An Economic Analysis of Texas Shrimp Season Closures

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Introduction

The Gulf of Mexico penaeid shrimp fishery is one of the most valuable fisheries in the United States in terms of ex-vessel value, and Texas has traditionally led all Gulf states in ex-vessel value of shrimp landed. The total impact on the Texas economy, including multiplier effects, is about $580 million annually with the fishery employing some 20,000 fishermen (Cody et al., 1989). The Texas shrimp fishery relies primarily on brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus*. The life cycle of shrimp makes them both estuarine- and Gulf-dependent; thus, two distinct harvesting fleets have evolved, inshore and offshore.

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ABSTRACT—Management of the Texas penaeid shrimp fishery is aimed at increasing revenue from brown shrimp, Penaeus aztecus, *landings and decreasing the level of discards. Since 1960 Texas has closed its territorial sea for 45–60 days during peak migration of brown shrimp to the Gulf of Mexico. In 1981 the closure was extended to 200 miles to include the U.S. Exclusive Economic Zone. Simulation modeling is used in this paper to estimate the changes in landings, revenue, costs, and economic rent attributable to the Texas closure. Four additional analyses were conducted to estimate the effects of closing the Gulf 1- to 4-fathom zone for 45 and 60 days, with and without effort redirected to inshore waters. Distributional impacts are analyzed in terms of costs, revenues, and rents, by vessel class, shrimp species, vessel owner, and crew.*

An important aspect of the inshore fishery relates to the function of bays in the life cycle of shrimp. Penaeid shrimp spawn in the Gulf of Mexico and larvae are carried into estuaries. During the early stages of shrimp growth, marshes and shallow bay areas serve as nursery grounds. As juvenile shrimp grow and mature, they emigrate offshore to the open waters of the Gulf.

The timing and duration of this cycle differs between species, but the major harvesting implications remain the same. During bay shrimping seasons, small shrimp found in shallow bays and near-offshore areas are subjected to harvest by inshore commercial (food and bait) and recreational fishermen before they move to deeper water and become available to the offshore fleet. The offshore fleet is characterized by large vessels capable of staying offshore for long periods of time. They target larger shrimp that roam deeper waters, and the amount of shrimp available to them is partially a function of the inshore harvest.

Since 1960, Texas has enacted a 45- to 60-day closure of its territorial sea from the 4-fathom depth contour to 9 n.mi. from shore during peak migration of brown shrimp to the Gulf of Mexico. In 1981, as mandated by the Gulf of Mexico Shrimp Management Plan, the Texas closure was extended to 200 n.mi. to include the U.S. Exclusive Economic Zone (EEZ)[1]. During this closure, however, the shallow offshore area from the shoreline to 4 fathoms deep was left open to white shrimp fishing. The economic thrust behind the closure is to increase the value of the brown shrimp harvest by protecting brown shrimp until they reach a larger, more valuable size, as well as to reduce waste through discarding. In conjunction with the 200-mile closure, the Texas Legislature repealed the count laws to reduce discarding.

The Texas Legislature historically has managed the fishery to maximize ex-vessel value of shrimp landed (Cody et al., 1989). In 1985 the Texas Parks and Wildlife Commission was granted authority to regulate the shrimp fishery in Texas's bays and territorial sea. The Texas Shrimp Fishery Management Plan was adopted in 1989, and in 1990 the 4-fathom offshore area, previously left open to white shrimp fishing, was closed[2].

Since 1981, the year the EEZ closure regulation began, the National Marine Fisheries Service (NMFS) has annually assessed the effects of the closure in terms of size distribution of shrimp, catch patterns in the fishery, overall

[1]In 1986, 1987, and 1988, the Texas closure was modified to extend to only 15 n.mi.

[2]There has been speculation that leaving the 4-fathom zone open could have detrimental effects on the overall fishery for the following reasons: 1) Enforcement of the closure is more difficult with this depth zone left open, 2) one-third of all brown shrimp discards are coming from the 4-fathom zone during the closure months, and 3) excess pressure on spawning white shrimp may have caused a reduction in recruitment of white shrimp to the fishery (data indicate a decline in white shrimp recruitment in Texas waters since 1981 (Cody et al., 1989)).

yield, and value of landings associated with changes in yield (Klima et al., 1983–85; Nichols, 1983–85, 1987; and Poffenberger, 1982, 1984, 1986a,b,c). NMFS uses the results for a given year the closure is in effect, and simulates for that year what landings would have been if there had been no closure. In contrast to the yearly evaluations conducted by NMFS, this study uses simulated average fishery conditions for the pre-closure period (1963–80) and compares the results to a closure (1981–85) simulation average, holding all environmental conditions constant. In other words, this analysis compares a simulated pre-closure average to a simulated closure average.

The purpose of this study was to analyze the economic effects of the 200-mile Texas closure as well as the economic effects of a total offshore closure including the 4-fathom zone. Distributional impacts were examined in terms of costs, revenue, and rent, by vessel class, shrimp species, vessel owner, and crew. Because the closure can range from 45 to 60 days, depending on biological conditions in the fishery, this study examined the effects of closing the fishery for the minimum and maximum number of days. Simulations also were run with and without effort redirected to inshore waters; the Texas closure caused a redirection of effort into the 4-fathom zone offshore, and it is expected that closing the 4-fathom zone will prompt a redirection of effort to inshore waters. Compliance of 100% was assumed (i.e., no illegal effort) when the 4-fathom zone was closed because shrimp vessels would have no reason to be in offshore waters and enforcement of the closure would be more effective. The policies analyzed are as follows:

1) 200-mile, 45-day closure, with the 4-fathom zone open;

2) 200-mile, 45-day closure, with the 4-fathom zone closed[3];

3) 200-mile, 45-day closure, with the 4-fathom zone closed and effort redirected inshore;

4) 200-mile, 60-day closure, with the 4-fathom zone closed;

5) 200-mile, 60-day closure, with the 4-fathom zone closed and effort redirected inshore.

Methodology

Model Description

The General Bioeconomic Fishery Simulation Model (GBFSM) was developed specifically for annual crop fisheries, and it is particularly applicable to the Gulf shrimp fishery (Grant et al., 1981; Griffin and Grant, 1982). The simulation model, or adaptations of GBFSM, have been used in several practical applications prior to this analysis (Blomo et al., 1982; Blomo et al., 1978; Griffin et al., 1979, 1981, 1990; Griffin and Grant, 1982). In the GBFSM, effects are assessed in terms of total harvest—species, size class, and seasonal distribution of the harvest; total revenue, total costs, and rent in the fishery; and distribution of revenue, costs, and rent among different classes of fishing vessels.

The user may select any number of species, size classes, fishing areas, depths, and vessel classes for inclusion in the model. The time-step, extent, and resolution of model output are also variable. The model is currently set with 8 fishing areas, 6 shrimp size classes, and 3 vessel classes (Table 1). The model is also set with 144 time steps, i.e., the model goes through its cycle—recruitment, growth, movement, mortality—144 times per year, or about once every 2.5 days.

The biological submodel represents recruitment of new organisms into the fishery by species, area, and time frame. Organisms grow and move from one size class to another and mortality results from both natural causes and fishing. Bait and recreational fishing occur within the model in inshore depths only. The model represents fishing effort exerted on each species by vessel class, depth zone, area, and time frame. Nominal days fished are exogenous to the model and are converted to real days fished based on the relative fishing power of vessels involved. The economic submodel represents monetary costs of fishing, value of harvest, and rent to the fishery. The economic submodel is built on top of the biological submodel and calculates economic effects based upon the biological effects of any proposed management strategy put into the model.

Table 1.—Characteristics of categories into which shrimp vessels, shrimp landings, and fishing areas were placed for modeling purposes.

Category	Fishing areas (Depth in fm)	Shrimp (No./lb)	Vessels
1	<1 (Nursery)	<20	Unregistered, inshore
2	<1 (Bays)	20 – 30	Registered, Texas based[1]
3	1 – 5	31 – 50	Registered, non-Texas based[2]
4	6 – 10	51 – 67	
5	11 – 15	68 – 116	
6	16 – 20	117 – 160	
7	21 – 25		
8	>25		

[1]Usually less than 55 feet in length.
[2]Usually greater than 55 feet in length.

Reported shrimp landings for 1963–85 were obtained from NMFS master files. These data are categorized into landings by area, species, size class, depth zone, and month for the entire 23-year period except 1969 and 1984; these years were excluded because effort data was incomplete when this study was undertaken. Nominal days fished were derived from the effort expansion data developed by Nichols (NMFS Pascagoula Laboratory) and were categorized by area, species, vessel class, depth zone, and time period. Given these data, it is possible to tune and validate the model by comparing model simulations to historical landings.

Model Tuning and Validation

Tuning the model requires the biological coefficients in the model to be set to the best estimate of values (obtained from Cody et al., 1989, and the Texas Parks and Wildlife Department[4]) and then adjusted until the tuned model depicts reality. The first step is to use average effort patterns and levels from the NMFS data set for the pre-closure period (1963–80) to generate average landings for the same period. These landings are expressed as total landings, landings by month, landings by depth zone, and landings by size class for both brown and white shrimp. The various

[3]Because this study was conducted prior to implementation of the 4-fathom zone closure, 1981–85 fishing patterns were used.

[4]Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, TX, 78744. Unpubl. data.

biological coefficients within the model are then adjusted (within the range of realistic possibilities) until the simulated landings match the historical average in terms of depth zone, size class, seasonal distribution, and total landings.

The first step in model validation is to test the tuned model against a time period not used in the tuning process. Average effort patterns and levels for the 1981–85 period are inserted into the tuned model and the average landings generated are compared to reported average landings for the closure period.

The second step in validation indicates how well the model depicts landings over the range of effort levels actually exerted between 1963 and 1985. The model is run through a 21-year simulation with the actual effort for each year (1963–85) imposed. All biological coefficients remain constant. This procedure generates a yield plot of landings (with environmental conditions held constant) for the 21-year period which is compared to actual data points to determine how well simulated landings fit within the range of actual data points. The tuning and validation process was carried out individually for brown and white shrimp[5].

Policy Analysis

The analysis presented herein is a short-run analysis that estimates the effects the closure had on landings, revenue, costs, and rent to the shrimp fishery. To measure the effects of the closure and avoid capturing the effects of different effort levels, effort must be held constant throughout the analysis. Figure 1 helps illustrate this point. The 200-mile closure forced a change in the offshore shrimp fleet's fishing patterns. Yield curve Y1 is assumed to be the yield curve before the closure, and Y2 is the yield curve after the closure. The question is, what effect did the closure have on landings, revenue, costs, and rent to the fishery, omitting the effects of different effort levels. Movement from A to B in Figure 1 represents a change in landings due to an increase in effort from E1 to E2 under the pre-closure scenario, whereas movement from B to C represents a change in landings due to a policy change at a given level of effort. The change in landings induced by a change in policy, and the consequent effects on revenue, cost, and rent, while holding effort constant, is the subject of this paper.

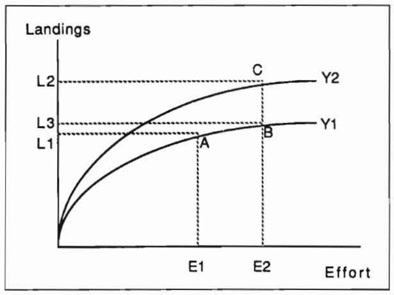

Figure 1.—Comparison of different fishing patterns at equal total effort levels.

To compare economic rent between the pre-closure and closure offshore fishing patterns, the pre-closure simulation is set to economic equilibrium, i.e., rent is zero. This is accomplished by establishing the appropriate variable costs by vessel class[6], then adjusting fixed costs (including opportunity costs) until rent to vessel owners is equal to zero. Figure 2 represents the theoretical framework upon which this process is based. The R1 curve represents the revenue curve associated with the pre-closure offshore fishing patterns. Because this analysis assumes an equilibrium position for the pre-closure offshore fishing patterns, total costs represented by C1 must equal R1 at effort level E2. This implies rent is zero. The closure affects revenue and cost as shown by curves R2 and C2, respectively. Cost is affected by the closure because crew shares and packing charges are calculated as a percentage of landings; if landings increase, so do crew shares and packing charges. The closure causes revenue to increase from B to C, costs to increase from B to D, and rent is measured from D to C.

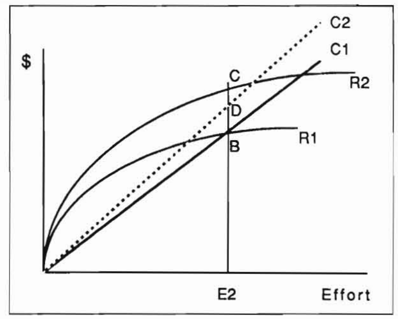

Figure 2.—Setting of zero rents to each vessel class (economic equilibrium) for base simulation.

Because effort levels in the pre-closure and closure periods were not the same (Table 2), the effort level in the pre-closure period was set to the effort level of the closure period by the following procedure. Days fished for brown shrimp in the inshore area increased substantially over the entire period considered (1963–85). This increase in days fished is assumed to be unrelated to the closure because it began before the closure was implemented and would have continued with or without the closure. Therefore, inshore effort was held constant at the 1981–85 level for both the pre-closure and closure periods[7]. Environmental conditions, unit price received, and unit costs of fishing also were held constant.

The average offshore effort level was greater in the closure period (1981–85) than in the pre-closure period (1963–80). In the offshore area, average days

Table 2.—Average days fished for brown and white shrimp.

	Brown shrimp		White shrimp	
Years	Days fished inshore	Days fished offshore	Days fished inshore	Days fished offshore
1963–80	2,458	44,679	7,698	12,567
1976–80	4,008	49,510	8,158	13,551
1981–85	9,935	46,150	9,623	16,296

[5]The results of tuning and validating the model are too lengthy to present here. They are reported in Griffin et al. (1990) and will be provided by the author upon request.

[6]Because out-of-state vessels spend a limited amount of time in Texas, all costs for vessel class 3 were categorized as variable.

[7]The closure may have had a dampening effect on inshore effort expansion because some effort may have been redirected inshore by smaller boats (Nance et al., 1991). Because large vessels could fish in the 1–4 fathom area offshore during the closure, increased crowding in the 1–4 fathom area forced smaller boats into the inshore area. However, for this analysis, fishing patterns and effort levels were held constant for the inshore area in both the pre-closure and closure periods.

fished for brown shrimp in 1981–85 increased by 1,471 over the 1963–80 average. Average days fished for white shrimp in the offshore area increased also, particularly in June and July (Griffin et al., 1990) because the 1–4 fathom area offshore was left open to white shrimp harvesting during the closure. Offshore fishing patterns for the 1963–80 period were held constant but the level of effort was inflated to the average 1981–85 offshore effort level.

Results

200-mile, 45-day Closure, 4-fathom Zone Open

Fishing Patterns

Total fishing effort for both brown and white shrimp increased from the pre-closure to closure periods (Table 3). Brown shrimp effort in the inshore area (depth zone 2) increased by a factor of 4, and brown shrimp effort in the offshore depths shifted from depth 6 (16–20 fathoms) to depth 8 (>25 fathoms). When effort in the pre-closure period was inflated to closure levels and compared to the closure period (Table 3), total effort was the same but the distribution of effort between brown and white shrimp changed. The average number of days fished for brown shrimp declined by 2,000 days, and the average number of days fished for white shrimp increased by 2,000 days. Vessels that had been fishing in the EEZ from mid-May through mid-July in the pre-closure period now must either fish in the EEZ illegally, fish off other Gulf states, fish in Mexican waters illegally, not fish at all, or redirect effort to inshore areas to fish for brown shrimp, or to the 4-fathom zone offshore to fish for white shrimp. Effort on brown shrimp was reduced overall, though some of that effort was redirected to white shrimp, particularly in June when there was a shift from depth 4 (6–10 fathoms) to depth 3 (1–5 fathoms). Fishermen apparently spent more time fishing for white shrimp when the EEZ was closed than when it was open.

Brown Shrimp Landings

Annual brown shrimp landings increased from 33.8 million pounds in the pre-closure simulation to 35.4 million pounds in the closure simulation (Table 4). Landings of medium sized shrimp (sizes 3 and 4) decreased in the closure simulation, whereas landings of large sized shrimp (sizes 1 and 2) increased. Landings of the smallest shrimp (sizes 5 and 6) also increased in the closure simulation, probably due to rescission of the count laws. The increase in landings of small shrimp accounted for most of the increase in total landings. The closure simulation also revealed a reduction in discards. Brown shrimp discards generated by the pre-closure simulation were 2.4 million pounds, compared to 0.76 million pounds under the closure simulation.

To distinguish between changes in landings and discards attributable to the closure and changes attributable to elimination of the count laws, two additional simulations were performed: A simulation with closure effort patterns and the old count laws in effect (65 whole shrimp per pound) and a simulation with pre-closure effort patterns and no count laws. Compared to the pre-closure simulation with the count laws, the closure simulation with count laws produced virtually no change in total landings, but landings were distributed toward the larger, more valuable size classes. A small reduction in discards resulted from reduced effort during the 45-day closure. The pre-closure simulation with no count laws produced a 2-million-pound increase in total landings (compared to the pre-closure simulation with count laws), but this increase occurred in the smallest size classes; there was no redistribution of the harvest toward larger size shrimp. Discards were virtually eliminated, which translated to increased landings of smaller shrimp. These simulations indicate that the closure resulted in redistribution of the brown shrimp harvest from mid-sized shrimp to large shrimp, and elimination of the count laws resulted in a substantial reduction of discards.

White Shrimp Landings

Simulations for white shrimp produced an increase in total landings in the closure period. Pre-closure effort patterns landed 11.49 million pounds of white shrimp compared to the closure effort patterns which landed 12.97 million pounds (Table 5). White shrimp landings were slightly higher for all size

Table 3.—Average days fished for all vessels.

	Brown shrimp			White shrimp		
Depth zone	Pre-closure days fished	Closure days fished	Pre-closure inflated	Pre-closure days fished	Closure days fished	Pre-closure inflated
1	0	0	0	0	0	0
2	2,305	9,629	9,629	7,143	9,321	9,321
3	281	697	281	3,462	4,003	3,579
4	2,137	3,345	2,325	7,400	9,707	8,052
5	11,372	11,077	12,374	996	999	1,084
6	12,807	10,708	13,935	182	248	198
7	7,881	7,363	8,575	32	50	34
8	8,593	11,558	9,350	26	59	28
Total	45,376	54,377	56,469	19,241	24,387	22,296

Table 4.—Distribution of brown shrimp landings (in thousands of pounds).

Depth	Discards	Size 1	Size 2	Size 3	Size 4	Size 5	Size 6	Total
Pre-closure simulation								
1	0	0	0	0	0	0	0	0
2	216	0	4	217	466	1,946	1,995	4,627
3	413	0	2	31	44	70	22	170
4	783	20	311	992	290	241	6	1,860
5	678	357	2,045	4,797	967	219	0	8,386
6	285	665	3,002	4,298	1,129	90	0	9,184
7	32	862	2,197	1,521	183	10	0	4,773
8	1	1,998	2,168	641	19	0	0	4,826
Total	2,408	3,902	9,729	12,497	3,098	2,576	2,023	33,826
Closure simulation								
1	0	0	0	0	0	0	0	0
2	42	0	4	217	466	1,946	2,169	4,801
3	281	0	3	58	62	217	151	490
4	213	24	421	1,173	249	761	48	2,676
5	173	333	1,989	4,447	693	574	0	8,036
6	41	749	2,854	2,956	552	158	0	7,269
7	9	907	2,457	1,489	112	20	0	4,985
8	1	2,389	3,598	1,176	17	1	0	7,180
Total	760	4,402	11,326	11,516	2,151	3,677	2,368	35,437

Table 5.—Distribution of white shrimp landings (in thousands of pounds).

Depth	Discards	Size 1	Size 2	Size 3	Size 4	Size 5	Size 6	Total
Pre-closure simulation								
1	0	0	0	0	0	0	0	0
2	300	84	880	1,817	980	1,323	504	5,588
3	399	325	498	440	252	154	18	1,686
4	182	819	1,365	966	300	101	2	3,554
5	5	160	184	137	68	2	0	552
6	0	43	29	17	9	0	0	98
7	0	9	2	1	0	0	0	12
8	0	0	0	0	0	0	0	0
Total	886	1,440	2,958	3,378	1,609	1,580	524	11,490
Closure simulation								
1	0	0	0	0	0	0	0	0
2	219	84	880	1,817	980	1,323	585	5,669
3	0	410	509	454	285	424	190	2,271
4	0	904	1,471	1,224	440	384	38	4,462
5	0	111	196	120	65	5	0	497
6	0	19	19	11	10	0	0	58
7	0	9	1	0	0	0	0	10
8	0	0	0	0	0	0	0	0
Total	219	1,537	3,076	3,626	1,780	2,136	813	12,967

classes, though most of the increase in total landings came from the two smallest size classes (sizes 5 and 6). White shrimp discards were 0.885 million pounds under the pre-closure simulation and 0.219 million pounds under the closure simulation. When the simulation was performed under closure effort patterns but with the old count laws, total landings fell by 0.8 million pounds and discards increased by the same amount. Under the pre-closure simulation with no count laws (other than the fall inshore count law), landings increased 0.5 million pounds and discards decreased by 0.5 million pounds. These results indicate that discards were traded for landings when the count laws were repealed.

Economics

Cost and returns information for the pre-closure and closure simulations, categorized by vessel class and shrimp species, is outlined in Tables 6 and 7. For vessel class 1, the $0.159 million increase in rent under the closure simulation was primarily due to a slight increase in landings and revenue, as fixed and variable costs remained relatively constant. For vessel class 2, fishing patterns under the closure simulation led to a minor increase in costs and a substantial increase in landings and revenue, which translated into a $4.855 million increase in rent. Even though out-of-state vessels (vessel class 3) incurred a substantial increase in variable costs under the closure simulation, these costs were more than offset by increases in landings and revenue, such that vessel class 3 realized a $2.042 million increase in rent.

In the base simulation, with rent to the fishery equal to zero, rent for brown shrimp was –$0.557 million and rent for white shrimp was $0.557. Under the closure simulation, rent for brown shrimp increased to $7.438 million (a $7.995 million increase) and rent for white shrimp fell to –$0.382 million (a $0.939 million decrease). Total rent to vessel owners under the closure simulation was $7.056 million, with about 71% of the rent going to Texas vessels and 29% to out-of-state vessels. When the $1.851 million increase in crew rent[8] was added to owners' rent, the total increase in economic rent attributable to the closure was $8.907 million.

[8]The model takes into account the number of crew members for each vessel and the percentage of revenues attributable to the crew. Because the model assumes all vessels are owner-operated, vessel class 1 (unregistered inshore boats) has 0 crew members and 0% crew share. Vessel classes 2 and 3 both have 2 crew members who receive a 20% share of revenues.

Table 6.—Pre-closure simulation (all values in thousands except days fished and price/pound).

Item	Vessel owners' costs and returns					
	Vessel class			Shrimp species		Total
	1	2	3	Brown	White	owners
Days fished	16,286	54,859	7,619	56,468	22,296	78,764
Price/pound	1.84	3.29	3.31	3.05	3.04	3.04
Landings	7,829	32,581	4,907	33,827	11,490	45,317
Revenue	14,414	107,294	16,257	103,057	34,908	137,965
Variable cost	3,241	64,990	16,257	65,038	19,450	84,488
Fixed cost	11,173	42,304	0	38,576	14,901	53,477
Total cost	14,414	107,294	16,257	103,614	34,351	137,965
Rent	0	0	0	–557	557	0

Item	Crews' costs and returns		
	Vessel class		
	2	3	Crews + owners
Revenue	21,459	3,251	
Variable cost	652	98	
Fixed cost	20,807	3,153	
Total cost	21,459	3,251	
Rent	0	0	0

Table 7.—200-mile, 45-day closure simulation, 4-fathom zone open (all values in thousands except days fished and price/pound).

Item	Vessel owners' costs and returns					
	Vessel class			Shrimp species		Total
	1	2	3	Brown	White	owners
Days fished	16,203	54,456	8,106	54,378	24,387	78,765
Price/pound	1.81	3.32	3.18	3.09	2.93	3.05
Landings	8,039	34,096	6,270	35,437	12,968	48,405
Revenue	14,557	113,138	19,948	109,646	37,997	147,643
Variable cost	3,225	65,979	17,906	65,259	21,851	87,110
Fixed cost	11,173	42,304	0	36,949	16,528	53,477
Total cost	14,398	108,283	17,906	102,208	38,379	140,587
Rent	159	4,855	2,042	7,438	–382	7,056

Item	Crews' costs and returns		
	Vessel class		
	2	3	Crews + owners
Revenue	22,628	3,990	
Variable cost	682	125	
Fixed cost	20,807	3,153	
Total cost	21,489	3,278	
Rent	1,139	712	8,907

200-mile, 45-day Closure, 4-fathom Zone Closed

The Texas Parks and Wildlife Department recently modified the Texas closure to include closure of the 4-fathom zone offshore. This narrow, near-shore depth zone remained open to daytime white shrimp fishing during the Texas closure until 1990. Effort data in the previous simulation included illegal effort exerted in offshore waters during the closure. This analysis closed all offshore waters to shrimping from 1 June through 15 July and assumed 100% compliance by fishermen.

Closing the 4-fathom zone in conjunction with the EEZ closure caused a $0.103 million drop in rent for vessel class 1 (compared to the EEZ closure with the 4-fathom zone open) due to a greater decline in revenue than total cost (Table 8). Vessel class 2, on the other hand, benefited from a decline in total costs which more than offset the drop in revenue, and rent increased by $1.182 million. Out-of-state vessels also experienced a cost savings greater than the loss in revenue, and rent to vessel class 3 increased by $0.679 million.

Landings of brown shrimp fell by 610,000 pounds and revenue remained almost unchanged (due to a higher price per pound), but a decline in total costs resulted in a $2.102 million increase in rent for this species. Though the white shrimp fishery also experienced a drop in total costs, it was not enough to offset the decline in landings and revenue, and rent to the white shrimp fishery fell by $0.344 million. Total rent to vessel owners increased $1.758 million to $8.814 million under this scenario. Rent to crew members decreased $0.219 million because of the decline in landings. Total rent to the fishery was $10.446 million, a $1.63 million increase over the EEZ closure with the 4-fathom area open.

200-mile, 45-day Closure, 4-fathom Zone Closed, Effort Redirected Inshore

When the closure regulation first went into effect in 1981, effort in the 4-fathom zone expanded. It was assumed closing the 4-fathom zone would lead to a redirection of effort into the inshore waters. For this simulation, only vessels that were fishing in both the 4-fathom zone and inshore waters were allowed to redirect effort (from the 4-fathom zone to inshore waters).

Compared to the prior simulation (without redirected effort), landings and revenue for vessel class 1 declined slightly, total costs rose, and rent to vessel class 1 fell $0.189 million to –$0.133 million (Table 9). Even though landings increased, vessel class 2 incurred a decline in revenue because the increase in landings was made up of smaller shrimp from inshore waters. Coupled with an increase in total cost, due to more days fished, vessel class 2 lost $1.08 million in rent. Landings and revenue for vessel class 3 declined, costs remained stable, and rent fell by $0.181 million.

Though landings of brown shrimp increased slightly, the drop in revenue and increase in total cost led to a $1.503 million loss in rent to the brown shrimp fishery. Only the white shrimp fishery benefited under this simulation. Landings were virtually unchanged, but the decline in total cost was greater than the fall in revenue, which resulted in a $0.053 million boost in rent. Vessel owners' rents under this scenario shrank to $7.364 million, compared to $8.814 million under the previous simulation, for a $1.45 million loss due to redirection of effort to inshore waters. As with vessel owners, crews' revenues dropped due to landings of smaller, less valuable shrimp. When the crews' economic losses were added to the vessel owners' losses, rent fell from $10.446 million (under the previous simulation) to $8.847 million, for a $1.599 million loss in economic rents to the fishery. Compared to the first closure simulation, closing the 4-fathom zone and redirecting effort

Table 8.—200-mile, 45-day closure simulation, 4-fathom zone closed (all values in thousands except days fished and price/pound).

Item	Vessel owners' costs and returns: Vessel class 1	2	3	Shrimp species: Brown	White	Total owners
Days fished	16,049	51,970	7,574	52,079	23,514	75,593
Price/pound	1.80	3.36	3.22	3.15	2.89	3.08
Landings	8,000	33,396	6,119	34,827	12,688	47,515
Revenue	14,423	112,228	19,681	109,652	36,680	146,332
Variable cost	3,194	63,887	16,960	63,128	20,913	84,401
Fixed cost	11,173	42,304	0	36,984	16,493	53,477
Total cost	14,367	106,191	16,960	100,112	37,406	137,518
Rent	56	6,037	2,721	9,541	–726	8,814

Item	Crews' costs and returns: Vessel class 2	3	Crews + owners
Revenue	22,446	3,936	
Variable cost	668	122	
Fixed cost	20,807	3,153	
Total cost	21,475	3,275	
Rent	971	661	10,446

Table 9.—200-mile, 45-day closure simulation, 4-fathom zone closed, effort redirected inshore (all values in thousands except days fished and price/pound).

Item	Vessel owners' costs and returns: Vessel class 1	2	3	Shrimp species: Brown	White	Total owners
Days fished	16,204	52,827	7,590	53,054	23,567	76,621
Price/pound	1.80	3.33	3.22	3.12	2.88	3.06
Landings	7,944	33,567	6,054	34,879	12,686	47,565
Revenue	14,265	111,694	19,481	108,855	36,585	145,440
Variable cost	3,225	64,433	16,941	63,638	20,961	84,599
Fixed cost	11,173	42,304	0	37,180	16,297	53,477
Total cost	14,398	106,737	16,941	100,818	37,258	138,076
Rent	–133	4,957	2,540	8,037	–673	7,364

Item	Crews' costs and returns: Vessel class 2	3	Crews + owners
Revenue	22,339	3,896	
Variable cost	671	121	
Fixed cost	20,807	3,153	
Total cost	21,478	3,274	
Rent	861	622	8,847

yielded a $0.308 million increase in rent to vessel owners and a $0.368 million decrease in rent to crews. The net effect was a $0.060 million loss in rent to the fishery.

200-mile, 60-day Closure, 4-fathom Zone Closed

This simulation extended the closure period to 60 days, from 15 May to 15 July, closed all offshore waters including the 4-fathom zone, and allowed no illegal effort. It is the same scenario as the second simulation (to which it will be compared), except the closure lasted 60 days instead of 45.

Vessel class 1 was virtually unaffected by the 15-day extension (Table 10). Landings for vessel class 2 declined, and even though they received a higher price per pound for their shrimp, revenue also fell. The decline in days fished however, translated into a considerable reduction in total operating costs which more than made up for the drop in revenue, and this vessel class realized an increase in rent of about $1.09 million. Landings and revenue for vessel class 3 increased, costs remained stable, and rent increased by $0.484 million.

Landings decreased for both brown and white shrimp. Revenue from white shrimp declined, but revenue from brown shrimp increased because of the higher price per pound received for larger shrimp. Rent to the brown shrimp fishery increased by $1.953 million and rent to the white shrimp fishery decreased by $0.374. The increase in rent to vessel owners was $1.579 million, for a total of $10.393 million. When crews' rents were added to owners' rents, total rent to the fishery climbed to $11.984 million, which was $1.538 million more than the same scenario under a 45-day closure. Compared to the first closure simulation, rent to vessel owners was $3.337 million higher, rent to crews was $0.260 lower, and the net increase in rent from closing the 4-fathom zone for 60 days was $3.077 million.

200-mile, 60-day Closure, 4-fathom Zone Closed, Effort Redirected Inshore

This simulation was the same as the previous analysis but allowed some effort to be redirected to inshore waters. Compared to the prior simulation, redirection of effort caused a reduction in net economic benefits. Days fished for vessel class 1 increased, total costs rose, landings and revenue fell, and rent dropped to –$0.176 million, a $0.237 million loss (Table 11). Vessel class 2 was hurt the most by redirected effort. Days fished and total costs increased, revenue declined due to a lower average price per pound for shrimp, and rent fell by $1.49 million to $5.637 million. For vessel class 3, costs remained stable, revenue declined, and rent fell by $0.254 million.

The results by species revealed almost no change for white shrimp but a considerable change for the brown shrimp fishery. A lower price per pound, reduced revenue, and increased costs due to more days fished resulted in a $2.0 million loss in rent to the brown shrimp fishery. Rent to vessel owners was $8.413 million, a $1.981 million decline. Crews' economic rent also shrunk under this simulation such that the total loss in rent from redirected effort was $2.202 million. Although total rent to the fishery fell from $11.983 million to $9.782 million because of redirected effort, it remained $0.875 million higher than under the first closure simulation.

Conclusions

The 1-year impact analysis of the Texas closure (45 days, 4-fathom zone open) revealed a positive effect on all vessel classes (some more than others) and on all crews; the total gain in rent from the closure was $8.907 million. Closing the 4-fathom zone and extending the closure to 60 days increased rent to the fishery by more than $3 million (compared to the 45-day closure

Table 10.—200-mile, 60-day closure simulation, 4-fathom zone closed (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,037	49,784	7,512	50,613	22,720	73,333
Price/pound	1.80	3.41	3.23	3.20	2.86	3.11
Landings	8,000	32,739	6,240	34,677	12,302	46,979
Revenue	14,425	111,486	20,172	110,880	35,203	146,083
Variable cost	3,191	62,055	16,967	62,249	19,964	82,213
Fixed cost	11,173	42,304	0	37,138	16,339	53,477
Total cost	14,364	104,359	16,967	99,387	36,303	135,690
Rent	61	7,127	3,205	11,493	–1,100	10,393

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	22,297	4,034	
Variable cost	655	125	
Fixed cost	20,807	3,153	
Total cost	21,462	3,278	
Rent	835	756	11,984

Table 11.—200-mile, 60-day closure simulation, 4-fathom zone closed, effort redirected inshore (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,204	50,890	7,529	51,790	22,833	74,623
Price/pound	1.80	3.36	3.23	3.16	2.85	3.08
Landings	7,919	32,974	6,146	34,738	12,301	47,039
Revenue	14,222	110,678	19,879	109,671	35,108	144,779
Variable cost	3,225	62,737	16,928	62,833	20,057	82,890
Fixed cost	11,173	42,304	0	37,345	16,132	53,477
Total cost	14,398	105,041	16,928	100,178	36,189	136,367
Rent	–176	5,637	2,951	9,493	–1,081	8,412

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	22,136	3,976	
Variable cost	659	123	
Fixed cost	20,807	3,153	
Total cost	21,466	3,276	
Rent	670	700	9,782

with the 4-fathom area open) and reduced discards to 42,000 pounds. This closure scenario seems to represent the best alternative for achieving the objectives of the closure management policy: Elimination of discards and increasing the value of the brown shrimp harvest. When effort was redirected to inshore waters, benefits of the 60-day closure declined, but were still greater than the benefits from the original closure. The only segment of the fishery which did not benefit from the 60-day closure was the crew. All four scenarios that closed the 4-fathom zone left the crews worse off than the original Texas closure.

Relevant to any discussion of policy analysis must be consideration of what happens in the industry when you make vessel owners better off. In the Gulf of Mexico shrimp fishery, the objectives are to implement management policies which increase economic benefits to the participants and to society as a whole. In an open-access fishery such as the Gulf shrimp fishery, it is useful to consider the implications of increasing economic rents to the participants. As rents rise, due to a price increase or a new policy, it is likely that effort will expand and absorb the excess profit until the fishery reaches a new equilibrium and rent is again driven to zero. Without some form of effort limitation or limited entry program, any policy that generates an increase in rent for the fishery will be short-lived in its effectiveness.

The above discussion assumes that inshore effort, environmental conditions, prices, and unit costs are all held constant. In the real world, however, these elements are not held constant and an expansion of effort may not be the result. For example, Griffin and Beattie (1978) examined the impact of closing Mexico's 200-mile offshore fishing zone on the U.S. Gulf of Mexico shrimp fishery. Their results indicated a negative impact on the shrimp fleet, which implied vessels would leave the industry in the long run. However, because of the price structure at that time (high price for shrimp, low cost for fuel) and the backlog of orders for new vessels, they concluded that shrimp fishermen were making large enough profits to withstand being shut out of Mexican waters and still remain profitable. Thus, even though the closure of Mexico's waters had a negative impact on the U.S. Gulf shrimp fleet, market conditions at that time were so favorable that the industry expanded anyway, though it expanded less than it would have if Mexican waters had remained open.

The Texas closure had the same type of effect, but in the opposite direction. Inshore effort increased dramatically during 1979–85, which implies that fewer brown shrimp reached offshore waters. Second, double-digit inflation in the late 1970's and early 1980's caused unit costs of shrimping to increase. Third, shrimp culture was rapidly expanding around the world, and the increase in U.S. shrimp imports caused the price of shrimp to remain relatively constant while unit costs increased. Thus, unfavorable conditions put pressure on vessels to exit the industry, whereas the effects of the Texas closure would induce vessels to enter the industry.

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