Estimation of Standardized Effort in the Heterogeneous Gulf of Mexico Shrimp Fleet

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Introduction

The Gulf of Mexico penaeid shrimp fishery is one of the most valuable single U.S. fisheries and represents one of the greatest sources of fishing pressure within the Gulf. Because the otter trawl used in this fishery is nonselective, it has a direct impact on important finfish utilized in other directed commercial and recreational fisheries. There is an increasing emphasis on reducing the extent of this bycatch in order to rebuild certain fish stocks (particularly the red snapper, *Lutjanus campechanus*). Although Nichols et al.[1] attempted to estimate the impact, accurate measurement of bycatch has not been possible because only estimates of nominal fishing effort (actual hours of fishing per trip; not standardized effort[2]) have been available from the National Marine Fisheries Service (NMFS).

The effort data set[3] available from NMFS is based both upon landings as reported to NMFS port agents by dockside dealers and agent interviews with shrimpers who are in port. Several concerns have arisen about this effort data set. First is the possibility that the number of interviews may not represent the true proportion of landings and effort by craft type. Secondly, NMFS has had to estimate CPUE (catch per unit of effort) for certain areas and times due to lack of interviews with shrimpers in those areas and times (Nance, 1992). Finally, several characteristics of fishing power (vessel size, number of nets per craft, number of vessels operating) have varied during the period represented by the historical data set.

Recently, interest in accurate estimates of current bycatch and its mandated reduction, was coupled with concern (expressed both by shrimp fishermen and the Gulf of Mexico Fisheries Management Council (GMFMC)) about potential bias inherent in the effort data set as produced by NMFS. Therefore, a "Shrimp Fishing Effort Estimation Workshop" was held June 1992 at the Galveston Laboratory of the NMFS Southeast Fisheries Science Center. The goals of the workshop were to: "1) use the shrimp total landing data (pounds by area and month) and trip interview data (pounds per fishing hour by area and trip) to develop methods to estimate nominal effort (actual days fished) in the shrimp fishery of the U.S. Gulf of Mexico and 2) recommend which method should be used by the NMFS to estimate nominal effort each year. Since the effort values are used to estimate finfish bycatch in the shrimp fishery, there is a critical need to develop a statistically valid effort estimation method" (Nance, personal commun., 1 June 1992).

The NMFS expands interviewed effort data into nominal days fished using a simple average CPUE for boats and vessels in each cell, where a cell is defined by a combination of month, area, and depth (Nance, 1992). Since the simple average CPUE of all boats and vessels does not take into account any nonproportionality in sampling of boats and vessels, the resulting estimates could be biased. This bias may be in any direction depending on the nonproportionality in sampling of boats and vessels in each of the cells (see box on next page). To realize the extent of nonproportional sampling over the years, Figure 1a shows the percent of

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ABSTRACT—In this paper we estimate nominal and standardized shrimping effort in the Gulf of Mexico for the years 1965 through 1993. We accomplish this by first developing a standardization method (model) and then an expansion method (model). The expansion model estimates nominal days fished for noninterview landings data. The standardization model converts nominal days fished to standard days fished. We then characterize the historical trends of the penaeid shrimp fishery by vessel configuration, relative fishing power, and nominal and standardized effort. Wherever possible, we provide comparison with previous estimates by the National Marine Fisheries Service, NOAA.

[1] Nichols, S., A. Shah, G. J. Pellegrin, Jr., and K. Mullin. 1990. Update estimates of shrimp fleet bycatch in the offshore shrimp fishery of the U.S. Gulf of Mexico 1972–1989. Rep. to Gulf Mex. Fish. Manage. Counc., by NMFS Mississippi Laboratories, Pascagoula MS 39568-1207.

[2] A unit of nominal effort is defined as net(s) being pulled in the water for a period of 24 h (known in the industry as a day fished). Standardized effort is defined as adjusted nominal effort based on the relative fishing power (RFP) of each vessel in the Gulf of Mexico shrimp fleet relative to a standard vessel.

[3] The NMFS uses catch per unit of effort (CPUE) generated from landings data with associated days fished obtained from interviewing fishermen to calculate effort for noninterviewed landings data (Nance, 1992).

Example of Simple Average Resulting in Biased Total Days Fished

Example 1 represents a hypothetical case where proportional sampling was accomplished. In this example total landings is 100,000 pounds each by vessels and boats, giving total landings of 200,000 pounds. The total amount of interviewed pounds for vessel and boats is 10,000 each, giving total interviewed landings of 20,000 pounds. This means that 10% of total pounds were interviewed for both vessels and boats, i.e. proportional sampling. Interviewed days fished is 40 for vessels and 20 for boats. The CPUE for vessels is 250 and the CPUE for boats is 500. The simple average CPUE for both vessels and boats is 333 (20,000/60 = 333). Estimated days fished for vessels would be 400 (100,000/250 = 400) and the estimated days fished for boats would be 200 (100,000/500 = 200). Adding expanded days fished for vessels and boats gives 600 estimated days fished (400 + 200 = 600). Using the CPUE for vessels and boats we get the same results (200,000/333 = 600). Thus, when interviews pounds are proportional to total pounds for vessels and boats, then using the simple average leads to a correct estimate of total days fished.

It is interesting to note that if only vessels had been sampled, the estimated days fished would have been 800 (200,000/250 = 800) and if only boats had been sampled the estimated days fished would have been 400 (200,000/500 = 400). The reason this calculation is added is that there are many month, statistical zone, and depth combinations in the Gulf of Mexico where both vessels and boats fish but only vessels or boats are interviewed, but not both. A prime example would be Texas where only large vessels are targeted for interview.

Example 2 is almost the same as example 1 except boats now have 20,000 interviewed pounds and 40 interviewed days fished. Notice that the CPUE for vessels and boats is the same as in example 1 and the weighted average estimated total days fished is unchanged at 600. However, the simple average CPUE has changed from 333 in example 1 to 375 (30,000/80 = 375) in example 2. Boats now are weighted heavier than vessels in example 2. As a result of this nonproportional sampling the estimated days fished is 533 (200,000/375 = 533) using the simple average CPUE of 375. Estimated days fished are underestimated by 67 days fished (600–533 = 67).

Examples 3 and 4 are actual data from the Gulf of Mexico at a given month, statistical zone, and depth. In example 3 estimated days fished are under estimated by 51% using the simple average. In example 4 estimated days fished are over estimated by 20%.

Example 1.—Hypothetical data showing proportional sampling results in unbiased estimate of days fished.

Item	Total pounds	Pounds (interviewed)	Days fished (interviewed)	CPUE	Days fished (estimated)
Vessels	100,000	10,000	40.0	250	400
Boats	100,000	10,000	20.0	500	200
Total vessels & boats	200,000	20,000	60.0	333	600
Simple average					600
Weighted average					600
Only vessels					800
Only boats					400

Example 2.—Hypothetical data showing nonproportional sampling results in biased estimate of days fished.

Item	Pounds	Pounds (interviewed)	Days fished (inteviewed)	CPUE	Days fished (estimated)
Vessels	100,000	10,000	40.0	250	400
Boats	100,000	20,000	40.0	500	200
Total vessels & boats	200,000	30,000	80.0	375	533
Simple average					533
Weighted average					600
Only vessels					800
Only boats					400

Example 3.—Nonproportional sampling results in biased estimate of days fished in the Gulf of Mexico for the month of August, statistical zone 12 and inshore.

Item	Pounds	Pounds (interviewed)	Days fished (interviewed)	CPUE	Days fished (estimated)
Vessels	241,812	26,997	37.9	712	339
Boats	225,288	221,768	68.0	3,261	69
Total vessels & boats	467,100	248,765	105.9	2,349	199
Simple average					199
Weighted average					409
Only vessels					656
Only boats					143

Example 4.—Nonproportional sampling results in biased estimate of days fished in the Gulf of Mexico for the month of December, statistical zone 17 and 0–5 fathoms.

Item	Pounds	Pounds (interviewed)	Days fished (inteviewed)	CPUE	Days fished (estimated)
Vessels	119,289	45,644	66.5	686	174
Boats	22,799	22,799	79.7	286	80
Total vessels & boats	142,088	68,443	146.2	468	304
Simple average					304
Weighted average					253
Only vessels					207
Only boats					497

Figure 1a.—Percent of inshore landings by vessels and boats compared to percent of inshore interviewed landings by vessels and boats (data for 1976–80 is unavailable).

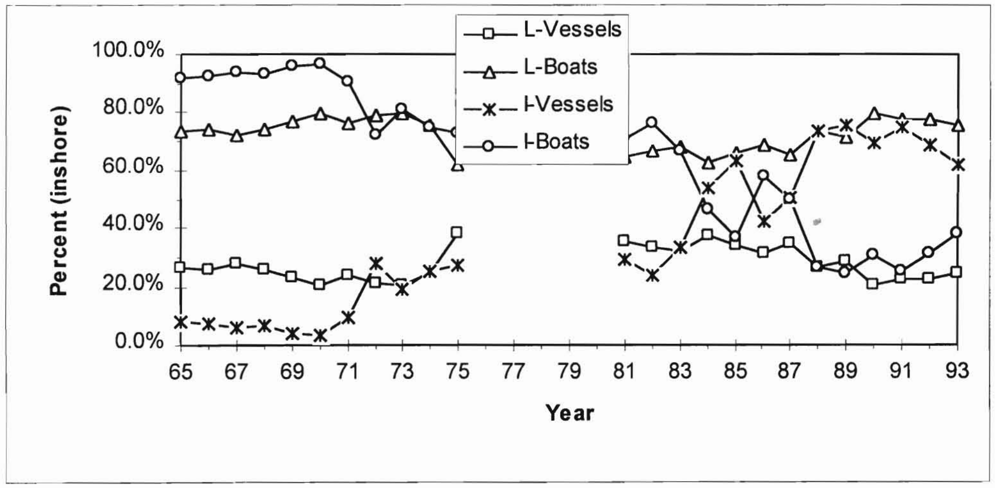
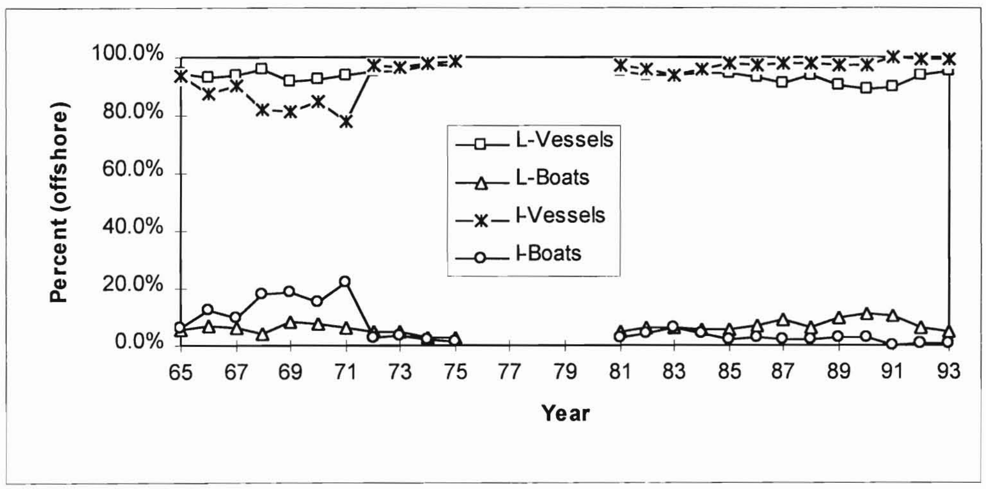


Figure 1b.—Percent of offshore landings by vessels and boats compared to percent of offshore interviewed landings by vessels and boats (data for 1976–80 is unavailable).



landings by vessels and by boats in the inshore shrimp fishery. The lines labeled L-Vessels and L-Boats show the percent of total landings in the inshore by vessels and boats, respectively. The lines labeled I-Vessels and I-Boats show the percent of interviewed landings in the inshore by vessels and boats, respectively. In 1965, boat total landings were about 72% and vessel landings were about 28%. Boat interviewed landings, however, were about 92% and vessel landings were about 8%. Sampling of vessels and boats was nonproportional (nonrepresentative) since there were too many boats being interviewed in the inshore shrimp fishery relative to vessels in 1965. This pattern continues until 1972. Sampling of vessels and boats was much more representative from 1972 to 1983 (ignoring 1976–80). In 1984, obviously, vessels are more frequently targeted for interview than boats even though this is a predominately a boat-type fishery. The interviewed data have become highly nonrepresentative in these latter years causing higher bias in the estimated total days fished through simple average CPUE in the inshore shrimp fishery. Figure 1b shows the trend on the offshore shrimp fishery. Under proportional sampling, the lines for L-Vessels and I-Vessels should coincide and the lines for L-Boats and I-Boats should coincide. The degree of noncoincidence of these lines reflects the nonproportionality in the Figures 1a and 1b. Figure 2a, which shows the percent of inshore landings by boats and vessels being interviewed, illustrates this problem more clearly. While the 30–60% of boat landings were interviewed in early years, virtually no interviews have occurred since 1989. Interviewed vessels landings have remained around 10% until 1989 when these interviews also began to decline.

In the offshore shrimp fishery, which is predominantly a vessel fishery, the same general pattern occurs for both vessels and boats. Higher proportions of boats were sampled in the earlier years and higher proportions of vessels were sampled in the latter years (Figure 2b). As with the inshore shrimp fishery the percent of boat landings interviewed from the offshore is very small whereas the same for the vessels has varied around 20% for the entire time period. Ideally, under the proportional sampling, the two lines in Figures 2a and 2b should coincide. The degree of noncoincidence reflects the degree of nonproportionality.

Figure 2a.—Percent of inshore landings interviewed by vessels and boats (data for 1976–80 is unavailable).

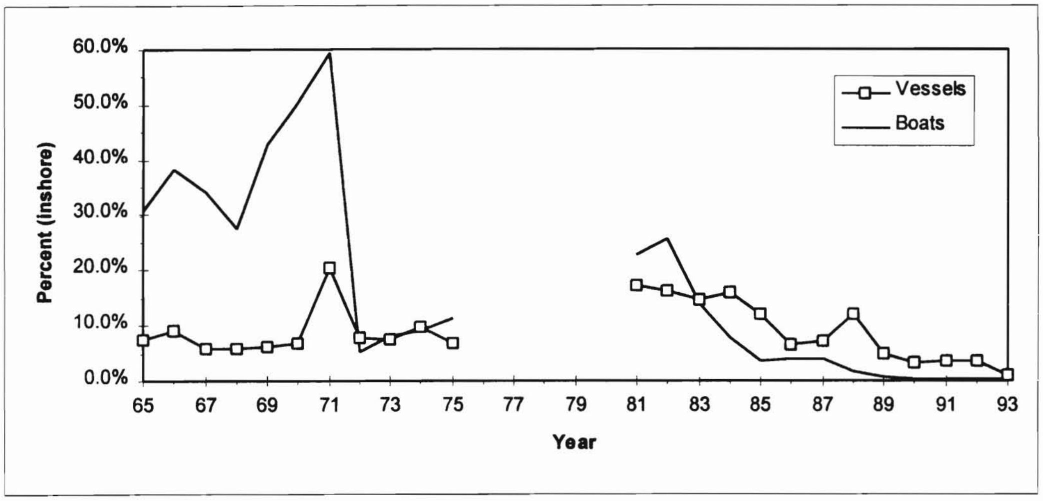
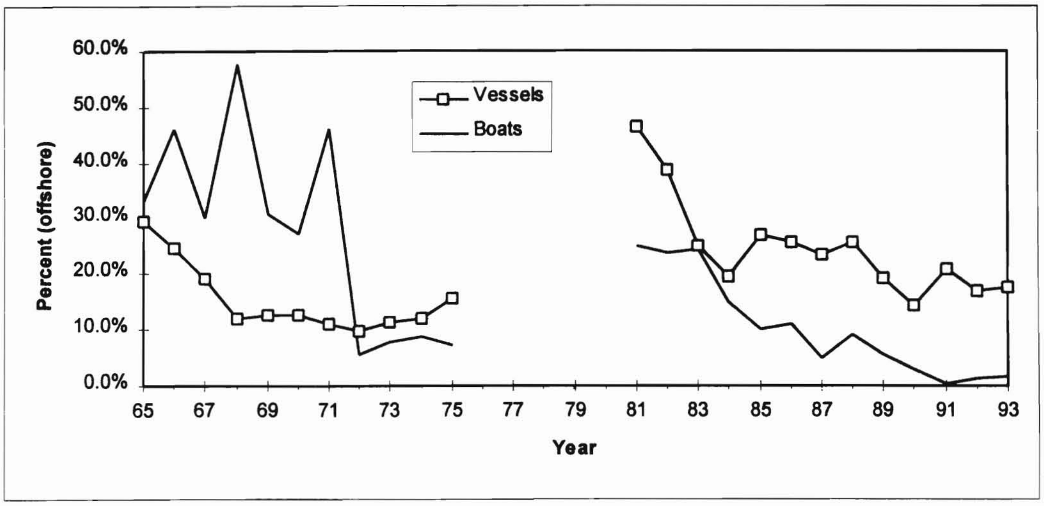


Figure 2b.—Percent of offshore landings interviewed by vessels and boats (data for 1976–80 is unavailable).



This paper presents the development of a method to standardize effort. It also presents an alternative to the NMFS method to estimate nominal effort. These methods are expected to produce better estimates of nominal and standardize effort suitable for use in research both by biologists (Nichols et al.[1]) and economists (Grant and Griffin, 1979; Griffin et al., 1993a, b; Hendrickson and Griffin, 1993) on issues such as bycatch. We also characterize the historical trends of vessel configuration in the shrimp fishery, relative fishing power, and nominal and standardized effort.

Methods

The Modeling Approach

Shrimp catch for a given vessel at a given location × time (cell) is a function of vessel effort and abundance of shrimp, i.e.

$$C_{ijt} = E_i\left(\alpha A_{ji}^{\beta}\varepsilon_{ijt}\right), \qquad (1)$$

where, C_{ijt} is catch by vessel i in location j and time t, E_i is effort level (power or ability) of vessel type i, A_{jt} is abundance level in location j and time t, ε_{ijt} is the random error term, and α and β are the model parameters.

Equation (1) is log-linear which is expected to provide a better fit than a straight linear model (Gulland, 1956; Beverton and Holt, 1957; Robson, 1966). The standard assumptions associated with such models (Draper and Smith, 1981; Kleinbaum et al., 1988; Sen and Srivastava, 1990; Hamilton, 1992), were checked statistically for validity. Only C_{ijt} is directly observable and available, while variables E_i and A_{jt} can be modeled as a function of other variables as discussed below.

Effort (Power or Ability) Model

Vessel effort produced during a unit of fishing time is a function of its physical characteristics. The skills of the captain and the crew, as well as the onboard technology (electronic equipment, etc.), are important variables, but often are difficult to measure and incorporate in the model. The lack of data prevented inclusion of these variables in the model. The log-linear effort model for vessel i can be written as

$$E_i = \alpha_E V_{i1}^{\beta_{E1}} V_{i2}^{\beta_{E2}} \ldots V_{in}^{\beta_{En}} \varepsilon_{Ei} \qquad (2)$$

where, V_{ik} is the kth characteristics ($k = 1, 2, \ldots, n$) of vessel i, (e.g. horsepower, length, gear type, etc.), α_E, β_{E1}, β_{E2}, . . ., β_{En}, are the model parameters, and ε_{Ei}, is the random error term. This type of function allows for diminishing returns. That is, as inputs (vessel length, quantity of fishing gear, etc.) increase for a given level of stock abundance, output (catch of shrimp) will increase but at a decreasing rate.

Abundance Model

Abundance, defined as the amount of shrimp available for harvest, is dependent upon time and location[4]. When necessary, some of these factors were incorporated into the model using dummy variables. The log-linear abundance model can be written as

$$A_{jt} = \alpha_A X_{jt1}^{\beta_{A1}} X_{jt2}^{\beta_{A2}} \ldots X_{jtm}^{\beta_{Am}} \varepsilon_{Ajt} \qquad (3)$$

where, X_{jtl} is the lth abundance factor, $l = 1,2, ..., m$, in time period t in location j, α_A, β_{A1}, β_{A2}, . . ., β_{Am}, are the model parameters, and ε_{Ajt}, is the random error term.

Catch Model

Using equations (2) and (3), the catch model can now be expressed as

$$\begin{aligned} C_{ijt} &= \left(\alpha_E \prod_{k=1}^{n} V_{ik}^{\beta_{Ek}} \varepsilon_{Ei}\right)\alpha \\ &\quad \left(\alpha_A \prod_{l=1}^{m} X_{jtl}^{\beta_{Al}} \varepsilon_{Ajt}\right)^{\beta} \varepsilon_{ijt} \\ &= \left[\begin{aligned} &\alpha_E \alpha \alpha_A^{\beta} \prod_{k=1}^{n} V_{ik}^{\beta_{Ek}} \\ &\prod_{l=1}^{m} \left(X_{jtl}^{\beta_{Al}}\right)^{\beta} \left(\varepsilon_{Ei} \varepsilon_{Ajt}^{\beta} \varepsilon_{ijt}\right) \end{aligned}\right] \\ &= \lambda \prod_{k=1}^{n} V_{ik}^{\lambda_k} \prod_{l=1}^{m} X_{jtl}^{\delta_l} \xi_{ijt} \qquad (4) \end{aligned}$$

[4] Shrimp is an annual crop and very dependent on environmental parameters such as water temperature, salinity, etc., in any given time period and location. However, these environmental parameters were not used in the model since they were not available throughout the Gulf.

where, $\lambda = \alpha_E \alpha \alpha^{\beta}_A$; $\lambda_k = \beta_{Ek}$ (k = 1, 2, ... n); $\delta_l = \beta_{Al}\beta$ (l = 1, 2, ... , m); and $\xi_{ijt} = \varepsilon_{Ei}\varepsilon^{\beta}_{Ajt}\varepsilon_{ijt}$.

Using the Beverton and Holt (1957) definition of relative fishing power (*RFP*), the *RFP* index of vessel *i* can be calculated simply by taking the ratios of the estimated C_{ijt} to C_{sjt}, where the subscript *s* refers to the standard vessel chosen subjectively. For any given time-location stratum and for a constant level of nominal days fished, the estimated *RFP* index of vessel *i* is defined as,

$$RFP_i = \frac{\prod_{k=1}^{n} V_{ik}^{bk}}{\prod_{k=1}^{n} V_{sk}^{bk}} = \prod_{k=1}^{n} \left(\frac{V_{ik}}{V_{sk}}\right)^{bk} \qquad (5)$$

The model in (5) proposed here is a more general model than the ones used by Beverton and Holt (1957) and Robson (1966) by allowing the inclusion of dummy variables.

Now, the estimated standardized total effort (*TE*) of all vessels (*V*) can be computed as

$$TE = \sum_{i=1}^{V} (RFP_i)(DF_i), \qquad (6)$$

where DF_i is the nominal days fished by vessel *i*, and *V* is the total number of vessels. It should be noted that DF_i is both estimated and observed data. Only noninterview landing data has estimated days fished, whereas, interview landings data has observed days fished.

Results

The Standardization Model

The General Linear Model (GLM) procedure, utilizing SAS software, was used to derive the standardization of effort. This is the most common procedure used in the situations where the cells have missing values and are unbalanced. Moreover, it has been shown to be robust to the departures from some of the standard GLM assumptions. The log transformation was used in an attempt to normalize the data, to homogenize the variances, and to achieve additivity in the model. We modeled the natural log (ln) of catch per trip (*CPT*)[5] as function of several abundance and vessel characteristics variables:

$$\ln(CPT) = g[\text{month, area, depth, year, construction, ln(gross tons), ln(length), ln(year built), ln(horsepower), ln(no. crew), ln(footrope), ln(no. nets), ln(days fished/trip)}] + \varepsilon. \qquad (7)$$

The only variables contributing significantly to the models were month, area, depth, year, ln(length), ln(footrope), and ln(days fished/trip). The coefficient of determination (R-square) for this reduced model was 0.7935. The fitted model (Table 1a) as well as all the terms in the fitted model (Table 1b) are highly significant (with each $P < 0.0001$). Table 2 gives the regression coefficients and corresponding *P* values for the model. The *RFP* index estimate can now be computed as follow:

$$\begin{aligned} RFP\ index &= \frac{(FRL_{CV})^{0.34}(VL_{CV})^{0.31}}{(FRL_{SV})^{0.34}(VL_{SV})^{0.31}} \\ &= \left(\frac{FRL_{CV}}{FRL_{SV}}\right)^{0.34} \left(\frac{VL_{CV}}{VL_{SV}}\right)^{0.31} \quad (8) \end{aligned}$$

[5] Some may prefer to use ln(*CPUE*) as the independent variable. This would be algebraically identical to our model since ln(*CPUE*) = ln(*CPT*/*DFPT*) = ln(*CPT*) – ln(*DFPT*) where *DFPT* is days fished/trip.

Table 1a.—ANOVA table for the standardization model for ln(*CPT*)[1].

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	55	455,828	8,288	20,594	0.0001
Error	294,841	118,657	0.4024		
Corrected	294,896	574,484			

[1] *CPT* is catch per trip.

Table 1b.–Breakdown of model degrees of freedom from Table 1a.

Source	DF	F Value	Prob > F
Month	11	3,763	0.0001
Year	27	1,034	0.0001
Area	9	579	0.0001
Depth	5	343	0.0001
Ln(DFPT)	1	100,000	0.0001
Ln(Footrope)	1	2,993	0.0001
Ln(Length)	1	1,091	0.0001

Table 2.—Estimates of standardization model parameters and p-values.

Variable	Estimate	Prob > ITI	Variable	Estimate	Prob >ITI
Intercept	2.7214	0.0001	1981	0.3856	0.0001
January	−0.1116	0.0001	1982	0.0746	0.0001
February	−0.3244	0.0001	1983	−0.0184	0.0667
March	−0.3793	0.0001	1984	0.1848	0.0001
April	−0.4081	0.0001	1985	0.3328	0.0001
May	−0.1872	0.0001	1986	0.2428	0.0001
June	0.2324	0.0001	1987	0.0050	0.6139
July	0.4172	0.0001	1988	−0.1059	0.0001
August	0.2917	0.0001	1989	0.0132	0.2287
September	0.1447	0.0001	1990	0.0183	0.109
October	0.1246	0.0001	1991	0.1433	0.0001
November	0.1098	0.0001	Area 1–3	0.6861	0.0001
1965	0.6380	0.0001	Area 4–6	0.5443	0.0001
1966	0.6384	0.0001	Area 7–9	0.6066	0.0001
1967	0.6807	0.0001	Area 10–12	0.4355	0.0001
1968	0.5792	0.0001	Area 13–15	0.6432	0.0001
1969	0.3223	0.0001	Area 16–17	0.6098	0.0001
1970	0.5948	0.0001	Area 18–19	0.5995	0.0001
1971	0.4782	0.0001	Area 20–21	0.4557	0.0001
1972	0.4472	0.0001	Area 22–28	0.6285	0.0001
1973	0.2613	0.0001	Depth 1 (inshore)	0.0978	0.0001
1974	0.3107	0.0001	Depth 2 (1–5 fm)	0.1819	0.0001
1975	0.3645	0.0001	Depth 3 (6–10 fm)	0.0502	0.0001
1976	0.3320	0.0001	Depth 4 (11–15 fm)	0.0824	0.0001
1977	0.3358	0.0001	Depth 5 (16–25 fm)	0.0071	0.1227
1978	0.2862	0.0001	Ln(Days fished)	0.9942	0.0001
1979	0.1717	0.0001	Ln(Footrope length)	0.3377	0.0001
1980	0.1337	0.0001	Ln(Vessel length)	0.3146	0.0001

where *FRL* is footrope length, *VL* is vessel length, *CV* denotes the candidate vessel for standardization, and *SV* denotes the standard vessel. If the standard vessel[6] has a *FRL* = 30 yd and *VL* = 55 ft and the candidate vessel has a *FRL* = 48 yd and a *VL* = 65 ft, then the *RFP* can be computed as

$$RFP\ index = \left(\frac{48}{30}\right)^{0.34}\left(\frac{65}{55}\right)^{0.31} = 1.24.$$

Thus, the candidate vessel would be expected to land 24% more shrimp if both vessels were fishing at the same time and in the same location. Since consolidated vessels do not have vessel characteristics recorded, we first estimated the average *RFP* for the documented vessel in a given cell and applied that *RFP* to the consolidated vessels.

[6] The average fishing craft (vessel and boat) in 1965 is assumed to be the standard vessel for 1965 and across all years. Since boats are smaller than the standard vessel, their *RFP* in 1965 will be less than 1.0. Conversely, vessels will be larger than the standard vessel, and their *RFP* will be greater than 1.0 in 1965.

Expansion Model Selection

Ideally the form of the expansion model should be similar to the standardization model. In the expansion model, however, much of the data is consolidated and vessel identities are unknown; therefore, vessel characteristic information is unavailable for a portion of the interview landings data set. Consolidated records do, however, distinguish between boats and vessels.[7] In the equation, we considered any U.S. Coast Guard registered vessel ≤60 feet in length as a boat, since that size craft can fish in most state waters.

Several different models (various functions of boat/vessel, area, depth, month, catch per trip, catch per unit effort, price, and dollars per trip) were considered. Interestingly, equations that were not price related had a much higher error sum of squares (on the origional scale) than models that were price related. Shrimpers are commercial fishermen and earn their living by harvesting shrimp that have value; thus, while catch is important in explaining effort, the value or price of shrimp is also very important. Of the price-related models, the following model was judged to be the most appropriate for expansion due to its simplicity and its relatively lower error sum of squares over all years

$$ln(dfpt) = f\{vess, area, depth, month, ln(cpt), ln(price), [ln(price)]^2\} \quad (9)$$

where *dfpt* is days fished per trip. The variables *vess* (boat or vessel), *area* (10 area groups: 1–3, 4–6, 7–9, 10–12, 13–15, 16–17, 18–19, 20–21, 22–28, and ≥29), *depth* (6 depth groups: inshore, 1–5 fm, 1–10 fm, 11–15 fm, 16–25 fm, and ≥26 fm), and *month* (12 months) are included in the model through use of dummy variables. A separate regression equation was estimated for each year (1965–93) for which data were available. Using the fitted model, interviewed effort estimates were calculated as *exp*(*ln*(*dfpt*)) and compared with effort data based on actual interviews. The model underestimated the actual days fished as the mean of the log normal distribution $exp(\mu+0.5\sigma^2)$ (Dudewicz and Mishra, 1988; Seber and Wild, 1989). Thus, multiplying the model estimate with a bias correction factor of $exp(s^2/2)$ provided an effort estimate with greater accuracy (Fig. 3). This correction factor accounts for the log transformation.

[7] Boats are generally smaller craft (from 25 to 60 feet in length) fishing predominately in bays and shallow offshore waters and are not registered with the U.S. Coast Guard. Vessels are generally larger craft (from 60 to 90 feet in length) fishing predominately in offshore waters and registered with the U.S. Coast Guard.

Expansion Model Validation

Table 3 provides the R-square values for the selected expansion model (discussed above) by year. It also provides the actual total interviewed effort and predicted total interviewed effort, which helps to assess the predictability of the expansion model. The difference between actual and predicted total interviewed effort is expressed as percent of actual total interviewed effort. Examination of Table 3 shows the difference between actual and estimated interviewed days fished to be within 1% for

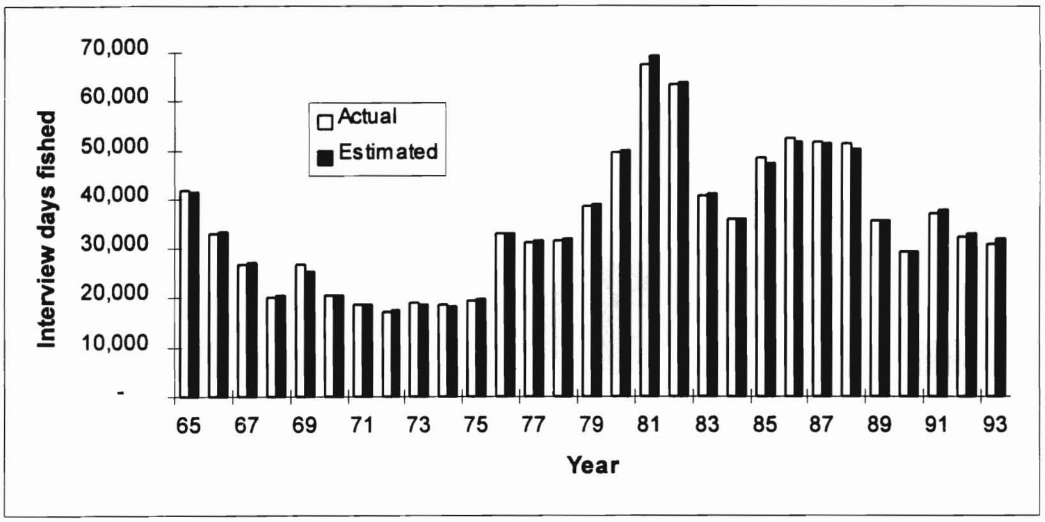


Figure 3.—Actual interviewed days fished vs. adjusted estimated interviewed days fished by year.

Table 3.—The R-square and cross validation of the expansion model.

		Interview days fished		
Year	R-square	Actual	Estimated	% Difference
1965	0.7770	41,858	41,675	–0.44%
1966	0.8169	32,917	33,196	0.85%
1967	0.8174	26,724	27,120	1.48%
1968	0.8140	20,280	20,393	0.56%
1969	0.8001	26,762	25,226	–5.74%
1970	0.8661	20,356	20,419	0.31%
1971	0.8535	18,527	18,640	0.61%
1972	0.8672	17,189	17,461	1.58%
1973	0.8273	18,980	18,707	–1.44%
1974	0.8418	18,599	18,477	–0.66%
1975	0.8696	19,501	19,821	1.64%
1976	0.8803	32,880	33,133	0.77%
1977	0.8576	31,135	31,724	1.89%
1978	0.8457	31,481	31,739	0.82%
1979	0.7762	39,107	39,012	–0.24%
1980	0.7975	49,581	50,106	1.06%
1981	0.8186	67,445	69,308	2.76%
1982	0.8136	63,369	64,060	1.09%
1983	0.8506	40,839	41,198	0.88%
1984	0.8410	35,913	35,790	–0.34%
1985	0.8685	48,380	47,158	–2.53%
1986	0.8521	52,385	51,832	–1.06%
1987	0.8556	51,846	51,231	–1.19%
1988	0.8510	51,182	50,072	–2.17%
1989	0.8098	35,686	35,493	–0.54%
1990	0.8128	29,245	29,144	–0.35%
1991	0.8232	36,948	37,645	1.89%
1992	0.8627	32,151	33,052	2.80%
1993	0.8752	30,926	31,842	2.96%

13 out of 29 years, and within 2% for 23 out of 29 years. Other annual validation comparisons by area, depth, and month are reported in Griffin and Shah.[8]

The actual interviewed effort is predicted with very high precision through the selected expansion model.

Relative Fishing Power

The *RFP* of the average fishing craft (vessels and boats for the total fleet) moved upward from 1.00 in 1965 to 1.23 in 1980, then dropped in 1981 to 1.15 and remained relatively constant through 1988 and then increased again (Fig. 4). This implies that the *RFP* of craft fishing in the Gulf of Mexico shrimp fishery (boats and vessels) in 1980 was 23% more powerful than the standard craft fishing in 1965. In 1993 the relative fishing power was slightly less than that in 1980. The *RFP* of the inshore and offshore fisheries follows the same trend as the total, but the curve is much smoother for the offshore fishing. Comparing the *RFP* between craft that fish inshore and those that fish offshore, we find that craft fishing inshore in 1965 were only 80% as powerful as those fishing offshore. This was still true in 1993.

The drop in 1981 in *RFP* (which remained constant through 1987) can be explained using fuel price and price received for shrimp (Fig. 5). The fuel price began to increase at the end of 1973 and doubled in 1974. At the same time, shrimp prices declined from 1973 to 1974. Shrimpers had a hard time covering cost in 1974 and 1975 (Warren and Griffin, 1980). The fuel price continued to increase, but more slowly, into the beginning of 1979. However, the real shrimp price also increased in 1979 offsetting the increase in the fuel price. As a result, shrimpers invested in new vessels during the profitable years, 1976–78, increasing the *RFP*. During 1979 fuel prices began to rise rapidly, and in 1980 the real shrimp price began to decline from US$5/pound in 1979 to US$2 by 1993. Shrimpers who ordered vessels in 1978 received them in 1979 and 1980; therefore, the *RFP* continued to increase through 1980. Beginning in 1979, shrimpers began to take steps to be more fuel-efficient. Investment in new vessels nearly came to a halt, causing the *RFP* to remain stable through 1987. After 1987, *RFP* increased through 1993, except for 1989; however, this increase was due not to the entry of newer and more powerful vessels into the fishery, but rather, to older and less powerful vessels leaving the fishery. Although the price of fuel declined through 1986, it was not sufficient to generate interest in investing in new shrimp vessels.

Comparison of Estimated Nominal Effort

Figures 6a–c compare our estimates with those of NMFS for total, inshore, and offshore nominal days fished, respectively, by year. Through 1975, our

[8] Griffin, W. L., and A. K. Shah. 1995. Estimation of standardized effort in the heterogeneous Gulf of Mexico shrimp fleet. NOAA, NMFS, MARFIN Contr. Rep. NA37FF0053-01, 50 p.

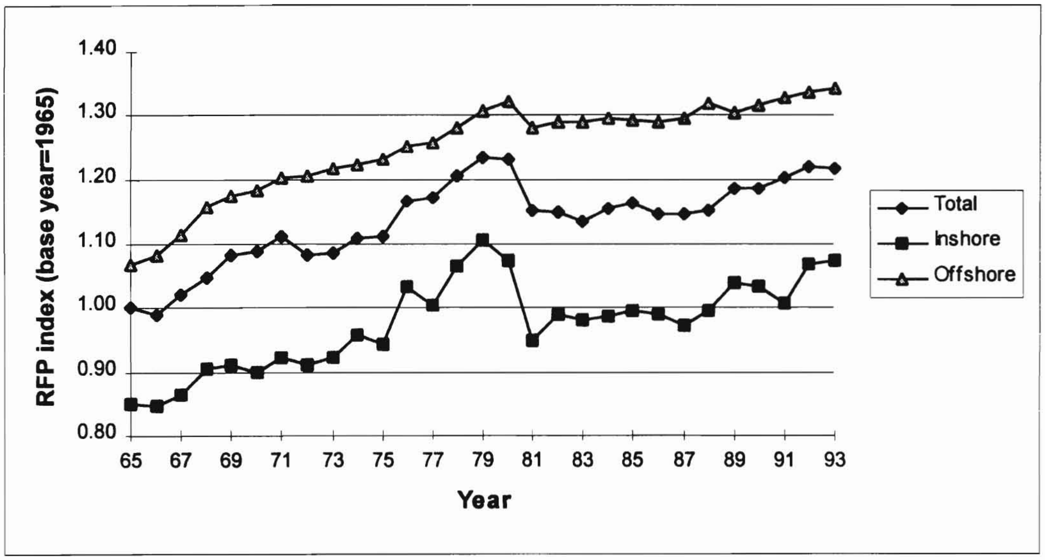


Figure 4.—Change in *RFP* in the total, inshore and offshore shrimp fishery by year.

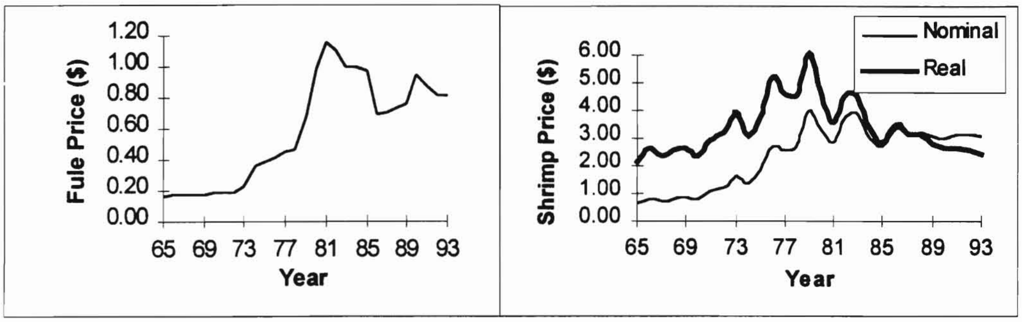


Figure 5.—Price of diesel fuel and average price of shrimp (nominal and real dollars) in offshore shrimp fishery. Real dollars based on the consumer price index (1982–84=100).

estimates of total nominal days fished (Fig. 6a) almost coincide with those of NMFS. After 1975, both estimates have the same trend, but ours are higher for all years except 1979, 1980, and 1992. Inshore (Fig. 6b), estimates coincide through 1971. Beginning in 1981, our estimates of inshore days fished exceed those of NMFS. Offshore estimates (Fig. 6c) by both methods track reasonably well. However, total days fished decreased beginning in 1988, largely due to a decline in the inshore fishery.

The discrepancies between these estimates and those of NMFS may be explained in part by a bias in data obtained by NMFS. Their nominal effort data is generated entirely from interviews obtained by port agents. Therefore, interview bias, including that from selection of craft type by the interviewer, becomes important. In 1965, 72% of inshore shrimp landings came from boats (≤60 ft), and 28% from vessels (> 60 ft and registered by the U.S. Coast Guard). Inshore, agents interview landings were 92% from boats and 8% from vessels. Beginning in 1989, vessels were targeted for interview more frequently than boats, and virtually no boats have been interviewed either inshore or offshore since 1989. Thus, the interview process in itself has introduced a bias in nominal effort data inshore resulting from non-proportionate sampling of the craft types. During the 29 years from 1965 through 1993, interviews with offshore shrimpers have remained at about 20% of the recorded vessels, however.

Standardization of Effort

Figures 7a–c show nominal days fished compared to standard days fished for total, inshore, and offshore shrimp fisheries, respectively. Using 1965 as the base year[9], real effort has increased 165% in the total shrimp fishery from 1965 to 1993, whereas nominal days fished increased only 118%. Thus, taking account of the increased fishing power of the fishing craft, there are 47% more standard days in 1993 than would be suggested by the nominal days fished. Examining the inshore shrimp fishery we find nominal days fished has increased 266% during this time period, whereas standard days increased 361%. Offshore nominal days fished increased 75% and standard days fished increased 120%. This increase in days fished is the actual increase in U.S. waters only.

[9] Choosing the base year is an arbitrary choice. We could just as easily have chosen 1993 instead of 1965. The trend will be the same as will the percentage change in real days fished over time. The absolute magnitudes will differ, however.

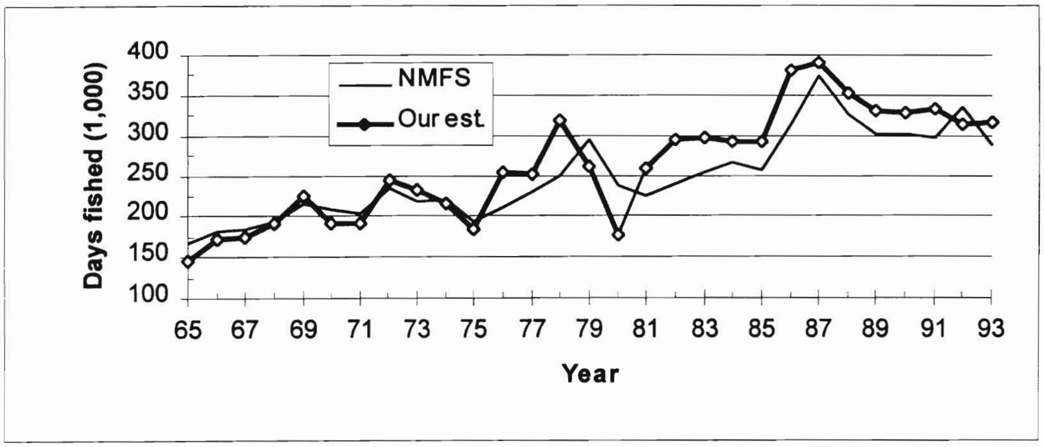


Figure 6a.—Comparison of our estimates with the NMFS estimates of total nominal days fished by year.

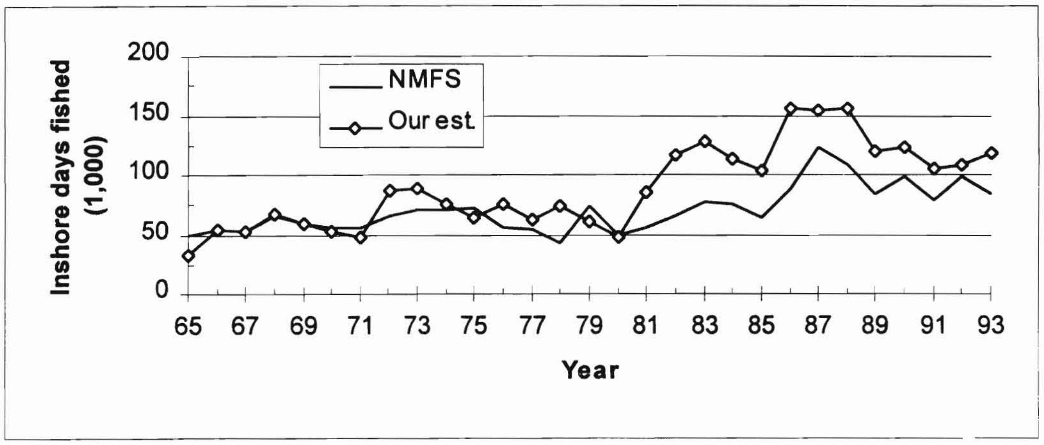


Figure 6b.—Comparison of our estimates with the NMFS estimates of nominal days fished in inshore shrimp fishery by year.

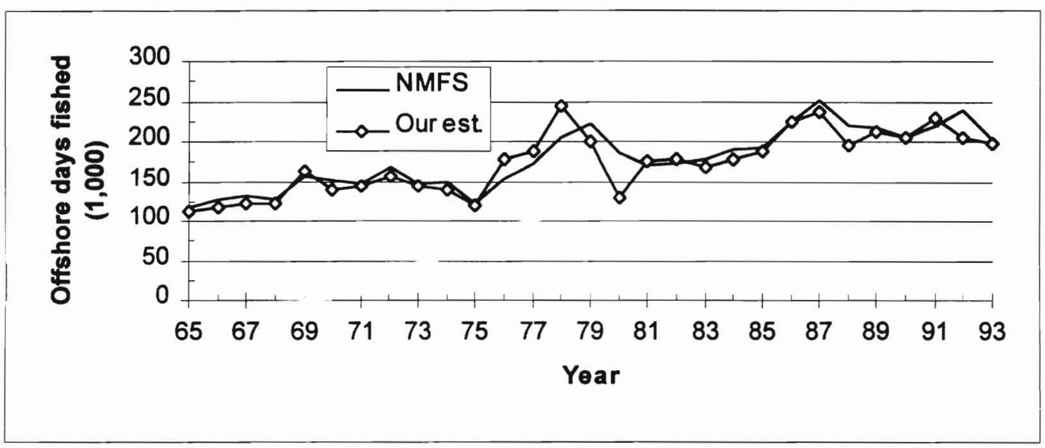


Figure 6c.—Comparison of our estimates with the NMFS estimates of nominal days fished in offshore shrimp fishery by year.

Prior to 1977 when Mexico extended its territorial limits, offshore shrimpers also fished a significant amount of time in Mexican waters (Fig. 8). Therefore, comparing 1993 to 1965, U.S. shrimpers in offshore waters of the Gulf of Mexico increased nominal days fished only 16%. Nominal days fished inshore increased 266% during this same 29-year period, most in Louisiana and Texas (about 315%). In response to the increase in the days fished inshore, the Texas Legislature passed Senate Bill 750, a shrimp license management program with a buy-back option, designed to stop the increase in licenses sold for the bay and bait shrimp fisheries.[10]

[10] Texas sells a commercial shrimp bay license, a commercial shrimp Gulf license, and a bait license.

Figure 7a.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for total U.S. shrimp fishery in the Gulf of Mexico by year.

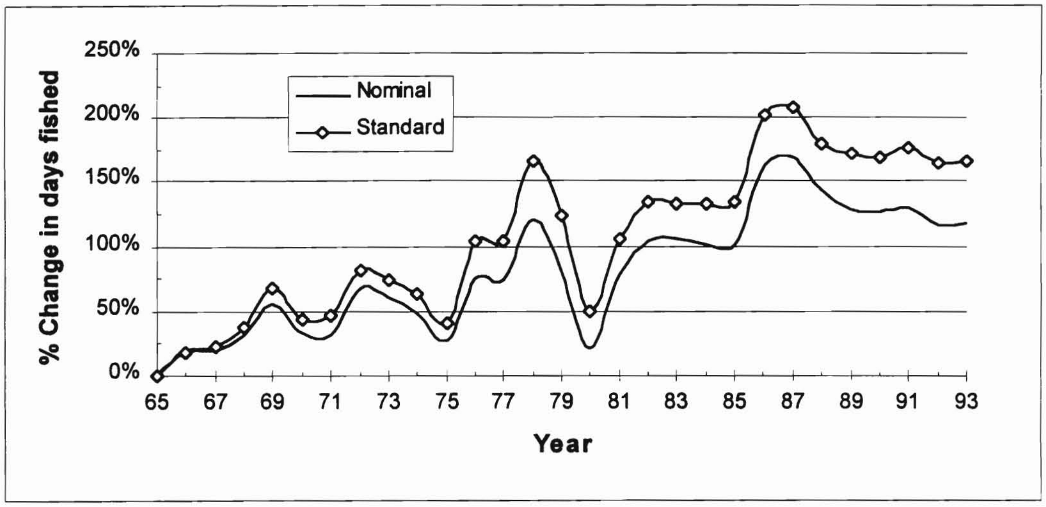


Figure 7b.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for the inshore shrimp fishery in the Gulf of Mexico by year.

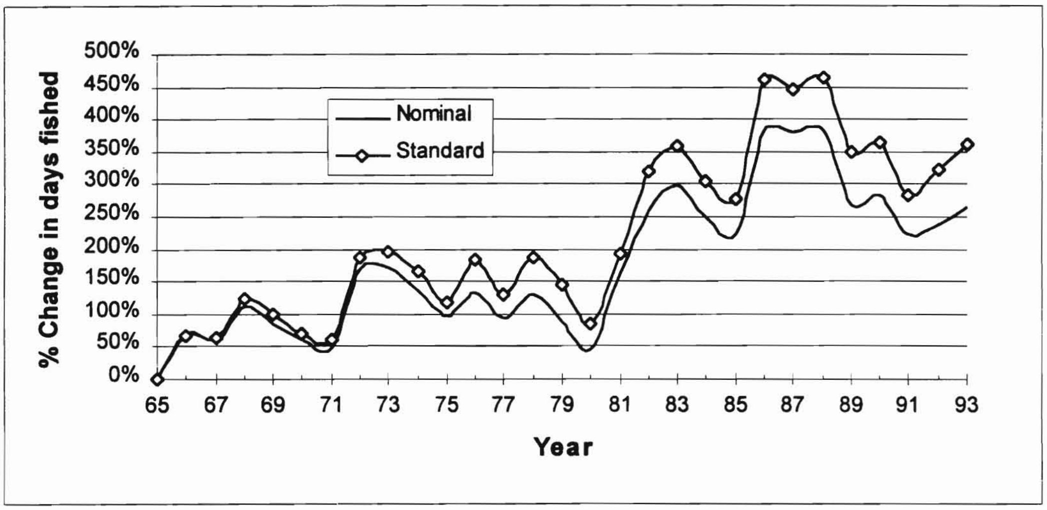
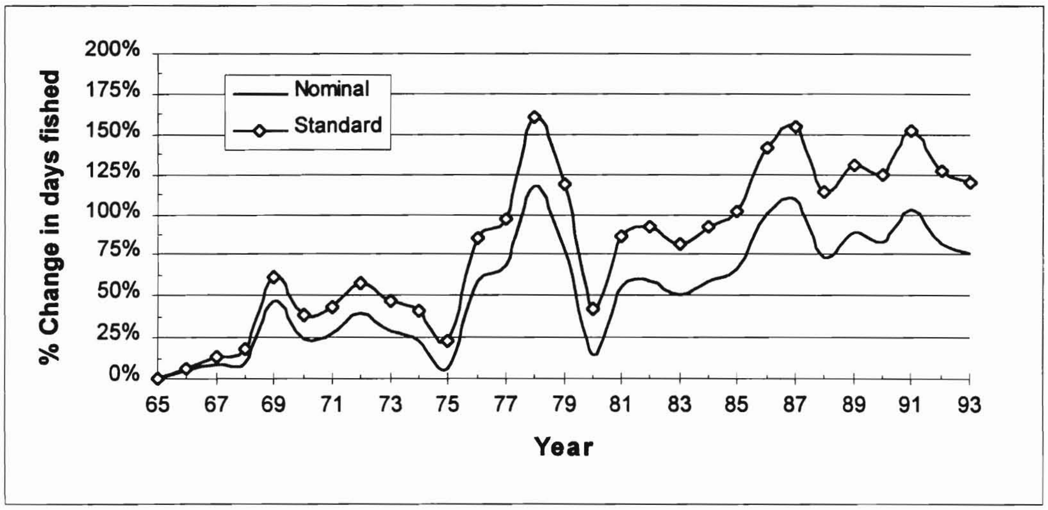


Figure 7c.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for the offshore shrimp fishery in the Gulf of Mexico by year.



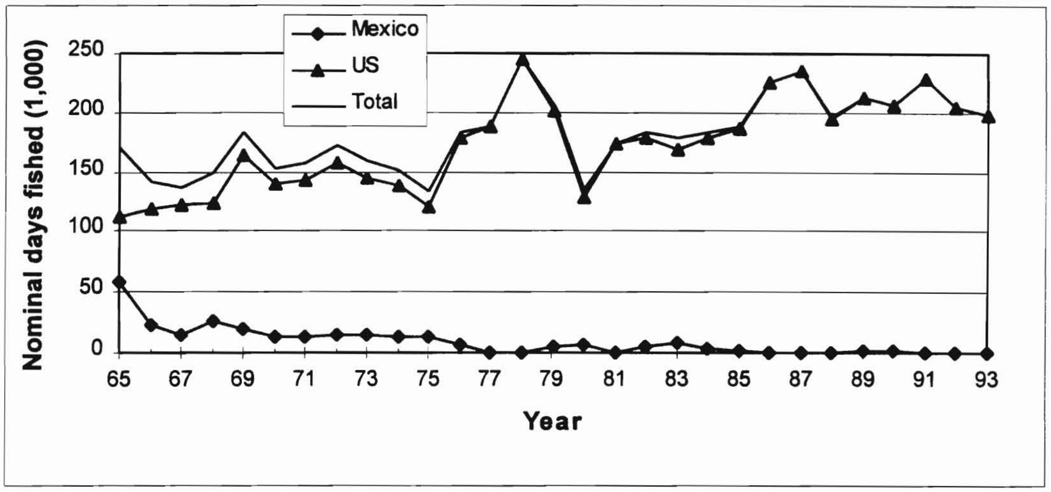


Figure 8.–Nominal days fished (our estimates) in U.S. waters, Mexican waters, and total offshore waters, in the Gulf of Mexico by year.

Conclusions and Recommendation

The modeling approach presented here is a reasonable and logical alternative to the NMFS approach. Our approach eliminates the need for subjectivity in pooling over neighboring cells, in the case of missing cells, to estimate nominal days fished. Since we fit an expansion model for each year, our approach is more sensitive to yearly changes and is more likely to capture these changes. Our approach yields higher inshore days fished in the latter years than does the NMFS due to the reduction in interview landings data in the inshore area. This causes a bias in the NMFS estimates of days fished and most probably in our estimate as well. It is strongly recommended that future data collection by the NMFS be more proportional than what it has been since 1984.

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