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List of Acronyms

AC	Average Cost
AR	Average Revenue
AS	Aggregate Supply
BRO	Bycatch Reduction Devices
COD	Curse of Dimensionality
CPUE	Catch Per Unit Effort
DP	Dynamic Programming
EEZ	Exclusive Economic Zone
FG	Fractional Gear
FL	Fractional License
FTEV	Full Time Equivalent Vessels
GBFSM	General Bioeconomic Fisheries Simulation Model
GOMFMC	Gulf of Mexico Fisheries Management Council
LVM	Large Vessel Market
MC	Marginal Cost
MPI	Modified Policy Iteration
MSY	Maximum Sustainable Yield
NMFS	National Marine Fisheries Service
NPV	Net Present Value
OA	Open Access
OLS	Ordinary Least Squares
PV	Present Value
SPR	Spawning Potential Ratio
SVM	Small Vessel Market
TAC	Total Allowable Catch
TS	Total Surplus
WTA	Willingness To Accept
WTP	Willingness To Pay

EXECUTIVE SUMMARY

I. Introduction

The red snapper fishery, the fourth most valuable fishery in the Gulf of Mexico, is overfished. Recently, the Gulf of Mexico Fishery Management Council suggested a new rebuilding plan to restore the stock to a level of 20 % spawning potential ratio (SPR) by the year 2032. The decline of red snapper stocks is attributed to the direct harvesting of adult red snapper by commercial and recreational vessels and the indirect bycatch of the juvenile red snapper by shrimp vessels. The recovery of the red snapper population will probably require policies imposed on both the directed and bycatch fisheries. This research has evaluated management policies for the shrimp and red snapper fisheries of the Gulf of Mexico by examining their impact on red snapper stock and present value of surplus.

The project was composed of two main parts. First, we evaluated two new policies to reduce bycatch by reducing the effort levels of shrimp vessels: fractional license (FL) and fractional gear (FG). Gear is measured in yards of footrope. Under FL and FG programs, fractional rights to the license or specific gear type rather than the full rights are granted to the fishermen. With a FL program a vessel must have a complete license to fish. That is, if a 30% FL program is implemented, then a vessel would retain 70% of its license and, in order to fish, would be required to buy 30% of a license from another vessel or vessels. With the FG program, a vessel owner can choose whether or not to buy additional gear rights. In a FG program the reduction diminishes the owner's rights to use gear, but does not preclude fishing with a reduced level of gear. In this analysis we assume that a vessel cannot fish with less than 80% of its original gear level. So, for example, under a 10% FG program vessels start out with rights to use 90% of their original level of gear, but they could either buy or sell rights from that level, increasing their gear back closer to the original level, reducing it closer to the 80% level or exiting the fishery entirely and selling all their rights.

The theoretical properties of a FG program were studied by Staniford for the South Australian rock lobster fishery and have recently been suggested by Townsend. However, a combination of theoretical and empirical analysis of such programs has not been carried out. Both the theoretical basis and an empirical application for FL and FG are provided in this research. A simulation model is used to analyze FL and FG and to compare them with the current regulatory policy requiring shrimp vessels to use BRDs to rebuild red snapper stocks.

The FL and FG policies were analyzed in a six-market system for the Gulf, where there are five markets for small vessels (one for each state in the Gulf of Mexico) and one market for large vessels throughout the Gulf of Mexico since the EEZ is controlled by the federal government. In addition, since this project began there has been increasing interest in a permit system for fishing for shrimp in the EEZ and a program in which a vessel would be required to acquire two permits and retire one of them to be able to fish in the EEZ (Amendment 13, alternative V.H). This possible alternative is equivalent to the 50% FL scenario except that there is only one FL market, which is for the large vessels. To allow consideration of such a case, therefore, we have included a one-market system, with and without BRDs, for the large vessels fishing in the offshore of the Gulf of Mexico.

The second main part of the analysis was the evaluation of policies to control direct harvest of the red snapper. A Total Allowable Catch (TAC) has been imposed on both the commercial and recreational red snapper fishermen for many years. We predict the time-path for the TAC that would maximize the present value of future surplus. While simulation modeling can do detailed and complicated analysis with large numbers of variables, it is not designed to find an optimal policy path among the many policies through time. On the other hand, dynamic programming (DP) models, which are used to carry out optimization, cannot include many variables because the problems become computationally intractable as the size of the problem grows (Rust). We identify the dynamically optimal policy paths by developing a DP model that retains linkages to the simulation model, thus taking advantage of the strengths of both approaches.

II. Fractional License and Fractional Gear

II.A.Theory

The FL and FG are evaluated both theoretically and using GBFSM. The theory is developed for an open-access (OA) fishery with heterogeneous vessels by extending the graphical representation of Anderson and Staniford and an analytical representation of both Karpoff and Clark. Theoretically, in comparison with the open-access fishery, the aggregate number of vessels in the fishery is reduced by the FL rate. Average revenue to the participating vessel increases relative to cost, therefore, his or her own effort level increases. However, aggregate effort decreases. The FL program is not achieve full economic efficiency because the aggregate marginal cost is increased as fishermen exit the fishery. The FG program also reduces aggregate effort without achieving efficiency because the program's gear restriction forces vessels to use input mixes other than those that minimize costs. Hence, the FL and FG programs are theoretically "second best" policies.

II.B.Simulation models

The FL and FG policies are each modeled through new subroutines in GBFSM. First, the vessel sizes and footrope lengths of all licensed vessels were simulated. Based on the simulated fleet, the vessels' profit and WTP and WTA of the licenses or the gear rights are calculated. Finally, the market is cleared, reducing the number of vessels participating in the next year of the simulation.

II.C. Scenarios

To evaluate the impacts of the FL and FG programs, the following scenarios were examined:

Six-Markets	
Base scenario	Total Allowable Catch (TAC) =9.12 million pounds in red snapper Recreational bag limit in red snapper=4 fish/trip
BRDs scenario	Year 1998 policies (Base plus BRD)
FL scenario	Base plus 10-50% license reduction at 10 % intervals in the shrimp fishery
FG scenario	Base plus 10-50% footrope reduction at 10 % intervals in the shrimp fishery
One-Markets	
FL scenario w/o BRDs	Base plus 10-50% license reduction at 10 % intervals in the shrimp fishery
FL scenario w/BRDs	Base plus 10-50% license reduction at 10 % intervals in the shrimp fishery

In the FL (FG) scenarios, a one-time reduction in shrimp licenses (footrope) occurs at the end of the first year (1998) of simulation and the FL (FG) markets determines who will remain in the shrimp fishery at the beginning of the second year. The FL (FG) markets will continue to operate for the additional 34 years (until 2032) although no additional reduction in licenses (gear) will be imposed.

II.D. Results

Figure 1 shows that the use of BRDs will increase the red snapper spawning stock biomass by year 2032 by approximately 150 million pounds compared to the Base scenario. The use of BRDs will decrease the PV of total surplus the shrimp fishery by year 2032 compared to the Base year.

The FL six-market scenario is best when considering the PV of total surplus of the shrimp fishery for any given level of license reduction or gear reduction. A 50% FL would increase the PV of total surplus to the shrimp fishery by $400 million and increase spawning stock biomass by approximately 290 million pounds relative to the Base scenario.

For FG programs that reduce gear by less than approximately 25%, the shrimp fishery is worse off then they would be under the Base scenario. Higher FG rates cause an increase in the PV of total surplus to the shrimp fishery; however, FG programs still lead to an increase in the PV of surplus approximately $100 million below the level achieved in the FL program with six markets. Further, the FG scenario does not perform as well in rebuilding the spawning stock biomass by 2032 as the FL six-market scenario.

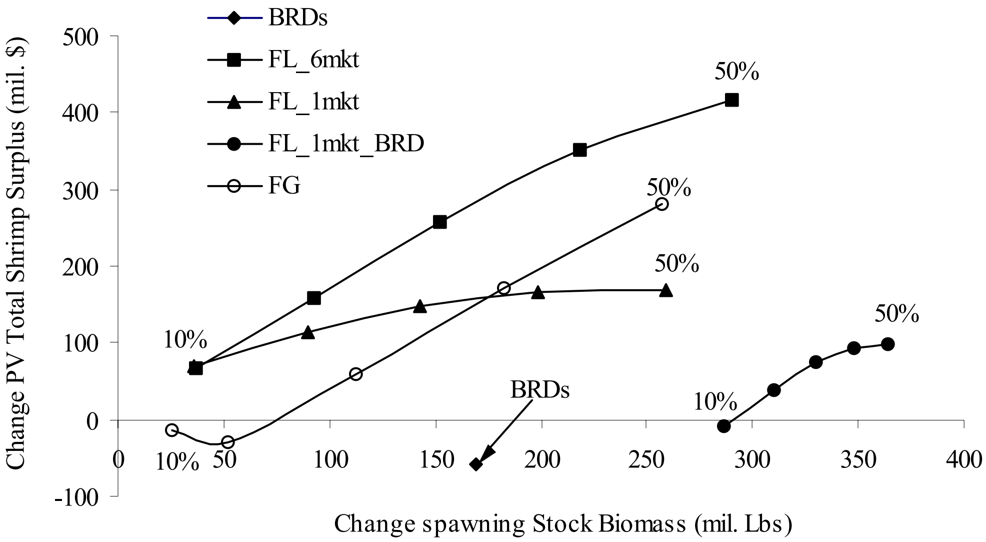

Figure 1. **Tradeoff between the change from the base year scenario in the present value of total (producer and consumer) surplus of shrimp fishery and in the red snapper spawning stock biomass (in year 2032) under FL with six markets (FL_6mkt), FL with one market without BRDs (FL_1mkt) and with BRDs (FL_1mkt_BRD), and FG scenarios**

The FL one-market without BRDs scenario has a positive affect on the PV of total shrimp surplus. A 10% FL program is as effective as the FL six-market scenario in rebuilding spawning stock biomass and increasing the PV of total shrimp surplus. The reason is there are considerable excess licenses in the small boat fishery in each state and a 10% FL reduction does not reduce the number of full time equivalent vessels (FTEV) needed to harvest the shrimp resource.

When a FL program imposed only on the offshore fishery is combined with BRDs, the result is the most significant increase in the red snapper spawning stock biomass. For example, a 10% FL one-market with BRDS is as effective as a 50% FL six-market scenario. However, when considering the effect on the shrimp fishery this scenario is less desirable than most of the FL and FG scenarios.

While the FL and FG scenarios generally show an increase in the PV of surplus for the shrimp fishery, it is important to determine the up-front costs for vessels to stay in the fishery by purchasing the additional FL or FG needed. Table 1 shows the average price paid for the additional license or gear needed per vessel to remain in the shrimp fishery. As can be seen the average price increases with the increases in the percentage reduction in FL or FG. The three FL scenarios have a much greater cost to remain in the fishery then with FG scenario. This is because under a FL program any vessel that remains in the fishery must make purchases, while in the FG program a boat may simply choose to operate with the lower gear level. It is much less expensive for the small vessels to remain in the fishery then the large vessels. This is because the number of small vessel licenses exceeds the number of FTEV by two to one, whereas, the large vessels the number of license only exceed the number of FTEV by 2%.

Given the generally positive PV of total surplus for the shrimp fishery, will individual vessels desire these programs? That is, after taking into account the fact that they will have to pay to retain their licenses, will they prefer the restricted program under the FL or FG program to the unrestricted case? This can be determined by calculating the NPV of their investing in the additional license or gear needed to remain in the fishery. The NPV per individual vessel is calculated as follows:

$$NPV = \Delta PV - P_R \times \bar{R},$$

where ΔPV is the change in producer surplus per vessel (i.e. the PV of producer surplus under the program less the PV of surplus in the base case), P_R is the equilibrium price per FL or FG right, and $\bar{R}$ is the average number of rights purchased by vessels remaining in the fishery. For the small vessels the FG scenario is undesirable for the 10 to 40% range and is just above breakeven for the 50% level. With the FL one-market scenario the small vessels are operating in an open access environment (except in Texas), so the license reduction by the large vessels gives a windfall gain (economic profits, i.e., profits above normal profit) to the small vessels. However, this windfall gain only lasts a few years since small vessels move into the fishery dissipating the economic profits.

Table 1. Average price paid for the additional license or gear needed per vessel and remaining in the shrimp fishery

	FL			
	6-Markets	1-Market w/o BRDs	1-Market w/BRDs	FG
Vessels < 60 ft in Length				
10%	382	na	na	151
20%	2,571	na	na	1,139
30%	6,486	na	na	4,183
40%	11,710	na	na	5,307
50%	18,284	na	na	6,285
Vessels >= 60 ft in Length				
10%	45,770	45,650	40,710	2,158
20%	100,800	100,300	90,420	11,349
30%	165,510	164,610	149,790	30,413
40%	240,040	240,320	220,560	37,867
50%	323,100	319,450	294,800	43,674

Table 2. Net present value (NPV) of FL & FG programs for vessels that remain in the fishery assuming a 7% discount rate

	FL			
	6-Markets	1-Market w/o BRDs	1-Market w/BRDs	FG
Vessels < 60 ft in Length				
10%	1,725	1,307	1,700	(151)
20%	2,467	2,061	2,425	(1,978)
30%	2,709	2,957	3,287	(3,674)
40%	3,468	4,087	4,379	(2,445)
50%	5,484	5,503	5,746	877
Vessels >= 60 ft in Length				
10%	63,423	31,699	35,655	26,989
20%	114,625	57,356	68,188	16,005
30%	189,669	89,753	106,875	89,306
40%	292,788	129,002	153,221	223,172
50%	435,441	191,831	224,484	401,050

II.E.Limitations

As with any modeling exercise, there are limitations to our analysis due to data restrictions, modeling assumptions that must be made and computational considerations.

First, the license data of shrimp vessels is limited because the distribution on vessel length in Alabama was incomplete. In this analysis, the distribution of licenses per vessel size in Alabama was obtained by distributing them according to Mississippi.

Second, this analysis used brown, pink and white shrimp landings and assumed that they were all caught with a shrimp trawl. In Louisiana, however, a large percent of the shrimp are being caught by skimmers and butterfly nets. These different types of gear may affect the outcome for the small vessels when considering the FL and FG scenarios.

Third, the price of shrimp fell in 2001 and continued to fall in 2002 due to a sudden increase of imports into the U.S. If these low prices continue into the future, our estimates of PV of surpluses, the average price that can be paid for the additional FL and FG needed and the NPV to vessels remaining in the fishery will be over estimated. With respect to this, the use of the Gillig et al. price flexibility model for shrimp should also be updated because the price structure has changed in recent years in the sense that domestic landings may not have nearly as significant of an impact on prices as before. This would directly affects the estimates of shrimp producer and consumer surplus.

Fourth, in this analysis we considered expected profits at the harvest level as the sole factor in determining the value placed on a license by a potential buyer or seller, a common assumption for policy analysis in fisheries. We realize that the shrimp fishery is made up a heterogeneous group of fishermen who may consider factors other then profit. For example, a multi-vessel owner who is vertically integrated would be concerned with the volume of product, and therefore the profitable at all levels of the production process where as owner-operator of an individual vessel may be concerned with household income.

Fifth, transaction costs, the costs to facilitate the trading of license or gear, were not included in this analysis. There would certainly be transaction costs in a market for fractional rights, as we present here and these would diminish the benefits obtained from such markets. However, because of a lack of data, it was not possible to model such costs.

Finally, since the simulation model is parameterized based on 1998 policies, the results associated with high FL and FG rates are quite speculative and should be interpreted with caution.

II.F. Conclusions about the FL and FG programs

We find in our analysis that either a FL program or a FG program would be an alternative approach that will reduce effort and the related problem of bycatch resulting in improving red snapper stocks and at the same time increase the producer surplus of the shrimp fleet. While BRDs tackle the bycatch problem directly by restricting the trawls of shrimp vessels without considering the economic consequences, a FL program or FG program solves the bycatch problem indirectly by reducing the real effort with economic benefits of the increased producer and consumer surplus in shrimp fishery. As Townsend (1992) mentioned, FL or FG programs might be implemented more easily than many other effort reduction policies.[1] Hence, this approach merits further research. Our confidence in the results from the high FL rate scenarios and FG scenarios rate is limited as such a policy would represent a fundamental change in the fishery that cannot be completely anticipated based on existing data.

III. Dynamically optimal TAC in the Red Snapper fishery

III.A. Theory

A dynamically optimal policy is one that seeks to achieve a policy goal with the knowledge that policies in the future will adapt to changing conditions. Regardless of the goal sought, it is clear that fishery policy should seek to be dynamically optimal. In the analysis presented in this report, we assume that the policy goal is to maximize the present value of the economic surplus (aggregating producer and consumer surplus). Alternative policy objectives could potentially be considered, but the desire the resulting policy path to be dynamically optimal would remain.

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[1] No concern has been given to the cost of implementing the FL or the FG programs or their enforcement.

One of the main policies used in the Gulf's red snapper fishery is a limit on the total allowable catch (TAC). If the TAC is dynamically optimal, then the restrictions imposed today will be done with the knowledge that policies in the future will react to the evolving conditions over time. Although the pursuit of dynamically optimal policies is intuitively appealing, there are significant barriers to carrying out such analysis. In chapter 3 of this report we explain how these hurdles were overcome.

In general, identifying dynamically optimal policies in the context of a large simulation model would naturally face "the curse of dimensionality" (COD). The COD is the fact that the computational size of dynamic optimization problems grows geometrically with the number of variables that describe the state of a system. For large-scale simulation models, therefore, direct identification of dynamically optimal policies is not possible. There are two ways to get around this problem, both of which require the identification of a smaller set of state variables that represent the large set in the full model. The direct approach uses a simulation model directly to obtain the benefits function and state transition. The indirect approach uses a simulation model to generate "data" that can then be used to estimate parametric specifications of the benefit function and state equations.

We argue that the direct approach has advantages in terms of the ability to integrate the identified policy paths with a complete version of a large simulation model. While the indirect approach would be computationally much faster, it would require us to specify a parametric functional form for the dynamics of the simulation model and could easily lead to results that are far removed from those that would actually be predicted by the simulation model. Hence, a direct approach is implemented here.

III.B. The Linked DP-GBFSM model

In light of the COD problem, we developed a scaled down version of large simulation model (GBFSM) in order to reduce the computing time. We then evaluated the DP problem at a finite grid of points, interpolating linearly between the grid points to approximate the value function. The control variables used in the DP model are the commercial and recreational total allowable catch (TAC). The state variables in the DP model are the young and adult stocks the red snapper fishery at the beginning of the year and recreational catch per unit effort (CPUE) in the previous period. Estimates of the disaggregated variables used in the simulation model were determined as follows. First, a translog relationships between DP state variables and disaggregated simulation variables are specified. Second, the data to estimate these equations were generated using a wide range of GBFSM simulations. Third, the functional relationships were estimated using ordinary least squares (OLS) estimation.

The DP model was solved to identify the policy path that maximizes the infinite horizon NPV using the modified policy iteration (MPI) techniques (Rust, 1996). In addition, a policy path that satisfies a sustainability constraint (Woodward 2000), and a variety of paths that seek to achieve a level of red snapper spawner biomass are also identified.

III.C. Results

Figure 4 presents the path for the commercial and recreational TAC that maximizes the present value of the producer and consumer surplus (the PV-optimal policy path). In each period the DP model identifies the total TAC and the allocation between the commercial and recreational sector. A limit was placed so that the recreational sector could not be allocated more than 70% of the total TAC and, as seen in Figure 4, this limit is reached in each simulated year. The emphasis on the recreational sector is due to the high estimates of the value per trip of recreational fishing opportunities (Gillig 1999).

Figures 5 and 6 present the policy paths for the PV-optimal and sustainability-constrained policies. We see that the two policies are very similar both in terms of the total TAC and as a percentage of the biomass. What this shows is that in this system, given the current conditions, the PV-optimal policy leads to an increase in the total surplus from the fishery over time -- the requirement imposed under Woodward's sustainability constraint that present value of the fishery not decline is satisfied without imposing an outside constraint.

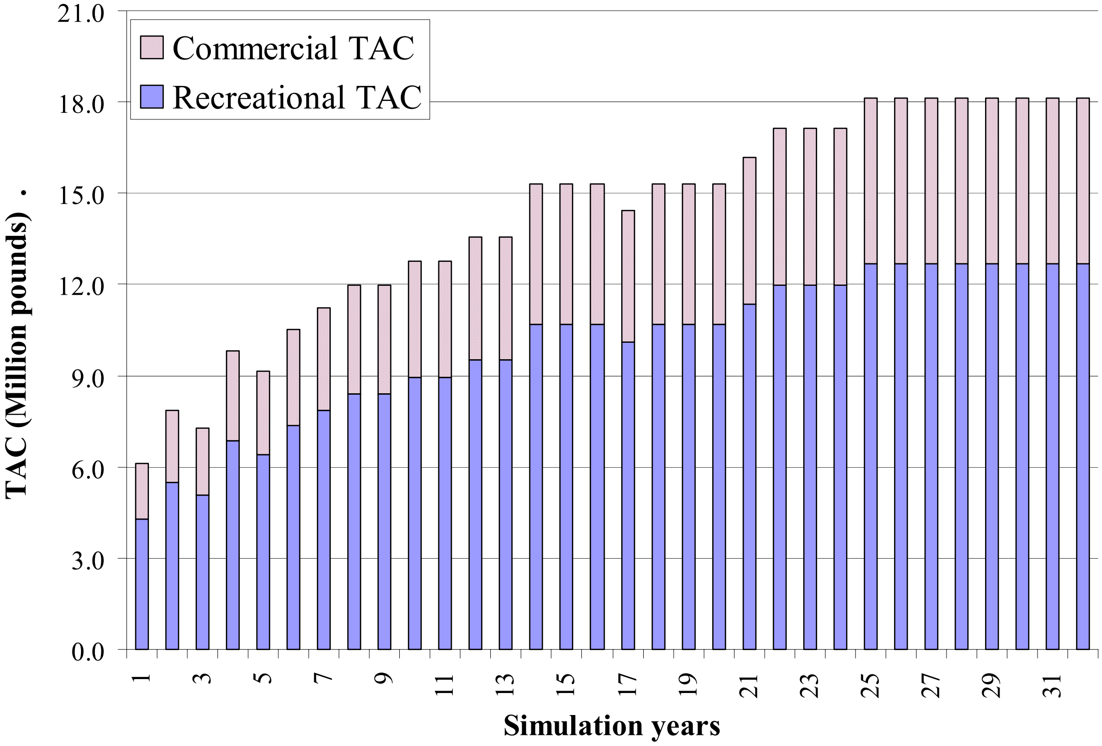

Figure 2. **PV-Optimal time-path recreational and commercial red snapper TAC (million pounds per year)**

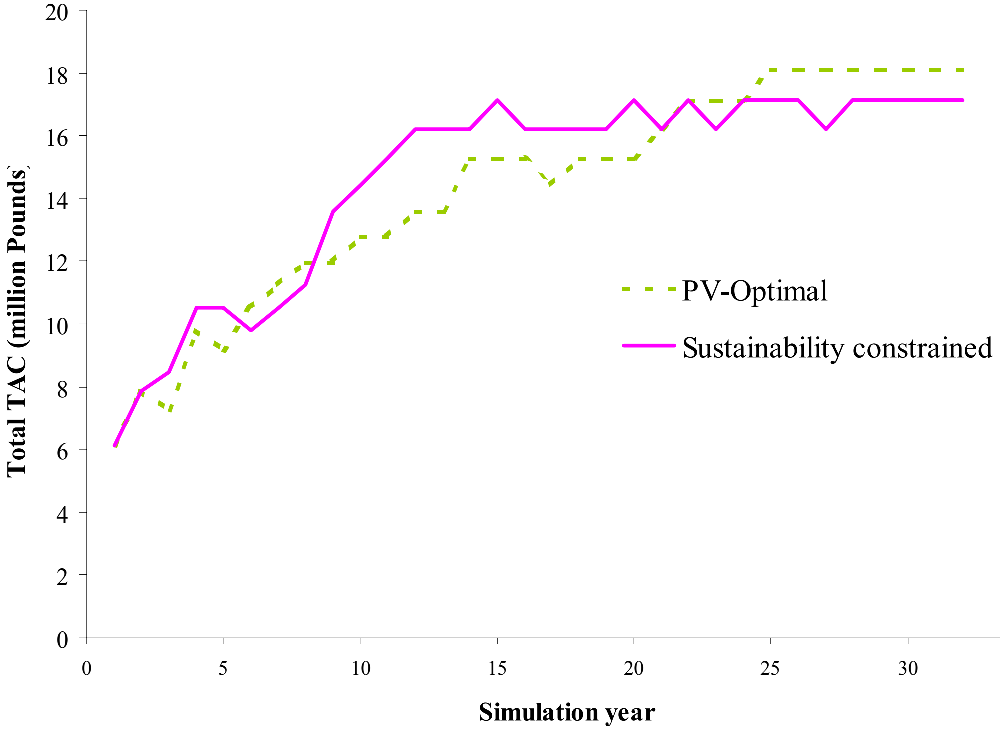

Figure 3. Comparison of time path for the total TAC under the PV-maximizing and sustainability-constrained objective functions (million pounds)

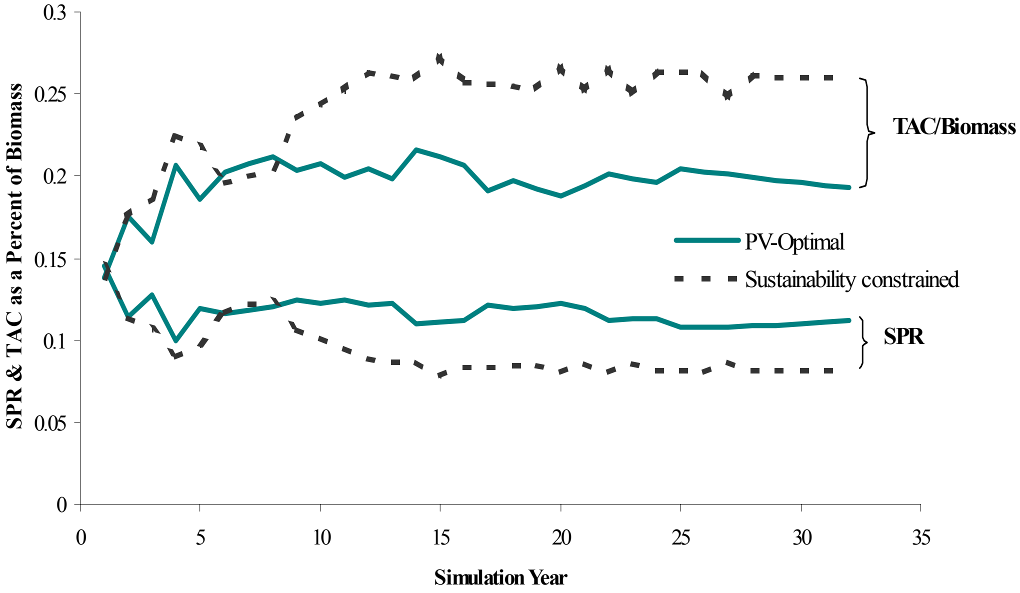

Figure 4. Comparison of SPR and TAC as a Percent of Biomass along the PV-optimal and sustainability-constrained paths

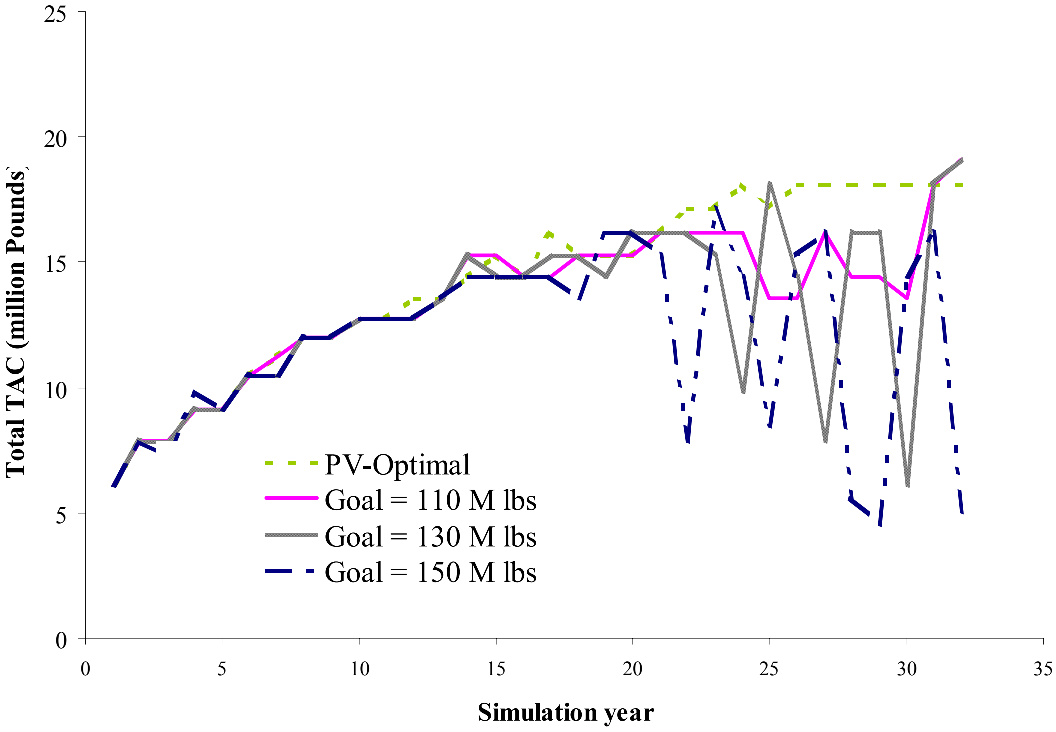

Figure 5. **Time-paths for PV-Optimal TACs that achieve goals of 100, 110, 120 and 130 million pounds of spawner stock by 2032**

In Figure 5 we present the PV-optimal policy paths comparing the policy that maximizes the present value of surplus to policies that require a variety of stock targets ranging from 110 to 150 million tons of spawner stock by 2032. As can be seen in this figure, over the first 15 years of the simulation the PV-optimal policy regime is insensitive to the policy goal; whether the goal is to maximize the present value of producer and consumer surplus or to achieve a particular stock objective, the optimal policy involves an initial TAC of about 6 million pounds, increasing to about 15 million pounds by the 15th year.

Finally, in Figure 6 we present the stocks associated with all of the policy paths considered above. The first thing to note is that the sustainability-constrained version has a lower stock than any of the other policies. This suggests that in the model higher stock levels cannot be sustained indefinitely and eventually a reduction in harvests would be required. Hence, under a sustainability constraint, overstocking the fishery -- and growing accustomed to higher harvests -- can be a concern. The PV maximizing policy leads to a spawning stock of about 90 million pounds by the 32nd year of the simulation, slightly more than doubling the stock in that period. As indicated above, it is possible to achieve higher stock levels, but at some cost in terms of producer and consumer surplus.

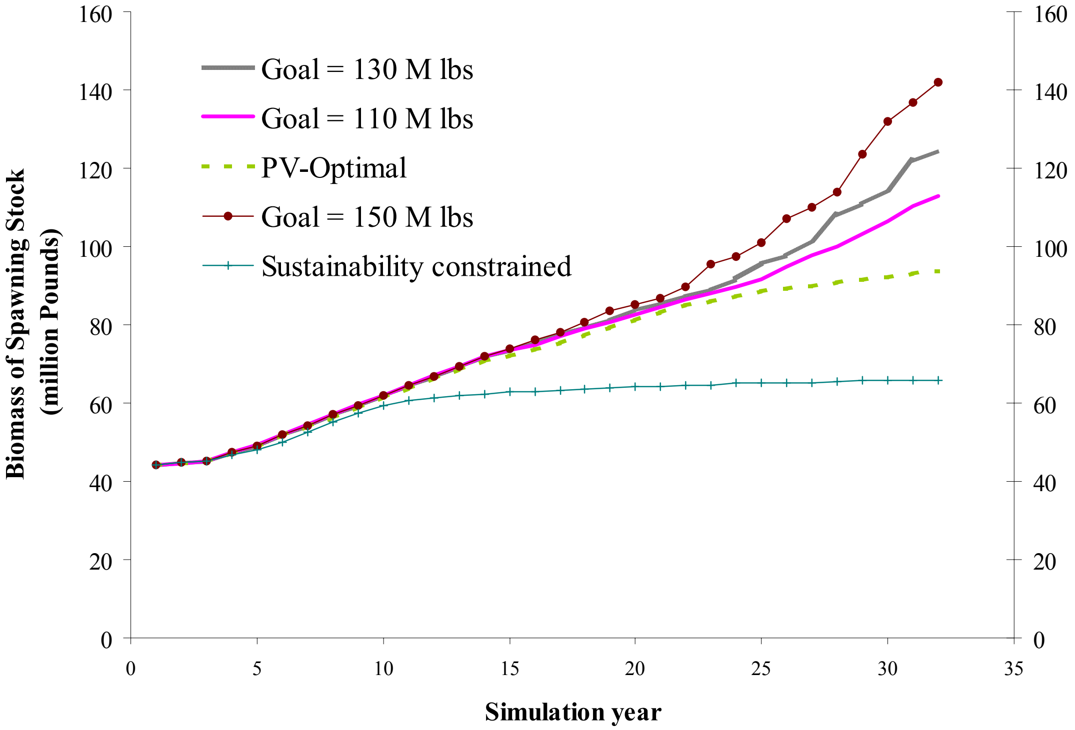

Figure 6. **Time-paths of spawning stocks along the PV-Optimal paths to achieve goals of 100, 110, 120 and 130 million pounds of spawn stock by 2032**

III.D. Limitations

The first limitation of the dynamic optimization model is that the value function is approximated based on a relatively small subset of the full body of states. There are a number of limitations that are imbedded in GBFSM used here, many of those that are discussed above. Of particular relevance here is the fact that the stock-recruit relationship of the red snapper fishery requires a choice between the Ricker and the Beverton and Holt model. This paper analyzed only the Beverton and Holt model. It should also be noted that GBFSM was calibrated to data through 2000. An updated version of the model would need to be developed in order to make policy recommendations for current conditions. There is also significant uncertainty surrounding many of the variables that go into the model. Finally, the general limitations of the economic approach to fisheries management are imbedded in the analysis here. Given all these factors, the results should be treated as representative more of qualitative trends than of the absolute levels.