Estimation of Effort, Maximum Sustainable Yield, and Maximum Economic Yield in the Shrimp Fishery of the Gulf of Mexico

By

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Ad Hoc Shrimp Effort Working Group

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Introduction

The Gulf of Mexico Fishery Management Council (GMFMC) established an Ad Hoc Shrimp Effort Working Group (SEWG) in the spring of 2006. In general, the SEWG was established and charged with determining the appropriate level of shrimp fishing effort in the Exclusive Economic Zone (EEZ) of the Gulf of Mexico. Specifically, the SEWG was directed to address and answer two questions:

> 1) What would be the minimum level of effort necessary to achieve Optimal Yield (OY) in the shrimp fishery (harvest sector) in the EEZ; and
> 2) What level of effort in the EEZ would derive the maximum benefits to the shrimp fishery (harvesting sector)?

This report provides a description of the data and data collection procedures that are used to collect statistics from the shrimp fisheries in the Gulf of Mexico, outlines the procedures used in the estimation of shrimp fishing effort in the statistical subareas of the Gulf of Mexico, and presents the assumptions and analysis used to respond to the two questions posed by the GMFMC to the SEWG.

Shrimp Data Files

The Southeast Fisheries Science Center (SEFSC) maintains shrimp databases from the commercial harvesting sector. Similarly, SEFSC databases do not include catch by commercial fishermen sold through non-dealer channels. In addition, the databases do not include data on catch of shrimp that are discarded at sea. Although the shrimp database is complex, the procedures used to collect these data are conceptually straightforward. The data collection procedures are described below in the section entitled "Data Collection Procedures," and a detailed description of the data files follows entitled "Data File Descriptions."

Data Collection Procedures

Currently, there are about 20 port agents employed by state or federal agencies participating in the SEFSC Gulf shrimp program. Shrimp statistics for commercial fisheries are collected by these port agents located in coastal ports around the Gulf of Mexico and also by dealer trip ticket programs in the states of Alabama and Louisiana. Florida has a dealer trip ticket system, but the data are not used in the current shrimp system. These data from the Florida trip ticket system are inconsistent with the Gulf shrimp system, for example size information is not collected consistently.

Port agents collect shrimp statistics from two sources, seafood dealers and fishermen, while the trip ticket system collects data only from the seafood dealer. Data on the amount and value of the shrimp that are unloaded, i.e., landed, at the dealers are collected from dealer records. For discussion purposes, these census data are referred to as "dealer data" in the landings file. The second type of data includes detailed information on fishing effort and location for an individual trip and is collected by interviewing either the captain or a member of the crew. These data are referred to as "interview data" in the landings file.

Because a port agent is responsible for a specific geographical area, the same person collects the landings statistics, and interviews fishermen for effort and location information. Consequently, it is the port agent's responsibility to ensure the correct effort and location information are associated with the landings data from the same trip. This procedure prevents the possibility of double counting fishing activity which could occur if more than one individual were responsible for collecting data in the same geographical area. The trip ticket system has added a little more complexity to the issue. Currently, NMFS Galveston Laboratory is responsible for merging the dealer information from the state trip ticket collection system with the interview information from NMFS port agents.

Because the fishing trip is the basic sampling unit, the fundamental principle of the data collection procedures is to collect both landings and interview data on a trip-by-trip basis. However, because the number of fishing trips that occur in the shrimp fishery is so large (e.g., 155,138 total trips in 2002), it is difficult for a record to be made of every fishing trip by the port agents (the trip ticket system is able to collect data on every trip). Consequently, data collection procedures by port agents include two modifications to this principle.

The first modification is that the port agents are only required to record landing statistics for fishing trips made by documented vessels (fishing craft registered with the U.S. Coast Guard) that fish offshore (seaward of the COLREG line). The port agents may combine the landings statistics and record only monthly totals for the pounds, value and number of trips that are made by boats (state licensed fishing craft) in these offshore statistical subareas. In contrast, port agents may combine the landings statistics and record only monthly totals for the pounds, value and number of trips that are made by both boats and vessels that fish in inshore statistical subareas (inside the COLREG line). Consolidation of data is also used for trips that are made in offshore statistical subareas, when the vessel that made the trip could not be identified from the dealer's records.

The second modification is that port agents only conduct interviews from a sample of the vessels that fish offshore. The intent of this protocol is to select a few individuals that are representative of the total population and collect information from the sample rather than the entire population. The logistics of fishing, however, make it impossible for the port agents to perform interviews that are selected randomly from the vessel population. Most of the time port agents do not know where and when vessels are going to land, so specific vessels cannot be targeted in advance for selection. As a result, the port agents are instructed to regularly visit the docks in their areas and interview vessel captains as the opportunity arises. If there are more vessels in port than can be interviewed, the agents are instructed to select the vessels by "random" process, in an attempt to avoid systematic bias (i.e., always interviewing the same vessels at the same port).

In summary, port agents visit all the shrimp dealers in their assigned area at least once per month, and collect landings statistics for individual fishing trips for all the vessels fishing offshore that can be identified. From a sample of these trips, the port agents interview the captain or member of the crew to collect fishing effort and catch location information. For offshore trips made by boats, and inshore trips made by both boats and vessels, the port agents may combine the landings statistics for the trips made each month. The trip ticket data from Alabama and Louisiana is able to capture landings statistics for all individuals fishing trips from inshore and offshore statistical subareas.

Data File Descriptions

Port agents record the landings and interview data on a standard collection form. If only landings statistics are collected, or if the data come from a trip ticket system (no interview from trip tickets), only part of the form or record is completed. If both landings and interview data are collected for the same trip, the entire form is completed. The individual data elements for the landings and interview portions of the database are listed below. The data elements that are collected from the dealer's sales receipts or pack-out sheets are listed under the column titled "Landings Information," and the elements that are recorded from interviews with the captains are listed under the column titled "Interview Information." All of the data are entered into a file, which is termed the "Shrimp Landings File."

Landings Information

Port
Vessel Name
Official Documentation Number
Date of Unloading
Number of Trips
Grading
Dealer Number
Species
Size
Condition (heads on or off)
Pounds
Subarea (assigned)
Depth (not in trip ticket system)
Price per Pound

Interview Information

Total Days Fished
Size of Trawls
Port of Departure
Departure Date
Number of Trawls
Hours Fished During Day / Night
Subarea (given by captain)
Depth (given by captain)
Number of Crew
TED Type

These data elements are, for the most part, self-explanatory; however, there are several that should be explained in more detail.

The term "Days Fished" is used to report the number of 24-hour days that the gear were in the water fishing. For example, if a vessel fished 10 hours one day, 12 hours the next, and 12 hours the third day, the number of days fished would be 1.4 (i.e., (10 hr +12 hr +12 hr)/24 hr = 1.4 days).

In order to assign fishing activity to a geographical location, the continental shelf of the Gulf has been divided into 21 statistical subareas or grids (Figure 1). These subareas are further subdivided into 5-fathom depth increments from the shoreline out to 50 fathoms.

The data elements, "Subarea" and "Depth," refer to these statistical and depth subdivisions. Note, these data elements appear in both the "Landings" and "Interview" lists, but they are collected following slightly different procedures. The subarea and depth information that is recorded when only landings data are collected, and no interview is conducted, is "assigned" by the port agent (there is currently no depth “assignment” made in the trip ticket system). To assign the landings data to a specific subarea and depth the port agents usually use information obtained from the dealer, or in a few cases assign the fishing location based on their knowledge of the fleet's activity. In contrast, the subarea and depth information for an interview is actually provided by the fishermen.

The port agents attempt to identify the species of shrimp as accurately as possible. There are nine species of shrimp species landed but the major commercial species, white (*Litopenaeus setiferus*), brown (*Farfantepenaeus aztecus*), and pink (*F. duorarum*) are familiar to most seafood dealers and properly identified by them. However, in Texas, many of the dealers combine pink and brown shrimp together as brown shrimp landings.

In addition, the port agents record all of the landings statistics by market category or size of shrimp as the dealers have recorded them on their pack-out or sales receipts. Also, the port agents record whether the shrimp have been purchased as headed or whole (i.e., heads on). This identification is important because all of the statistics are converted to the same weight (i.e., heads-off or tails) when reported.

As discussed in the section on data collection procedures, the distinction between a vessel and a boat is important for the Gulf shrimp data. This distinction is based on the size and registration of the fishing craft. Vessels are defined as five net tons or greater and registered with the U.S. Coast Guard (USCG). The USCG issues a unique six or seven-digit documentation number to each vessel, and this number is the "Official Documentation Number" that is recorded by the port agent on the shrimp data collection form. Boats, on the other hand, are defined as all fishing craft that are not registered by the USCG, but are registered with the state from which they operate. However, some of these boats may be five net tons or greater.

Generalized Fishing Effort Estimation

There are currently two different methods used by research scientists to estimate effort in the Gulf of Mexico shrimp trawl fishery. The first methodology is termed the pooled model, while the second is termed the General Linear Model (GLM) Method. Both of these methods have been reviewed and discussed at various workshops over the years (SEDAR 7 Data Report). Currently, the pooled model is the methodology employed by the National Marine Fisheries Service (NMFS) to estimate shrimp effort. However, both of these methods are summarized below and effort values from each were used in the Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY) analysis presented in this document.

Pooled Model Methodology

Every data record in the commercial shrimp files has three primary fields that categorize it into its spatial and temporal location components (i.e., location cell). The finest resolution for any of the data would be month, statistical subarea, and 5-fathom depth zone. The data can be “pooled” or summarized into larger location cells by combining months, statistical subareas, and / or depths (i.e., collapsing interview and landing data from several depths, subareas, or seasons into one larger cell). Any combination of these three data location elements can be used to group the shrimp data.

To estimate fishing effort for each location cell, there must be two elements of data for each cell: 1) total pounds of shrimp caught by species and 2) the average catch per unit of effort (CPUE; pounds per day fished) (Nance 1992a). Total pounds caught by species are acquired from commercial seafood dealers located along the Gulf coast, while CPUE is obtained from interviews with captains from shrimp vessels at the termination of their trip. Although the interview level has no effect on the collection of total pounds data, it does have a direct effect on the estimation of average CPUE. Obviously, the more interviews that port agents can gather during a particular time period, the more representative the estimate of this sample's average CPUE is of the population average CPUE.

The ratio estimator (Σ catch / Σ effort) has been used to calculate average catch per unit of effort (CPUE) for a given location cell (month/subarea/depth combination). This is accomplished by summing all the catches and efforts from all the trips in a given location cell. The more collapsed (i.e., larger) the location cell, the more trip catches and trip efforts that go into these summations.

In previous workshops (Nance 1992b, GMFMC 1994), plots of trip catch against trip effort within a given location cell revealed that variability among trip catches appears to increase as trip effort increases. It was therefore concluded that the mean CPUE ratio estimator currently used (Σ trip catch / Σ trip effort) is the correct one. However, some analyses conducted by working group members suggest the ratio estimator Σ(trip catch/trip effort) / number of trips may be a more precise estimator of the mean CPUE for a location cell, because there generally was a straight line (through the origin) relationship between the standard deviation of trip catches and trip effort. Through group consensus, we chose to adopt the currently used mean CPUE estimator for all the analysis presented in this report, but further analysis into the appropriate mean CPUE estimator is warranted by other interested individuals.

Effort (days fished) for each location cell is estimated by dividing the shrimp landings from a location cell by the average CPUE during the same time and location combination. To calculate total shrimp effort in a particular location cell, total pounds of shrimp (i.e., all species combined) are divided by the average CPUE calculated from all the interviewed trips within that location cell. Total annual effort is calculated as the sum of the individual location cell effort values. While this is the accepted methodology used for effort calculation in the Gulf of Mexico shrimp fishery, some concern has been expressed in the past that use of this algorithm for estimating location cell effort could be biased by lack of statistical independence between the total catch in a cell and the estimate of CPUE for the same cell (Kutkuhn 1962)

It should be mentioned that the amount of potential bias is likely to increase as the amount of pooling gets larger, but the variance may tend to get smaller due to an increase in sample size. Several considerations have been pointed out at past workshops with regards to location cell determination and effort estimation techniques (Nance 1992b, GMFMC 1994). These include: 1) minimum acceptable number of observations used to determine average CPUE, 2) collapsed cells must be from homogeneous subareas as defined by subarea/depth plots of CPUE, 3) collapsed cells must make biological sense, and 4) collapsed cells must make management sense.

GLM Methodology

The pooling methodology has remedied some of the issues with the calculation of effort expressed in previous workshops. However, there are still some concerns with the current method of effort estimation in the shrimp fishery. These concerns include; 1) the sample of interviewed trips and pounds may not be statistically representative of the total number of trips and pounds within a location cell, 2) other gear types, e.g., wing nets, skimmer, etc., have recently become important harvesting gears in inshore waters, particularly in Louisiana, 3) there may be a more precise estimator to estimate mean CPUE for a location cell, and 4) there is a possible lack of statistical independence between total catch and mean CPUE within a location cell.

Beginning in the early 1980's, a disproportionate amount of interview data was being collected from large vessels that fish offshore of Texas. This has caused the interview data to become non-representative with respect to vessel size, states, and inshore/offshore waters.

Because the recent interview data may no longer be representative, an alternative to the pooling model was developed. This effort allocation method is the GLM. The GLM incorporates all the data across years from 1965 to 2005 so interviewed data from representative years will be combined with interviewed data from non-representative years. This GLM method also expands effort on a trip-by-trip basis allowing inclusion of the landings files within the effort expansion model.

The GLM regression model considered for estimating days fished for non-interviewed vessels is:

$$\ln(dfpt)=f[\ln(cpt), \ln(price), \ln(price)^2, vessel, area, depth, month, gear, year, species]$$

where,

dfpt is the days fished per trip
cpt is the catch per trip
price is the average real price per pound

vessel (< 60 ft, ≥ 60 ft in length)[1]
area (8 area groups: 1-3, 4-6, 7-9, 10-12, 13-15, 16-17, 18-19, 20-21)[2]
depth (6 depth groups: inshore, 1-5 fm, 6-10 fm, 11-20 fm, 21-30 fm, ≥ 30 fm)[3]
month (12 months)
gear (2 gear groups: trawls and skimmers/butterfly nets)
species (3 shrimp species: brown, pink, and white)
year (1965-2005).

A separate regression model and resulting coefficients were estimated for the time period 1965-2005.
As noted above, interviewed trips are no longer representative of what is actually occurring in the commercial shrimp fishery. For example, interviewed pounds landed (Gulf wide) were at least 10% of the total landings for the time period of 1965-2005. However, the percentage of interviewed trips began to decline in 1985. Interviewed trips dropped to less than 5% in 1989, reaching a low of 2% in 1994. Interviewed trips have remained below 5% through 2005. This decline may imply that vessels being interviewed since 1985 are those having greater landings per trip. However, this has not been investigated using statistical methodology.

Prior to 1985 the number of interviewed vessels and boats were representative of their total trip and landings. However, beginning in 1985, a disproportionately greater number of vessels began to be interviewed when compared to boats. By 1993 very few boats were being interviewed. Therefore, the interviewed data may not be truly representative with respect to vessel size.

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[1] Documented vessels were assigned a length from the vessel operating units file. Records with a 9999985- 9999989 were assumed to be ≥ 60 ft in length and vessels with a 9999995- 9999999 were assumed to be < 60 ft in length.
[2] Mexican waters were the 9th area. Griffin et al, (1997) used 9 areas where the 8th and 9th were Mexican waters.
[3] This is a higher aggregation of depths than used in previous GLM analysis (Griffin et al, 1997).

Louisiana ports usually have the largest percent of total trips taken within the Gulf of Mexico region. However, Texas ports had an equivalent number of total trips from 1991 to 1998. However, in the late 1980s there was a movement away from interviewing trips in Louisiana, while Texas trip interviews increased in absolute terms. Louisiana has maintained at least 40% of the total trips in the Gulf of Mexico. Yet since 1987, only about 10-20% of interviewed trips come from Louisiana. Likewise, since 1987 Texas has maintained about 40% of the trips, yet accounted for 50-70% of the interviewed trips in the Gulf of Mexico. Since 1985 Alabama has accounted for 2-3% of the vessels trips, while 10% of the interviewed trips were taken from this state. However, in 2000-2001 the interviewed trips from Alabama increased to 20-30%, falling to 0% in 2002. For all of the states, landings records indicate interviewed pounds were proportional to total pounds until the early 1980's. Yet, beginning in the mid 1980's Texas began to dominate the interviewed pounds while Louisiana interviewed pounds dropped to less than 10%. Thus, similar to landings by vessel size, interviewed data may no longer be representative with respect to landings by state.

Interviewed trips and pounds in the inshore and offshore were fairly representative until the early 1980s. However, since 1990 interviewed trips and pounds inshore are basically non-existent. This explains why there is little interview data for boats because they predominantly operate inshore. It appears that the port agents are targeting only vessels and/or boat operators have become non-cooperative. Therefore, with respect to activity in inshore as opposed to offshore waters, the interviewed data may no longer be representative. Interviewed trips and pounds in state waters (i.e., waters under state regulatory control) are representative through 1984. State waters become under-represented after that year.

In 1985, the NMFS landings file began to record the gear type used by vessels. In 1985-1987, the percentage of interviews of skimmers was representative. Other gear types were representative from 1985 through 1990, although landings using these other gear types accounted for less than 1% of the total landings. Unfortunately, by 1988 few skimmers were interviewed, even though they are being used more often, recently accounting for 40% of the trips and 20% of the landings. This is because the skimmers operate almost exclusively in inshore waters, and port agents have been directed to focus their attention on vessels operating in offshore waters.

SEWG Analysis

Optimal Yield (OY) vs. Maximum Sustainable Yield (MSY)

The SEWG determined that OY would be calculated for all shrimp species combined, since our charge was to look at the shrimp fishery as a whole, and not various types. By definition, OY is equal to MSY as has been mandated by the Gulf Council in the Shrimp Management Plan.

State Waters (Territorial Sea) vs. Federal Waters (EEZ)

The analyses further required that the SEWG reconcile the disparity between the effort data, which are gathered by 5-fathom depth zones, and the distance-from-shore criterion that is used to distinguish between state and federal waters of the EEZ. The correspondence between 5-fathom depth contours and distance from shore at which these contours occur varies by geographic region. Further, a given 5-fathom contour seldom corresponds exactly with the 3- and 9-mile distance from shore values used to determine the boundary between state and federal waters.

The SEWG determined that in statistical subareas 1-9, depths of 0-10 fathoms would be equivalent to state waters, and waters >10 fathoms would be used to approximate the federal portion of the EEZ. State waters in Statistical Areas 10-11 were also defined by depths out to 10 fathoms, but the federal portion of the EEZ was subdivided into two depth zones, 11 to 30 fathoms and >30 fathoms. The SEWG believed subdivisions of federal waters would ultimately be useful if effort caps or reductions are required to reduce shrimp trawl bycatch mortality of juvenile red snapper. Juvenile red snapper are relatively scarce in the eastern Gulf offshore Florida but are abundant from Alabama to Texas. In the latter area, juvenile snapper are most abundant at depths between 10 and 30 fathoms (Gallaway et al. 1999). Effort reductions in these particular areas and depths would be far more effective in reducing juvenile red snapper mortality than would effort reductions in Florida's offshore waters or at shallower or deeper depths in the "western" Gulf (statistical subareas 10-21).

Statistical subarea 12 occurs entirely in state waters and consensus was reached that the federal-state boundary in statistical subareas 13-17 was best approximated by the 5-fathom depth contour. The federal EEZ of this region was subdivided into three depth zones; 6-10, 11-30, and >30 fathoms. In statistical subareas 18-21 (Texas), the 10 fathom contour was used as the boundary between state and federal waters and the federal portion of the EEZ was divided into two zones: 11 to 30, and >30 fathoms.

Sequence of Years Used in Analysis

Commercial shrimp files are available from 1960 to 2005. Discussions by the SEWG centered on which set of years to use in the MSY and MEY analyses. A summary of changes in the Data Collection and Management of the fishery were presented to the group. These changes included 1) offshore vessels moving from twin-rigged to quad-rigged nets in the late 1970's; 2) modifications in the SEFSC data collection protocols from 1978-1980; 3) Federal / State cooperative closures off Texas and Florida established in 1981; 4) Turtle Excluder Devices (TEDs) required in all nets in the offshore fishery beginning in 1989; 5) Bycatch Reduction Devices (BRDs) required in all nets in federal waters beginning in 1998; and 6) in 2002 state trip ticket data collection replaced NMFS port agent data collection in Louisiana and Alabama. Initially we evaluated three different year periods (1960-2005, 1981-2005, and 1990-2005) as possible time frames for our analyses. Model parameter estimates differed greatly among these periods. Following extensive discussions we ultimately reached consensus the period 1990-2005 is the most appropriate time frame for our modeling analyses. The group concluded that estimates based on data from 1990-2005 time frame were more appropriate than estimates based on other time frames. The primary reason for this was many changes took place in the fishery in the early time period and were also encapsulated in the entire 1960-2005 time series which could contribute to the overall variability and possible bias in the data set.

Pooling Model Technique

At the seventh Southeast Data Assessment Review (SEDAR 7) the SN pooled method (3 trimesters, 4 subareas, 2 depths) was selected as the preferred pooling methodology for the estimation of shrimp effort in the Gulf of Mexico shrimp fishery (Nance 2004). The SN pooling method is one of many pooling techniques which were initially attempted when shrimp effort estimation methodologies were being developed. The 3 monthly trimesters were January to April, May to August, and September to December; the 4 subareas were statistical subareas 1-9, 10-12, 13-17, and 18-21; while the 2 offshore depths were 0-10 fathoms and > 10 fathoms. By group consensus we chose to use this standard as the pooling technique to combine our shrimp data, with exceptions noted above (state water based on regional subareas, and federal waters split into state water boundary to 30 fathoms, and > 30 fathoms).

Depth Estimation for Data in Trip Ticket System

In the Alabama and Louisiana Trip Ticket systems depth of shrimp catch is not recorded for the trip. Thus, we developed a technique to estimate the depth location of catch for each trip in the trip ticket system (2002 to 2005). Data from the 2002 to 2005 NMFS landings file were split into inshore and offshore components using the “RIVER, SUBAREA, INOFF” key generated by SEFSC. The key file creates a cross-reference between the index code and the shore code value of 1 for offshore and 2 for inshore records. The data set was reduced to only the offshore component. Each remaining offshore record was assigned a new key based on the trimester that the landing occurred

(1-3), the SEDAR area in which the SUBAREA to which the landing was assigned is located (1-4), and the species of shrimp in the record (1=brown, 2=pink, 3=white, 4=others). The offshore data set was then further split into two components: those records with a valid FATHOMZONE value, and those with unknown depth. The records with the valid FATHOMZONE values were grouped by the TAS (trimester, subarea, species) key into 3 depth pools (0-10, 10-30, greater than 30). The distribution of depth pool values for each TAS key value was used as a pool to sample from for assignment of the unknown depth records containing the same TAS key. Sample distribution pool depths for records with unknown depths with an INOFF code that indicated Federal waters in SUBAREAS less than 12 were restricted to the distribution of known records in pooled depth zones 2 and 3, since our proxy for Federal waters in those subareas is the 10 fathom curve. After the depth zone assignments were made to all records, each record was assigned a field to indicate if it was from state (code = 0) or EEZ (code = 1) waters.

ELB Adjustments to Effort

Effort estimates for 2004-2005 used the SEDAR 7 SN pooled method, adjusted or corrected using Electronic Logbook (ELB) data where available. Total landings (the numerator in the effort estimate equation) and CPUE values (the denominator) were calculated for each cell as described above. The next step was to sort landings by geographic regional ports and allocate the port landings to each of the SN cells. For those ports having completely random and voluntary ELB sampling coverage, the ELB landings data were allocated to the SN cells and the percentage of the total ELB landings was determined for each cell. The total pounds for the ports having ELB coverage were distributed to the SN cells based upon the ELB sample distribution, and these values replaced the original estimates. For 2005, ELB effort and catch rate data were also used to adjust the denominator values of the SN cells fished by fleets determined to have complete ELB coverage.

Models and Results

In this analysis, the minimum effort required to harvest MSY for the shrimp fishery is estimated using a standard production model (Ricker 1973). The results of these data will later be used to estimate MEY as described by Gulland (1983) using the generated yield curve and economic data.

Maximum Sustained Yield; Graham-Schaefer Production Model

In June 2006, the SEWG prepared and evaluated estimates of shrimp fishing effort, landings and MSY based upon data for the period of record 1960-2005. The group concluded that estimates based on data for more recent time frames were more appropriate than estimates based on the entire period of record. As previously noted, many changes have taken place in the fishery since the 1960s and these changes would contribute to the overall variability of the data input into the models, and may cause a bias in results.

Thus, MSY estimates were developed using data for 1) two recent periods (1981 through 2005 and 1990 through 2005) and 2) for the latter time period, two time series of effort estimates (pooled model and GLM). The so-called pooled effort time series is the historical time series whereas the “GLM” effort estimates are those yielded by the GLM model described above. In each case, MSY is calculated for 1) the total fishing effort, inshore and offshore combined; 2) the total offshore fishery; and 3) the EEZ fishery.

We used the Graham-Schaefer production model (Ricker 1973) to express the catch rate as a function of effort:

$$\frac{Y}{E} = a - bE$$

where, Y is catch (yield), E is effort and a and b are fitted parameters. From this equation MSY is calculated:

$$\text{MSY} = \frac{a^2}{4b}$$

and E_s or the effort required to harvest MSY is calculated as

$$E_s = \frac{a}{2b}$$

The derivation of these equations are provided in Ricker (1973).

The data for the most recent time period (1990-2005) were selected as the best available data for calculating MSY and, as described below, MEY. The landings data were common to both the MSY estimates; one of which was based on effort estimates using the pooled effort expansion approach and the other was based on the GLM effort expansion approach (Table 1). Historically, the GLM effort estimates have been consistently lower than the pooled effort estimates in the offshore and EEZ waters (Figure 2).

The Graham-Schaefer regression model results and the corresponding MSY and E_s estimates are provided in Appendix 1 and summarized in Table 2. For both data sets, the best model fits of CPUE on effort, as indicated by the observed r^2 values, were the catch and effort data for the total fishery, followed by the data for the total offshore fishery, followed by the data for the EEZ fishery. The r^2 values observed for the CPUE/effort regressions for the respective pooled and GLM effort data sets were similar for the total fishery and the total offshore fishery. In these instances, level of effort explained over 80 percent of the variance in catch rate or CPUE. A similar level of r^2 was obtained for the EEZ regression model based upon the GLM effort estimates ($r^2 = 0.81$), but the corresponding r^2 for the pooled effort model was only 0.69.

Based upon the pooled effort model estimates, MSY levels for the total shrimp fishery, the offshore fishery and the EEZ fishery were 156.7, 101.2, and 62.6 million pounds of tails, respectively. The corresponding levels of effort needed to harvest MSY were 234.9, 178.8 and 109.9 thousand nominal days fished, respectively. Slightly higher MSY levels were indicated from the GLM effort estimates (158.7, 101.9, 64.9 million pounds of tails for total, offshore and EEZ, respectively). In contrast, the $E_{(s)}$ values derived from the GLM effort data for offshore and EEZ were decidedly lower than the E_s value from the pooled data (166.7 vs. 178.8 and 98.1 vs. 109.9 thousand nominal days fished, respectively). The opposite was true for the total stock; E_s based upon the pooled data (234.9 thousand nominal days fished) was lower than the GLM estimate of 248.9 thousand nominal days fished.

The estimates of MSY and the effort required to harvest MSY vary depending upon which effort expansion method is used, either the pooled or GLM method. Arguments can be presented for using either of the two effort expansion methods, but we recommend using the estimates derived from the pooled effort expansion method for use in comparisons with effort estimates used in the red snapper stock assessment. The two primary reasons for this recommendation are as follows. First, the SEDAR 7 red snapper stock assessment is based upon effort estimated using the pooled method. For consistency, the same method should be utilized for this assessment, or the stock assessment should be redone using the GLM estimates of effort to calculate red snapper bycatch, etc. It is not practical to re-run the current stock assessment assignments using a different set of effort estimates. The second reason is that the ongoing expansion of the ELB program will result in data that are increasingly more representative of the Gulf offshore shrimp fishery. The resulting data should solve the perceived interview sampling deficiency characteristic of recent years.

Maximum Sustainable Yield: Modified Surplus Production Model

The SEWG was less certain about calculating MSY for the EEZ given that it is a politically-defined rather than a biologically-defined area or stock division. We determined that MSY calculations for this area should, at least, take into account the effort that occurs in state inshore waters and territorial seas. A modified surplus production model was developed which included both an abundance index and effort in state waters as exogenous variables in the analysis. The overall model actually included both an EEZ and a state water equation. Given the expected correlation in error terms between the two equations, each of the models was estimated using regression analysis. The abundance index was set as equal across the two equations. While the model consists of two equations, only the EEZ equations are discussed. The analysis was conducted using the 1980 to 2005 and the 1990-2005 time periods for both the pooled and GLM effort data series. As described below, emphasis is placed on results for 1990-2005.

The modified surplus production models were estimated:

$$\begin{aligned} H(eez)/E(eez) &= A0 + A1*E(eez) + A2*E(si) + A3*ACREAGE + \square \qquad (1)\\ H(si)/E(si) &= B0 + B1*E(si) + B2*ACREAGE + \square \end{aligned}$$

Where:
H(eez) = annual harvest from EEZ waters;
H(si) = annual harvest from state and inshore waters;

E(eez) = annual effort (days fished) in EEZ waters;
E(si) = annual effort in state and inshore waters;
ACREAGE = indicator of shrimp abundance (wetland acreage in Louisiana with salinity above 10 ppt, in millions);
A0-A3 and B0-B2 = parameters to be estimated;
ε = error term.

The results of this analysis are provided in “Appendix 2: Modified Surplus Production Model Results.” The models for each time period exhibited high explanatory power based upon adjusted r^2 values. These exceeded 0.85 for each data set for the 1990-2005 period compared to adjusted r^2 values about 0.73 for the data sets beginning in 1981. First-order serial correlation was found when the analysis began in 1981 but no serial correlation was evident when the analysis began in 1990.

The balance of this discussion is based upon the results for 1990-2005. As indicated by the statistical summaries in Appendix 2, harvest in the EEZ is significantly influenced by effort in state inshore waters and territorial seas. Failure to “capture” this interdependency would result in biased parameter estimates in the model.

Multiplying equation 1 by E(eez) yields the traditional quadratic relationship:

$$H(eez) = A0*E(eez) + A1*E(eez)^2 + A2*E(si)*E(eez) + A3*ACREAGE*E(eez) \quad (2)$$

Differentiating equation 2 with respect to E(eez) yields:

$$\partial H(eez)/\partial E(eez) = A0 + 2*A1*E(eez) + A2*E(si) + A3*ACREAGE \qquad (3)$$

Setting this equation equal to zero and solving for E(eez) gives

$$(A0 + A2*E(si) + A3*ACREAGE)/2*A1 = E(eez)$$

This indicates that effort required to harvest MSY in the EEZ is a function of the prior effort that was expended in state and inshore waters (Figure 3). In other words, the amount of effort needed to harvest MSY will vary depending upon the amount of effort in state and inshore waters. Using the GLM data set, MSY decreased from about 80 million pounds at 100 thousand days fished inshore of the EEZ to less than 60 million pounds when effort inshore of the EEZ was set at 200 thousand days fished (Figure 3). A similar trend of decrease in MSY is reflected by the pooled data (Figure 3 panel B). Note that under this model formulation, effort required to harvest MSY given the 1990-2005 average effort occurring inshore of the EEZ and average abundance was 145.4 and 120.4 thousand days fished for the pooled and GLM data, respectively (see Table 2). These estimates compare to the Graham-Schaefer EEZ estimates of 109.9 (pooled) and 98.1 (GLM) thousand days (see Table 2).

<u>Maximum Sustainable Yield: Modified Exponential or Fox Model</u>

The SEWG was also less certain that, as indicated by the Graham-Schafer and modified surplus production models, an appropriate doubling of the EEZ effort would drive the shrimp stock to extinction (see Figure 3 and Appendix 1). Fox (1970) developed an exponential yield model to address this problem. We modified this approach as described above to take into account abundance and effort occurring inshore of the EEZ (i.e., state inshore waters and territorial seas). The modified exponential or Fox model is estimated:

$$\text{Log}\,(H(eez)/E(eez)) = A0 + A1*E(eez) + A2*E(si) + A3*ACREAGE + \varepsilon$$
$$\text{Log}\,(H(si)/E(si)) = B0 + B1*E(si) + B2*ACREAGE + \varepsilon$$

After estimation, this can, of course, be rearranged as:

$$H(eez)/E(eez) = \exp^{(A0 + A1*E(eez) + A2*E(si) + A3*ACREAGE + \varepsilon)}$$

$$H(si)/E(si) \quad = \quad \exp^{(B0 \; + B1*E(si) + B2*ACREAGE + \varepsilon)}$$

Finally, harvest can be expressed as:

$$H(eez) \; = E(eez) *\exp^{(A0 + A1*E(eez) + A2*E(si) + A3*ACREAGE + \varepsilon)}$$
$$H(si) \quad = E(si) * \; \exp^{(B0 \; + B1*E(si) + B2*ACREAGE + \varepsilon)}$$

As with the surplus production model, four scenarios of the modified Fox model were considered (starting periods of 1981 and 1990 respectively, and GLM and pooled data). Results associated with each of these scenarios are presented in Appendix 3 and discussed below (see also Table 2 above).

Like the quadratic, the Fox models all exhibited relatively high explanatory power, based on the adjusted r^2 values (Appendix 3). The models beginning in 1990, however, were characterized by a somewhat higher explanatory power than those beginning in 1981. While not provided in the summary statistics, no significant serial correlation was found when the time period for analysis began in 1990. However, first-order serial correlation was evident when the analysis began in 1981.

As with the quadratic model, state and inshore effort was found to significantly influence EEZ harvest in each of the Modified Fox models (Figure 4). Omitting it, therefore, is likely to lead to “biased” parameter estimates of the remaining variables. Effort associated with MSY is simply equal to -1/A1. Hence, for the GLM model, effort at MSY will equal 143.1 thousand days if 1990 is selected as the starting point for analysis. For the pooled model, effort at MSY will equal 199.6 thousand days if 1990 is selected as the starting point for analysis.

Discussion: Estimates of MSY and E_{MSY} Specific for the EEZ

Based upon the model results obtained, there are at least three important considerations that need to be taken into account when attempting to estimate MSY and E_{MSY} specifically for the EEZ. The first consideration is the starting point for the analysis. We are using nominal days fished as the effort measure; i.e., these data are not standardized to take into account changes in fishing power over time. Therefore, the most recent data are probably more representative of today's fishery than older data. We selected 1990 data as the starting point for our analyses as a trade-off between having the most recent data and yet enough data for conducting the analyses. We described a number of changes that occurred at about this time that support using 1990 as the break-point. The second issue is whether one should include effort in inshore and state waters when attempting to estimate MSY for the EEZ alone. We attempted to address this issue because we had a difficult time justifying omission of this important variable. If one wants to view MSY and E_{MSY} for the EEZ rather than for the total fishery, or the total offshore fishery, our results indicate that corresponding effort inshore of the EEZ should be taken into account.

Finally, we have the issue of the functional form of the model that should be used in the analysis. It seems unlikely that the shrimp stock can be driven to extinction with a doubling of effort in the EEZ alone. The modified Fox model, while allowing for a declining harvest beyond some point, does so at a very slow rate as effort is increased. This seems to be a more realistic model, but we do not have any data points on the right side of the curve to confirm which functional form of the model is appropriate.

Maximum Economic Yield

This section examines the MEY in the Gulf of Mexico shrimp fishery from 1990 to 2005. Since this shrimp fishery has historically been an open access fishery, the analysis also examines expected results in long-run equilibrium under open access conditions. MEY is defined as the level of landings that would maximize profits to the harvesting sector.[4] In Figure 5, this occurs where the vertical distance is greatest between the total revenue (TR) curve and the total cost (TC) curve (i.e. the difference between total revenue and total costs is the greatest).[5] The effort needed to harvest the MEY is E_{MEY}. Since the total cost curve is positively sloped, E_{MEY} will be less than E_{MSY}. Given that the Gulf shrimp fishery has historically been an open access fishery, the analysis also examines expected results in long-run equilibrium under open access conditions. In an open access fishery, opportunity costs are included in the TC curve. Normal profits represent the opportunity cost of capital. That is, normal profits represent a return to vessel owners that must be paid in order for them to continue operations in the fishery. Therefore, the distance between the TR and TC curves is a measure of profits that exceed normal profits (i.e. economic or pure profits).

In the short-run, vessel owners currently participating in the fishery have sufficient time to alter their levels of effort, but do not have sufficient time to enter or exit the fishery. In the long-run, vessel owners have enough time to enter or exit the fishery. Assuming the goal of vessel owners is to maximize profits, and no barriers to entry or exit exist in the fishery (e.g., a limited entry management system), economic profits are expected to be zero. That is, in the long-run, the fishery is expected to operate at the open-access equilibrium where landings are at OAE and effort is at E_{OAE}.

In an open access fishery, when there are greater than normal profits in the long-run (i.e., economic profits are positive), additional vessel owners will enter the fishery in an attempt to capture these economic profits. The entry of additional vessels will increase effort, eventually to the point where TR equals TC (i.e., all economic profits have been

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[4] Costs and benefits considered in this analysis reflect only those internal to the shrimp fishery. As such, the level of effort associated with "MEY" may not represent that level of effort which is socially optimal.

[5] The slopes of the two curves are also equal at this point. The slopes of the two curves represent the marginal revenue (MR) and marginal cost (MC) per unit of effort respectively. By definition, profits are maximized where MR=MC.

captured and are thus zero), which occurs at E_{OAE} units of effort and landings are at OAE. Conversely, if less than normal profits are being earned (economic losses are being incurred) in the long-run, which would occur at levels of effort greater than E_{OAE} where TC exceed TR, vessel owners will exit the industry in search of better profit opportunities. The exit of vessels will reduce effort and the exodus will continue until TR equals TC, where normal profits are being earned and economic profits are zero. Thus, long-run equilibrium in an open access fishery is a condition under which no vessel entry or exit is expected and fleet size is stable.

Figure 5 represents a static fishery where the underlying conditions affecting the positions of the TR and TC curves remain unchanged (e.g., price of shrimp, price of fuel, etc.). However, these conditions frequently change from year to year, and sometimes even within relatively short periods of time. Figure 6 illustrates the expected impact on MEY and OAE and their associated levels of effort as a result of an increase in the costs per unit of effort and a decrease in revenue per unit of effort. For example, if fuel prices increase, costs per unit of effort would increase, which would cause the TC curve to shift up to TC`. Conversely, if shrimp prices decrease, revenue per unit of effort would decrease, which would shift the TR curve down to TR`. The new OAE (OAE`) would occur at the intersection of TR` and TC`. Landings at the new long-run access equilibrium would be lower and thus so would be the level of effort ($E_{OAE`}$) required to harvest this lower level of landings. This result indicates the fishery cannot economically support as much effort as before the increase in costs per unit effort and the decrease in revenue per unit of effort (i.e. the decline in profitability would cause vessels to exit the fishery). Similarly, the increase in costs and decrease in revenues per unit of effort would also cause profits to be maximized at lower levels of landings and effort, thereby also leading to a lower level of MEY (MEY`) and lower level of effort at MEY ($E_{MEY`}$).

Equations for Calculating MEY

The equations used to calculate MEY, E_{MEY}, OAE, and E_{OAE} are derived as follows. Total revenue (TR) is equal to price/lb (p) times pounds landed (Y). That is,

$$TR = pY.$$

The total cost (TC) in this analysis is equal to fuel costs (F), maintenance and supplies (M), net shares to the crew (S), cash overhead (H), and opportunity costs (O). That is,

$$TC = F + M + S + H + O.$$

Now let

$F = fE$,

$M = mE$,

$S = spY$, and

$H = hE$

$O = oE$

where f is the fuel cost per unit effort, m is the maintenance and supply cost per unit effort, s is the net share of one dollar of revenue, h is the overhead cost per unit of effort, o is the opportunity cost per unit of effort. As previously explained, the values of a and b are fitted parameters associated with the estimated yield curve. Based on the equations,

$$E_{MEY} = \frac{pa(s-1) + f + m + h + o}{2pb(1-s)},$$

$$MEY = a\, E_{MEY} + b\, E_{MEY}^2,$$

$$\mathrm{E_{OAE}} = \frac{\dfrac{f+m+h+o}{p} + a(s-1)}{b(1-s)}, \text{ and}$$

$$\mathrm{OAE} = a\,\mathrm{E_{OAE}} + b\,\mathrm{E_{OAE}}^2.$$

Cost data were estimated from a cost model developed by Funk et al. (1998). Using information available from the National Marine Fisheries Service's (NMFS) Gulf shrimp landings file, Funk et al. (1998) developed a method to forecast costs (fuel, maintenance and supplies, labor, and overhead) associated with every fishing trip made by commercial fishing vessels. The method is applied to the shrimp fishery. When the fishery is in long run equilibrium, $TR = TC$. Therefore, $O = TC - (F + M + S + H)$. Thus, opportunity costs are derived rather than estimated via. a particular function like the other costs. Obviously, the shrimp fishery is never in long run equilibrium. However, there are periods of time when the fishery is approaching long-run equilibrium conditions. During such periods of time, very little effort enters or leaves the fishery. Figure 7 shows the landings and effort data for 1990-2005. A cluster of data points can be seen to the right of the dashed line, where the dashed line is associated with MSY (62.6 million pounds of tails) and $\mathrm{E_{MSY}}$ (109.9 thousand days fished) in the EEZ under the pooled modeling approach. We will assume the shrimp fishery is basically in long run equilibrium during this time period, which in turn provides a means to calculate the average opportunity cost for that time period.

Analysis of MEY and OAE

In conjunction with the price of shrimp, the yield curve determines the shape and position of the TR curve. A single yield curve is assumed in this analysis for each of the effort estimation methods (i.e., pooled and GLM) during the 1990-2005 time period. Thus, for example, Figure 7 illustrates the yield curve for the EEZ under the pooled modeling approach.

The graphs in the upper portion of Figure 8 illustrate the estimates of MEY, E_{MEY}, OAE, and E_{OAE} under the pooled and GLM approaches given price and cost conditions as they existed in 1990. The dotted line indicates profits that would be earned at the various levels of potential effort. The graphs in the lower portion of figure 8 illustrate how MEY and E_{MEY} in 1990 compare to actual and MSY levels of landings and effort during the 1990-2005 time period. As theory suggests, these graphs indicate that MEY is less than OAE and actual landings, and E_{MEY} is less than E_{OAE} and actual effort. However, even though MEY is less than MSY and actual landings, the difference is not that pronounced when compared to the differences between E_{MEY}, E_{MSY}, and actual effort values. Further, actual effort for the 1991-2003 period hovers just to the right of E_{MSY}, indicating that actual effort slightly exceeded that necessary to harvest MSY in the EEZ. However, actual effort using the pooled method in 1990 is 106.0 thousand days fished (107.7 thousand days fished using GLM method) is less than E_{OAE}, which is 126.7 thousand days fished for the days for the pooled method (124.8 thousand days fished using GLM method), which in turn implies that economic profits were being earned in the EEZ component of the fishery in 1990. Thus, at that time, economic conditions would have promoted the entry of additional effort into the fishery. According to information in Tables 3 and 4, this appears to have happened. This can be seen in Figure 7.

Tables 3 and 4 show the estimates of MSY, E_{MSY}, OAE, E_{OAE}, MEY and E_{MEY} in the EEZ using the pooled and GLM methods for estimating effort in each year during the 1990-2005 time period respectively. Also included are estimates of value (total revenue), each of the various types of costs (fuel, maintenance and supplies, shares, overhead, and opportunity costs) and profits (value less total cost) at MEY in each year. Table 5 indicates the differences between these estimates under the pooled and GLM approaches. Estimates for the offshore fishery (i.e., EEZ plus state offshore waters) and the total shrimp fishery (all offshore and inshore waters) are presented in Tables 6 through 8 and 9 through 11 respectively. Table 12 presents a summary of these results in five-year increments (i.e., 1990, 1995, 2000, and 2005) for each area (EEZ, offshore, and total) under the pooled and GLM approaches.

In general, these results suggest that, during the 1990's through at least 2001, actual landings, MSY, and OAE vacillated in close proximity to each other (i.e., the fishery was fluctuating around the long-run equilibrium). The same is true of actual effort and E_{OAE}. However, actual effort always exceeded E_{MSY}, indicating that more effort was being expended than necessary to harvest MSY (i.e., overcapacity existed in the fishery). Further, MEY and E_{MEY} were relatively stable during this time period, reflecting only relatively minor changes in the fishery's economic conditions.
But, this time of relative stability appeared to change in 2002. As noted in other reports, shrimp prices began to decline in mid to late 2001, with the effects on total value (revenue) being particularly pronounced in 2002 and 2003. As expected, according to the theoretical considerations previously noted, a reduction in shrimp prices caused the TR curve to shift down and, in turn, OAE, E_{OAE}, MEY, E_{MEY}, and profits at all levels of landings and effort to decrease. At least initially, in 2002, effort appears to have remained stable or possibly increased in 2001-2002, depending on the model and component of the fishery being analyzed. It is possible that fishermen initially

attempted to adjust to the reduction in shrimp prices by increasing production via. increased effort. However, if that strategy eventually fails as a result of continually falling prices and revenues, and possibly increased costs as well, then effort must eventually fall as losses are incurred. In other words, the decline in actual effort is likely to lag behind the decline in E_{OAE} and E_{MEY}, which is in fact what has occurred. Costs per unit of effort began to increase in 2003, and increased significantly in 2005 as a result increases in fuel prices. As previously noted, such increases cause the TC curve to shift up. From 2003 through 2005, the combination of lower revenue and higher cost per unit of effort caused significant declines in OAE, E_{OAE}, MEY, E_{MEY}, and profits at all levels of landings and effort as illustrated by Figure 9. And though the effect is lagged, significant declines in actual effort have also transpired (see bottom graphs in Figures 8 and 9 and note dates for actual landings).

For the EEZ component of the fishery, the situation as it existed in 2005 is graphically depicted in Figure 9 according to the pooled and GLM approaches. Relative to conditions in 1990, as portrayed in Figure 8, OAE, E_{OAE}, MEY, and E_{MEY} are now significantly below MSY and E_{MSY}, indicating that there is insufficient effort in the fishery to harvest MSY and that this condition is likely to remain for the foreseeable future, particularly as long as shrimp prices remain relatively low and/or fuel prices remain relatively high by historical standards. Current levels of effort exceed E_{OAE} in the EEZ, particularly according to the pooled approach, indicating that economic losses are being incurred and thus that additional vessels and effort will continue to exit this component of the fishery in the foreseeable future. The same holds true for the offshore component of the fishery (Tables 6 and 7).

However, for the fishery as a whole, actual effort and E_{OAE} are nearly equal under both the pooled and GLM approaches in 2005 (Tables 9 and 10). This finding suggests that in 2005 the fishery as a whole may have been in or near a new long-run equilibrium where the total number of vessels and level of effort are expected to change very little in the near-term as a result of economic conditions.[6]

Given this, and the conclusions noted above regarding the EEZ and offshore components of the fishery, effort might be expected to spatially redistribute from deeper, farther offshore areas into inshore areas. This conclusion is logically consistent with observed events. For example, historically, larger vessels have tended to operate farther offshore and in the EEZ because they could access fishing grounds that smaller vessels could not (i.e. reduced competition) and thus could target larger shrimp. A significant premium has historically been attached to larger shrimp. However, the rise in fuel prices, and the accompanying increase in costs per unit of effort, particularly for large vessels with larger engines, has created a disincentive for vessels to operate farther from shore. The decrease in effort in all components of the fishery has decreased competition on the fishing grounds, increased catch per unit of effort (CPUE), and also allowed shrimp to grow to a larger average size. Simply put, vessels no longer need to go out as far from shore in order to catch large shrimp. Furthermore, the once significant premium attached to larger shrimp is considerably less than what it used to be. Therefore, it is not necessary for shrimp vessels to travel as far offshore as in the past in order to maximize revenue per unit of effort. The combination of these effects supports the conclusion that, even if effort in the fishery as a whole remains relatively stable, it will shift out of the EEZ and relatively distant state offshore waters to inshore waters at least in the short-term.

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[6] The hurricanes of 2005, and the destruction they brought to the harvesting sector, and the onshore sector (i.e. dealers, processors, ice plants, etc.), are a separate factor that could generate additional short-term and possibly long-term reductions in effort.

It is also worth noting that, on September 26, 2006, NMFS published the final rule implementing Amendment 13 to the Gulf of Mexico Shrimp Fishery Management Plan. For current purposes, the most important action under the new rule is the establishment of a 10-year moratorium on federal shrimp permits. The moratorium is expected to cap participation in the EEZ component of the fishery at approximately 2,700 vessels. Thus, at present, the EEZ component of the shrimp fishery is no longer truly an "open-access" fishery, as presumed within the long-run equilibrium analysis. However, with the exception of inshore waters in Texas, all other components of the Gulf shrimp fishery remain open access in nature. More importantly, of the vessels expected to qualify for moratorium permits, only about 1,800 were actually active in the GOM shrimp fishery during 2005. Thus, the cap on vessel participation in the EEZ component of the fishery is not presently binding. Rather, it is the economic conditions currently faced by the industry that will limit participation and effort in the foreseeable future. This conclusion is consistent with the finding that, in 2005, actual effort exceeded E_{OAE}, indicating the presence of economic losses in the EEZ component of the fishery, and thus that additional reductions in participation and effort are expected.

MEY Sensitivity Analyses

MEY estimates for the EEZ (Table 13) and the total offshore (Table 14) fisheries were developed assuming a range of fuel ($1.75 to $2.75) and shrimp prices ($2.75 to $3.50). We also estimated the yields and corresponding effort that would characterize the break-even point for the fishery at open access equilibrium (OAE and E_{OAE}). The cost data for 2005 was used as the base case.

Under the most optimistic scenario evaluated (shrimp price = $3.50/pound; fuel price = $1.75/gallon), the MEY for the EEZ was 33.0 million pounds of tails (Table 13) and MEY for the total offshore fishery was 55.9 million pounds of tails (Table 14). The corresponding MEY effort levels were 33.7 and 59.3 thousand nominal days fished, respectively. MEY and E_{MEY} values for the total offshore fishery were 122.3 million pounds of tails and 125.2 thousand nominal days fished, respectively (Table 15). The estimated OAE levels of fishing effort for the EEZ, total offshore, and total Gulf shrimp fisheries were 67.4, 118.5, and 250.3 thousand nominal days fished, respectively. This compares to the estimates of about 108.3, 178.8, and 235.0 thousand nominal days fished required to harvest MSY. Assuming the 2005 cost estimates are reflective of the current conditions in the fishery, these data would indicate that the break-even point for the offshore components of the fishery occurs at an effort level that is only 2/3 of that required to harvest MSY, and the maximum profits occur at levels of effort that are about 1/3 of the effort required to harvest MSY. The less optimistic scenarios reflect a rapid decline in profits at MEY, and the fishery reflects no profits at shrimp prices of $2.75/pound and fuel prices equal to or greater than $2.25 per gallon.

OAE effort levels were well below the MSY levels of effort. This finding suggests that 1) costs have increased dramatically in conjunction with declining revenues, 2) the cost data may not be representative of today's fishery, or 3) both. Further, we note that the estimated OAE level of effort for 2005 was 118.5 thousand nominal days fished and that the actual offshore effort was 102.8 thousand nominal days fished.

The fishery is presently in a pronounced economic decline and the strategies being employed to deal with low shrimp prices and high fuel costs vary considerably across the heterogeneous Gulf shrimp fleet. In some instances, insurance policies are not being renewed; crew shares are being reduced to contribute to fuel costs; the number of trips taken are being reduced; the duration of trips and the subareas fished on trips are being altered to minimize costs; and maintenance is being reduced to only that absolutely necessary to keep the vessel seaworthy. The cost estimates that we have developed for these analyses are based, in large part, on past practices and these practices may not accurately represent today's fishery.

For the following reasons we as a committee, do not believe MEY is a useful concept for managing effort in the Gulf shrimp fishery. First, use of MEY for management requires regulatory authority for the total fleet (inshore, state territorial seas, and EEZ) and the regulatory authority is restricted in this case to the EEZ. Among other reasons, restricting effort to the level of MEY in the EEZ may cause displacement of effort to state waters. This effort displacement would result in a change in yield and cost, which, in turn, would change MEY. Second, the price/cost structure is highly volatile at present and subject to large change depending on the duties situation and other factors. As noted above, present cost estimates may not reflect current conditions in the fishery. If MEY is to be pursued further, an accurate characterization of the remaining fleets and current cost estimates will be necessary.

Summary

The proceeding text has given a detailed discussion of MSY and MEY in the Gulf of Mexico shrimp fishery. The analysis has shown that in all cases (effort model types and geographic areas) the average effort during the 2001 - 2003 time period was above or very close to the estimated effort necessary to achieve MSY in the shrimp fishery (Table 16). However, the effort values in 2005 are all 30% to 43% below the effort required to harvest MSY in the various areas of the Gulf of Mexico shrimp fishery (Table 16).

As economic theory would suggest, our findings indicate that MEY, E_{MEY}, OAE, and E_{OAE} have changed during the 1990 through 2005 time period as a result of changes in the economic conditions facing the shrimp fishery. These values peaked in the mid

1990's, were relatively stable from 1990 through 2001, began a clear downward trend in 2002, and declined significantly in 2005 (Table 17). Recent declines have been caused by a combination of lower shrimp prices and higher operating costs, particularly fuel costs. Between 1990 and 2002, actual effort is either greater than or approximately equal to E_{MSY}, vacillates around E_{OAE}, and is always significantly greater than E_{MEY}. As of 2005, actual effort decreased to a level between E_{MSY} and E_{MEY}. For the offshore and EEZ components of the fishery, actual effort is also below E_{OAE} in 2005. This result indicates that losses are being incurred in the fishery and thus that additional contraction in these components of the fishery is expected in the foreseeable future. Further reductions in shrimp prices and/or increases in operating costs from their 2005 levels would be expected to accelerate this downward trend, as might the impacts arising from the 2005 hurricanes.

The results of the MEY sensitivity analysis suggest that, for every $.25 decrease (increase) in the price of shrimp or increase (decrease) in the price of fuel, MEY decreases (increases) by between 2.8 and 3.5 million pounds and E_{MEY} decreases (increases) by between 5,200 and 6,400 days fished in the offshore component of the fishery. For the EEZ component of the fishery, these figures are between 1.9 and 2.6 million pounds and between 3,100 and 4,800 days fished respectively. The results also suggest that current estimates of MEY and E_{MEY} are more sensitive to shrimp and fuel price changes under the pooled model approach relative to the GLM approach. The noted recent reductions in effort have caused the fishery to move into the upward sloping portion of the yield curve. Since this section of the curve has a steeper slope under the pooled model approach relative to the GLM approach, changes in shrimp prices and/or operating costs will cause a relatively larger change in the estimates of MEY and E_{MEY} under the pooled model approach. Given the lack of actual data points in the upward sloping portion of the estimated yield curves, these particular findings should be used with caution.

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Table 1. Landings (million pounds of tails) and effort (nominal days fished) data used in the calculation of maximum sustainable yield (MSY).

	Landings			Pooled Effort			GLM Effort		
Year	EEZ	Offshore	Total	EEZ	Offshore	Total	EEZ	Offshore	Total
1990	50.71	107.56	159.28	106044	211860	310087	107736	216161	359535
1991	66.79	107.33	144.81	137391	223389	301492	139974	217654	324161
1992	57.73	93.69	138.16	140883	216669	314541	135990	205925	346909
1993	53.76	86.38	128.43	132746	204482	288132	129354	184066	296260
1994	54.70	90.27	131.38	117855	195742	304220	128344	193372	317097
1995	61.84	93.90	145.62	114648	176588	254281	124934	183952	306402
1996	62.59	101.09	139.68	121128	189653	255804	129922	191250	284465
1997	49.82	86.98	131.26	130522	207912	291778	121694	185699	307653
1998	68.19	111.92	163.76	135530	216998	281334	118548	182699	284349
1999	55.34	100.42	150.87	113641	200475	270000	112785	180005	275857
2000	68.12	113.81	180.36	117156	192073	259842	109260	172874	292359
2001	60.92	97.71	159.97	126408	197645	277777	119125	178459	314487
2002	63.59	92.63	145.51	140431	206621	304640	120163	174829	279291
2003	69.36	99.72	159.87	116283	168135	254598	96414	139088	222549
2004	64.93	96.12	161.16	99999	146718	214738	85737	126404	201184
2005	60.48	86.54	134.30	74609	102840	150019	68426	93953	148948

Table 2. MSY (million pounds of tails) and effort (E_s) (nominal days fished) required to harvest MSY for total Gulf shrimp fishery (inshore and offshore); the total offshore component (state, territorial seas, and the EEZ); and the EEZ component only (three different estimates). The adjusted r2 value relates to the corresponding regression of catch rate on effort used to calculate MSY and $E_{(s)}$. Results are based on data beginning in 1990.The modified EEZ model estimates assume mean abundance and mean inshore and state territorial sea effort.

		Pooled		GLM	
		Value	r^2	Value	r^2
Total	MSY	156.7	0.86	158.7	0.87
	$E_{(s)}$	234,935		248,873	
Offshore	MSY	101.2	0.82	101.9	0.84
	$E_{(s)}$	178,765		165,700	
EEZ	MSY (Surplus Production)	62.6	0.69	64.9	0.81
	$E_{(s)}$	109,935		98,078	
	MSY (Modified Surplus Production)	58.8	0.85	62.9	0.88
	$E_{(s)}$	145,391		120,368	
	MSY (Modified Fox)	63.3	0.81	62.1	0.87
	$E_{(s)}$	199, 600		143,061	

Table 3. Estimates of maximum economic yield (MEY) using the pooled method for the EEZ in the Gulf of Mexico shrimp fishery, 1990 - 2005.

Pooled Method									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	50.7	106.0	62.8	108.3	61.0	126.7	52.0	63.4	242.2	33.3	37.3	56.3	19.8	18.7	165.3	76.9
1991	66.8	137.4	62.8	108.3	61.0	126.8	52.0	63.4	248.5	30.2	39.4	58.2	23.3	18.7	169.8	78.7
1992	57.7	140.9	62.8	108.3	60.2	130.6	52.9	65.3	232.5	29.0	32.8	52.7	21.1	19.3	154.9	77.6
1993	53.8	132.7	62.8	108.3	59.3	133.9	53.7	67.0	235.1	29.2	34.1	53.1	17.5	19.8	153.7	81.4
1994	54.7	117.9	62.8	108.3	55.5	145.3	56.0	72.7	308.2	32.5	44.3	72.0	18.7	21.4	188.9	119.2
1995	61.8	114.6	62.8	108.3	59.4	133.7	53.6	66.9	260.5	26.8	49.5	60.8	14.5	19.7	171.4	89.1
1996	62.5	121.1	62.8	108.3	60.6	128.8	52.5	64.4	233.1	29.4	43.1	52.3	12.8	19.0	156.6	76.5
1997	49.8	130.5	62.8	108.3	57.1	141.1	55.2	70.6	292.6	36.9	41.5	65.6	18.0	20.8	182.9	109.7
1998	68.2	135.5	62.8	108.3	62.7	113.8	48.7	56.9	207.7	23.3	51.2	47.2	11.9	16.8	150.5	57.2
1999	55.3	113.6	62.8	108.3	59.0	135.0	53.9	67.5	269.0	26.9	53.5	61.2	13.4	19.9	175.0	94.1
2000	68.1	117.2	62.8	108.3	62.8	104.4	46.0	52.2	240.7	35.0	61.9	56.9	13.1	15.4	182.4	58.3
2001	60.8	126.4	62.8	108.3	62.7	112.6	48.4	56.3	211.4	31.0	46.1	46.5	13.3	16.6	153.5	57.9
2002	63.5	140.4	62.8	108.3	61.4	91.6	41.9	45.8	135.1	21.8	32.2	27.9	10.9	13.5	106.3	28.8
2003	69.3	116.3	62.8	108.3	52.8	64.9	32.0	32.5	90.5	18.1	22.8	19.7	7.8	9.6	78.0	12.5
2004	64.0	100.0	62.8	108.3	53.2	65.9	32.4	33.0	94.0	20.1	23.2	20.5	7.4	9.7	80.8	13.2
2005	62.1	74.6	62.8	108.3	37.7	39.8	21.0	19.9	65.2	20.1	14.0	14.9	5.2	5.9	60.1	5.1

Table 4. Estimates of MEY using the GLM method for the EEZ in the Gulf of Mexico shrimp fishery, 1990 - 2005.

GLM Method									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	50.7	107.7	64.9	98.1	60.1	124.8	56.3	62.4	262.0	32.7	36.7	60.9	19.5	18.4	168.2	93.8
1991	66.8	140.0	64.9	98.1	60.1	124.8	56.3	62.4	268.8	29.7	38.8	63.0	22.9	18.4	172.8	96.0
1992	57.7	136.0	64.9	98.1	58.9	127.9	57.0	63.9	250.4	28.3	32.1	56.8	20.6	18.9	156.8	93.6
1993	53.8	129.4	64.9	98.1	57.8	130.5	57.6	65.2	252.2	28.5	33.2	56.9	17.0	19.2	154.9	97.3
1994	54.7	128.3	64.9	98.1	53.3	139.5	59.5	69.8	327.0	31.2	42.5	76.4	18.0	20.6	188.7	138.3
1995	61.8	124.9	64.9	98.1	57.9	130.3	57.6	65.1	279.6	26.1	48.2	65.3	14.2	19.2	173.0	106.6
1996	62.5	129.9	64.9	98.1	59.5	126.4	56.7	63.2	251.6	28.8	42.3	56.4	12.6	18.7	158.8	92.8
1997	49.8	121.7	64.9	98.1	55.1	136.2	58.8	68.1	311.7	35.6	40.1	69.8	17.4	20.1	183.1	128.6
1998	68.2	118.5	64.9	98.1	63.0	114.5	53.6	57.3	228.7	23.4	51.5	52.0	12.0	16.9	155.9	72.8
1999	55.3	112.8	64.9	98.1	57.4	131.3	57.8	65.7	288.3	26.2	52.1	65.6	13.0	19.4	176.2	112.1
2000	68.1	109.3	64.9	98.1	64.3	107.0	51.5	53.5	269.5	35.9	63.5	63.7	13.4	15.8	192.3	77.2
2001	60.8	119.1	64.9	98.1	63.3	113.5	53.4	56.8	233.3	31.2	46.5	51.3	13.4	16.8	159.2	74.1
2002	63.5	120.2	64.9	98.1	64.9	96.9	48.3	48.4	155.4	23.0	34.1	32.1	11.5	14.3	115.0	40.4
2003	69.3	96.4	64.9	98.1	61.5	75.6	40.4	37.8	114.1	21.1	26.6	24.8	9.1	11.2	92.8	21.3
2004	64.0	85.7	64.9	98.1	61.7	76.4	40.7	38.2	118.1	23.3	26.9	25.7	8.6	11.3	95.7	22.4
2005	62.1	68.4	64.9	98.1	52.8	55.7	31.6	27.9	98.2	28.1	19.6	22.5	7.3	8.2	85.7	12.5

Table 5. Difference in values between Table 4 (pooled) and Table 5 (GLM).

Difference in Methods									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	0.0	-1.7	-2.0	10.2	1.0	2.0	-4.3	1.0	-19.8	0.5	0.6	-4.6	0.3	0.3	-2.9	-16.9
1991	0.0	-2.6	-2.0	10.2	1.0	2.0	-4.3	1.0	-20.3	0.5	0.6	-4.8	0.4	0.3	-3.0	-17.3
1992	0.0	4.9	-2.0	10.2	1.3	2.8	-4.1	1.4	-17.8	0.6	0.7	-4.0	0.4	0.4	-1.9	-16.0
1993	0.0	3.4	-2.0	10.2	1.5	3.4	-3.9	1.7	-17.1	0.8	0.9	-3.9	0.5	0.5	-1.3	-15.9
1994	0.0	-10.5	-2.0	10.2	2.2	5.8	-3.4	2.9	-18.9	1.3	1.8	-4.4	0.7	0.9	0.3	-19.1
1995	0.0	-10.3	-2.0	10.2	1.5	3.4	-3.9	1.7	-19.0	0.7	1.3	-4.4	0.4	0.5	-1.6	-17.4
1996	0.0	-8.8	-2.0	10.2	1.1	2.4	-4.2	1.2	-18.4	0.5	0.8	-4.1	0.2	0.4	-2.2	-16.2
1997	0.0	8.8	-2.0	10.2	2.0	4.9	-3.6	2.5	-19.1	1.3	1.5	-4.3	0.6	0.7	-0.2	-18.9
1998	0.0	17.0	-2.0	10.2	-0.4	-0.7	-4.9	-0.3	-21.1	-0.1	-0.3	-4.8	-0.1	-0.1	-5.4	-15.7
1999	0.0	0.9	-2.0	10.2	1.6	3.7	-3.9	1.8	-19.3	0.7	1.5	-4.4	0.4	0.5	-1.3	-18.0
2000	0.0	7.9	-2.0	10.2	-1.6	-2.6	-5.5	-1.3	-28.8	-0.9	-1.6	-6.8	-0.3	-0.4	-10.0	-18.8
2001	0.0	7.3	-2.0	10.2	-0.5	-0.9	-5.0	-0.5	-21.9	-0.3	-0.4	-4.8	-0.1	-0.1	-5.7	-16.2
2002	0.0	20.3	-2.0	10.2	-3.5	-5.2	-6.3	-2.6	-20.4	-1.2	-1.8	-4.2	-0.6	-0.8	-8.7	-11.7
2003	0.0	19.9	-2.0	10.2	-8.7	-10.7	-8.4	-5.4	-23.6	-3.0	-3.8	-5.1	-1.3	-1.6	-14.8	-8.9
2004	0.0	14.3	-2.0	10.2	-8.5	-10.5	-8.3	-5.3	-24.0	-3.2	-3.7	-5.2	-1.2	-1.6	-14.9	-9.1
2005	0.0	6.2	-2.0	10.2	-15.1	-15.9	-10.6	-7.9	-33.1	-8.0	-5.6	-7.6	-2.1	-2.3	-25.6	-7.4

Table 6. Estimates of MEY using the pooled method for the offshore in the Gulf of Mexico shrimp fishery, 1990 - 2005.

Pooled Method									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	107.5	211.9	101.1	178.8	99.7	199.8	81.4	99.9	314.9	42.9	53.1	68.7	26.0	28.8	219.4	95.4
1991	107.3	223.4	101.1	178.8	99.7	200.4	81.6	100.2	338.5	44.7	54.6	75.0	32.8	28.9	235.9	102.6
1992	93.7	216.7	101.1	178.8	99.2	203.3	82.3	101.7	314.1	41.5	48.5	68.1	28.9	29.3	216.3	97.7
1993	86.4	204.5	101.1	178.8	100.4	194.3	80.1	97.1	295.1	42.5	49.6	64.5	24.4	28.0	209.0	86.0
1994	90.3	195.7	101.1	178.8	94.9	223.2	86.9	111.6	408.4	48.1	65.8	92.0	26.7	32.2	264.8	143.6
1995	93.9	176.6	101.1	178.8	97.8	211.0	84.1	105.5	368.9	39.7	74.6	83.8	21.1	30.4	249.5	119.4
1996	101.0	189.7	101.1	178.8	100.6	191.4	79.3	95.7	301.2	41.3	63.2	65.3	17.6	27.6	215.0	86.2
1997	86.9	207.9	101.1	178.8	98.0	210.2	84.0	105.1	373.0	51.4	64.3	81.5	24.1	30.3	251.6	121.4
1998	111.9	217.0	101.1	178.8	101.0	173.4	74.3	86.7	283.6	32.8	75.6	63.0	16.6	25.0	213.0	70.6
1999	100.4	200.5	101.1	178.8	100.0	197.5	80.9	98.7	333.2	36.5	78.0	73.5	17.6	28.5	234.1	99.1
2000	113.8	192.1	101.1	178.8	100.1	160.5	70.4	80.3	326.2	48.4	89.7	74.7	17.4	23.1	253.3	72.8
2001	97.6	197.6	101.1	178.8	100.9	170.3	73.4	85.1	282.9	43.6	67.1	60.4	17.8	24.5	213.3	69.5
2002	92.5	206.6	101.1	178.8	98.8	151.6	67.6	75.8	214.8	34.9	50.7	43.7	17.6	21.8	168.8	46.0
2003	99.7	168.1	101.1	178.8	85.2	107.7	51.8	53.9	143.1	28.8	36.0	30.5	12.3	15.5	123.2	20.0
2004	96.1	146.7	101.1	178.8	86.0	109.7	52.6	54.9	148.2	31.2	36.7	31.8	11.7	15.8	127.1	21.1
2005	86.5	102.8	101.1	178.8	60.3	65.2	33.5	32.6	100.9	31.0	21.8	22.9	8.0	9.4	93.1	7.8

Table 7. Estimates of MEY using the GLM method for the offshore in the Gulf of Mexico shrimp fishery, 1990 - 2005.

GLM Method									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	107.5	216.2	101.9	165.7	98.3	196.9	85.1	98.4	329.2	42.2	52.4	71.8	25.6	28.4	220.4	108.8
1991	107.3	217.7	101.9	165.7	98.2	197.4	85.3	98.7	353.7	44.0	53.8	78.3	32.3	28.4	236.9	116.8
1992	93.7	205.9	101.9	165.7	97.6	200.0	85.9	100.0	327.6	40.9	47.7	71.0	28.4	28.8	216.8	110.8
1993	86.4	184.1	101.9	165.7	99.3	192.2	83.9	96.1	309.4	42.1	49.1	67.6	24.2	27.7	210.6	98.8
1994	90.3	193.4	101.9	165.7	92.2	216.9	89.8	108.5	422.0	46.7	63.9	95.1	26.0	31.3	263.0	159.0
1995	93.9	184.0	101.9	165.7	95.7	206.5	87.4	103.2	383.3	38.8	73.0	87.0	20.7	29.7	249.2	134.0
1996	101.0	191.3	101.9	165.7	99.8	189.8	83.3	94.9	316.4	40.9	62.7	68.6	17.5	27.3	217.0	99.4
1997	86.9	185.7	101.9	165.7	95.9	205.8	87.3	102.9	387.8	50.3	63.0	84.7	23.6	29.7	251.3	136.5
1998	111.9	182.7	101.9	165.7	101.6	174.4	79.0	87.2	301.7	33.0	76.1	67.0	16.7	25.1	217.9	83.8
1999	100.4	180.0	101.9	165.7	98.7	195.0	84.6	97.5	348.8	36.1	77.0	77.0	17.4	28.1	235.5	113.3
2000	113.8	172.9	101.9	165.7	101.9	163.5	75.7	81.7	350.8	49.3	91.3	80.3	17.7	23.6	262.2	88.5
2001	97.6	178.5	101.9	165.7	101.8	171.8	78.3	85.9	301.7	43.9	67.7	64.4	17.9	24.7	218.7	83.0
2002	92.5	174.8	101.9	165.7	101.6	155.8	73.3	77.9	233.0	35.9	52.1	47.4	18.1	22.4	176.0	57.0
2003	99.7	139.1	101.9	165.7	93.6	118.4	59.8	59.2	165.4	31.6	39.6	35.3	13.5	17.1	137.1	28.3
2004	96.1	126.4	101.9	165.7	94.2	120.1	60.5	60.1	170.6	34.1	40.2	36.6	12.8	17.3	141.0	29.7
2005	86.5	94.0	101.9	165.7	76.0	82.2	44.3	41.1	133.3	39.0	27.5	30.2	10.1	11.8	118.7	14.6

Table 8. Difference in values between Table 6 (pooled) and Table 7 (GLM).

Difference in Methods									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	0.0	-4.3	-0.8	13.1	1.4	2.9	-3.7	1.4	-14.3	0.6	0.8	-3.1	0.4	0.4	-1.0	-13.3
1991	0.0	5.7	-0.8	13.1	1.5	2.9	-3.7	1.5	-15.2	0.7	0.8	-3.4	0.5	0.4	-1.0	-14.2
1992	0.0	10.7	-0.8	13.1	1.7	3.4	-3.6	1.7	-13.6	0.7	0.8	-2.9	0.5	0.5	-0.5	-13.1
1993	0.0	20.4	-0.8	13.1	1.1	2.1	-3.9	1.0	-14.3	0.5	0.5	-3.1	0.3	0.3	-1.6	-12.7
1994	0.0	2.4	-0.8	13.1	2.7	6.3	-2.9	3.2	-13.6	1.4	1.9	-3.1	0.8	0.9	1.8	-15.4
1995	0.0	-7.4	-0.8	13.1	2.1	4.5	-3.3	2.3	-14.4	0.8	1.6	-3.3	0.5	0.7	0.3	-14.7
1996	0.0	-1.6	-0.8	13.1	0.9	1.6	-4.0	0.8	-15.2	0.4	0.5	-3.3	0.2	0.2	-2.0	-13.2
1997	0.0	22.2	-0.8	13.1	2.1	4.4	-3.3	2.2	-14.7	1.1	1.3	-3.2	0.5	0.6	0.3	-15.1
1998	0.0	34.3	-0.8	13.1	-0.6	-1.0	-4.7	-0.5	-18.1	-0.2	-0.4	-4.0	-0.1	-0.1	-4.9	-13.2
1999	0.0	20.5	-0.8	13.1	1.3	2.5	-3.8	1.3	-15.5	0.5	1.0	-3.4	0.2	0.4	-1.4	-14.2
2000	0.0	19.2	-0.8	13.1	-1.8	-2.9	-5.3	-1.5	-24.6	-0.9	-1.6	-5.6	-0.3	-0.4	-8.9	-15.7
2001	0.0	19.2	-0.8	13.1	-0.9	-1.5	-4.9	-0.7	-18.8	-0.4	-0.6	-4.0	-0.2	-0.2	-5.3	-13.4
2002	0.0	31.8	-0.8	13.1	-2.8	-4.2	-5.7	-2.1	-18.2	-1.0	-1.4	-3.7	-0.5	-0.6	-7.2	-11.0
2003	0.0	29.0	-0.8	13.1	-8.5	-10.7	-8.1	-5.3	-22.3	-2.9	-3.6	-4.7	-1.2	-1.5	-13.9	-8.3
2004	0.0	20.3	-0.8	13.1	-8.2	-10.4	-7.9	-5.2	-22.4	-3.0	-3.5	-4.8	-1.1	-1.5	-13.8	-8.6
2005	0.0	8.9	-0.8	13.1	-15.7	-17.0	-10.7	-8.5	-32.3	-8.1	-5.7	-7.3	-2.1	-2.4	-25.6	-6.8

Table 9. Estimates of MEY using the pooled method for the Total Gulf of Mexico shrimp fishery, 1990 - 2005.

Pooled Method									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	159.2	306.8	156.5	235.0	140.6	309.9	138.4	154.9	473.5	49.4	56.5	92.8	31.2	56.3	286.2	187.2
1991	144.8	299.8	156.5	235.0	142.4	305.6	137.4	152.8	514.4	54.4	61.3	104.8	41.0	55.5	317.0	197.4
1992	138.1	319.9	156.5	235.0	136.8	318.3	140.2	159.1	484.9	47.6	51.3	93.5	34.2	57.8	284.5	200.4
1993	128.4	289.2	156.5	235.0	144.9	298.9	135.8	149.5	437.1	49.5	54.1	85.9	29.4	54.3	273.3	163.8
1994	131.4	299.2	156.5	235.0	127.8	335.5	143.7	167.8	601.5	54.0	67.5	121.4	31.0	61.0	334.9	266.6
1995	145.6	250.9	156.5	235.0	137.1	317.7	140.1	158.9	524.7	44.5	78.2	106.2	24.4	57.7	311.0	213.7
1996	139.6	253.5	156.5	235.0	146.5	294.4	134.7	147.2	454.1	50.2	72.4	90.1	21.8	53.5	288.1	166.0
1997	131.2	291.7	156.5	235.0	135.1	321.8	141.0	160.9	546.8	57.5	67.9	106.2	27.3	58.5	317.4	229.4
1998	163.7	280.6	156.5	235.0	151.7	276.0	129.9	138.0	424.5	40.0	87.7	85.8	20.0	50.1	283.7	140.8
1999	150.8	270.5	156.5	235.0	147.0	293.0	134.3	146.5	462.8	42.6	86.5	92.7	20.1	53.2	295.1	167.7
2000	180.3	260.1	156.5	235.0	151.8	275.7	129.8	137.9	505.4	60.4	104.5	102.0	20.9	50.1	337.9	167.4
2001	159.8	277.9	156.5	235.0	149.8	283.5	131.9	141.8	427.0	52.0	73.8	79.5	20.2	51.5	276.9	150.1
2002	145.3	304.6	156.5	235.0	156.3	244.2	120.4	122.1	324.3	46.2	61.0	59.8	20.1	44.4	231.4	92.8
2003	159.7	254.6	156.5	235.0	150.4	188.3	100.3	94.2	229.2	41.8	47.1	44.6	15.2	34.2	182.9	46.3
2004	161.2	214.7	156.5	235.0	148.6	182.1	97.8	91.0	220.3	42.5	45.5	43.0	13.6	33.1	177.7	42.6
2005	134.4	150.0	156.5	235.0	139.4	157.2	87.2	78.6	225.0	60.9	39.3	47.6	13.0	28.6	189.4	35.6

Table 10. Estimates of MEY using the GLM method for the Total Gulf of Mexico shrimp fishery, 1990 - 2005.

GLM Method									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	159.2	359.5	158.7	248.9	145.5	320.6	138.6	160.3	474.2	51.1	58.4	93.0	32.3	58.3	293.1	181.1
1991	144.8	324.2	158.7	248.9	147.1	315.9	137.5	158.0	514.8	56.2	63.3	104.9	42.4	57.4	324.2	190.5
1992	138.1	346.9	158.7	248.9	141.8	329.9	140.6	165.0	486.4	49.4	53.2	93.8	35.5	59.9	291.8	194.6
1993	128.4	296.3	158.7	248.9	149.6	308.5	135.7	154.3	436.9	51.1	55.9	85.9	30.3	56.0	279.3	157.6
1994	131.4	317.1	158.7	248.9	133.0	349.0	144.5	174.5	604.8	56.2	70.3	122.1	32.3	63.4	344.2	260.6
1995	145.6	306.4	158.7	248.9	142.1	329.3	140.5	164.6	526.2	46.1	81.1	106.5	25.2	59.8	318.7	207.4
1996	139.6	284.5	158.7	248.9	151.0	303.5	134.5	151.8	453.5	51.8	74.6	90.0	22.5	55.1	294.1	159.5
1997	131.2	307.7	158.7	248.9	140.2	333.8	141.5	166.9	548.7	59.6	70.5	106.6	28.4	60.6	325.7	223.1
1998	163.7	284.3	158.7	248.9	155.7	283.1	129.2	141.6	422.2	41.0	90.0	85.3	20.6	51.4	288.3	133.9
1999	150.8	275.9	158.7	248.9	151.4	302.0	134.1	151.0	462.1	43.9	89.1	92.5	20.7	54.9	301.2	160.9
2000	180.3	292.4	158.7	248.9	155.7	282.8	129.1	141.4	502.6	61.9	107.2	101.5	21.5	51.4	343.4	159.2
2001	159.8	314.5	158.7	248.9	154.0	291.4	131.4	145.7	425.5	53.4	75.8	79.2	20.8	52.9	282.2	143.4
2002	145.3	279.3	158.7	248.9	158.7	247.9	118.7	124.0	319.7	46.9	62.0	59.0	20.4	45.0	233.2	86.5
2003	159.7	222.5	158.7	248.9	148.6	186.1	96.5	93.1	220.4	41.3	46.5	42.9	15.0	33.8	179.6	40.8
2004	161.2	201.2	158.7	248.9	146.2	179.2	93.7	89.6	211.0	41.8	44.8	41.2	13.4	32.6	173.7	37.3
2005	134.4	148.9	158.7	248.9	134.4	151.6	81.9	75.8	211.5	58.8	37.9	44.8	12.6	27.5	181.5	30.0

Table 11. Difference in values between Table 9 (pooled) and Table 10 (GLM).

Difference in Methods									Values at MEY							
Year	Actual Landings (mil. lbs tails)	Actual Effort (1000 d. f.)	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity Costs (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1990	0.0	-52.7	-2.2	-13.9	-4.9	-10.7	-0.2	-5.4	-0.7	-1.7	-2.0	-0.1	-1.1	-2.0	-6.9	6.1
1991	0.0	-24.3	-2.2	-13.9	-4.8	-10.3	-0.1	-5.1	-0.4	-1.8	-2.1	-0.1	-1.4	-1.9	-7.2	6.8
1992	0.0	-27.0	-2.2	-13.9	-5.0	-11.6	-0.4	-5.8	-1.4	-1.7	-1.9	-0.3	-1.3	-2.1	-7.3	5.8
1993	0.0	-7.1	-2.2	-13.9	-4.6	-9.6	0.1	-4.8	0.2	-1.6	-1.7	0.0	-0.9	-1.7	-6.0	6.2
1994	0.0	-17.9	-2.2	-13.9	-5.1	-13.5	-0.8	-6.7	-3.3	-2.2	-2.7	-0.7	-1.2	-2.4	-9.2	5.9
1995	0.0	-55.5	-2.2	-13.9	-5.0	-11.6	-0.4	-5.8	-1.5	-1.6	-2.9	-0.3	-0.9	-2.1	-7.8	6.3
1996	0.0	-31.0	-2.2	-13.9	-4.5	-9.1	0.2	-4.5	0.6	-1.6	-2.2	0.1	-0.7	-1.7	-6.0	6.6
1997	0.0	-16.0	-2.2	-13.9	-5.0	-12.0	-0.5	-6.0	-1.9	-2.1	-2.5	-0.4	-1.0	-2.2	-8.3	6.3
1998	0.0	-3.7	-2.2	-13.9	-3.9	-7.1	0.7	-3.6	2.3	-1.0	-2.3	0.5	-0.5	-1.3	-4.7	6.9
1999	0.0	-5.4	-2.2	-13.9	-4.5	-8.9	0.2	-4.5	0.7	-1.3	-2.6	0.1	-0.6	-1.6	-6.0	6.8
2000	0.0	-32.3	-2.2	-13.9	-3.9	-7.1	0.7	-3.5	2.7	-1.6	-2.7	0.5	-0.5	-1.3	-5.5	8.2
2001	0.0	-36.6	-2.2	-13.9	-4.2	-7.9	0.5	-4.0	1.5	-1.5	-2.1	0.3	-0.6	-1.4	-5.2	6.8
2002	0.0	25.3	-2.2	-13.9	-2.4	-3.7	1.7	-1.9	4.6	-0.7	-0.9	0.8	-0.3	-0.7	-1.8	6.4
2003	0.0	32.0	-2.2	-13.9	1.8	2.2	3.8	1.1	8.8	0.5	0.6	1.7	0.2	0.4	3.3	5.4
2004	0.0	13.6	-2.2	-13.9	2.4	2.9	4.1	1.4	9.3	0.7	0.7	1.8	0.2	0.5	3.9	5.3
2005	0.0	1.1	-2.2	-13.9	4.9	5.5	5.2	2.8	13.5	2.1	1.4	2.9	0.5	1.0	7.9	5.7

Table 12. Summary of maximum economic yield (MEY) results (landings in millions of pounds of tails, effort in thousands of days fished).

Year	Model	Area	MSY	OAE	Actual Landings	MEY	E_{MSY}	E_{OAE}	Actual Effort	E_{MEY}
1990	GLM	EEZ	64.9	60.1	50.7	56.3	98.1	124.8	107.7	62.4
1995	GLM	EEZ	64.9	57.9	61.8	57.6	98.1	130.3	124.9	65.1
2000	GLM	EEZ	64.9	64.3	68.1	51.5	98.1	107.0	109.3	53.5
2005	GLM	EEZ	64.9	52.8	62.1	31.6	98.1	55.7	68.4	27.9
1990	GLM	Offshore	101.9	98.3	107.5	85.1	165.7	196.9	216.2	98.4
1995	GLM	Offshore	101.9	95.7	93.9	87.4	165.7	206.5	184.0	103.2
2000	GLM	Offshore	101.9	101.9	113.8	75.7	165.7	163.5	172.9	81.7
2005	GLM	Offshore	101.9	76.0	86.5	44.3	165.7	82.2	94.0	41.1
1990	GLM	Total	158.7	145.5	159.2	138.6	248.9	320.6	359.5	160.3
1995	GLM	Total	158.7	142.1	145.6	140.5	248.9	329.3	306.4	164.6
2000	GLM	Total	158.7	155.7	180.3	129.1	248.9	282.8	292.4	141.4
2005	GLM	Total	158.7	134.4	134.4	81.9	248.9	151.6	148.9	75.8
1990	Pooled	EEZ	62.8	61.0	50.7	52.0	108.3	126.7	106.0	63.4
1995	Pooled	EEZ	62.8	59.4	61.8	53.6	108.3	133.7	114.6	66.9
2000	Pooled	EEZ	62.8	62.8	68.1	46.0	108.3	104.4	117.2	52.2
2005	Pooled	EEZ	62.8	37.7	62.1	21.0	108.3	39.8	87.6	19.9
1990	Pooled	Offshore	101.1	99.7	107.5	81.4	178.8	199.8	211.9	99.9
1995	Pooled	Offshore	101.1	100.6	93.9	84.1	178.8	211.0	176.6	105.5
2000	Pooled	Offshore	101.1	100.1	113.8	70.4	178.8	160.5	192.1	80.3
2005	Pooled	Offshore	101.1	60.3	86.5	33.5	178.8	65.2	106.6	32.6
1990	Pooled	Total	156.5	140.6	159.2	138.4	235.0	309.9	306.8	154.9
1995	Pooled	Total	156.5	137.1	145.6	140.1	235.0	317.7	250.9	158.9
2000	Pooled	Total	156.5	151.8	180.3	129.8	235.0	275.7	260.1	137.9
2005	Pooled	Total	156.5	139.4	134.4	87.2	235.0	157.2	153.8	78.6

Table 13. Sensitivity analysis results from the pooled method for the EEZ. Base values are in italics.

Pooled Method 2005 Base Year								Values at MEY							
Price per Lb.	Price per Gal. Fuel	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
3.11	*1.97*	*62.8*	*108*	*21*	*20*	*38*	*40*	*65*	*20*	*14*	*15*	*5*	*6*	*60*	*5.1*
3.50	1.75	62.8	108.3	33.0	33.7	53.9	67.4	115.6	30.2	23.7	26.5	8.8	9.9	99.2	16.4
3.25	1.75	62.8	108.3	28.3	28.0	48.2	55.9	91.9	25.1	19.7	21.0	7.3	8.3	81.4	10.5
3.00	1.75	62.8	108.3	22.3	21.3	39.7	42.6	66.8	19.1	15.0	15.3	5.6	6.3	61.2	5.6
2.75	1.75	62.8	108.3	14.6	13.4	27.2	26.7	40.0	12.0	9.4	9.2	3.5	3.9	38.0	2.0
3.50	2.00	62.8	108.3	29.4	29.3	49.6	58.6	102.9	30.0	20.6	23.6	7.7	8.6	90.5	12.4
3.25	2.00	62.8	108.3	24.0	23.2	42.3	46.4	78.2	23.8	16.3	17.9	6.1	6.8	70.9	7.2
3.00	2.00	62.8	108.3	17.3	16.1	31.8	32.2	51.9	16.5	11.3	11.9	4.2	4.8	48.7	3.2
2.75	2.00	62.8	108.3	8.7	7.7	16.7	15.5	23.8	7.9	5.4	5.5	2.0	2.3	23.1	0.7
3.50	2.25	62.8	108.3	25.5	24.9	44.5	49.7	89.4	28.6	17.5	20.5	6.5	7.3	80.4	8.9
3.25	2.25	62.8	108.3	19.6	18.4	35.5	36.9	63.6	21.2	13.0	14.6	4.8	5.4	59.1	4.6
3.00	2.25	62.8	108.3	12.1	11.0	22.8	21.9	36.2	12.6	7.7	8.3	2.9	3.2	34.7	1.5
2.75	2.25	62.8	108.3	2.4	2.1	4.8	4.2	6.6	2.4	1.5	1.5	0.6	0.6	6.6	0.1
3.50	2.50	62.8	108.3	21.5	20.4	38.5	40.9	75.2	26.2	14.4	17.2	5.4	6.0	69.1	6.0
3.25	2.50	62.8	108.3	14.9	13.7	27.7	27.3	48.3	17.5	9.6	11.1	3.6	4.0	45.8	2.5
3.00	2.50	62.8	108.3	6.5	5.8	12.7	11.6	19.6	7.4	4.1	4.5	1.5	1.7	19.2	0.4
2.75	2.50	62.8	108.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.50	2.75	62.8	108.3	17.2	16.0	31.7	32.0	60.2	22.5	11.3	13.8	4.2	4.7	56.5	3.7
3.25	2.75	62.8	108.3	9.9	8.9	19.0	17.8	32.2	12.5	6.3	7.4	2.3	2.6	31.1	1.1
3.00	2.75	62.8	108.3	0.7	0.6	1.4	1.2	2.2	0.9	0.4	0.5	0.2	0.2	2.2	0.0
2.75	2.75	62.8	108.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 14. Sensitivity analysis of the pooled method for the Offshore. Base values are in italics.

Pooled Method 2005 Base Year							Values at MEY							
Price per Gal. Fuel	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
1.97	*101.1*	*178.8*	*33.5*	*32.6*	*60.3*	*65.2*	*100.9*	*31.0*	*21.8*	*22.9*	*8.0*	*9.4*	*93.1*	*7.8*
1.75	101.1	178.8	55.9	59.3	89.7	118.5	195.8	50.0	39.6	44.4	14.6	17.1	165.7	30.1
1.75	101.1	178.8	48.7	50.1	81.6	100.2	158.4	42.2	33.5	35.9	12.3	14.4	138.4	19.9
1.75	101.1	178.8	39.6	39.4	69.5	78.7	118.9	33.2	26.3	27.0	9.7	11.3	107.5	11.4
1.75	101.1	178.8	27.9	26.7	51.4	53.4	76.8	22.5	17.8	17.4	6.6	7.7	72.0	4.8
2.00	101.1	178.8	50.5	52.2	83.7	104.5	176.6	50.4	34.9	40.1	12.9	15.1	153.3	23.4
2.00	101.1	178.8	42.4	42.5	73.3	85.0	137.7	41.0	28.4	31.2	10.5	12.2	123.3	14.4
2.00	101.1	178.8	32.2	31.1	58.2	62.3	96.5	30.0	20.8	21.9	7.7	9.0	89.4	7.1
2.00	101.1	178.8	19.1	17.7	36.1	35.5	52.4	17.1	11.9	11.9	4.4	5.1	50.3	2.1
2.25	101.1	178.8	44.7	45.2	76.4	90.4	156.4	49.0	30.2	35.5	11.1	13.0	138.9	17.5
2.25	101.1	178.8	35.7	34.9	63.6	69.9	115.9	37.9	23.3	26.3	8.6	10.1	106.2	9.7
2.25	101.1	178.8	24.3	22.9	45.3	45.9	72.9	24.9	15.3	16.5	5.7	6.6	69.0	3.9
2.25	101.1	178.8	9.7	8.8	18.9	17.6	26.6	9.5	5.9	6.0	2.2	2.5	26.1	0.5
2.50	101.1	178.8	38.6	38.2	67.9	76.3	135.0	46.0	25.5	30.6	9.4	11.0	122.5	12.5
2.50	101.1	178.8	28.6	27.3	52.4	54.7	92.9	33.0	18.3	21.1	6.7	7.9	86.9	5.9
2.50	101.1	178.8	16.0	14.7	30.6	29.5	48.0	17.8	9.8	10.9	3.6	4.2	46.4	1.6
2.50	101.1	178.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.75	101.1	178.8	32.2	31.1	58.2	62.3	112.5	41.3	20.8	25.5	7.7	9.0	104.2	8.3
2.75	101.1	178.8	21.1	19.8	39.8	39.5	68.7	26.2	13.2	15.6	4.9	5.7	65.6	3.1
2.75	101.1	178.8	7.2	6.5	14.2	13.1	21.7	8.6	4.4	4.9	1.6	1.9	21.4	0.3
2.75	101.1	178.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 15. Sensitivity analysis of the pooled method for the total Gulf of Mexico. Base values are in italics.

Pooled Method 2005 Base Year								Values at MEY							
Price per lb.	Price per Gal. Fuel	MSY (mil. lbs tails)	E_{MSY} (1000 d. f.)	MEY (mil. lbs tails)	E_{MEY} (1000 d. f.)	OAE (mil. lbs tails)	E_{OAE} (1000 d. f.)	Value (mil. $)	Fuel (mil. $)	M&S (mil. $)	Shares (mil. $)	Overhead (mil. $)	Opportunity (mil. $)	Total Cost (mil. $)	Value Less Total Cost (mil. $)
2.58	*1.97*	*156.5*	*235.0*	*87.2*	*78.6*	*139.4*	*157.2*	*225.0*	*60.9*	*39.3*	*47.6*	*13.0*	*28.6*	*189.4*	*35.6*
3.50	1.75	156.5	235.0	122.3	125.2	155.8	250.3	428.2	86.2	62.6	90.6	20.8	45.5	305.6	122.6
3.25	1.75	156.5	235.0	116.9	116.7	156.5	233.4	379.8	80.4	58.4	80.4	19.4	42.4	280.9	99.0
3.00	1.75	156.5	235.0	110.0	106.9	155.2	213.7	330.0	73.6	53.4	69.8	17.7	38.8	253.4	76.6
2.75	1.75	156.5	235.0	101.2	95.2	150.9	190.4	278.2	65.6	47.6	58.9	15.8	34.6	222.4	55.7
3.50	2.00	156.5	235.0	118.3	118.9	156.5	237.8	414.1	93.6	59.4	87.6	19.7	43.2	303.5	110.5
3.25	2.00	156.5	235.0	112.2	109.9	155.9	219.9	364.7	86.5	55.0	77.2	18.2	40.0	276.9	87.8
3.00	2.00	156.5	235.0	104.5	99.5	152.9	199.1	313.5	78.3	49.8	66.3	16.5	36.2	247.1	66.4
2.75	2.00	156.5	235.0	94.6	87.2	146.1	174.4	260.2	68.6	43.6	55.1	14.5	31.7	213.5	46.8
3.50	2.25	156.5	235.0	114.1	112.6	156.2	225.2	399.2	99.7	56.3	84.5	18.7	40.9	300.0	99.2
3.25	2.25	156.5	235.0	107.3	103.2	154.2	206.3	348.6	91.3	51.6	73.8	17.1	37.5	271.3	77.3
3.00	2.25	156.5	235.0	98.7	92.2	149.3	184.4	296.2	81.6	46.1	62.7	15.3	33.5	239.2	57.0
2.75	2.25	156.5	235.0	87.7	79.2	139.9	158.4	241.3	70.1	39.6	51.1	13.1	28.8	202.7	38.6
3.50	2.50	156.5	235.0	109.6	106.3	155.1	212.6	383.5	104.6	53.2	81.2	17.6	38.6	295.1	88.4
3.25	2.50	156.5	235.0	102.1	96.4	151.5	192.8	331.8	94.8	48.2	70.2	16.0	35.0	264.3	67.5
3.00	2.50	156.5	235.0	92.6	84.9	144.4	169.7	277.9	83.5	42.4	58.8	14.1	30.8	229.6	48.3
2.75	2.50	156.5	235.0	80.5	71.2	132.2	142.4	221.4	70.1	35.6	46.8	11.8	25.9	190.2	31.2
3.50	2.75	156.5	235.0	104.9	100.0	153.1	200.0	367.1	108.2	50.0	77.7	16.6	36.3	288.8	78.2
3.25	2.75	156.5	235.0	96.6	89.6	147.7	179.3	314.1	97.0	44.8	66.5	14.9	32.6	255.7	58.4
3.00	2.75	156.5	235.0	86.2	77.5	138.4	155.0	258.7	83.9	38.8	54.7	12.9	28.2	218.4	40.3
2.75	2.75	156.5	235.0	72.9	63.2	123.1	126.4	200.4	68.4	31.6	42.4	10.5	23.0	175.9	24.6

Table 16. Maximum sustainable yield (MSY) in million pounds of tails and effort at MSY (E_{MSY}) in nominal days fished required to harvest MSY for total Gulf of Mexico shrimp fishery (inshore and offshore), the offshore component, and the EEZ component. The adjusted r^2 value relates to the corresponding regression of catch rate on effort used to calculate MSY and E_{MSY}. E_{MSY} comparisons are made against both 2001 - 2003 average effort and 2005 effort.

Model	Area	MSY(millions)	E_{MSY}	Adj. r^2	2001 to 2003 average effort	2005 effort	E_{MSY} minus 2001 to 2003 average effort	E_{MSY} minus 2005 effort
Pooled	Total	156.7	234,935	0.86	279,005	150,019	-44,070	84,916
GLM	Total	158.7	248,873	0.87	272,109	148,948	-23,236	99,925
Pooled	Offshore	101.2	178,765	0.82	190,800	102,840	-12,035	75,925
GLM	Offshore	101.9	165,700	0.84	164,125	93,953	1,575	71,747
Pooled	EEZ	62.6	109,935	0.69	127,707	74,609	-17,772	35,326
GLM	EEZ	64.9	98,078	0.81	111,901	68,426	-13,823	29,652

Table 17. Maximum economic yield (MEY) in million pounds of tails and effort at MEY (E_{MEY}) in nominal days fished required to harvest MEY for total Gulf of Mexico shrimp fishery (inshore and offshore), the offshore component, and the EEZ component in 2005. E_{MEY} in 2005 comparisons are made against both 2001 - 2003 average effort and 2005 effort.

Model	Area	MEY(millions)	E_{MEY}	2001 to 2003 average effort	2005 effort	E_{MEY} minus 2001 to 2003 average effort	E_{MEY} minus 2005 effort
Pooled	Total	87.2	78.6	279.0	150.0	-200.4	-71.4
GLM	Total	81.9	75.8	272.1	148.9	-196.3	-73.1
Pooled	Offshore	33.5	32.6	190.8	102.8	-158.2	-70.2
GLM	Offshore	44.3	41.1	164.1	94.0	-123.0	-52.9
Pooled	EEZ	21.0	19.9	127.7	74.6	-107.8	-54.7
GLM	EEZ	31.6	27.9	111.9	68.4	-84.0	-40.5

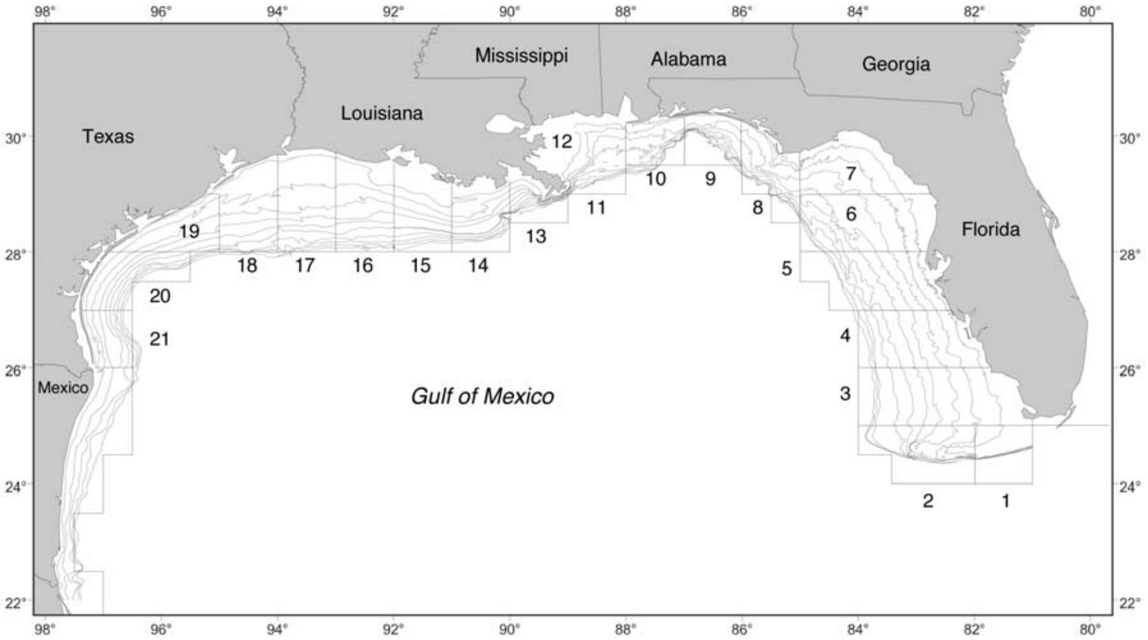


Figure 1. Statistical subareas and depth zones (five fathom increments) for the Gulf of Mexico.

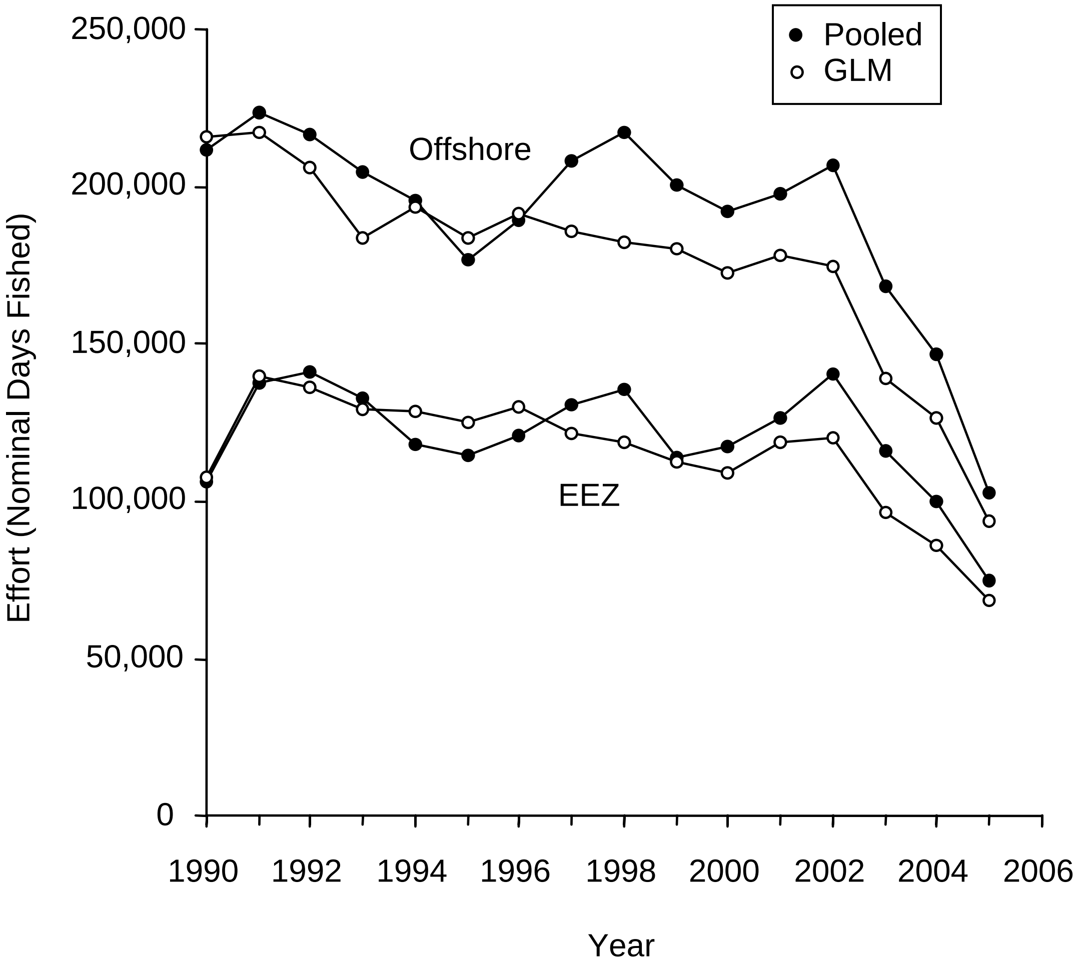


Figure 2. Total offshore and EEZ shrimp fishing effort levels (nominal days fished), 1990-2005. “Pooled” and “GLM” refer to the method used to expand sample effort to the total effort.

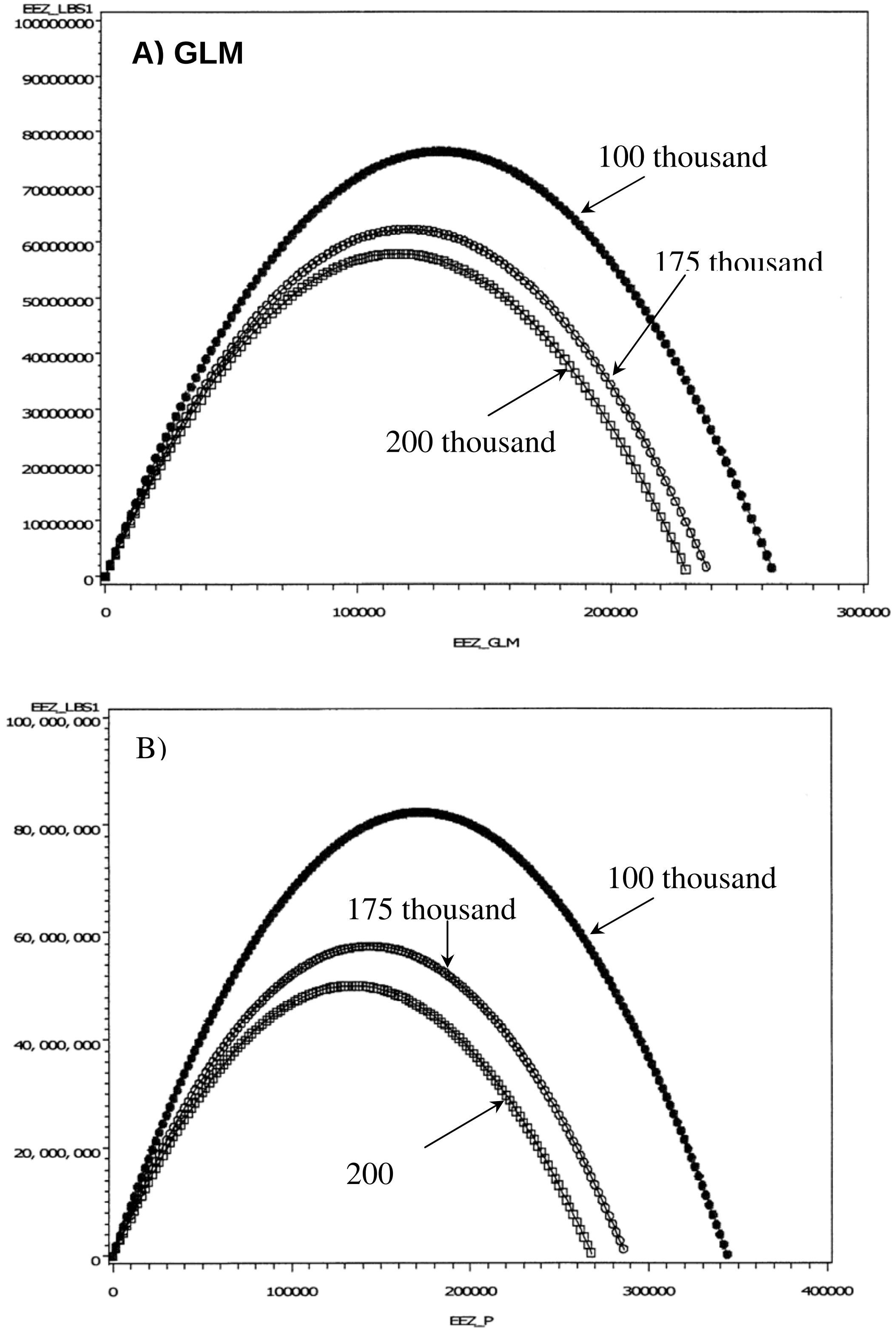


Figure 3. Modified surplus production model results beginning in 1990 using A) GLM data and B) pooled data. Inshore effort was set at three levels: 100 thousand days fished (upper curves), 175 thousand days fished (middle curves), and 200 thousand days fished (bottom curves).

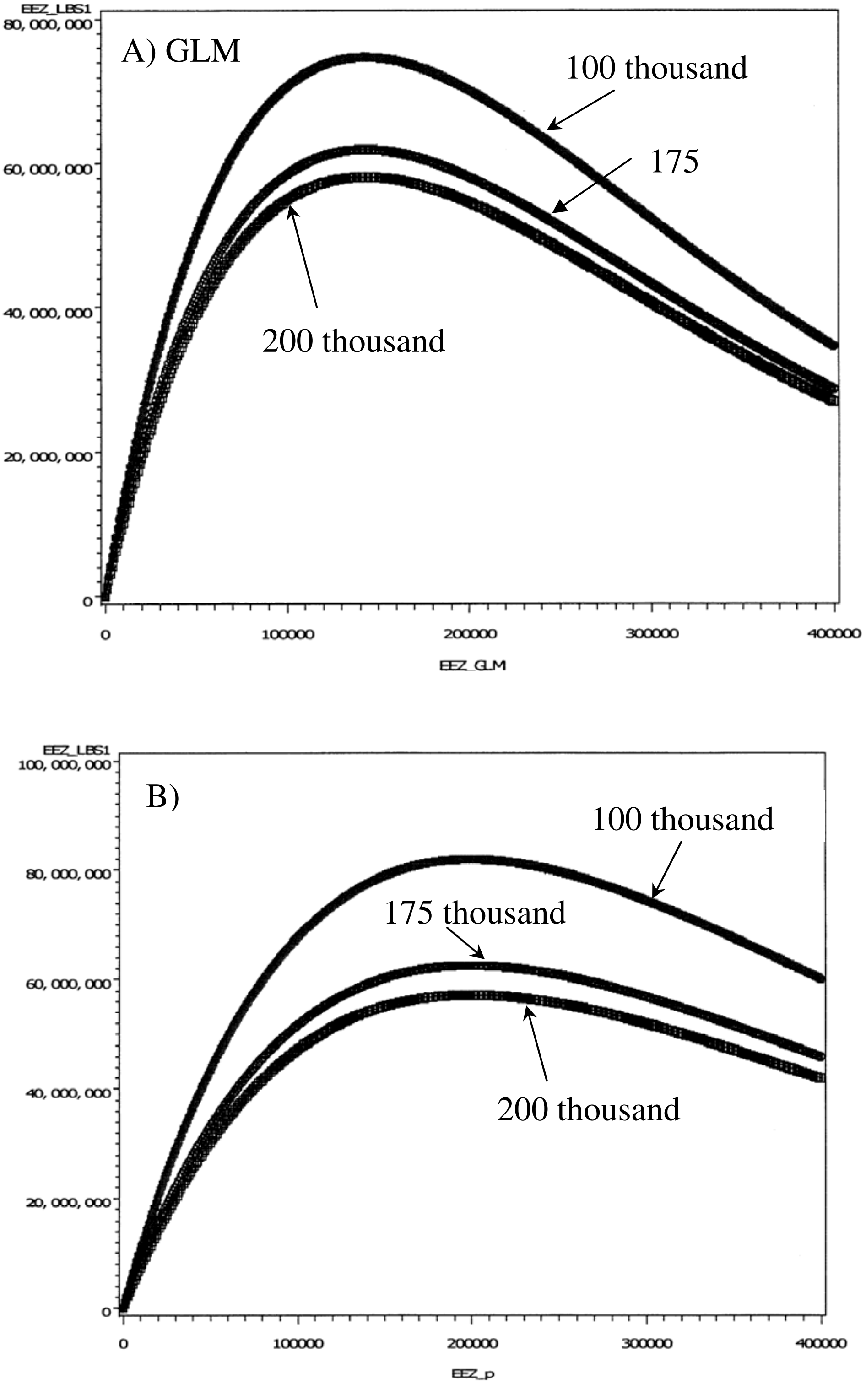


Figure 4. Modified Fox model results beginning in 1990 using A) GLM data and B) pooled data. Inshore effort was set at three levels: 100 thousand days fished (upper curves), 175 thousand days fished (middle curves), and 200 thousand days fished (bottom curves).

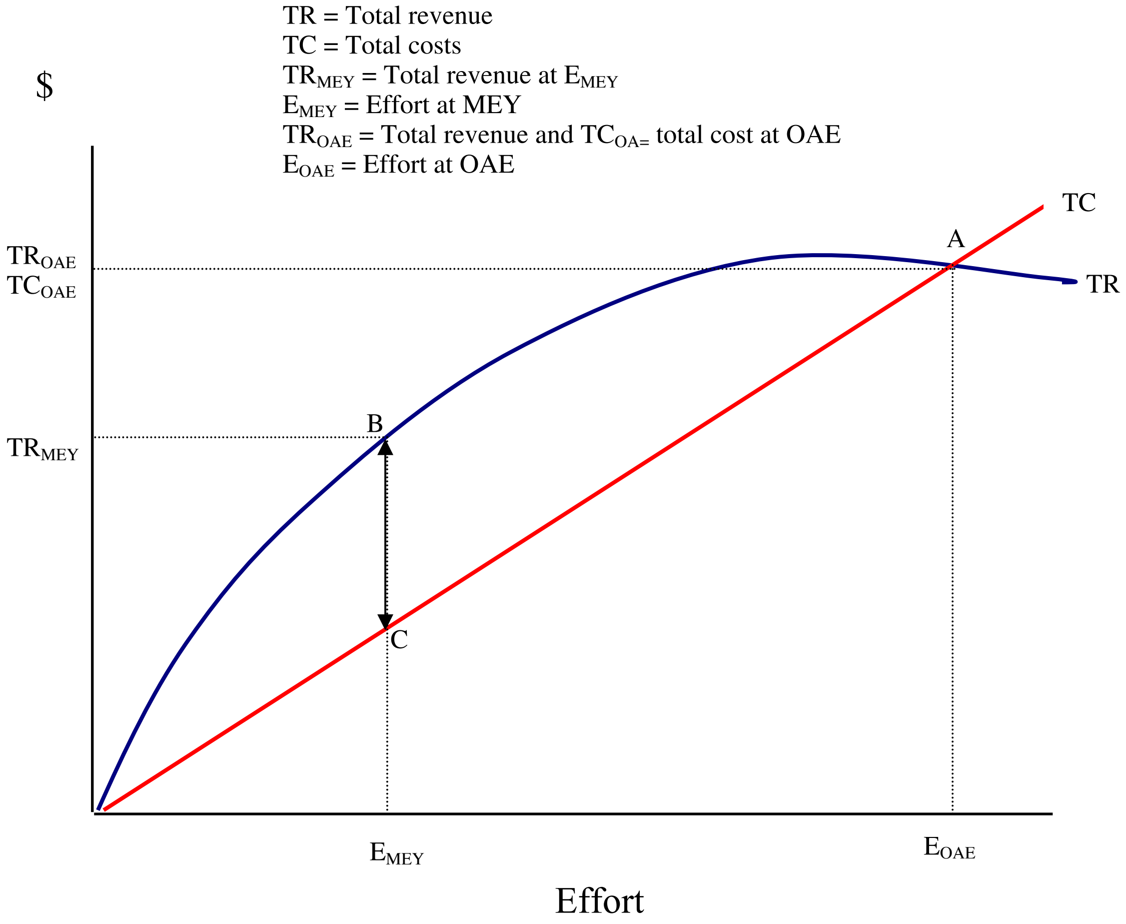


Figure 5. Revenue (curved line) and cost (straight line) curves showing 1) the level of effort (E_{MEY})associated with maximum yield (MEY) and 2) the level of effort (E_{OAE}) associated with long-term, open-access equilibrium (OAE) where costs and revenues are equal.

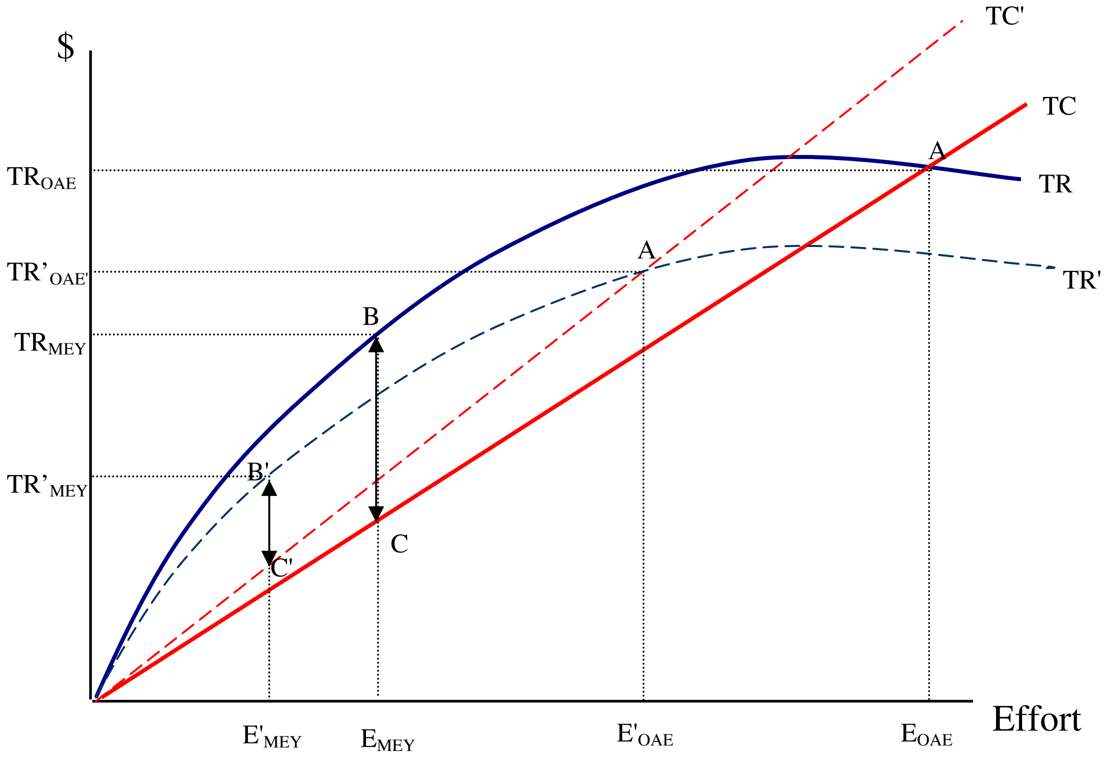


Figure 6. Impacts of decreased revenue and increased costs per unit of effort on maximum economic yield (MEY) and open access equilibrium (OAE).

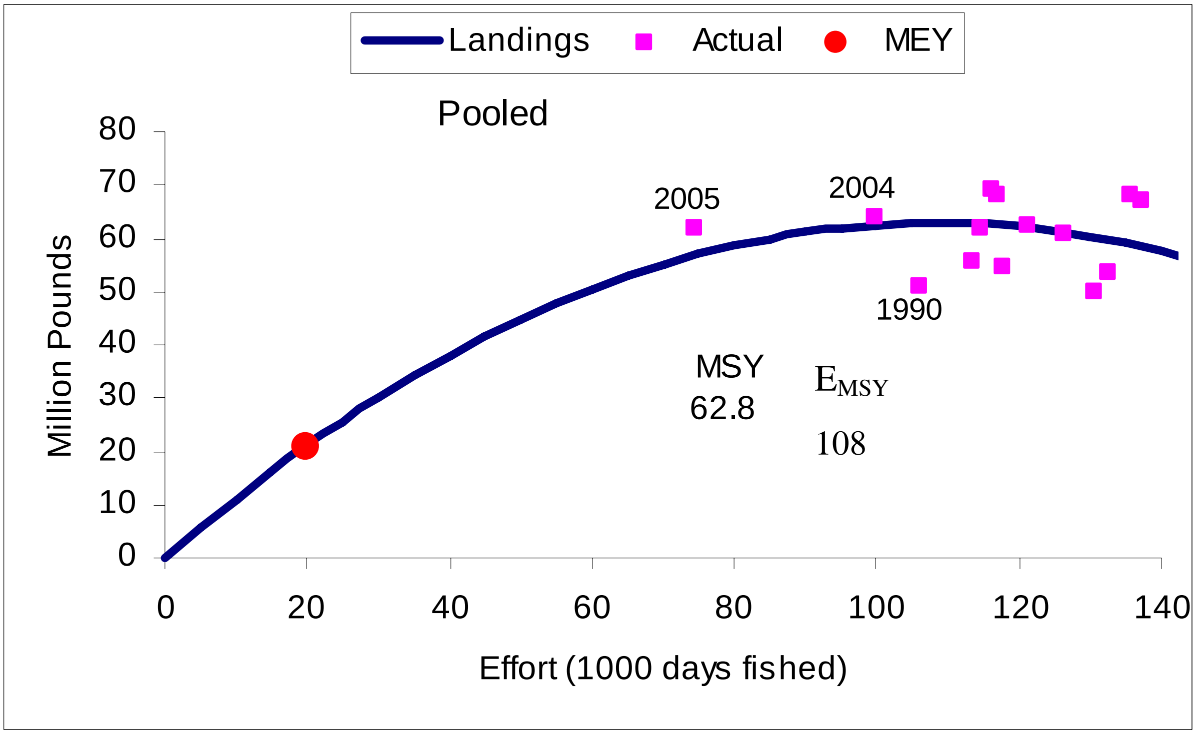


Figure 7. Yield curve and actual data in the EEZ for the period 1990-2005 Gulf of Mexico shrimp fishery. Round dot is MEY in 2005.

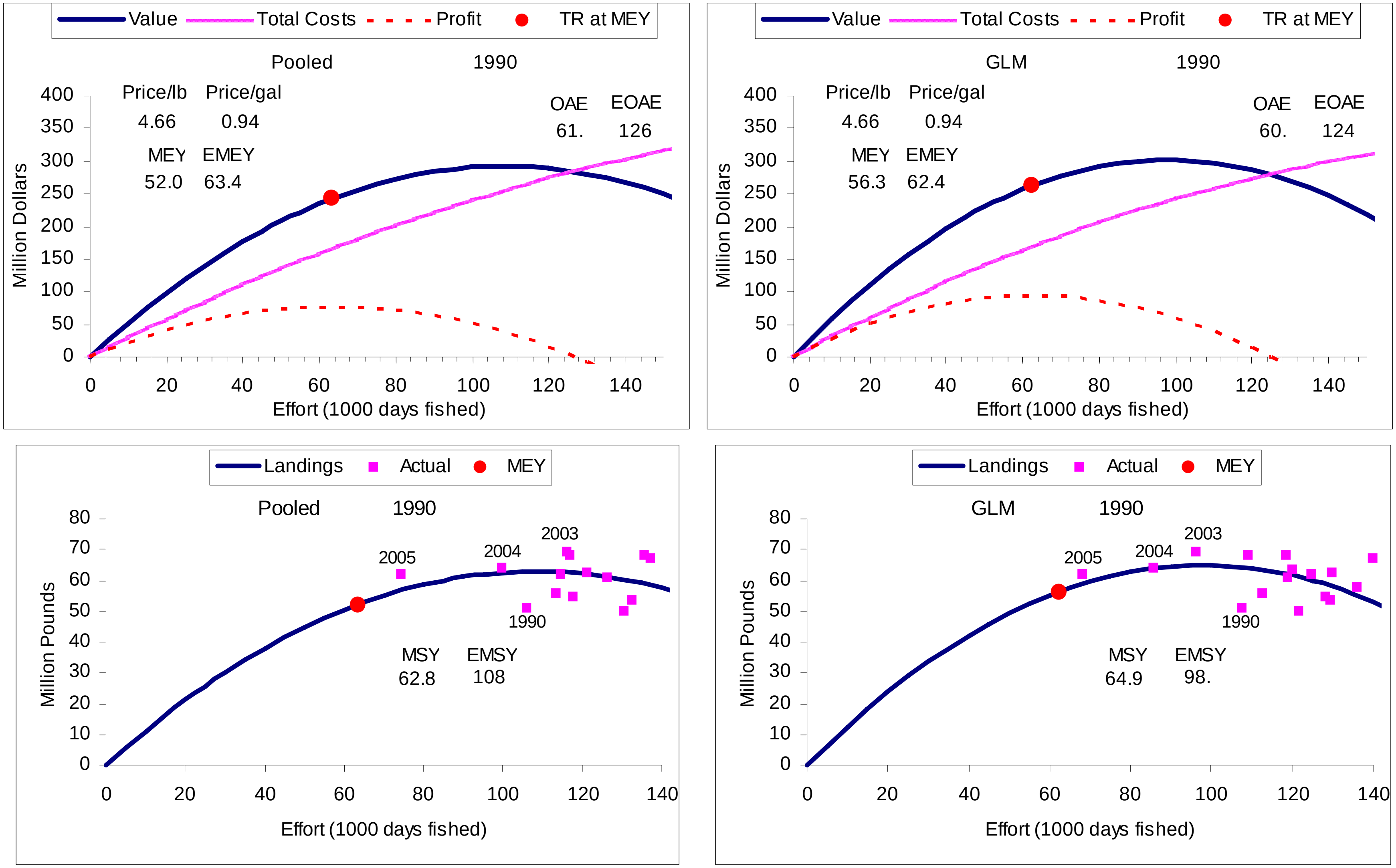


Figure 8. Estimates of MEY using the pooled and GLM methods for the EEZ in the Gulf of Mexico shrimp fishery, 1990.

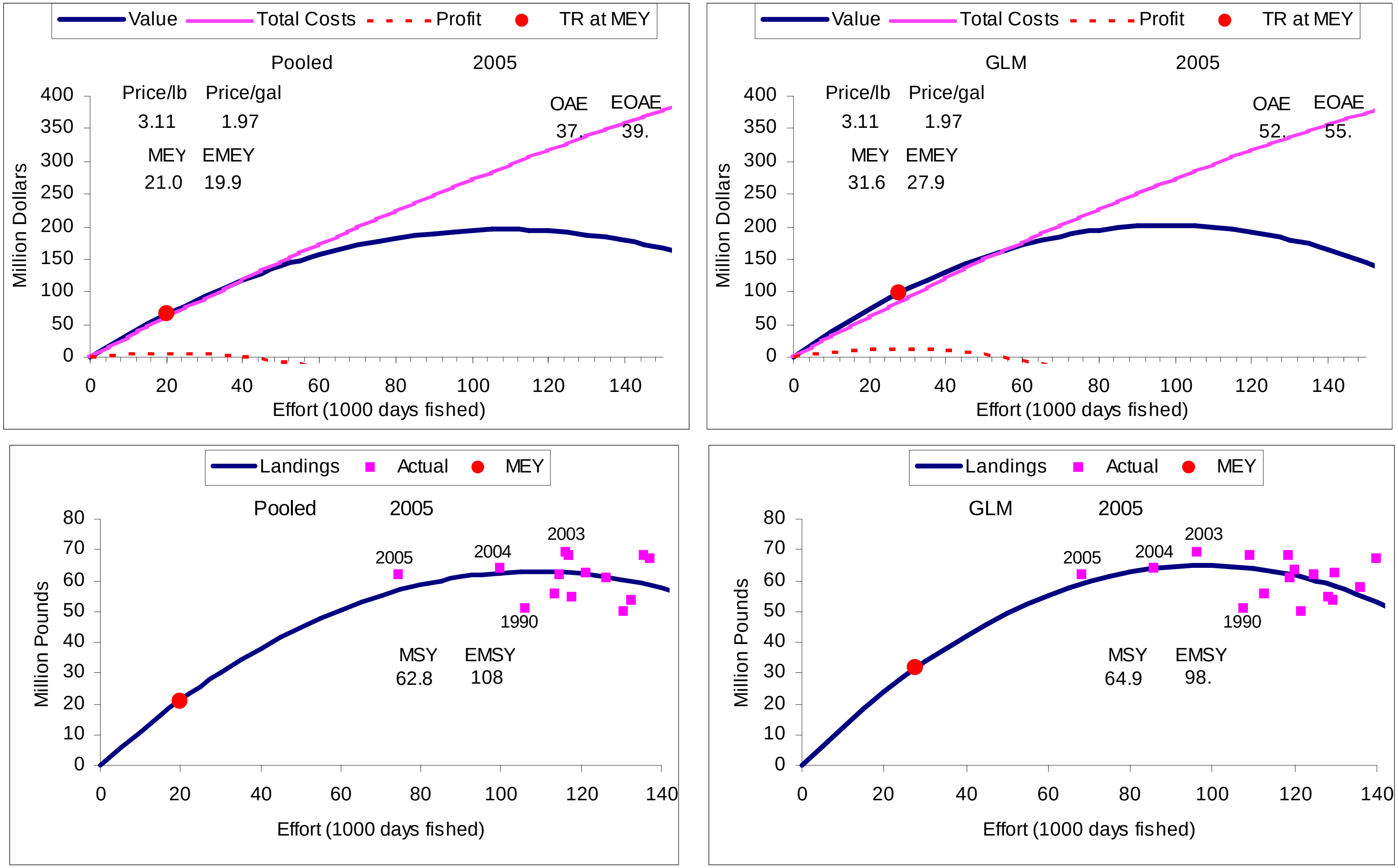
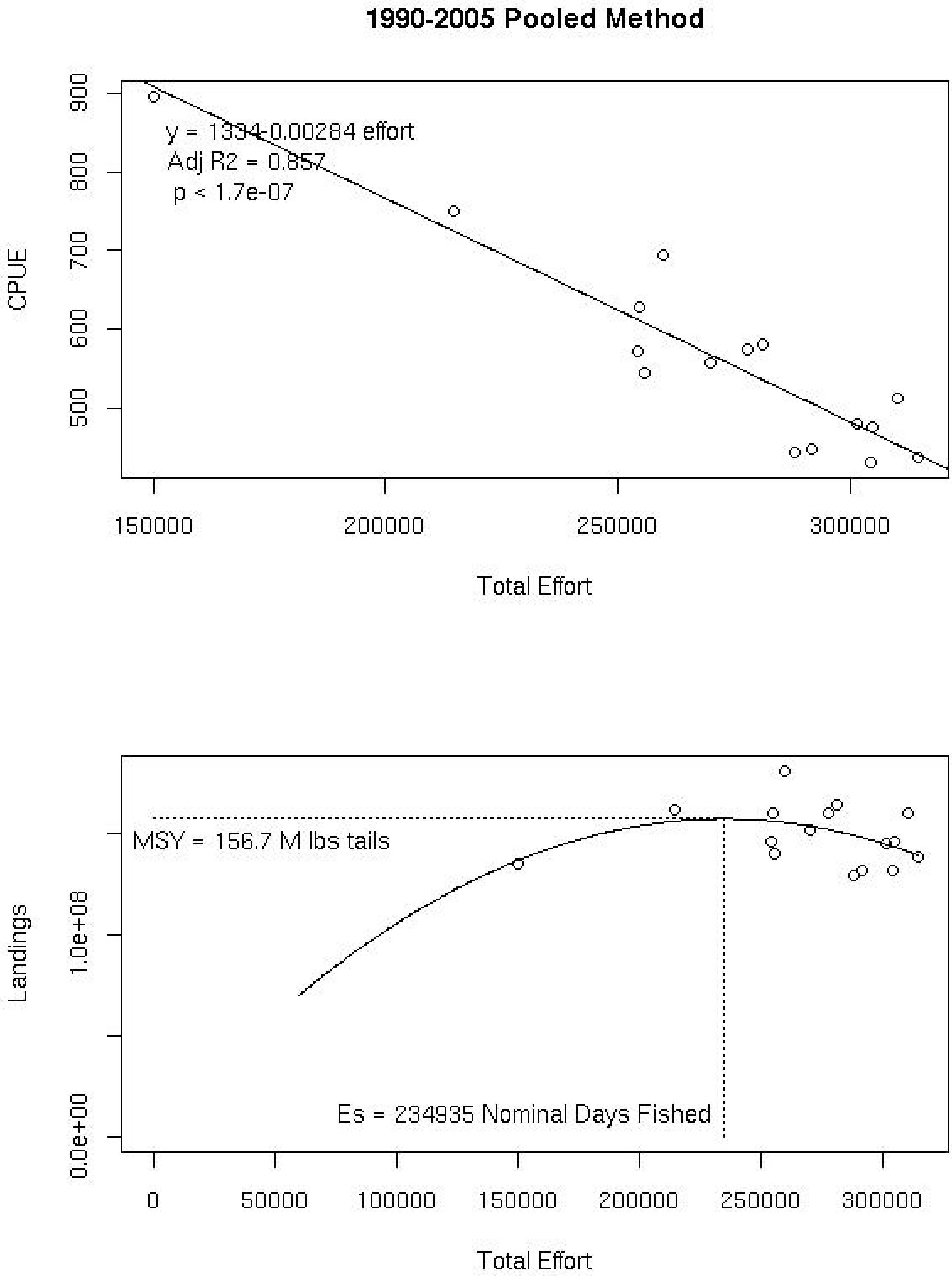
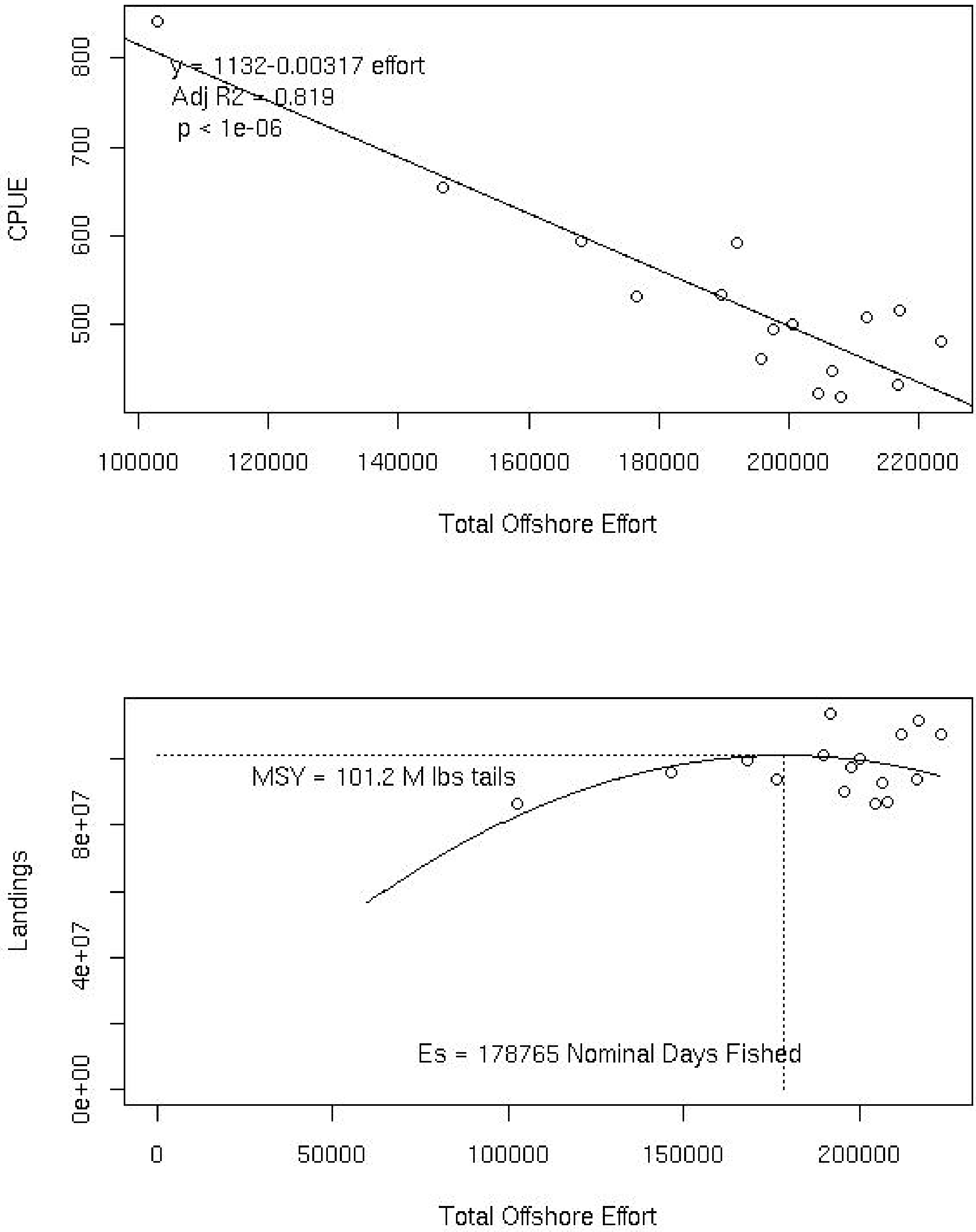


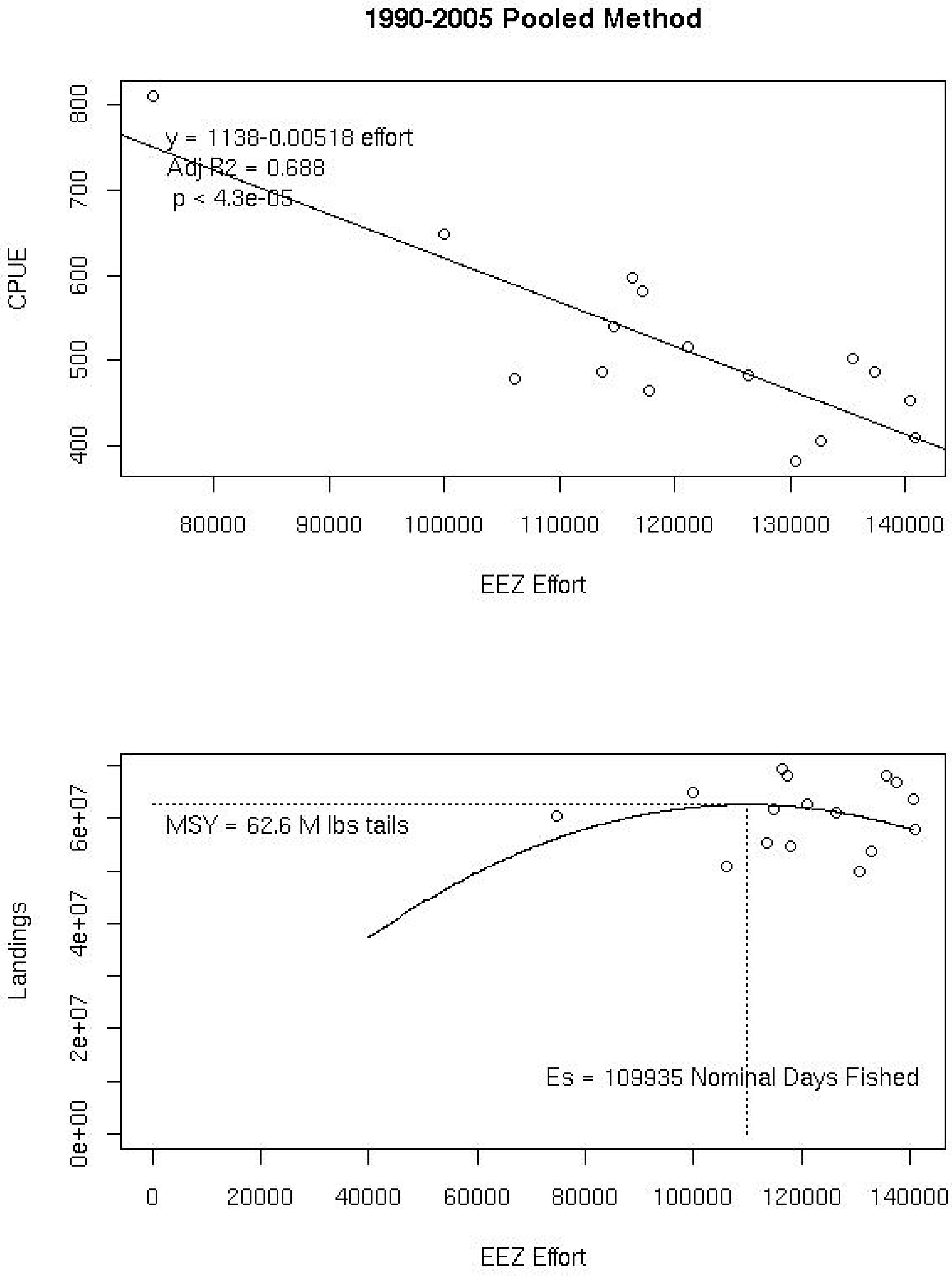
Figure 9. Estimates of MEY using the pooled and GLM methods for the EEZ in the Gulf of Mexico shrimp fishery, 2005.

APPENDIX 1: MSY ANALYSIS RESULTS

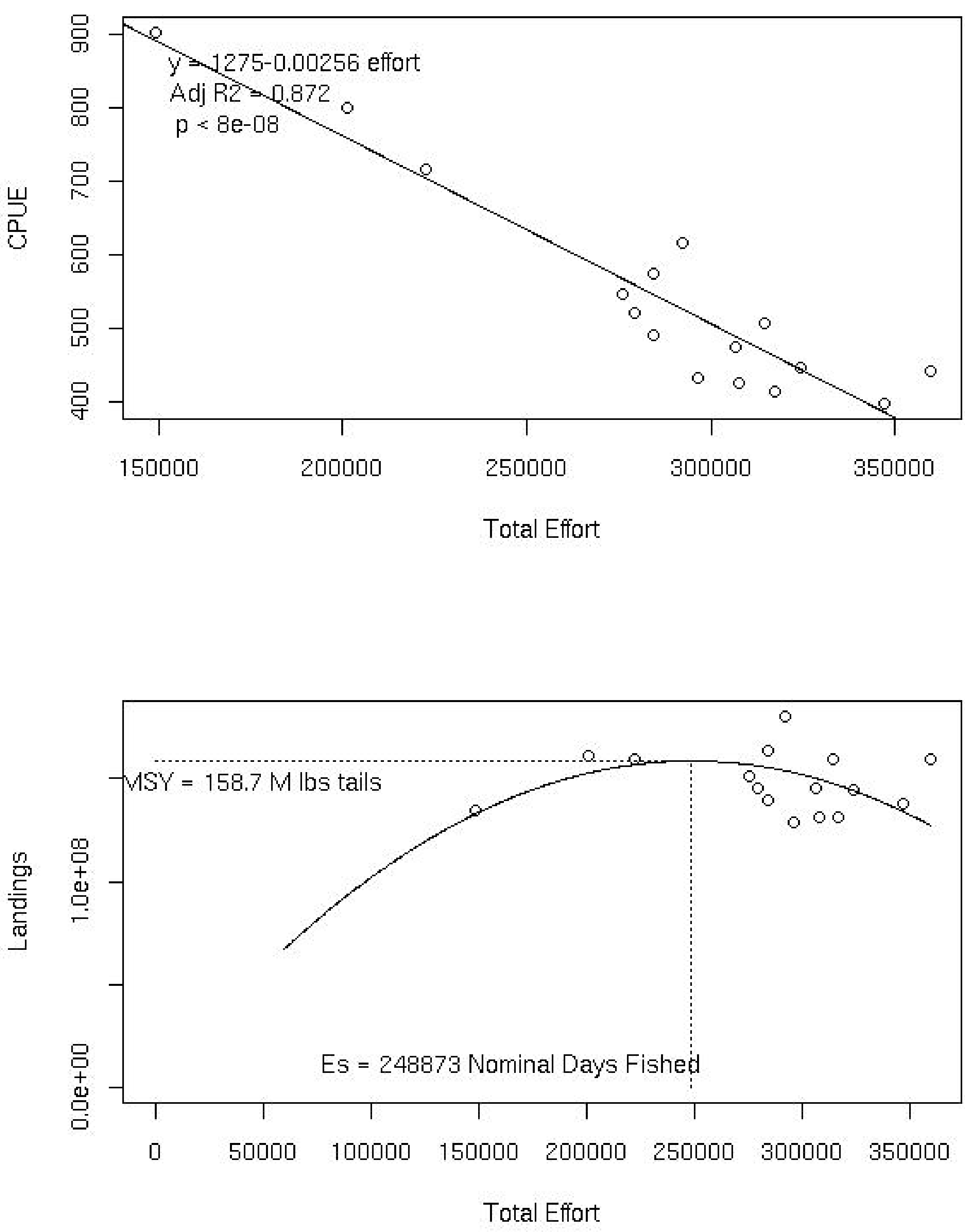

1990-2005 Pooled Method
CPUE
900
800
700
600
500
y = 1334-0.00284 effort
Adj R2 = 0.857
p < 1.7e-07
150000
200000
250000
300000
Total Effort
Landings
0.0e+00
1.0e+08
MSY = 156.7 M lbs tails
Es = 234935 Nominal Days Fished
0
50000
100000
150000
200000
250000
300000
Total Effort

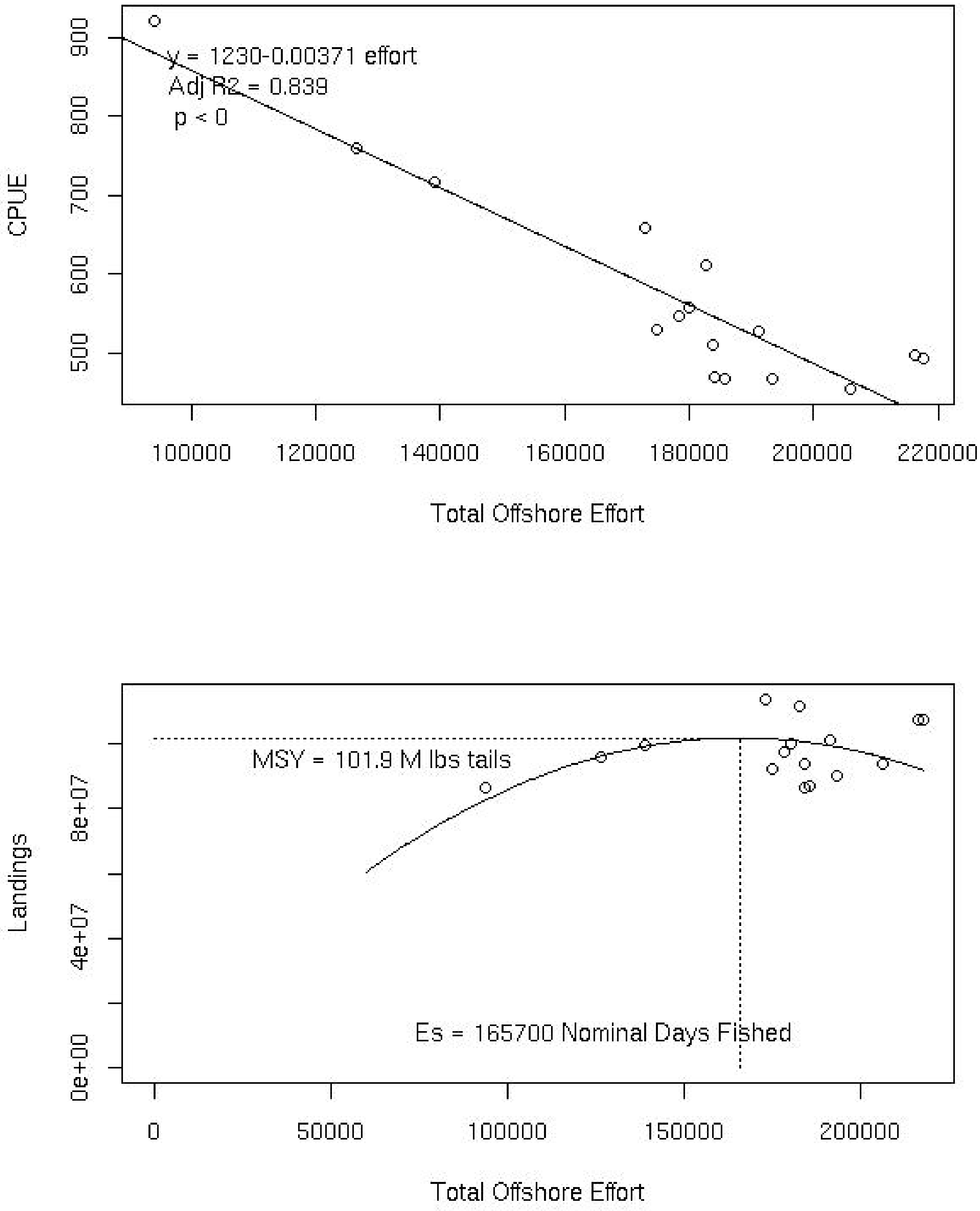


1990-2005 Pooled Method


1990-2005 Pooled Method
CPUE
400
500
600
700
800
y = 1138-0.00518 effort
Adj R2 = 0.688
p < 4.3e-05
80000
90000
100000
110000
120000
130000
140000
EEZ Effort
Landings
0e+00
2e+07
4e+07
6e+07
MSY = 62.6 M lbs tails
Es = 109935 Nominal Days Fished
0
20000
40000
60000
80000
100000
120000
140000
EEZ Effort

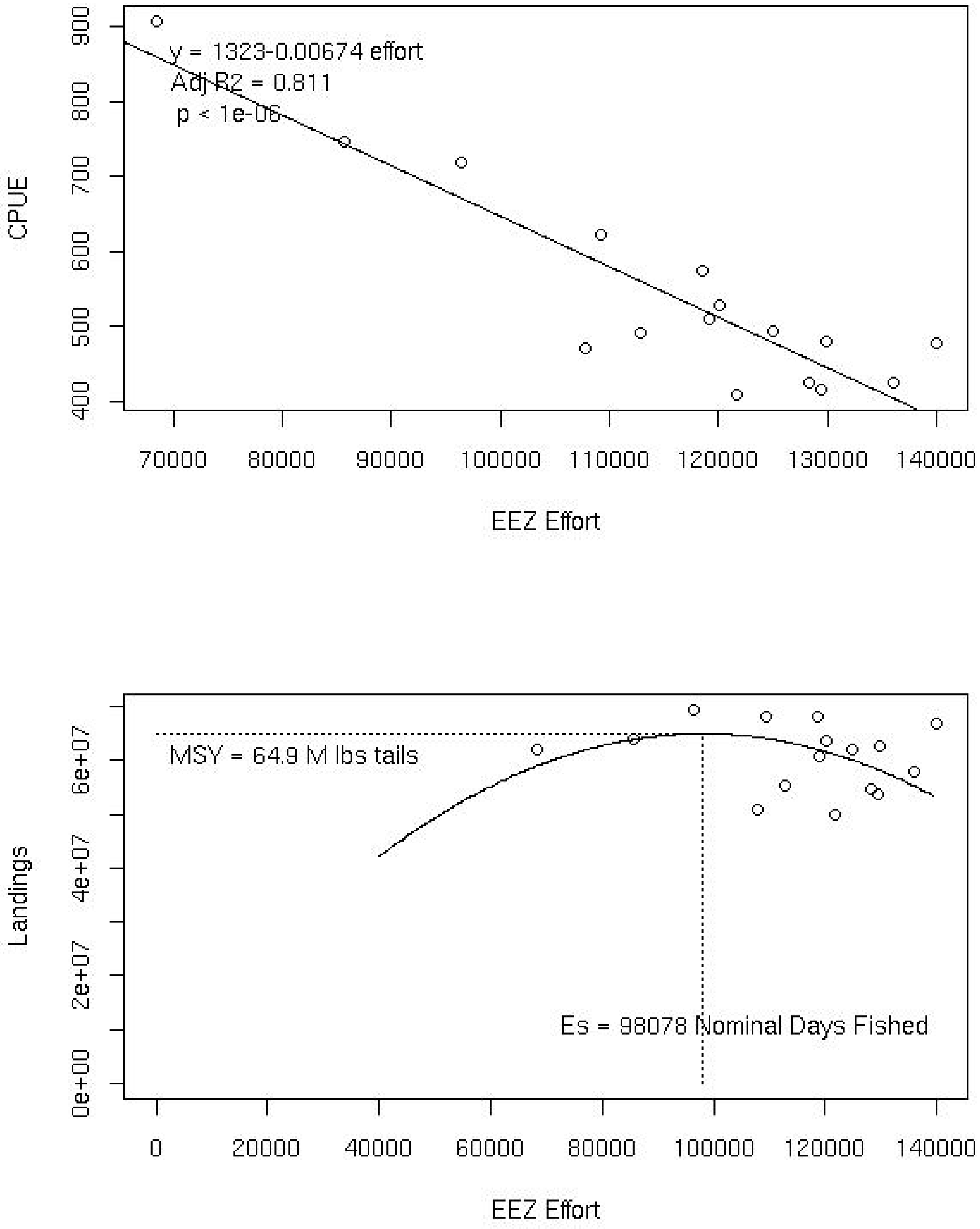
1990-2005 GLM Method





1990-2005 GLM Method

1990-2005 GLM Method



APPENDIX 2: MODIFIED SURPLUS PRODUCTION MODEL RESULTS

GLM Quadratic Model (1981-2005)

```
                   DF       DF                                                        Adj
Equation        Model    Error          SSE          MSE    Root MSE    R-Square      R-Sq

Y1                3.5     21.5      97319.8       4526.5     67.2793      0.7537    0.7251
CPUESINGLM        2.5     22.5       156780       6968.0     83.4747      0.6601    0.6374

                           SUR Parameter Estimates

                                 Approx                   Approx
  Parameter       Estimate      Std Err    t Value     Pr > |t|    Label

  A1              -0.00218     0.000784      -2.78       0.0113
  A2              -0.00179     0.000375      -4.77       0.0001
  A3              66.91015      24.8672       2.69       0.0137
  B1              -0.00277     0.000400      -6.92       <.0001
  B2              66.91015      24.8672       2.69       0.0134
  A0              1009.208      81.1939      12.43       <.0001
  B0                927.56      79.1885      11.71       <.0001
  Restrict0       -0.04384       0.0365      -1.20       0.2380    A3=B2
```

POOLED QUADRATIC MODEL (1981-2005)

```
                   DF       DF                                                        Adj
Equation        Model    Error          SSE          MSE    Root MSE    R-Square      R-Sq

Y2                3.5     21.5      61082.6       2841.1     53.3015      0.7570    0.7287
CPUESINP          2.5     22.5       140581       6248.1     79.0446      0.6725    0.6507

                           SUR Parameter Estimates

                                 Approx                   Approx
  Parameter       Estimate      Std Err    t Value     Pr > |t|    Label

  A1               -0.0017     0.000667      -2.54       0.0189
  A2              -0.00226     0.000442      -5.12       <.0001
  A3              67.41218      20.2669       3.33       0.0032
  B1              -0.00382     0.000576      -6.63       <.0001
  B2              67.41218      20.2669       3.33       0.0031
  A0              967.7306      78.4230      12.34       <.0001
  B0              1095.018      94.6025      11.57       <.0001
  Restrict0       -0.00055       0.0366      -0.01       0.9885    A3=B2
```

GLM QUADRATIC MODEL (1990-2005)

```
                        SUR Summary of Residual Errors

                   DF       DF                                                        Adj
Equation        Model    Error         SSE         MSE    Root MSE    R-Square       R-Sq

Y1                3.5     12.5     29212.7      2337.0     48.3427      0.8964     0.8757
CPUESINGLM        2.5     13.5     99387.5      7362.0     85.8023      0.7285     0.6983

                           SUR Parameter Estimates

                                Approx                  Approx
  Parameter       Estimate     Std Err    t Value     Pr > |t|    Label

  A1              -0.00434    0.000843      -5.15       0.0002
  A2              -0.00148    0.000412      -3.59       0.0037
  A3              31.00714     26.3987       1.17       0.2629
  B1              -0.00345    0.000566      -6.11       <.0001
  B2              31.00714     26.3987       1.17       0.2612
  A0              1252.988     77.8256      16.10       <.0001
  B0              1090.127       100.0      10.90       <.0001
  Restrict0        -0.0032      0.0192      -0.17       0.8755    A3=B2
```

POOLED QUADRATIC MODEL (1990-2005)

```
                        SUR Summary of Residual Errors

                   DF       DF                                                        Adj
Equation        Model    Error         SSE         MSE    Root MSE    R-Square       R-Sq

Y2                3.5     12.5     20632.8      1650.6     40.6279      0.8777     0.8532
CPUESINP          2.5     13.5     91259.0      6759.9     82.2188      0.7403     0.7114

                           SUR Parameter Estimates

                                Approx                  Approx
  Parameter       Estimate     Std Err    t Value     Pr > |t|    Label

  A1              -0.00278    0.000748      -3.72       0.0030
  A2               -0.0021    0.000455      -4.61       0.0006
  A3              19.18778     22.8038       0.84       0.4166
  B1              -0.00456    0.000730      -6.24       <.0001
  B2              19.18778     22.8038       0.84       0.4153
  A0              1137.987     75.7930      15.01       <.0001
  B0              1266.404       114.2      11.09       <.0001
  Restrict0       0.014014      0.0218       0.64       0.5433    A3=B2
```

APPENDIX 3: MODIFIED FOX (1990) EXPONENTIAL PRODUCTION MODEL

GLM Modified Fox Model (1981-2005)

```
                    DF       DF                                                        Adj
Equation         Model    Error         SSE         MSE    Root MSE    R-Square       R-Sq

logy1              3.5     21.5      0.2711      0.0126      0.1123      0.7602     0.7323
LN_CPUESINGLM      2.5     22.5      0.4154      0.0185      0.1359      0.6971     0.6769

                            SUR Parameter Estimates

                                 Approx                  Approx
   Parameter       Estimate     Std Err    t Value     Pr > |t|    Label

   A0               7.01758      0.1352      51.92       <.0001
   A1              -3.57E-6      1.3E-6      -2.75       0.0121
   A2              -3.07E-6    6.243E-7      -4.91       <.0001
   A3              0.136868      0.0414       3.31       0.0033
   B0              6.903359      0.1298      53.20       <.0001
   B1              -4.82E-6    6.542E-7      -7.37       <.0001
   B2              0.136868      0.0414       3.31       0.0032
   Restrict0       -17.5931     22.3455      -0.79       0.4446    A3=B2
```

Pooled Modified Fox Model (1981-2005)

```
                    DF       DF                                                        Adj
 Equation        Model    Error         SSE         MSE    Root MSE    R-Square       R-Sq

 LOGY2             3.5     21.5      0.1897     0.00882      0.0939      0.7584     0.7303
 LN_CPUESINP       2.5     22.5      0.3476      0.0154      0.1243      0.6704     0.6484

                            SUR Parameter Estimates

                                 Approx                  Approx
   Parameter       Estimate     Std Err    t Value     Pr > |t|    Label

   A0              7.007707      0.1390      50.41       <.0001
   A1              -3.17E-6    1.197E-6      -2.64       0.0152
   A2              -3.85E-6    7.847E-7      -4.91       <.0001
   A3              0.130427      0.0349       3.74       0.0012
   B0               7.09268      0.1498      47.35       <.0001
   B1              -5.85E-6    9.061E-7      -6.46       <.0001
   B2              0.130427      0.0349       3.74       0.0011
   Restrict0       -1.23585     22.2813      -0.06       0.9574    A3=B2
```

GLM Modified Fox Model (1990-2005)

```
                     DF       DF                                                        Adj
Equation          Model    Error         SSE         MSE    Root MSE    R-Square       R-Sq

logy1               3.5     12.5      0.1044     0.00835      0.0914      0.8668     0.8402
LN_CPUESINGLM       2.5     13.5      0.2725      0.0202      0.1421      0.7277     0.6974

                             SUR Parameter Estimates

                                  Approx                  Approx
   Parameter       Estimate      Std Err     t Value     Pr > |t|    Label

   A0              7.385068       0.1462       50.51       <.0001
   A1              -6.99E-6     1.582E-6       -4.42       0.0008
   A2              -2.51E-6     7.755E-7       -3.23       0.0072
   A3              0.085835       0.0488        1.76       0.1038
   B0              7.127999       0.1668       42.75       <.0001
   B1              -5.75E-6      9.39E-7       -6.12       <.0001
   B2              0.085835       0.0488        1.76       0.1019
   Restrict0       -0.45048      11.3885       -0.04       0.9705    A3=B2
```

Pooled Modified Fox Model (1990-2005)

```
                     DF       DF                                                        Adj
 Equation         Model    Error         SSE         MSE    Root MSE    R-Square       R-Sq

 LOGY2              3.5     12.5      0.0872     0.00697      0.0835      0.8377     0.8053
 LN_CPUESINP        2.5     13.5      0.2283      0.0169      0.1301      0.7258     0.6953

                             SUR Parameter Estimates

                                  Approx                  Approx
   Parameter       Estimate      Std Err     t Value     Pr > |t|    Label

   A0              7.278878       0.1553       46.88       <.0001
   A1              -5.01E-6     1.537E-6       -3.26       0.0069
   A2               -3.6E-6     9.347E-7       -3.85       0.0023
   A3              0.065184       0.0446        1.46       0.1698
   B0              7.331363       0.1835       39.96       <.0001
   B1              -6.91E-6      1.16E-6       -5.96       <.0001
   B2              0.065184       0.0446        1.46       0.1678
   Restrict0       7.816495      13.0456        0.60       0.5720    A3=B2
```