An Economic Analysis of a New Bycatch-Reduction Policy in the Gulf of Mexico

Yong Suhk Wui
Research Assistant, Dept. of Agricultural Economics, Texas A & M University
Richard T. Woodward
Assistant Professor, Dept. of Agricultural Economics, Texas A & M University
Wade L. Griffin
Professor, Dept. of Agricultural Economics, Texas A & M University

Abstract. This paper examines the ability of a new policy to reduce bycatch of red snapper by the shrimp fishery in the Gulf of Mexico: Fractional License as proposed by Townsend. The policy is evaluated both theoretically and using a simulation model.

Keywords: bycatch, fractional license, bycatch reduction devices, heterogeneous fishermen

1. Introduction

The red snapper fishery, the fourth most valuable fishery in the Gulf of Mexico, is in a precarious biological condition, and there is growing concern about its future sustainability. Stocks are estimated to have declined by 90% since the early 1970s (Goodyear and Phares) and the spawning potential ratio for the red snapper is estimated at about 1%, far below the 20% level at which the fishery is said to be overfished (MRAG Americas). The decline of red snapper stocks is attributed to the direct harvesting of adult red snapper by commercial and recreational fishermen and the indirect bycatch of the juvenile red snapper by shrimp fishermen.

In an effort to reduce bycatch of red snapper by shrimp fishermen, in 1998 Amendment 9 to the Fishery Management Plan for the shrimp fishery of the Gulf of Mexico mandated the use of certified bycatch reduction devices (BRDs) on all shrimp trawls. However, two problems exist with the current bycatch policy. First, the use of BRDs has imposed unexpectedly high costs on shrimp fishermen due mainly to a loss of shrimp from their nets. Second, BRDs have not achieved the 50 percent reduction of juvenile red snapper bycatch that was the goal set by the National Marine Fisheries Service (NMFS)[1]. This paper will evaluate an alternative approach to reduce bycatch through effort reduction in the open-access fishery.

The primary goal of this paper is to conduct an economic analysis of an alternative policy aimed at reducing the effort levels of shrimp boats in the Gulf of Mexico. The policy considered is called fractional licenses (FL) and was first suggested by Townsend (1992,1995). Under a FL program fractional rights to the license rather than the full rights are granted to the fishermen. The rights to a portion of a license can then be traded among the fishermen.

In our paper we first build a theoretical model for FL policies. The theory is developed for an open access fishery with heterogeneous fishermen by extending the graphical representation of Anderson and an analytical representation of Karpoff. We then present a simulation model of the FL policy for the joint shrimp/red-snapper fisheries by modifying a General Bioeconomic Fishery Simulation Model (GBFSM) of Grant and Griffin (1981).

The theory of a fractional license program

A theoretical model of an open-access fishery

Anderson (1989) provides a basic model of an open-access fishery with a heterogeneous fleet. Figure 1, adapted from Anderson (1989), shows three representative fishermen who have different cost structures and the industry effort supply curve. When the market price is constant, average revenue (AR) per unit of effort can be derived from a standard sustainable revenue curve leading to the downward sloping AR curve in the far right graph in the Figure 1. The aggregate supply (AS) curve is the horizontal aggregation of supply curves of each fisherman i.e., the marginal cost (MC) curves above the average cost (AC) curves.

The equilibrium effort level of the open-access fishery will be where the AS curve intersects the AR curve. At this effort level, the AR per unit of effort is R_0 and each fisherman will operate at the effort level at which his or her MC equals the AR. Notice that the first and second fishermen earn rent at the open-access equilibrium equal to R_0adf and R_0bgh, respectively. Anderson (1989) called this "open-access highliner rent". The curves have been

---

[1] Gillig reports zero percent reduction for age 0 fish and 44.5 percent reduction for age 1 fish.

drawn so that the third fisherman is marginal and earns zero rent. Since the efficient effort level of the fishery would be where the MC equals marginal revenue (MR), the open access equilibrium is inefficient and reducing effort would increase the surplus.

A more general presentation of an open access fishery can be obtained building on Clark (1980) and extending Karpoff (1987).[2] The fishery consists of *n* heterogeneous fishermen, where the catch for the *i*th agent is

$$h_i = h_i(e_i, e_{-i}, X); i = 1,2,3,...n .$$

Here e_i denotes the unit of standard fishing effort exerted by fisherman *i*, and e_{-i} denotes the aggregate effort of the other agents participating in the fishery.[3] The variable *X* represents the current stock of fish. As is in Figure 1, at the steady state, *X* is the sustainable stock given the level of aggregate effort, *E*.[4] Since the figures present the steady state, *X* is implicitly a function of *E*. The first derivatives of h_i are assumed to be positive with respect to e_i and *X*, and negative with respect to e_{-i}. We assume that each fisherman's effort is small relative to aggregate effort so that they can ignore the impact of changes in their effort on the fisherywide catch per unit of effort, $\tilde{h}(E, X(E))$ so that $h_i = e_i\tilde{h}(E, X(E)) = e_i\tilde{h}(E)$ with $\partial\tilde{h}/\partial e_i \approx 0$. For the time being, we assume that e_i can be observed directly.[5] Since the catch per unit of effort, $\tilde{h}(E, X(E))$ is the same for all fishermen, the marginal and average products of effort are equal for all fishermen. Each fisherman's costs, C_i, are an increasing function of the level of effort with fixed cost, FC_i, i.e., $C_i = c_i(e_i) + FC_i$.

When the price of landed fish, *P*, is constant and exogenously determined, the net rents received by fishermen *i* is given by

$$(1) \qquad \pi_i = Pe_i\tilde{h}(E) - c_i(e_i) - FC_i .$$

At the equilibrium, fishermen in the open access fishery seek to maximize their annual rents. Assuming that the marginal cost is increasing in effort, the first order condition of this optimization problem is,

$$(2) \qquad P\tilde{h}(E) = \frac{\partial c_i}{\partial e_i}, \text{ and } \pi_i \geq 0 \text{ for all } i.$$

That is, each fisherman expands his or her effort until the MC of a unit of effort equals its MR. Because of the presence of fixed costs, the effort level of each fisherman will be positive only if $\pi_i \geq 0$, and $e_i = 0$ if $\pi_i < 0$. Assuming that the marginal cost curve is monotonically increasing in effort, we can invert equation (2) to obtain the *i*th fisherman's effort in the open access fishery as a function of $P\tilde{h}$, i.e.,

$$(3) \qquad e^*_{i0} = \phi_i(P\tilde{h}(E)) .$$

When the individual fisherman is assumed a price taker in the OA fishery, and the average or marginal revenue are given as $AR = P\tilde{h}$, equation (3) can be written $e^*_{i0} = \phi_i(AR)$. Aggregating over *i*, we obtain the aggregate supply of effort in the open access fishery, E^A_0, as a function of AR,

$$(4) \qquad E^A_0 = \sum_{i=1}^{n} e^*_{i0} = \sum_{i=1}^{n} \phi_i(AR)^6.$$

The fisherywide equilibrium occurs when the aggregate effort supplied from the fishermen yields sustainable harvest per unit of effort equal to $\tilde{h}(E)$. As in Clark (1980), we assume that there exists a well-defined sustainable yield function, H^S, that identifies the combinations of *X* and *E* such that harvest equals the biological growth, i.e.,

$$(5) \qquad H^S = H(E).$$

While *H* can be nonmonotonic, we assume that average yield per unit of effort, $H(E)/E$, is monotonically decreasing in *E*. Hence, we can write the average sustainable revenue per unit of effort, as a function,

---

[2] While Karpoff built a static model, we extend it into a steady state model with an assumption of the constant situation over time, because the present value of rents is considered in the FL or FG. For convenience, we assume the constant rents over year, that is, the steady state in the OA.

[3] e_{-i} is a function of $\sum_{j \neq i} e_j$, not the vector (e_1, e_2, …, e_{i-1},e_{i+1}, … , e_N).

[4] In the steady state the fish stock is determined on the point where the growth rate of fish stock equals the harvest rate.

[5] Later the effort becomes a function of capital (*k*), labor (*l*), the specific abilities of fishermen that affect catching power (*T*), and the time length of fishing (*t*). $e_i = e(k_i, l_i, T_i, t)$. The effort is an increasing function of all inputs.

[6] As a supply function of effort in the OA fishery, MR or AR can be used in the effort function of an individual fisherman. However, for the consistency with the below sustainable effort function, AR is used.

$$(6) \qquad AR^S = P \cdot \tilde{h}(E),$$

where $\tilde{h}(E)$ represents the average yield per unit of effort, $H(E)/E$. Inverting this equation we obtain a sustainable effort function that maps from any level of revenue per unit of effort into the effort level that would sustain that revenue,

$$(7) \qquad E_0^S = \Psi\left(AR^S\right).$$

Setting (4) and (7) equal, we can obtain the AR level that would lead to an equilibrium. That is, the equilibrium will occur where

$$(8) \qquad E_0^S = \Psi\left(AR^S\right) = \sum_{i=1}^{n} \phi_i(AR) = E_0^A.$$

Equations (2), and (8) are sufficient to characterize the market equilibrium of the open-access fishery.

Although there are only a finite number of fishermen active in the fishery, it is still open access in the sense that all fishermen that are able to operate profitably are fishing. Although each individual acts optimally in the sense that $MC_i = MR_i$, the open-access equilibrium is inefficient since at the fisherywide level MR is less than MC.

A theoretical model of a FL program

In Figure 2 we present a model of a FL program as was introduced by Townsend (1992,1995) to permanently reduce effort in the fishery. In a FL program each fisherman is granted a tradable fractional license, i.e. a portion of a full license, yet can fish only if he or she obtains a full license. In Figure 2 we assume that each fisherman is given a 2/3 FL. Because only two of the three fishermen can remain in the fishery under the FL, at the equilibrium we know that the AS curve of effort will shift upward leading to a new equilibrium AR of R_1 at the intersection between the AS_1 and the AR. If the fishermen held a full license right, they would fish at the effort levels where their MC equals R_1, i.e., e_1^2, e_2^2 and e_3^2, leading to annual rents of $\pi_1 = R_1 dgh$, $\pi_2 = R_1 eij$ and $\pi_3 = R_1 fkn$, respectively. These potential profits will determine the fishermen's willingness to pay (WTP) to complete their license and the willingness to accept (WTA) to sell their license.

Assuming that trading leads to a permanent transfer of the right from one fisherman to another, each fisherman's WTP to complete his or her license will equal the present value of future annual rents, say Π_1, Π_2 and Π_3. When an α% fractional license is granted to a fisherman whose annual rent is π_i, the WTP and the WTA per percentage of a full license is Π_i /100.[7] In Figure 2 , the WTP and WTA per percentage of a license are Π_i/100 to each fisherman i=1,2,3.[8] The willingness to pay is discontinuous from zero to 100-α while the willingness to accept reaches Π_i/100 at α. The equilibrium price per percentage of a FL will be between p_h and p_l where the price is above the third fisherman's WTP and below the second fisherman's WTA. The third fisherman, whose WTP and WTA per percentage of a license are lower than the equilibrium price, will sell all fractions of his or her license and exit the fishery. The first and second fishermen whose WTP and WTA per percentage of a license are greater than the equilibrium price will buy the fractions from the third fisherman and remain in the fishery and use e_1^2 and e_2^2 units of fishing effort respectively.

After obtaining the full license, each fisherman's annual rents are defined by the equation,

$$(9) \qquad \pi_i = Pe_i \tilde{h}(E_2) - c(e_i) - FC_i.$$

The decision regarding whether to exit the fishery or to remain in the fishery under the FL is determined by the following maximization problem,

$$(10) \quad \max\left(\sum_{t=0}^{T_i} \frac{\pi_i}{(1+r)^t} - P_{FL}(100-\alpha), P_{FL}\alpha \right).^9$$

Here P_{FL} represents the price per percentage of license, and T_i represents the fishing lifetime length of ith fisherman. The first term of equation (10) is the present value of rents from fishing after completing the license, and the second term is the profits from exiting the fishery assuming zero salvage value for invested capital. By comparing these two profits, the fishermen will decide whether to buy or sell the fractions of the license at the market price, P_{FL}. After trading the fractions of the license, the equilibrium effort level for

---

[7] Assuming the transfer of a license is, each fisherman's maximum WTP to complete his or her license will equal the annual rents, say π_1, π_2 and π_3 so that the maximum WTP and the minimum WTA per percentage for a full license is π_i */100.*

[8] When there are many fishermen, each facing different costs, the aggregate WTP and the WTA curves will approach smooth lines. The equilibrium price per percentage of the FL will be determined by the intersection of the two curves.

[9] Here, since we are assuming the steady state rents, the rents will be constant over time as π_i.

fishermen that remain will be at the point where MR=MC, i.e., $\widetilde{Ph}(E_2) = \frac{\partial c_i}{\partial e_i}$ for the fishermen with $\pi_i \geq 0$. Assuming that the MC curve is monotonically increasing in effort with MC(e_i)<∞, effort level for the remaining i^{th} fisherman, e_{i2}^*, will be a function of AR($\widetilde{Ph}$) as in equation (3). The aggregate supply of effort, E_2^A, and the sustainable effort equation, E_2^S, for the fisherywide equilibrium will be analogous to the equations (4), (7) and (8). In comparison with the OA, since E_2 is less than E_0 due to the FL, and a new AR , $\widetilde{Ph}(E_2)$, will be higher than the AR on the OA fishery, $\widetilde{Ph}(E_0)$, the effort level of the individual fisherman increases under the FL. The number of fishermen will fall to (100-α)n by the FL.

A Simulation Model of a Fractional License Program

We now present a simulation model that has been developed to explore the implications of a FL program in the Gulf of Mexico Shrimp Fishery. The model used in our analysis builds on GBFSM that was originally developed to predict how alternative management policies would affect fisheries (Grant et al. 1981). GBFSM has been used extensively for analyzing the effects of management policies in the Gulf of Mexico (Blomo et al.; Grant and Griffin; Griffin and Stoll; Griffin and Oliver; Griffin et al. 1993; Gillig). GBFSM consists of two main parts: a biological submodel and an economic submodel. The biological submodel represents the recruitment, growth, movement, and mortality of shrimp and finfish. Mortality of both shrimp and finfish is due to both natural causes and fishing. In addition to harvests of both shrimp and finfish, effort targeted toward shrimp also leads to incidental bycatch of finfish. When a management policy is imposed on GBFSM, the biological submodel calculates the changes in days fished, number of vessels and landings of shrimp and red snapper. The economic submodel then calculates the monetary impact on fishermen in terms of costs, revenues, and rent for each vessel class in each area based upon the biological effects of the management policy implemented. GBFSM has been modified to incorporate values for the consumer surplus associated with the recreational fishery (Gillig).

In the version of GBFSM used in our analysis, the Gulf of Mexico is divided into 5 different regions: Florida, Alabama, Mississippi, Louisiana, and Texas. Two vessel categories are used: small vessels, under 60 feet in length, and large vessels, above 60 feet. In the FL algorithm, each vessel class is further segregated, into 9 groups in the small vessel class and into 6 groups in the large vessel class. Six independent FL markets are modeled: 5 markets for small vessels, one in each region, and one market for large vessels throughout the entire Gulf . The FL program is only applied to the shrimp fishery as a method of reducing effort in order to reduce red snapper bycatch by the shrimp fishery.

The FL program is modeled through a new submodel of GBFSM. Conceptually, this subroutine is established in the following manner. First, the number and size of vessels in each region and vessel size are simulated. The second step simulates characteristics of vessels in the fishery including the boats' WTP to complete the licenses. Third, we clear the FL market, reducing the number of boats participating in the next year of the simulation.

Table 1. Initial distribution of vessels by length

length	FL	AL	MS	LA	TX
>20	7	17	26	174	67
20-25	9	21	31	213	82
25-30	12	28	42	283	109
30-35	28	64	94	640	247
35-40	43	100	147	995	384
40-45	29	66	97	658	254
45-50	20	46	68	461	178
50-55	8	18	26	179	69
55-60	3	8	11	78	30
60-65	31	25	19	105	157
65-70	44	34	26	145	218
70-75	128	100	76	425	638
75-80	130	102	77	431	648
80-85	62	49	36	206	309
>85	19	15	11	62	94
all <60	159	368	542	3681	1420
all >60	414	325	245	1374	2064
Total	**573**	**693**	**787**	**5055**	**3484**

Source: Texas values for vessels under 60 feet are from TPWD 1995 data. Other values are calculated based on GBFSM output as described in the text.

The initial distribution of vessels by length is based on data provided by the Texas Parks and Wildlife Department (TPWD) at the beginning of the 1996 license year (Table 1). These data are available only for the small vessel class in the Texas bay shrimp fishery. GBFSM calculates the number of full time equivalent vessels (FTEVs) in each region and vessel class. The total number of licenses of the other states and vessel class are estimated by assuming that the ratio between the number of actual licenses and number of FTEVs in those states is the same as that ratio in the Texas bay shrimp fishery. Furthermore, for lack of data, we assume that the distribution among boat lengths in the other regions is the same as the distribution in the TPWD data. In the first simulated period, the number of licenses exceeds the number of FTEVs calculated in GBFSM suggesting that the fleet is overcapitalized.

The second step is to estimate the present value of annual rents for each boat *i*, , PV_i, in the fishery,

$$(11)\qquad PV_i = \sum_{t=1}^{\infty} \frac{R_{it}(L_{it}) - C_{it}(L_{it})}{(1+r_d)^{t-1}},$$

where R_{it}, C_{ti} and r_d represent the revenue, cost per fishing day and the daily discount rate on a daily basis. Each of these variables must be simulated for all vessels in the Gulf. As indicated in (11), we assume that future revenue and cost are functions of vessel length.

Each vessel's revenue and cost is simulated in two steps. First, using NMFS landing files of 1998 year in the Gulf of Mexico, we estimate revenue and cost per fishing day as a function of vessel length for the each region and each vessel class using a semilog specification, i.e., $R_i=\alpha_R+\beta_R L_i+\delta_R L_i^2+\varepsilon_{R,}$ $\ln(C_i)=\alpha_C+\beta_C L_i+\delta_C L_i^2+\varepsilon_{Ci}$ for i^{th} fisherman. The estimated revenue and cost functions are quadratic functions regressed on the vessel length and the squared vessel length, and the estimated parameters are shown in Table 2. In order to achieve a distribution consistent with the averages predicted by the main module of GBFSM, the intercept terms are adjusted in each period and not reported in the table.

Table 2. The parameters of semilog revenue and cost functions

Revenue			Cost		
β_R	δ_R	$\sigma_{R\varepsilon}$	β_C	δ_C	$\sigma_{C\varepsilon}$
8.753	-0.0204	755.81	12.09	0.067	749.1

Note: The intercepts of each equation are not shown because these parameters are changed in the simulation process as discussed in the text.

In Table 2, β_R, β_C, δ_R, δ_C, $\sigma_{R\varepsilon}$ and $\sigma_{C\varepsilon}$ represent the slope parameters of revenue and cost in terms of vessel length, the squared vessel length, and the standard deviations of the error terms. The $(j,k,i)^{th}$ vessel's original revenue and costs is then predicted as follows:

$$R_{0jki} = \left(\overline{R}_{0jk} - \beta_R \overline{L}_{jk} - \delta_R \overline{L}_{jk}^2\right) + \beta_R L_i + \delta_R L_i^2 + \varepsilon_{Ri}$$

$$C_{0jki} = \left(\overline{C}_{0jk} - \beta_C \overline{L}_{jk} - \delta_C \overline{L}_{jk}^2\right) + \beta_C L_i + \delta_C L_i^2 + \varepsilon_{ci}$$ where $\overline{R}_{0jk}, \overline{C}_{0jk}$ and $\overline{L}_{jk}$ represent the average revenue, cost and boat length in the j^{th} region and the k^{th} vessel class as calculated in GBFSM, and ε_{Ri} and ε_{Ci} represent the error terms of each equation. The revenue and cost were simulated assuming that the error terms, ε_{Ri} and ε_{Ci}, were distributed according to a bivariate normal distribution with standard errors as presented in Table 2 and correlation coefficients between revenue and cost.

The present value of the license, PV_i, of i^{th} fisherman is simulated using the simulated revenue, cost and the vessel length implemented in the equation (11). From equation (11), since the time series revenue and cost data is not available, the log-log functional form between present value of the license and the initial revenue and cost, and the initial vessel length was estimated on the landing file data as follows:

$$(12)\quad \begin{aligned} \ln PV_i &= \alpha_2 + \beta_{2i}\ln L_i + \beta_{3i}\ln R_{0i} + \\ &\beta_{4i}\ln C_{0i} + \varepsilon_{2i}. \end{aligned}$$

In order to estimate this relationship, we used data from the 1998 license buy-back program in Texas bay shrimp fishery[10]. We assumed that the bid price of license of the shrimp fishermen represents the present value of the license to the fishermen. Since the license buy-back data has only the bid price and the vessel length data, and the landing file has the data including the revenue and cost per fishing day, and the vessel length, the two data sets needed to be merged. A bid price was predicted for each vessel in the landing file, based on the relationship between bid and length in the license buy-back data. . The estimated equation of bid price in terms of the vessel length is as follows:

$$(13)\ \ln bid_i = 8.222 + 0.021 L_i,\ \sigma_\varepsilon = 0.312,$$

where the σ_ε represents the standard deviation of the error term in the equation.

Using data from the landing file, the parameters and the standard deviation of error terms of equation (12) are estimated and shown in Table 3.

Table 3. The parameters of equation 14, $lnPV_i$

Parameter	α_2	β_2	β_3	β_4	σ_ε
Value	4.8615	1.1335	0.0032	-0.0042	0.314

Using the values in Table 3, the present value of a fishing license is simulated for every boat in the sample. Since the present value of the license represents the WTP and WTA of the license, the WTP and the WTA per percentage of FL were calculated as $\frac{PV_i}{100}$ to the i^{th} fisherman.

In order to identify the market price per percentage of FL, the license value per percentage of all fishermen are sorted in a descending order within each license market. When a α represents the portion of the license that was granted in a license market with *n* participants, the license price per portion of a license equals the WTP of the α/n^{th} fisherman. Fishermen for whom the license price is less

---

[10] This data was obtained from the Texas Parks and Wildlife Department.

than the market price will sell the license fractions and exit the fishery. As the inefficient fishermen exit the fishery, the number of fishermen in each region and vessel size is adjusted.

Preliminary Results of Simulation Analysis

As a base model of a FL program, a 70% fractional license is granted to the shrimp fishermen in the Gulf of Mexico at the end of the fishing year to reduce a 30% reduction the number of vessels.

The WTP, WTA and the market price of FL

As discussed above, the data indicate that larger vessels have higher WTP and WTA. Figure 4 illustrated the situation, which represents the increasing WTP or WTA per percentage of FL as the vessel length increases. The market-clearing price per percentage of FL is shown in Table 4. There is a big difference above twice in the market price per percentage of FL between the small vessel markets and the large vessel market. The market price per percentage of FL in the small vessel market ranges from $59 in Florida to $64 in Mississippi. The market price difference among the regions within the small vessel class is slight. This result seems to be caused by applying only the one present value equation across the whole Gulf of Mexico. However, the market price of large vessel class established as one market is $144, which is more than twice the market price of the small vessel class.

Table 4. The market price per percentage of FL in each market

		FL	AL	MS	LA	TX
Market price	Small	$59	$62	$64	$61	$62
	Large	$144				

As seen in Figure 3, under the FL, the smaller boats exit the fishery first. This trend is equal across the regions and the markets. Across all the regions, almost 100% of the smallest vessels, 17.5 feet, exit the fishery.

The bycatch reduction of the juvenile red snapper

The FL program reduces bycatch of juvenile red snapper by decreasing shrimp fishing effort. Several scenarios were analyzed using GBFSM. First, a base case scenario was run that included neither BRDs nor FL. Second, the existing policy in which BRDs are required was simulated. Then, several FL programs were simulated corresponding to a 30, 40, 45, 50, 70 and 90% reduction in the shrimp licenses. The 30% program reduces total bycatch by 5%, while the BRDs without FL policy reduces bycatch by 6% (although the age structure of the reduction differs dramatically).

Table 5. The numbers of juvenile red snapper bycatch and reduced percentage by age(unit:1000 fish, %)

Age	Base	BRDs		30%FL		45%FL	
	Culls	Culls	Red%	Culls	Red %	Culls	RED %
0	31907	31609	1%	30025	6%	25549	20%
1	6334	4090	35%	6230	2%	5836	8%
2	282	224	20%	262	7%	217	23%
3	9	6	38%	9	8%	7	26%
Sum	38532	35929	7%	36526	5%	31608	18%

Note: 1. The reduction percentage of bycatch is based on the base model value.

2. These values belong to the results of the second year simulation for the comparison between the BRDs and FL policy. In the first year, the results of FL cannot be obtained, since the FL is imposed at the end of the first year.

The enhancement of the red snapper population

The reduction of juvenile red snapper bycatch will enhance the red snapper population. In a ten-year simulation, the trend of the red snapper population by scenario is illustrated in Figure 5. The FL program is compared to the BRDs for the effect of red snapper population. The Base scenario includes neither FL nor BRDs, but includes another policies such as closures, total allowable catch (TAC) and bag limit so that even under this scenario stocks increase. As the proportion of the license eliminated rises, the red snapper stock increases. In order to obtain a stock effect similar to the BRD policy, we find that approximately a 45% FL would need to be imposed.

The Welfare effect to shrimp fishermen

The Figure 6 shows the tradeoff between red snapper stock and the producer surplus of shrimp fishermen at the end of the ten years. While the producer surplus of shrimp fishermen declines under the BRDs by about 4%, under the FL program the producer surplus of the shrimp fishermen increases relative to the base case, even when 90% of licenses are removed from the fishery.

Conclusions

We find in our analysis that fractional license program represents a promising approach to effort reduction and the related problem of bycatch. While our results are somewhat tentative because of data limitations, there seems to be convincing evidence that reducing shrimp effort would be an attractive means of improving red snapper stocks. Furthermore, the fractional license program appears to be an approach that will reduce effort quite efficiently, eliminating the least cost-efficient fishermen first. As Townsend mentioned, FL programs might be more implemented more easily than many other effort reduction policies. Hence, this approach merits further research.

References

Anderson, G. Lee. Conceptual Constructs for Practical ITQ Management Policies, Rights Based Fishing, edited by Neher, P.A. & Mollett N. Kluwer Academic Publishers, 1989.

Blomo, V., K. Stokes, W. Griffin, W. Grant, and J. Nichols. “Bioeconomic Modeling of the Gulf Shrimp Fishery: An Application to Galveston Bay and Adjacent Offshore Areas.” *Southern Journal of Agricultural Economics* 10, 119-125, July 1978.

Clark, Colin W. Towards a Predictive Model for the Economic Regulation of Commercial Fisheries, *Can. J. Fish. Aquat. Sci.* vol 37: 1111-1129, 1980

Gillig, T. An Economic Assessment of Gulf of Mexico Red Snapper Management Policies, Ph. Dissertation, Department of Agricultural Economics, Texas A&M University, College Station, Texas, August. 1999.

Goodyear, C.P. and P. Phares. “Status of Red Snapper Stocks of the Gulf of Mexico: Report for 1990.” Contribution CRD 89/90-05, NOAA NMFS, SEFC, Miami Laboratory, 75 Virginia Beach Drive, Miami, FL 33149, 72 p, 1990.

Grant, W. E., K. G. Isaakson, and W. L. Griffin. A general bioeconomic simulation model for annual-crop marine fisheries. *Ecological Modeling* 13: 195- 219, 1981.

Griffin, W. L., and C. Oliver. “Evaluation of the Economic Impacts of Turtle Excluder Devices (TEDs) on the Shrimp Production Sector in the Gulf of Mexico.” Final Report MARFIN Award NA-87-WC-H-06139, Department of Agricultural Economics, Texas A&M University, College Station. 1991.

Griffin, W. L. and J. R. Stoll. “Economic Issues Pertaining to the Gulf of Mexico Shrimp Management Plan.” In L. G. Anderson, Editor. *Economic Analysis for Fisheries Management Plans*. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. pp.81 – 111, 1981.

Griffin, W. L., H. Hendrickson, C. Oliver, G. Matlock, C.E. Bryan, R. Riechers, and J. Clark. “An Economic Analysis of Texas Shrimp Season Closures.” *Marine Fisheries Review* 54,21-28, 1993.

Karpff, Jonathan M. Suboptimal Controls in Common Resource Management: The Case of the Fishery. *Journal of Political Economy* 95(1): 179-194, 1987.

MRAG Americas Inc., "Consolidated Report on the Peer Review of Red Snapper (Lutjanus campechanus) Research and Management in the Gulf of Mexico." Report prepared for U.S. Department of Commerce, NOAA, The Office of Science and Technology, National Marine Fisheries Service, December 1997.

Townsend, Ralph E. and Samuel G. Pooley. Fractional Licenses: An Alternative to License Buy-Backs. *Land Economics* 71(1):141-143, 1995.

Townsend, Ralph E. Fractional Licensing Program for Fisheries. *Land Economics* 68(2):185-190, 1992.

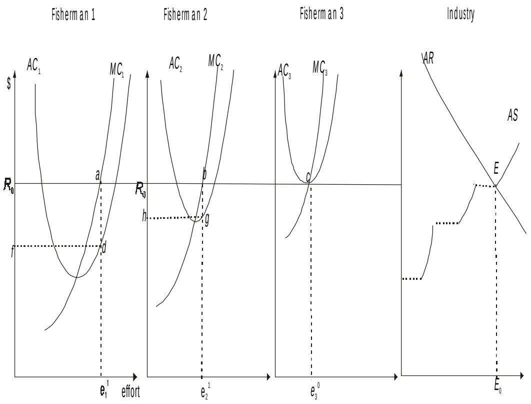

Figure 1. Open-access fishery with heterogeneous fishermen (adapted from Anderson, 1989)

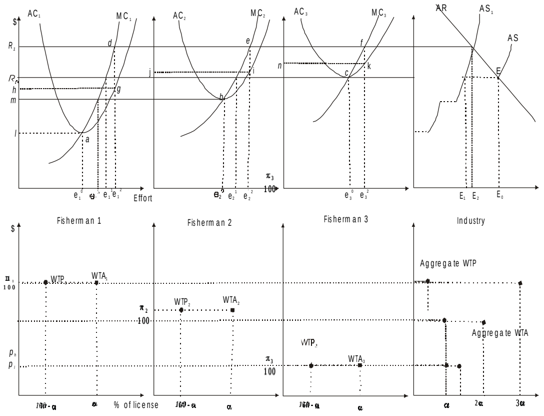

Figure 2 . Fractional License granted to fishermen and their WTP and WTA.

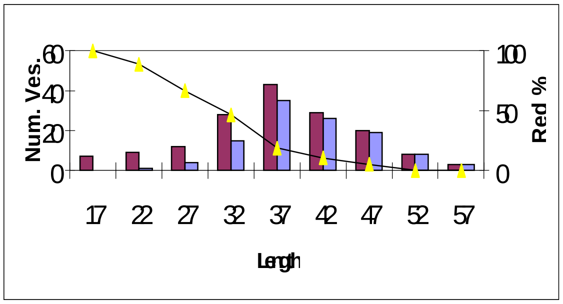

Figure 3a. License Reduction under a 70% FL program: the small vessel class in Florida

Note: The bars present the pre-and post-trading number of vessels. The line indicates the percentage of vessels that exited in each length class.

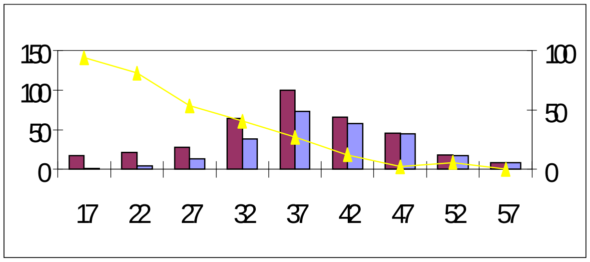

Figure 3b. License Reduction under a 70% FL program: the small vessel class in Alabama

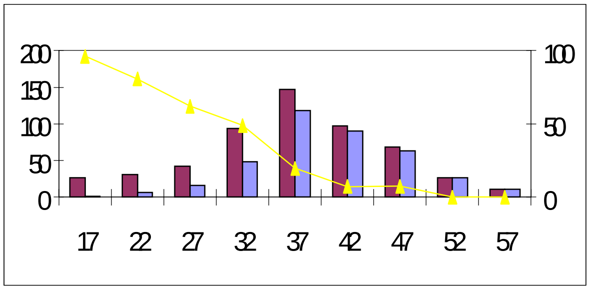

Figure 3c. License Reduction under a 70% FL program: the small vessel class in Mississippi

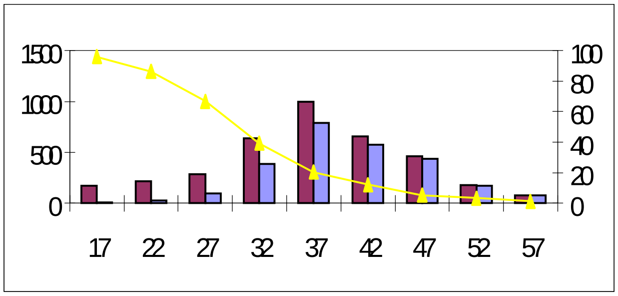

Figure 3d. License Reduction under a 70% FL program: the small vessel class in Louisiana

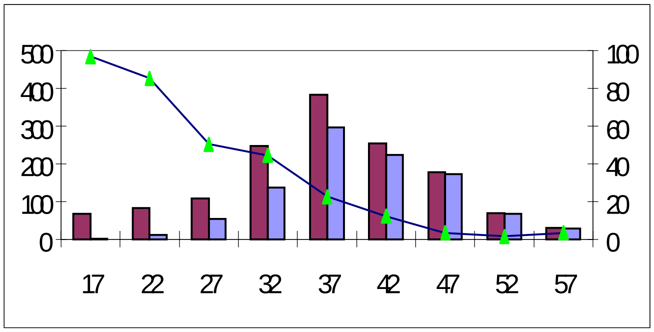

Figure 3d. License Reduction under a 70% FL program: the small vessel class in Texas

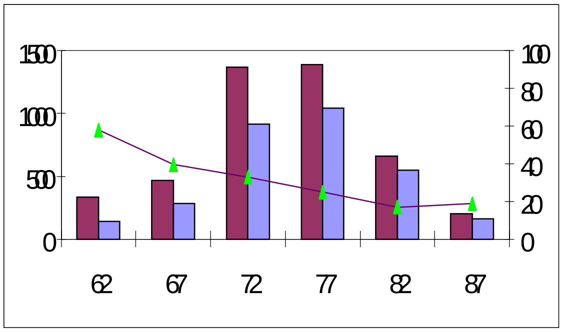

Figure 3E. License Reduction under a 70% FL program: the large vessel class in across the Gulf

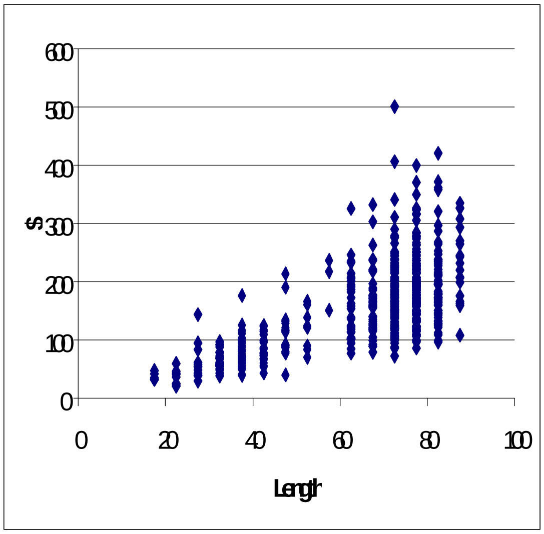

Figure 4. The willingness to pay per percentage of license and the vessel length in Florida

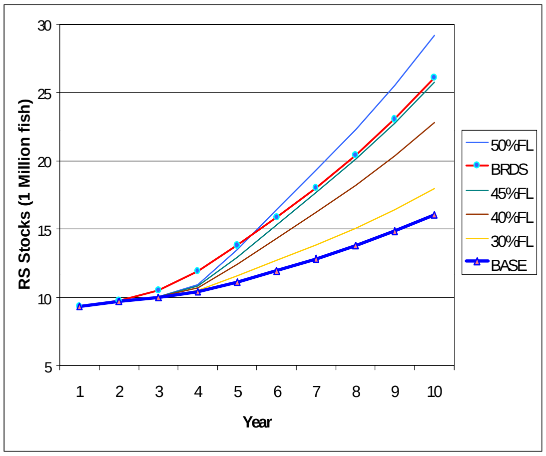

Figure 5. The trend of red snapper population in the Gulf of Mexico by scenario

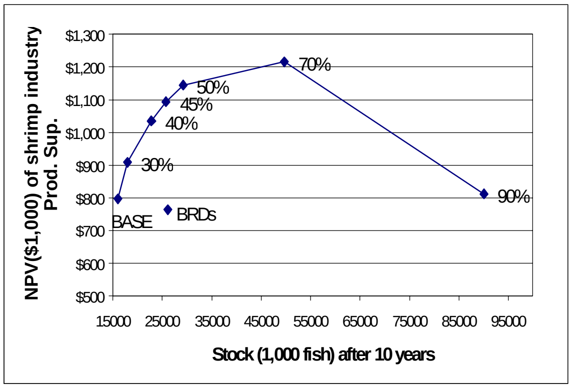

Figure 6. The tradeoff between the enhanced red snapper population and producer surplus of the shrimp fishermen by scenario. Percentages indicate the rate of license reduction under a FL program