portion of the artisanal shrimp catch is taken during this primary period before decreasing to very low levels in September to March. Mean size of shrimp in the estuary varies depending on the fishing area or month but usually runs 60–90 mm total length (TL) (Castro et al., 1982). Sampling during the main fishing period showed a size range of 40–130 mm TL with a mode of 65–75 mm TL (Fig. 3). Juvenile shrimp average about 4 g mean total weight.

The inshore fishery targets shrimp 2–3 months old, affecting their numbers and migration to the offshore marine environment. The annual documented inshore shrimp catches of the coastal region of Tamaulipas and Veracruz have shown an increased catch of young shrimp with some fluctuations. This has been observed since 1975, and in 1990 it reached a little over 6,255 t. Consequently, the inshore catch of young shrimp represents around 40–49% of total shrimp yield in the northwestern Mexican Gulf of Mexico from 1972 to 1992 (Fig. 4).

A simulation was performed to assess the impact of inshore growth overfishing on the brown shrimp yield. The analysis showed that every kilogram of juvenile shrimp caught inshore could yield between 1.75 and 4.2 kg offshore, depending on the natural mortality parameter used, assuming a mean life span of 16 months and fishing effort similar to the mean pattern of the prior 10-year period (1983–92). The simulation predicted that standing stock could be increased by up to 420% in weight, with the gain in growth offsetting the loss of mortality if juveniles are allowed to migrate to the sea (Fig. 5). Among the natural mortality values used, I consider that M=0.56 (Castro et al., 1986) is too high for this penaeid shrimp. Brown shrimp natural mortality could be around M=0.2, as some authors have estimated for brown shrimp in the northern Gulf of México (Rothschild and Brunenmeister, 1984; Parrack[1]). Thus it is more appropriate to consider M=0.2 and 0.3. The increase in the offshore standing stock will depend on the timing and duration of the inshore closure and/or the fishing effort exerted by the artisanal fishery.

Effects of inshore fishing vs. an offshore closure were also examined using a yield-per-recruit type of model. The simulation showed that the standing stock would increase around 80% if only an offshore closure is used. An offshore closure results in a remarkably lower increase in standing stock than closing both inshore and offshore fisheries (Fig. 5).

The inshore artisanal catch also causes an impact on spawning stock that could be higher than that exerted by offshore commercial fishing. According to the simulation exercise, an inshore-offshore closure of 45 days would allow an increase in spawning stock of more of 40% if the mean fishing mortality pattern is maintained. An inshore closure seems to have a higher impact on increasing the spawning stock than does an offshore closure (Fig. 6). Set-

[1] Parrack, M. L. 1981. Some aspects of brown shrimp exploitation in the northern Gulf of Mexico. Pap. pres. at Workshop on the Scientific Basis for the Management of Penaeid Shrimp. Key West, Florida, 18–24 November, 1981. Sponsored by Southeast Fisheries Center, NMFS, NOAA, Miami, Fla

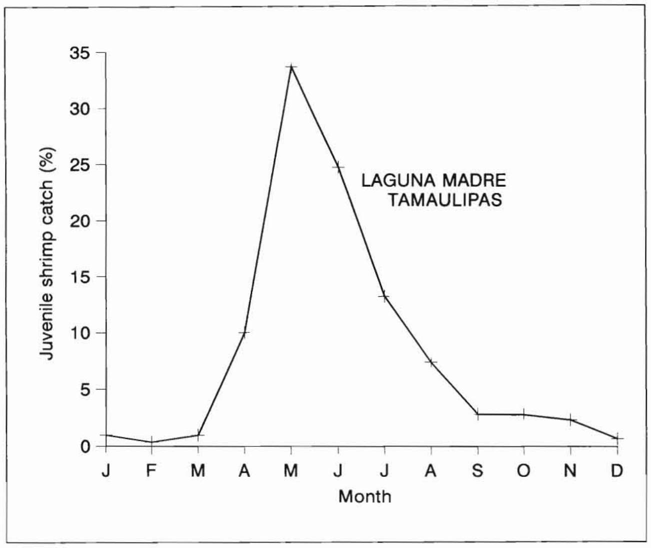

Figure 2.—Juvenile brown shrimp monthly mean catch in the Laguna Madre, Tamps. (1987–92).

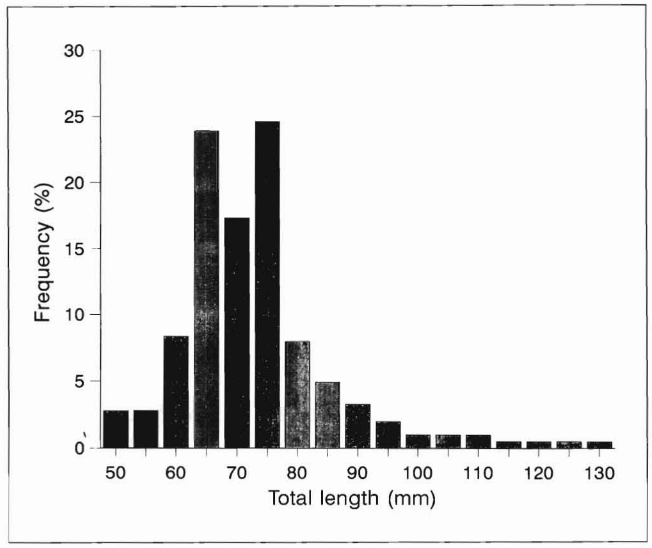

Figure 3.—Size composition of juvenile brown shrimp caught in Laguna Madre, Tamps., during 1993.

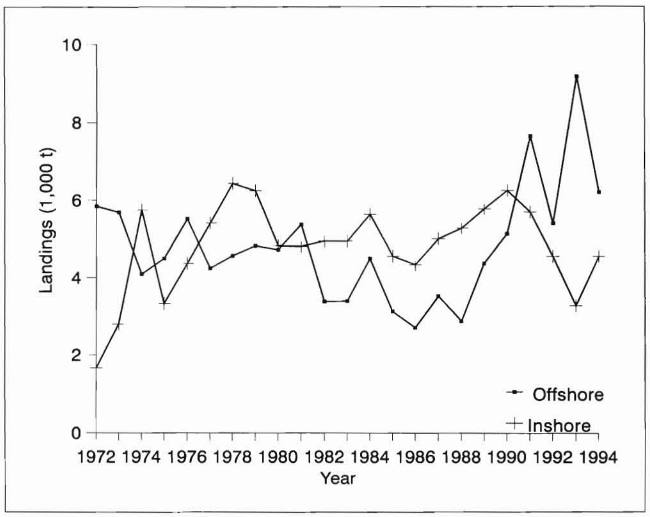

Figure 4.—Brown shrimp annual landings in the State of Tamaulipas. Source: Delegación de Pesca, Tamaulipas, SEMARNAP.

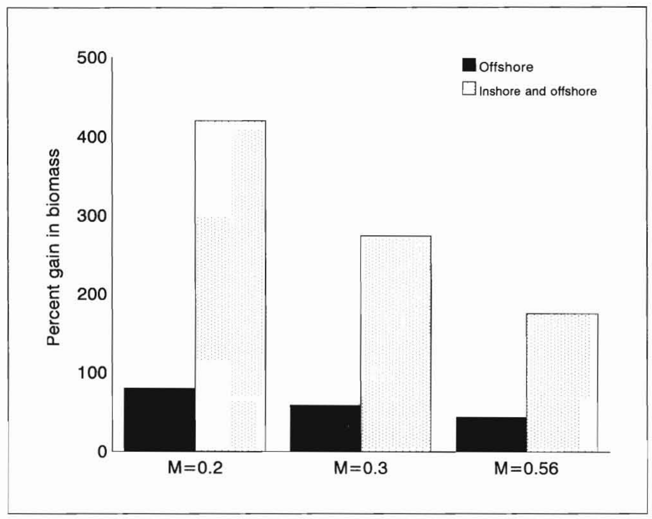

Figure 5.—Predicted gain in weight per recruit obtained with offshore and inshore-offshore closed seasons on brown shrimp.

ting a closure only in the offshore environment would reduce the spawning stock increase to less than 20%. Protecting juveniles inshore during the recruitment period seems to be more effective for allowing the stock to recover and increasing the spawning potential (García, 1989).

The present impact of artisanal fishing on the spawning stock was also simulated. According to this, an artisanal catch equivalent to 40% of the total brown shrimp yield could reduce the spawning stock 48% relative to the virgin biomass (Fig. 7). The impact of artisanal fishing adds to that of commercial fishing, which seems to exert a lower effect.

The 1993 Closure

The first closure of inshore and offshore fisheries for brown shrimp gave excellent results. Data for 1993 from offshore waters of Tamaulipas showed a catch 3,800 t higher than that registered the previous year at a historic offshore catch record of 9,194 t. This represented an increase of almost 72% over the mean catch of the previous 10-year average. The total artisanal catch of 1993 decreased 1,100 t in relation to 1992, as the inshore closure prevented exploitation of juvenile shrimp (Fig. 8).

The CPUE registered in the first days of the season had never been seen before in the Tamaulipas fishing grounds. Shrimp trawlers caught about 1,000 kg total weight per night for 2 weeks (Gracia, 1993). During the last 2 weeks

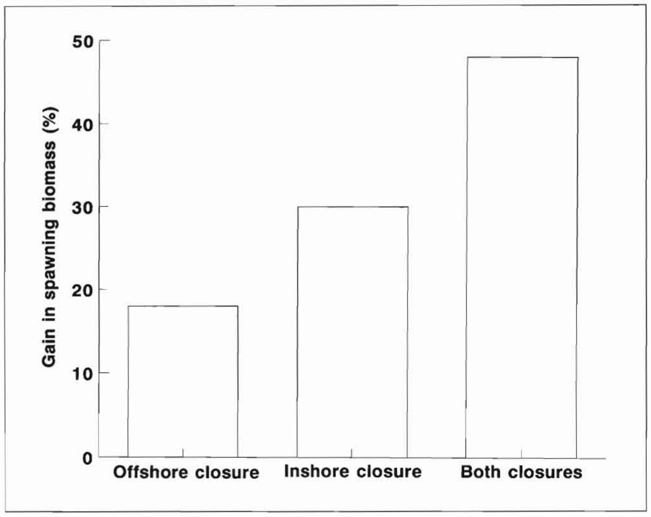

Figure 6.—Predicted impact of closed season on brown shrimp spawning stock.

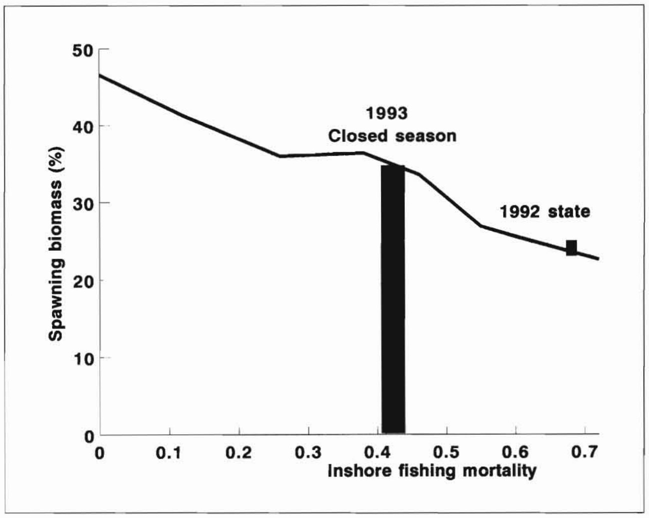

Figure 7.—Predicted impact of the artisanal catch on spawning stock of brown shrimp.

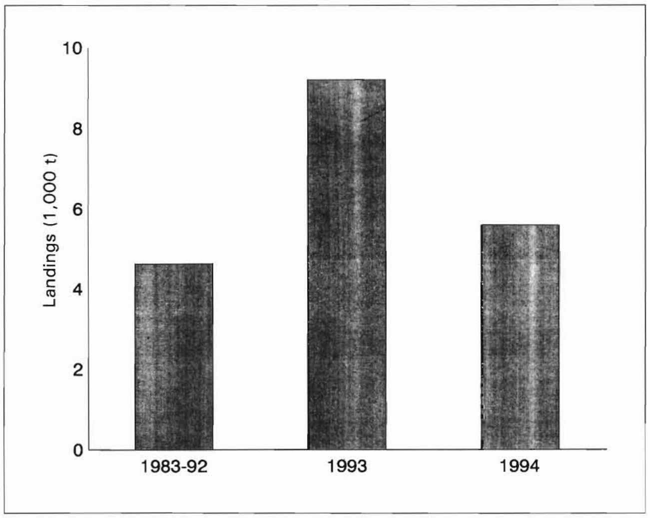

Figure 8.—Comparison of brown shrimp yields resulting from the 1993 and 1994 closed seasons with the 1983–92 mean harvest.

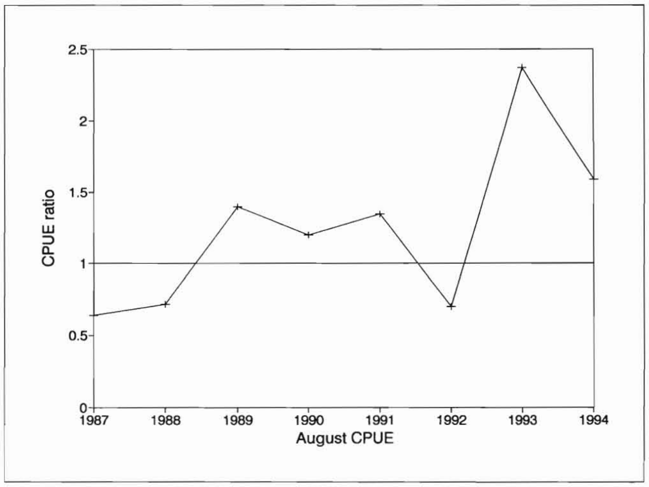

Figure 9.—Comparison of brown shrimp CPUE (kg/day) during August to average CPUE of the same month. The straight line represents the baseline average value for 1987–92 August CPUE.

of July and the month of August, shrimp catches were 1,357 and 2,759 t (whole weight), respectively, values never before reached in the history of the offshore fishery. CPUE during August 1993 was notably higher than the average August value during the period in 1987–92. Enhancement of biomass by the closure resulted in a ratio of August 1993 catch rates to August catch average of about 2.4:1 (Fig. 9). For the month of August in years prior to the closure, only those of 1989 and 1991 showed a CPUE ratio above the average value, but they were not comparable to that of 1993.

Fishing effort during August 1993 showed a clear increase of 1.9 times greater than the average value of the 1987–92 period after the closure ended. The value for 1993 exceeded all previous years. High expectations of large catches resulting from the closure undoubtedly attracted a greater number of shrimpers from all regions in the Gulf of Mexico (Fig. 10).

The composition of August landings by size categories was dominated by small shrimp. About 85% of the shrimp were 36–42 count and smaller and the mode was 51–60. Large shrimp (>36 count) represented only about 5% of the catch after the closure of 1993 (Fig. 11).

The 1994 Closure

Timing of the second closure, modified on the basis of nonbiological reasons, saw closure of the inshore fishery delayed to 15 June, whereas in the offshore fishery it began on 25 May.

Offshore landings for 1994 were 5,583 t, which was 3,311 t less than the

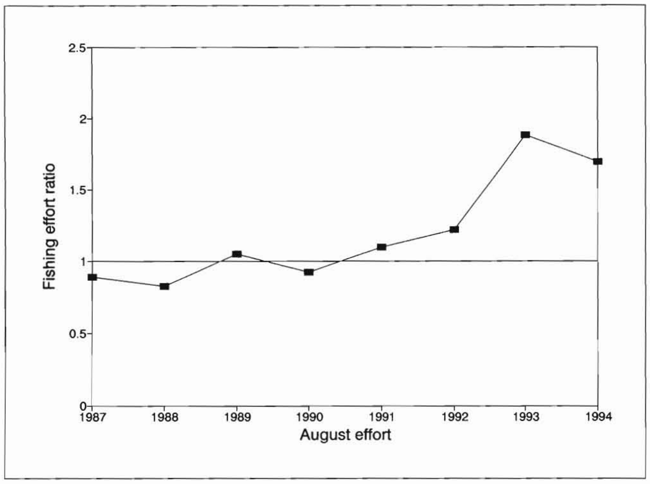

Figure 10.—Comparison of August fishing effort to August average value baseline. The straight line represents the baseline average fishing effort for August 1987–92.

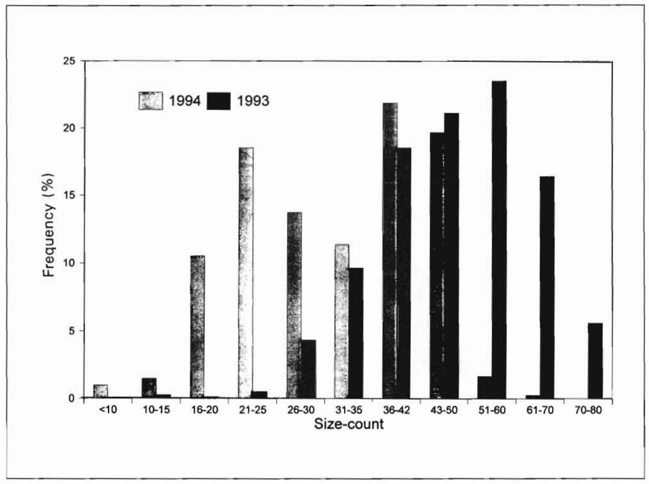

Figure 11.—Size composition of brown shrimp landings during opening seasons of 1993 and 1994.

catch obtained under the first closure in 1993. The 1994 offshore catch represented 64% of the yield achieved during 1993. With respect to offshore mean yield for the 10 years prior to 1993, the 1994 offshore catch increased only 10% (Fig. 8). On the other hand, the 1994 artisanal inshore catch increased by 1,280 t compared with 1993. The looming closure stimulated many artisanal fishermen to increase their inshore fishing effort to obtain large shrimp catches before the closure occurred. The artisanal catch in May was 1.5 times higher than the average of previous years. The result of the increased fishing pressure on juvenile shrimp was that the artisanal annual catch returned to a level similar to that obtained when there was no closure.

The offshore shrimp catch during August 1994 amounted to 1,647 t total weight. This was 40% less than in August 1993. If the catch of the first fifteen days after the closure during July of 1993 is included in the comparison, the percentage is even greater (60%); however, it cannot be directly compared as fishing was also closed in July of 1994. Nightly CPUE was estimated at 800 kg total weight, 20% less than in 1993. This high CPUE did not last more than 5 days, however, decreasing to normal CPUE values of a little over 100 kg per night. CPUE in August 1994 decreased 33% compared to August 1993 (Fig. 9); nonetheless, this value was still higher than the highest CPUE recorded in 1989, well before the onset of the first closure. August 1994 harvests gave a ratio of 1.6:1 with respect to the August mean yield of 1987–92.

Offshore fishing effort during August 1994 declined about 10% compared with effort in August 1993, although it was 1.7 times greater than the mean August fishing effort over the 1987–92 period (Fig. 10). This decline was attributed to the comparatively low shrimp abundance resulting from the second closure in 1994 preventing fishing boats from other ports of the Gulf of Mexico to join the fishery.

Size composition of offshore shrimp landings during the opening month of 1994 showed a clear difference in relation to 1993. The large size categories were more prevalent, whereas small shrimp declined. Almost 60% of the month's landings were between 16–20 and 31–35 count. Two modes were registered at size counts of 21–25 and 36–42 (Fig. 11). Bigger shrimp sizes after the 1994 closed season rendered better yield in value (per unit of weight) which was around 25% higher than the 1993 closure value.

Discussion

The first experimental closed season for brown shrimp along the Tamaulipas and Veracruz coasts set in 1974 (15 June to 31 July) seems less effective than the 1993 and 1994 closures. The shrimp catch in 1974 did not register any remarkable change following the closure. As a matter of fact, Castro and Villalobos (1976), comparing shrimp production of 1973–75 recognized that there was practically no variation between shrimp catch in those years, and that the difference seemed to be found only in size composition of the harvest. No other data is available to make a detailed comparison between that first experimental closure and the 1993 and 1994 closed seasons, but there is a basic difference between them: the 1974 closure was only offshore. That permitted the offshore recruits to grow and attain larger sizes, but the increment of yield was not so high as when recruits were also protected inshore in 1993 and 1994. Thus the 1974 closure period did not adequately cover brown shrimp recruitment.

Simulation exercises and the results of the 1993 and 1994 closures show that protecting inshore recruitment allows juveniles to grow more than 300% in weight, thus substantially increasing shrimp yields. Protecting juveniles inshore is thus the key to producing large shrimp yields like that of the 1993 closed season.

In Mexico, high fishing pressure on juvenile shrimp affects the overall yearly production of brown shrimp and

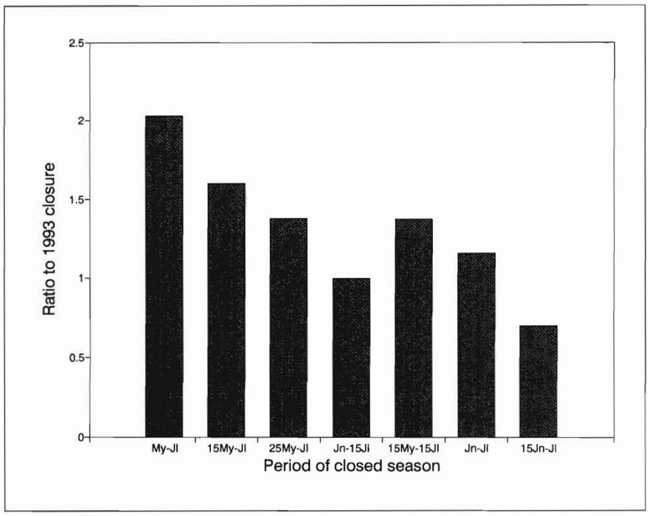

Figure 12.—Offshore yields ratio derived from different closed seasons in relation to the 1993 closure. My: May, Jn: June, Jl: July.

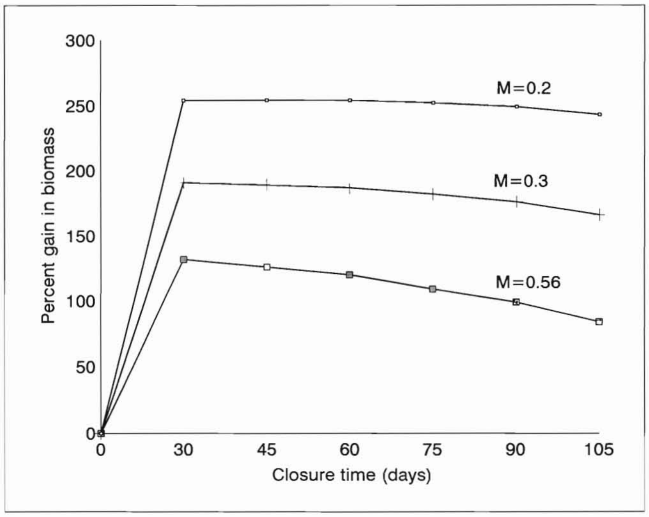

Figure 13.—Estimated brown shrimp yield in relation to different length of closed seasons and values of natural mortality (M).

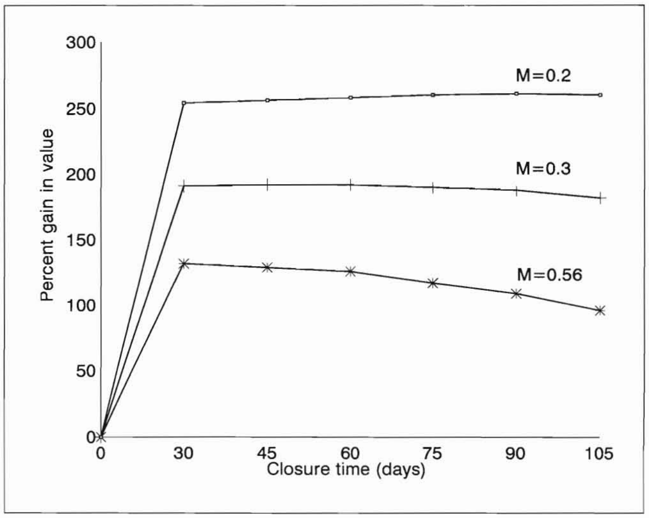

Figure 14.—Estimated brown shrimp value obtained with different length of closed seasons and values of natural mortality (M).

its subsequent recruitment to the sea (Gracia, In press). That is one of the reasons why the offshore shrimp increase shows a linear relationship with length of the protected recruitment period inshore. Maximal shrimp yields would be attained if the entire recruitment period were protected, but that would have a serious impact on inshore artisanal fishermen and their harvests. This reflects the classic conflict between sequential fishing on shrimp by artisanal and commercial fishermen.

A comparison of predicted offshore yields resulting from different closed season periods with offshore yield obtained in 1993 closure indicates that the increase in yield will depend on the extent of the closed seasons as well as on the starting dates (Fig. 12). Offshore yield compared to the 1993 closure yield can be doubled if the closed season is extended from 1 May to 31 July. Furthermore, including May for the beginning of the closed season will always give better results than the 1993 date. In contrast, delaying the closure until or after 1 June will reduce the closure effectiveness for the offshore fishery.

Offshore fishing would not be adversely affected by both closures, because brown shrimp can support an offshore closure period of about 2.5–4 months (depending on the natural mortality parameter) before the stock suffers any net loss due to mortality. Based on the simulations, weight gain by cohort is very rapid, reaching a maximum around 3 months and then declining slightly (Fig. 13). Maximum value of the cohort is attained at maximum weight around 15 days later (Fig. 14). The total yield increase will depend also on the number and strength of cohorts included in the closure period.

The yield difference between the closure regulations of 1993 and 1994 can be explained on the basis stated above. During 1994, inshore recruitment was not adequately protected as it was in 1993. Shifting the closed season to 15 June in 1994 reduced the protection of inshore recruits around 40%, which adversely affected the overall yield after the closure. Likewise, the difference in size composition of the shrimp landings in 1994 was a response to the increased closure period offshore. Even so, a smaller overall yield decrease of 36% registered offshore in 1994 (compared to 1993) was mainly due to less protection of the recruits. The offshore catch derived from the closure in 1994 only represented a 10% increase over the annual mean brown shrimp production. This also represented a lower economic return compared with that obtained in 1993, estimated at an increase of US$40 million; a net increase of about 70% in the offshore annual catch value. The value of the artisanal catch lost during that closure period was minimal compared to the offshore increase in brown shrimp owing to their larger size. It is estimated that the mean increase of brown shrimp value, inshore vs. offshore, could be in a ratio of 1:15–20, assuming a constant fishing pattern.

While the increased shrimp yield after the closure may be due to protection of part of the stock, it could also be due to a change in the fishing pattern. Increased offshore fishing effort can be attributed to the closure regulation. The whole Gulf of Mexico fishing fleet was attracted to the Tamaulipas fishing grounds owing to the expectations of more and larger shrimp as a result of the closure. This caused a concentration of shrimp trawlers in the area at the beginning of the season. Also, setting the closed season appears to have increased the offshore brown shrimp total annual yield 72% percent only in Tamaulipas landings during 1993. The amount of brown shrimp landed in other ports of the Gulf of Mexico is not known precisely. Neither is it known whether part of the short-term increased yields were obtained at the expense of the standing stock of the shrimp grounds. Yield increases seem to agree with simulation results, although special care should be taken to keep fishing pressure from growing and threatening the standing stock. The effect of concentrated offshore fishing effort on brown shrimp stock after the closure should be analyzed to evaluate the extent to which it can affect the brown shrimp population.

Another issue that requires attention is the estimation of M, the natural mortality parameter. Results of yield-per-recruit models are highly sensitive to this. Any change in M will either underestimate or overestimate the gains predicted for the closure regulation. Although in this case predicted yields are close to those observed, better estimates of M are needed to improve prediction accuracy.

Environmental factors are also important because they affect shrimp abundance at each life-cycle stage, and they could affect predictions based on these models. The main influence of environmental factors could be through limiting or increasing the carrying capacity of shrimp nursery areas (Gracia, 1989c). This would have definite impacts on shrimp abundance. Although more information is needed about environmental factors before including them in the simulations, they should be kept in mind when analyzing model predictions.

Fishing closures for brown shrimp exhibit ample potential for increasing shrimp yields. Yield-per-recruit analysis suggests that the gain in biomass could be up to 80% per cohort if the closed season is only set offshore. However, if closed seasons are established both inshore and offshore, the gain in weight could be more than 300% per cohort. Also, the final yield obtained from an offshore stock increase will depend on the fishing intensity. Results derived from this study could be useful for managing the two sequential brown shrimp fisheries and for examining alternatives that allow their coexistence while maintaining a high profitability in brown shrimp exploitation.

Acknowledgments

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