Bioeconomic Simulation Analysis of Alternative Bycatch, Commercial, and Recreational Policies for the Recovery of Gulf of Mexico Red Snapper

By

Dr. Wade Griffin
Professor
Agricultural Economics Department
Texas A&M University
College Station, TX 77843-2124

Dr. Richard Woodward
Assistant Professor
Agricultural Economics Department
Texas A&M University
College Station, TX 77843-2124

and

Yong Suhk Wui
Aquaculture/Fisheries Center
University of Arkansas at Pine Bluff
Pine Bluff, AR 71601

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INTRODUCTION

The Gulf of Mexico Fishery Management Council suggested a 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. 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 paper is composed of three parts. First, we give a brief overview of the general bioeconomic fishery simulation model (GBFSM) and how it was calibrated for red snapper. Second, we evaluated two new policies to reduce bycatch by reducing the effort levels of shrimp vessels: fractional license (FL) and fractional gear (FG). We then compare the FL and FG results with the use of the BRD. Last, we examine the tradeoffs between size and bag limits and the effect release mortality has on these tradeoffs.

DESCRIPTION AND CALIBRATION OF GBFSM

Model Description[1]

The GBFSM is a multiple species, multiple length-based model using cohort analysis and instantaneous mortality (Grant et al. 1981; Isaakson et al. 1982). The model has been used extensively for analyzing the effects of management policies in the Gulf of Mexico (Blomo et al. 1978; Blomo et al. 1982; Gillig et al. 2001; Grant and Griffin 1979; Griffin and Stoll 1981; Hendrickson and Griffin 1993; Griffin and Oliver 1991; Griffin et al. 1993). In Figure 1, the conceptual model represents the important processes and relationships within a fishery. The GBFSM was designed to be general enabling it to be used for many different kinds of fisheries. The biological submodel represents the movement of fish between the various compartments of a given fishery. The economic submodel which include a harvesting sector and a policy sector represents the flow of information between these various aspects of the fishery as well as the biological submodel.

In the biological submodel the nursery grounds can be located in the inshore, nearshore, and/or offshore fishery. For example, most species of shrimp in the Gulf of Mexico have no known stock recruitment relationship and their nursery ground is in the inshore area. Shrimp recruitment abundance is related to environmental factors in the inshore area. Shrimp grow to juveniles, move into the nearshore fishery, and may as adults move into the offshore fishery, depending on the species. As adults they spawn in the Gulf and their

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[1] A detailed description of GBFSM can be found at http://gbfsm.tamu.edu. Reports and papers can also be found at this website.

larvae are carried into the inshore nursery grounds where the cycle begins again. Shrimp are harvested in the inshore, nearshore and offshore fisheries. Red snapper, on the other hand, are an offshore fishery. They spawn offshore, are subject to shrimp trawls as juveniles, and are harvested as adults by commercial and recreational fishermen. If there is a stock recruitment relationship, such as with red snapper, there is a choice between the Ricker and the Beverton and Holt models.

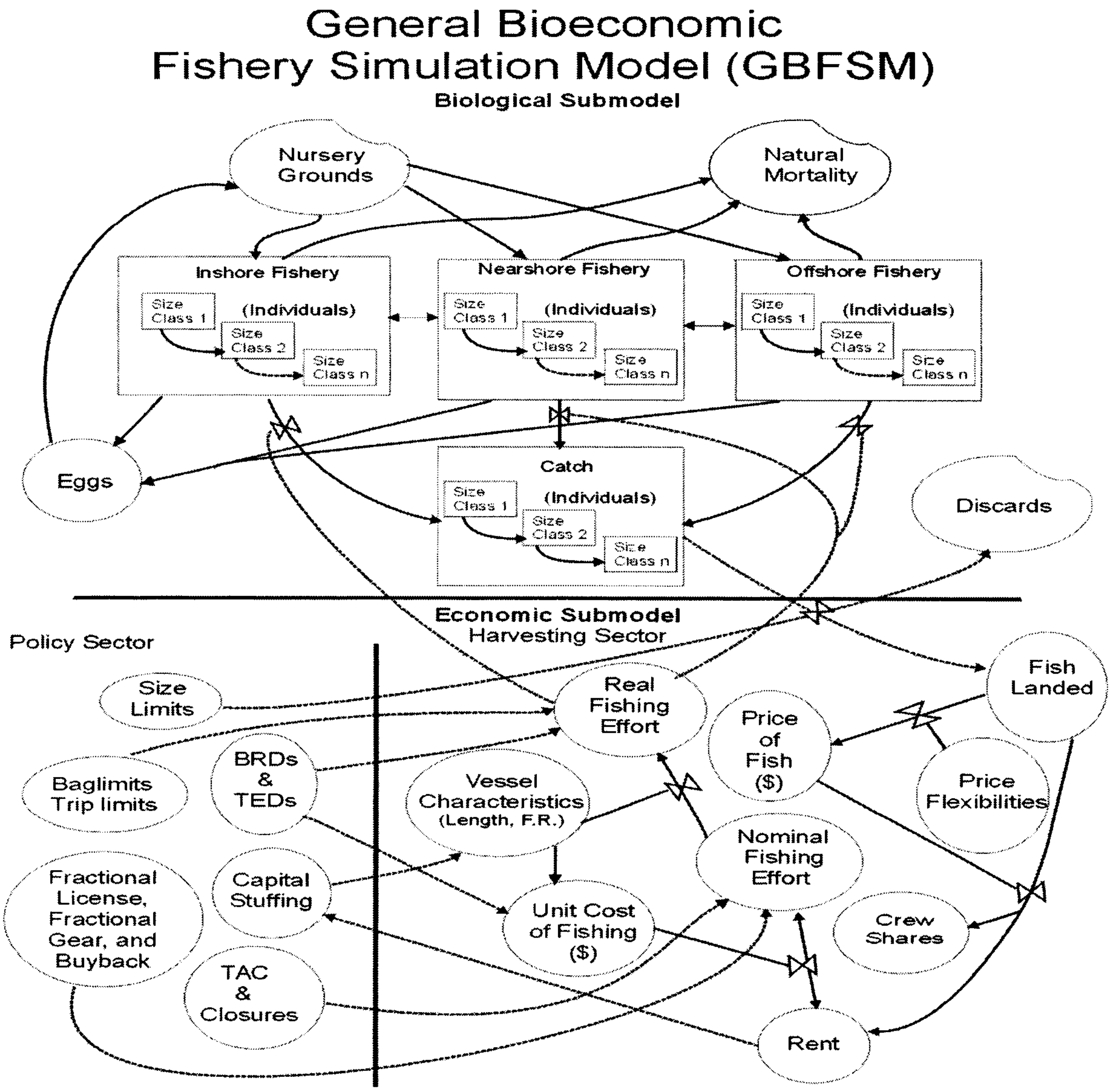

Figure 1

Figure 1: Conception of the general bioeconomic fisheries simulation model (GBFSM).

In the harvesting sector of the economic submodel, nominal fishing effort and vessel characteristics are exogenous during the first year of the analysis. Nominal fishing effort is converted to real fishing effort based on a vessel's characteristics, which determine the vessels relative fishing power. Real fishing effort, the catchability coefficient, and the number of harvestable size fish, determine catch. Landings are equal to catch less discards. Landings in the model are assumed to equal supply, which affects price though, price flexibilities. The variable cost of harvesting fish depends on the unit cost of fishing and nominal fishing effort and crew shares. Rent is determined as revenue less variable cost, fixed costs and opportunity costs. Rent, in an open access fishery, determines the amount of nominal effort (and vessels) that will be in the fishery the next year.

The GBFSM is capable of analyzing several different types of management policies. Policies affect the harvesting sector directly and the biological sector indirectly. Policies include:

1. Closures to fishing by area, species, depth and season.
2. TED/BRDs by area, species, depth, vessel class and season
3. License moratorium by region and vessel class
4. Texas Parks and Wildlife Department License Limitation Program with Buyback by license program and vessel class.
5. Total Allowable Catch (TAC) by area, species and vessel type.
6. Bag/trip limits for recreational/commercial fisheries by species and vessel type.
7. Size limit of fish being caught (produces discards, which may or may not return to the population depending on their mortality).
8. Fractional license by vessel class and market in which the vessel fished.
9. Fractional gear by vessel class and market in which the vessel fished.

Model Calibration

Two different calibration were used for the FL and FG research and the size and bag limit research. The size and bag limit research was conducted from an earlier version of the red snapper model and it calibration is reported in Griffin, Gillig, and Ozuna (1999, found at http://gbfsm.tamu.edu). The Ricker stock-recruitment relationship was used to calibrate the model for red snapper. The FL and FG research is reported in Woodward, Griffin and Wui (found at http://gbfsm.tamu.edu). The Beverton and Holt (1957) stock-recruitment relationship was used to calibrate this second version of the red snapper model. In this paper we will only show the results of the second version of red snapper model.

Coefficients were derived from information in the literature and/or data from federal/state management agencies whenever possible. When data is not available, or when there is a wide range of estimated values, these coefficients were determined from subjective estimation using an iterative simulation procedure. Calibrating the models involves matching simulation results to a historical data set.

Simulation models are only as good as the input data. In the case of red snapper the stocks are considered low and that they can be rebuilt to a larger amount. In the "Regulatory Amendment to the Reef Fish Fishery Management Plan to Set a Red Snapper Rebuilding Plan Through 2032" (Gulf of Mexico Fishery Management Council, Feb. 2001) it states that "...analysis suggested a high degree of uncertainty about the stock. Estimates of maximum sustainable yield (MSY) range from 22 to 205 mp...." Figure 2 shows the historical commercial red snapper landings in the Gulf of Mexico from 1948 to 1998 and recreational red snapper landings from 1981 to 1998. Since it is very time consuming to calibrate GBFSM to different MSY, we will only calibrate it to one level. Therefore, based on the historical landing we will calibrate GBFSM so that it will attain about 22 mp of landings by the year 2032 using a variable TAC that remains proportional to pounds of spawners beginning in 2001. We began with a 9.12 million pound TAC in 2001.

In the following discussion we will first describe the dimensions of model. This will be followed by the results of calibrating the red snapper for the model using a Beverton and Holt stock-recruitment relationship.

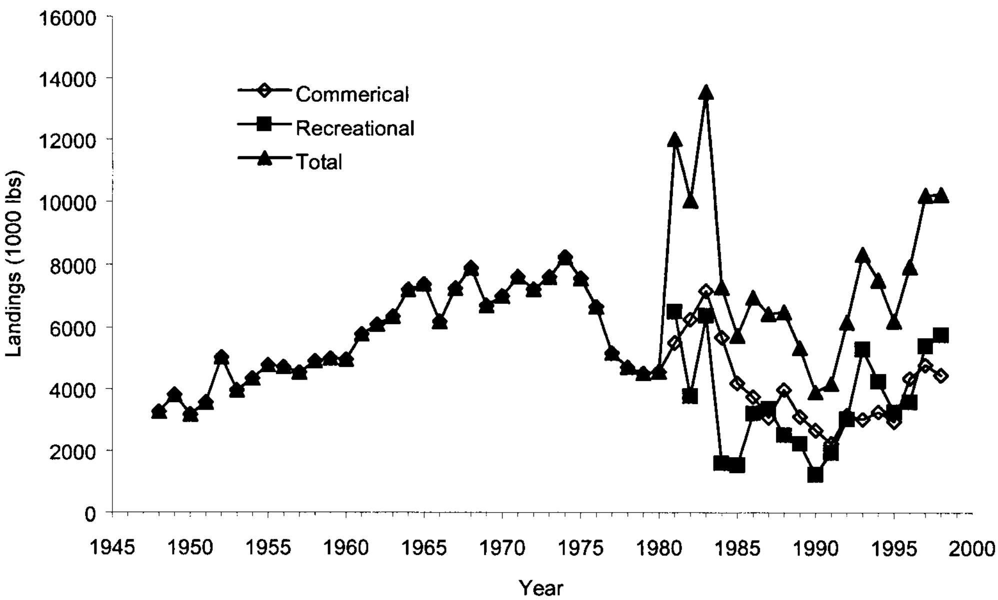

Figure 2: Red snapper commercial and recreational landings in the Gulf of Mexico for the period 1948 to 1998. Source: Schirripa and Legault (1997)

Model Dimensions

The dimensions of the large model in GBFSM for this study are as follows:

Four species of fish:

- Species 1: Brown shrimp (*Penaeus aztecus*)
- Species 2: Pink shrimp (*P. duorarum*)
- Species 3: White shrimp (*P. setiferus*)
- Species 4: Red snapper (*Lutjanus campechanus*)

Six size classes of fish (value indicates lower size limit):

Species	Size 1	Size 2	Size 3	Size 4	Size 5	Size 6
Brown (mm)	166.5	145.5	123.0	111.3	92.5	80.0
Pink (mm)	158.0	138.5	117.5	106.8	89.3	80.0
White (mm)	166.0	147.0	125.8	115.0	97.5	80.0
Red snapper (cm)	69.1	37. 7	28.7	18.2	10.0	1.7

The sizes of shrimp represent the following tail count per pound:

Size	Tail count/pound
1	20-up
2	21-30
3	31-50
4	51-67
5	68-116
6	> 117

The sizes of red snapper represent the following age classes:

Size	Age class
1	9 +
2	4
3	2
4	1
5	5-12 months
6	0-4 months

Five regions where landings occur:

- Region 1: Florida
- Region 2: Alabama
- Region 3: Mississippi
- Region 4: Louisiana
- Region 5: Texas

Six areas fished:

- Area 1: Lower Florida (Statistical grids 1-3)
- Area 2: Upper Florida (Statistical grids 4-9)
- Area 3: Alabama, Mississippi, E. Louisiana (Statistical grids 10-12)
- Area 4: W. Louisiana (Statistical grids 13-17)
- Area 5: Upper Texas (Statistical grids 18-19)
- Area 6: Lower Texas (Statistical grids 20-21)

Four vessel classes:
- Vessel class 1: Shrimp vessels ≤ 60 ft
- Vessel class 2: Shrimp vessels > 60 ft
- Vessel class 3: Commercial red snapper vessels
- Vessel class 4: Recreational red snapper vessels

Five depths fished:
- Inshore/bay
- 1-5 fathoms
- 6-10 fathoms
- 11-20 fathoms
- > 20 fathoms

Number of cohorts:

Red snapper are allowed to live up to 50 years in the model. Therefore, since there are 48 time steps per year, there are 2400 cohorts.

Calibration of Red Snapper

The red snapper biological model was calibrated to reflect the average fish stock in a given year rather than to replicate specific year classes. The concern in this analysis is the relative difference between different policies. While having historical year class strengths in the model may be beneficial, it will add very little to the outcome of the analysis when projecting to year 2032 in the future.

The biological red snapper model was tuned using 1995 data. The model was calibrated using several different indicators. One of the first steps in calibrating the model was to determine the growth curve. The von Bertelanffy growth equation is used to calculate the growth of fish and is represented by the following equation:

$$L_t = L_{t-1} + \mathrm{k}\,(L_\infty - L_{t-1})$$

where L_t is the length of fish in the current time step, L_{t-1} is the length of fish in the previous time step, L_∞ is the asymptotic length of fish and k is the growth coefficient. Figure 3 shows the plot of our simulated curve and that of Goodyear's simulated curve (Table 5, page 61, 1995).

The fishing mortality was determined as part of the calibration process. Fishing mortality F in the GBFSM is a function the catchability coefficient and effort. The catchability coefficients are assigned so as to generate the actual level of landings observed in 1995 by the recreational and commercial fisheries.

Figure 4 shows the actual versus simulated landings by depth zone and area fished, for the Gulf of Mexico recreational red snapper fishermen. There are no landings for Area 1, which are the first three statistical zones of Florida. Figure 5 shows the actual versus simulated landings by depth zone and area fished, for the Gulf of Mexico commercial red snapper fishermen.

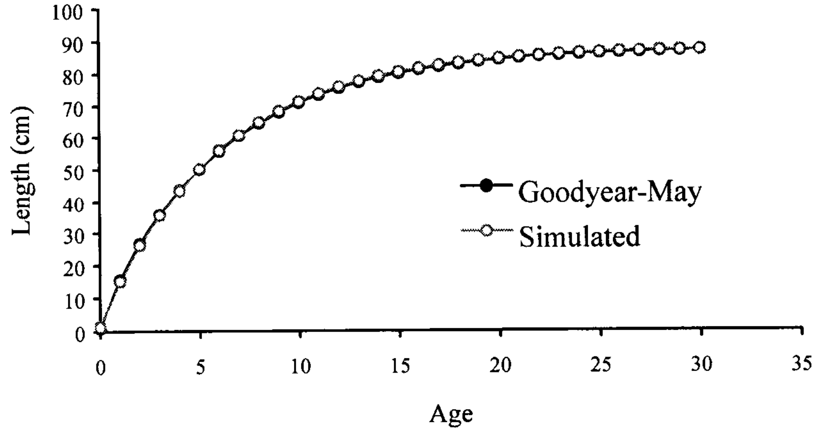

Figure 3: Estimated growth relationship used in the GBFSM compared with Goodyear's (1995) growth relationship

In Figure 6 the recreational landings, in inches, were compared to the actual recreation data from the NMFS. This comparison is made in inches instead of age since this is the only way the actual data could be categorized. The size frequency was generated from the actual recreational data and then the total number of fish in each size category was calculated. The GBFSM was then tuned so that it generated, as closely as possible, the same number of fish in each size category.

Wilson has determined the age distribution of commercially caught red snapper. The GBFSM was tuned so that it matched that same distribution as close as possible (Figure 7). From the onboard observer data, the distribution of juvenile red snapper bycatch by shrimp vessels, in inches, was determined. This was then compared to the simulated data. The results are shown in Figure 8 for the entire Gulf of Mexico. Also, from the observer data, the catch per unit effort (CPUE) of juvenile red snapper by a single shrimp trawl for vessels greater than 60 feet in length was calculated.

Finally, 1998 simulated data are compared to the population abundance in numbers of fish at the start of the year in the stock assessment by the NMFS (Schirripa and Legult, 1997) as shown in Figure 9. The year 1998 is the beginning year of the policy simulation runs.

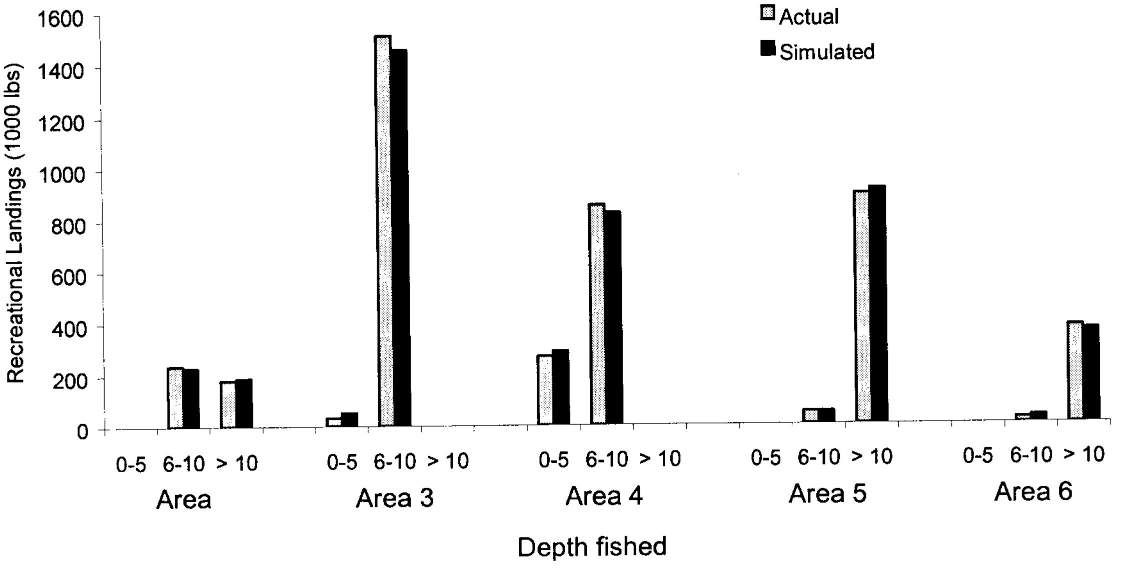

Figure 4: Actual versus simulated landings by depth zone and area fished, for the Gulf of Mexico Recreational red snapper fishermen

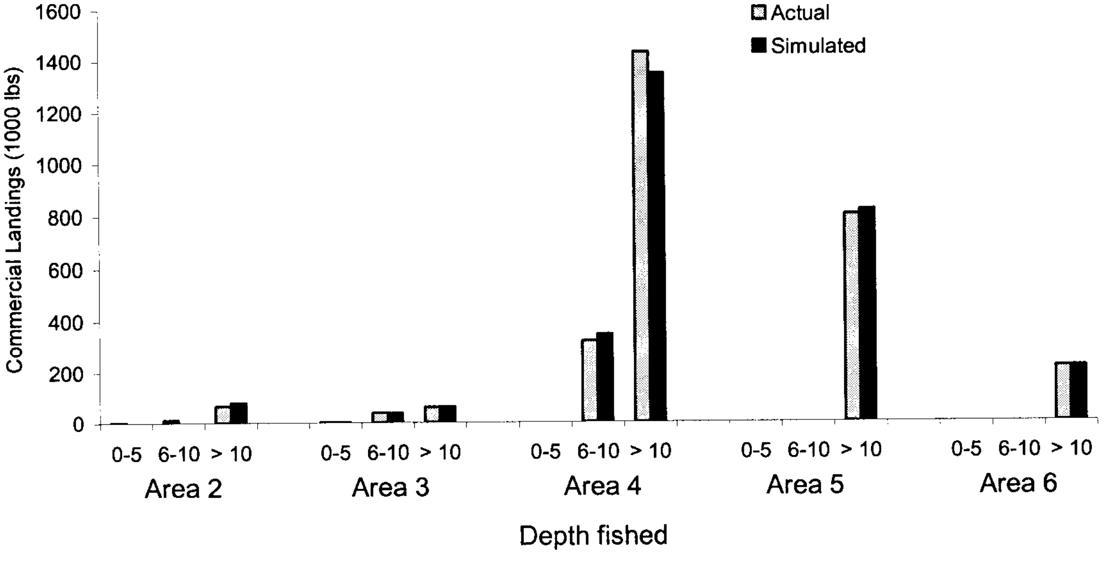

Figure 5: Actual versus simulated landings by depth zone and area fished, for the Gulf of Mexico Commercial red snapper fishermen.

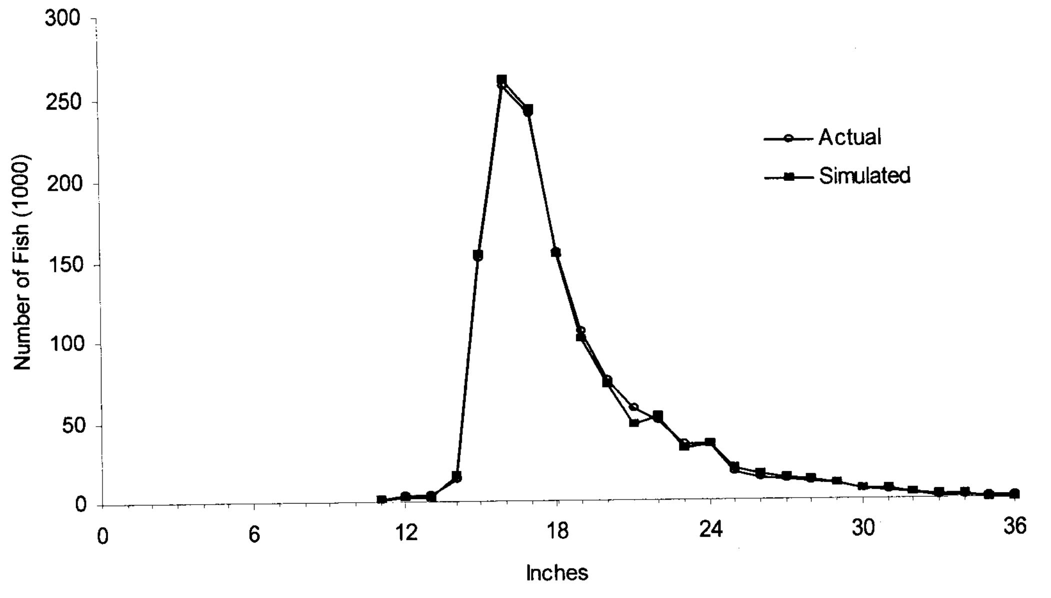

Figure 6: Simulated number of red snapper landed compared to actual for the Gulf of Mexico recreational red snapper fishermen

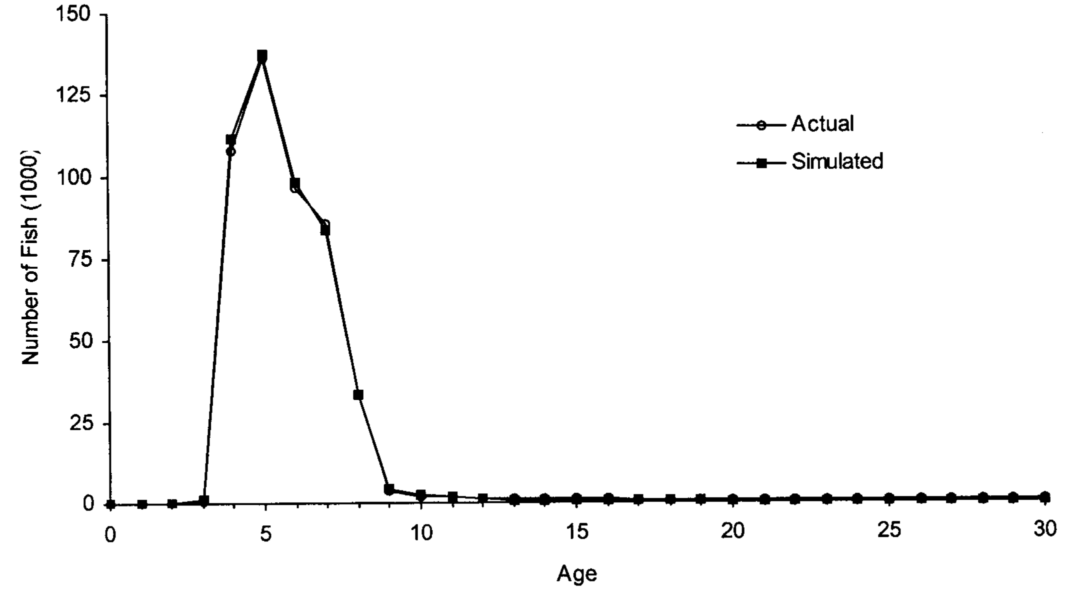

Figure 7: Simulated number of red snapper landed compared to the distribution of commercial landings in a study by Wilson

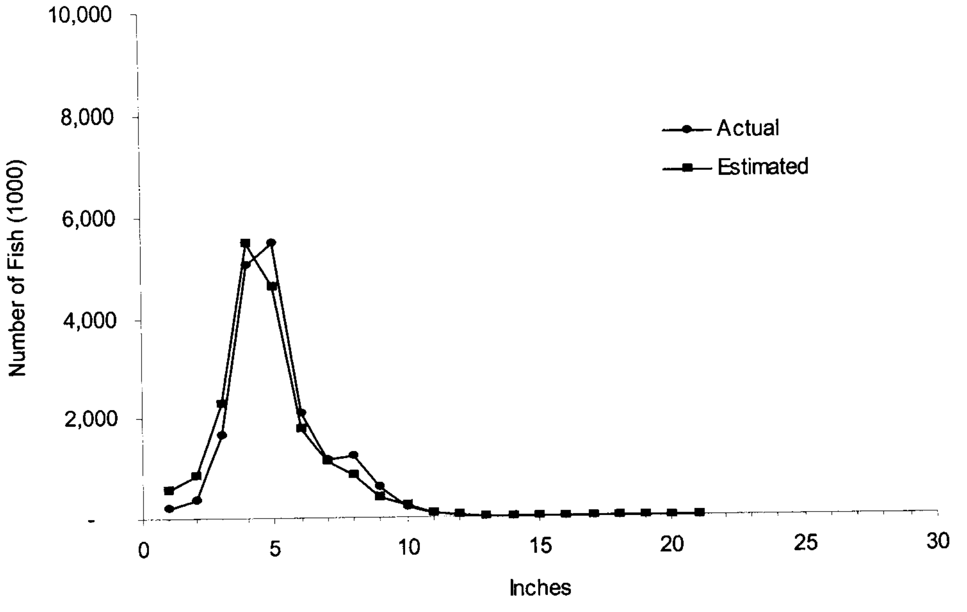

Figure 8: Simulated number of red snapper discarded bycatch by the shrimp fishery compared to the distribution of on board observer data in the Gulf of Mexico.

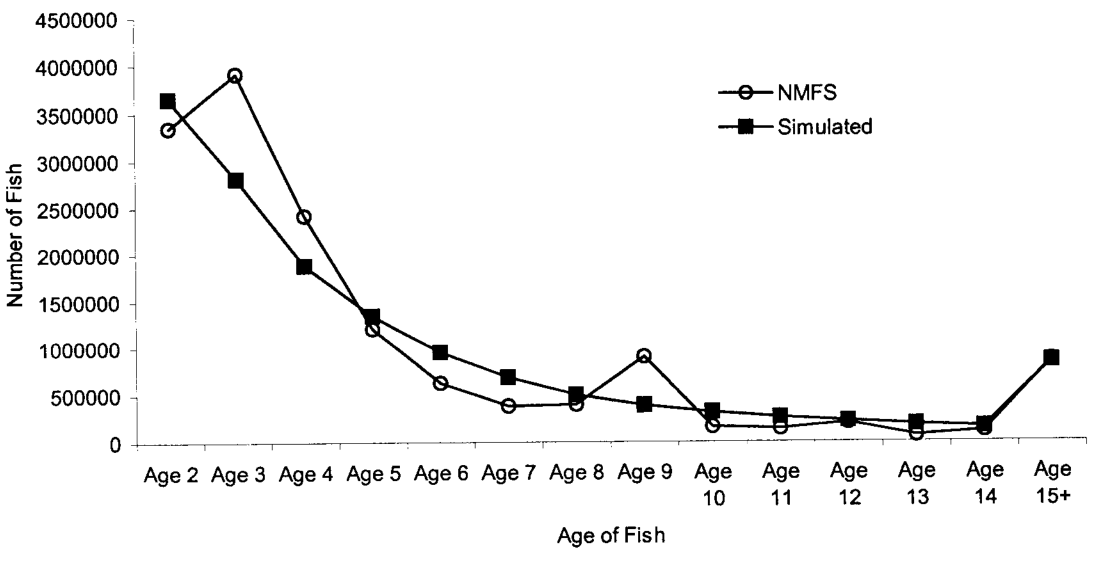

Figure 9: Simulated compared to NMFS (Schirripa and Legault, Table 28 between pages 83 and 84) population abundance at the start of the year for ages 2 an higher in 1998

FRACTIONAL LICENSE AND FRACTIONAL GEAR

Under FL and FG[2] programs, fractional rights are given 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 were 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 GBFSM 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. A permit system for fishing for shrimp in the EEZ has been implemented in the EEZ and a fractional license program is being considered in shrimp Amendment 14. 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 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.

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[2] Gear is measured in yards of footrope.

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.

Results

Figure 10 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.

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.

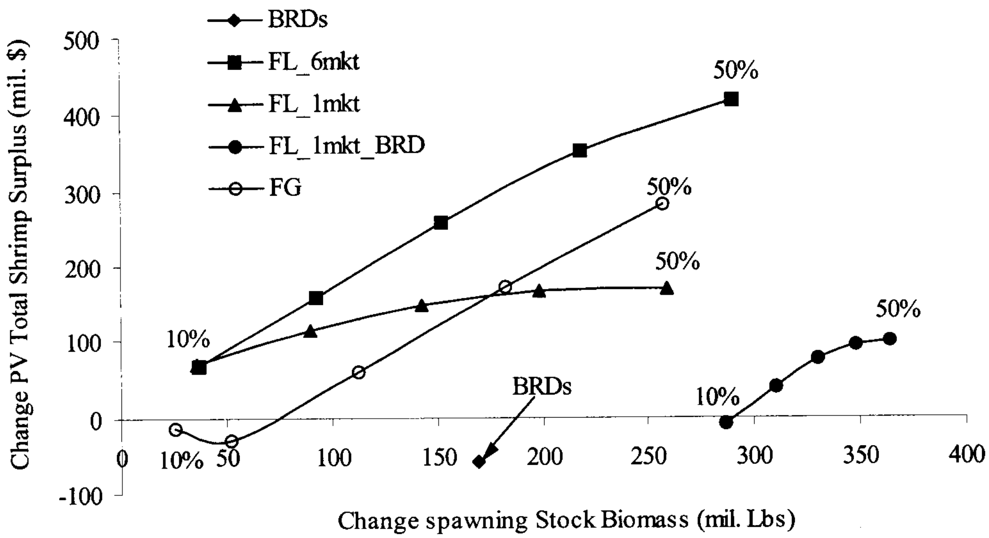

Figure 10: Tradeoff between the change from the base year scenario in the present value of total (producer and consumer) surplus of shrimp fishery and in the red snapper spawning stock biomass (in year 2032) under FL with six markets (FL_6mkt), FL with one market without BRDs (FL_1mkt) and with BRDs (FL_1mkt_BRD), and FG scenarios

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%.

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

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 (Table 2). 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 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

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 and 2003 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 of a license to a potential buyer or seller, which is the common method in used in 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 includes in this analysis.

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.

Conclusions

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 welfare of shrimp vessels. 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 social welfare in shrimp fishery. As Townsend (1992) mentioned, FL or FG programs might be implemented more easily than many other effort reduction policies.[3] 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.

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

SIZE AND BAG LIMITS[4]

Size- and bag-limit policies are widely used regulation, however, they have received only limited treatment in the economics literature. Homans and Ruliffson (1999) evaluate how size limits affect a fishery and Anderson (1993) considers the implications of bag limits. We analyze alternative policy mixes in the fishery by predicting long-term consequences of the policy in an environment in which changes in the fish stock depend on complex biological growth functions in which the stock's age structure plays an important role. We pay particular attention to the issue of discard mortality because this can have important consequences for the effectiveness of fishery policy. For example, when size limits are used, if a substantial portion of released fish die prematurely, this will diminish the policy's effect and the consequent long-term benefits for the fishery.

There is a high degree of uncertainty with release mortality because of the difficulty in measuring it. The limited evidence that is available suggests that release mortality could be significant. In catch-and-release bass fishing tournaments, Wilde (1998) estimates mortality at about 26 percent. When compared to freshwater fisheries, release mortality in deepwater might be higher as fish are hooked at greater depths and pulled rapidly to the surface, suffering rapid pressure changes. Harley, Millar and McArdle (2000) put discard mortality for recreational gulf snapper at between 15 and 35%. Burns, Koenig and Coleman (2002) report preliminary findings of release mortality in red snapper of 50 percent or higher for fish caught deeper than 35 meters and 60 to 70% for those caught at 40 to 60 meters (Woodward and Griffin).

Recreational Demand

Red snapper recreation is modeled based on the empirical analysis of Gillig et al. (2000) and discussed in Woodward et al. (2001). The demand for red snapper fishing trips by the *i*th angler, y_i, is specified as:

$$\ln(y_i) = b_0 + b_1 P_i + b_2 Inc_i + b_3 l_i + b_4 l_i^2 + b_5 E_i + b_6 E_i^2 + b_7 B_i + \varepsilon_i$$

where P_i represents travel costs incurred by the *i*th angler to gain access to the resource in the Gulf of Mexico; Inc_i is the individual's household income in thousands of dollars; l_i refers to expected red snapper catch rates; E_i denotes the number of years an angler has fished recreationally; B_i is a dummy variable that is equal to one if an angler owns a boat; and ε_i is a gamma distributed error term (Woodward and Griffin).

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[4] Woodward and Griffin provide a unifying economic framework for the analysis of recreational fishing behavior. The model is sufficiently flexible to allow the consideration of not only size and bag limits, either independently or together, but could also be used for the analysis of other policies that might be considered.

The specification of the recreation demand model has some direct implications for the predicted impacts of the size- and bag-limit policies. First, as is common in the literature, recreation demand was estimated based on the number of fish retained. Hence, it is implicitly assumed that all anglers are quantity-focused. Secondly, the relationship between catch rates and annual demand is such that any increase in the catch per day will increase the number of trips per year. Implicitly, therefore, it is assumed that fishing quality per day and days per year are complements in the angler's demand. Furthermore, anglers are assumed to follow a simple compliance response to bag limits. When their bag limit is reached, they stop fishing and do not discard fish prior to reaching their limit. Because of the specification, therefore, the short-term impacts of both bag and size limits on angler effort and welfare are known a priori: the policies will reduce catch, effort and per-angler welfare (Woodward and Griffin).

Results

Figure 11 presents the immediate impact of twenty-four different policy combinations of size and bag limits: four bag limits (from a limit of 2 fish per day to no limit), combined with six size limits (from an 20-inch minimum to a 10-inch minimum which is the minimum size at which red snapper are caught). Discard mortality is assumed to be at a "best guess" level of 10% for depths less than 5 fathoms, 20% for depth of 6 to 10 fathoms

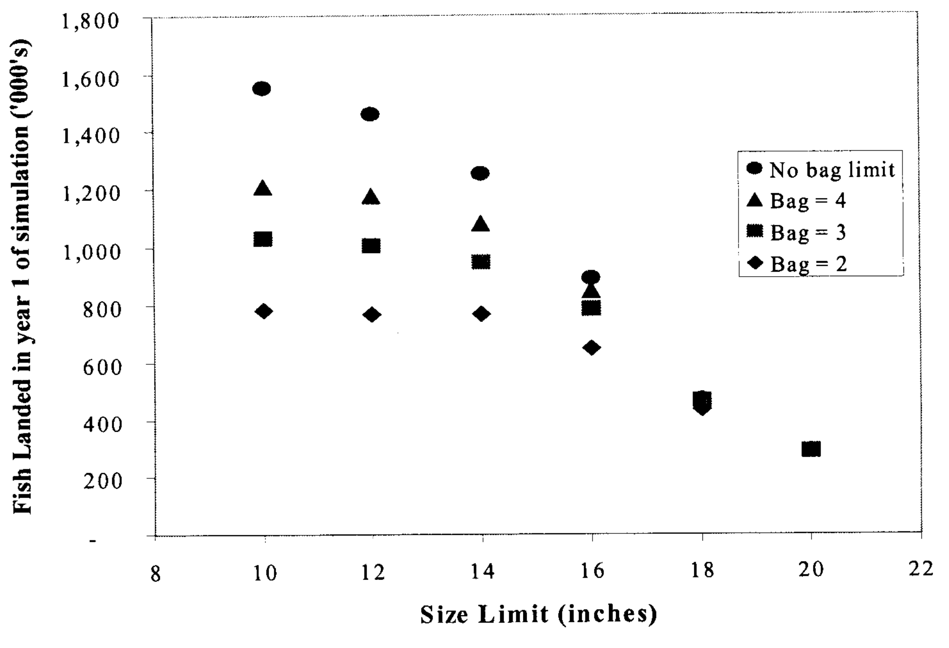

Figure 11: Fish landings under alternative size and bag limit policy combinations (First year of simulation). (Source: Woodward and Griffin).

and 33% for depths greater than 10 fathoms. As seen in the figure, for low size limits when all fish can be retained, the bag limit is the dominant factor in the reducing landings. As the size limit is increased, however, fewer fish can be retained so that eventually the bag limit constraint does not bind and total harvests are not affected by the bag limit (Woodward and Griffin).

The effect of these policies on fish stocks comes through two channels. First, fish stocks are affected by altering the number of fish caught and discarded. Second, the policies affect angler behavior by altering the catch per trip and thereby changing the number of trips that anglers choose to take over time. This secondary impact is presented in Figure 12, which shows the simulated number of trips taken over a twenty-year time horizon for a variety of size limits without a bag limit. As seen in the figure, size limits of 18 and 20 inches have a strong impact on trips in the short term. This follows from the model's assumed relationship between the desired number of trips and the number of fish landed. Over time, however, more aggressive policies lead to a substantial increase in the spawning stock -- increasing the stock by over 250% with a twenty-inch size limit. This leads to an increase in catch per unit of effort, causing trips per year to increase and by the end of the simulated period total trips are nearly back to their pre-regulation level (Woodward and Griffin).

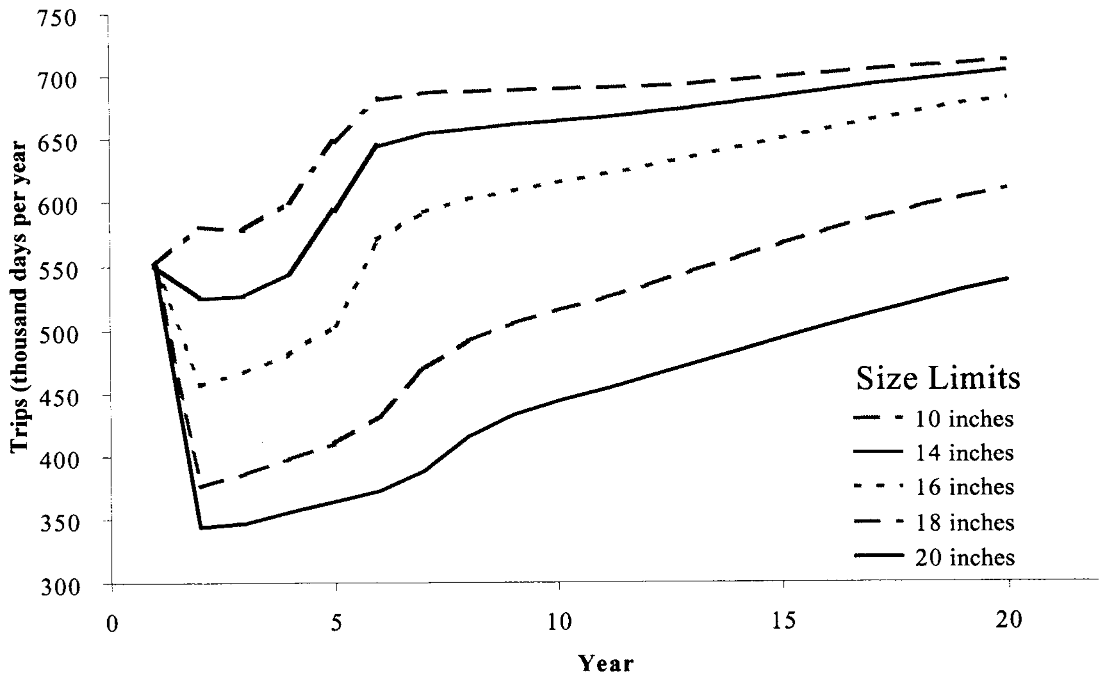

Figure 12: Trips taken under various size-limit policies in the absence of a bag limit[5] (Source: Woodward and Griffin)

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5 For any size limit, the addition of a bag limit policy uniformly reduces trips taken over the simulated time horizon with more aggressive policies (smaller bag limits) having a greater impact on trips taken.

We know that for quantity-focused anglers there is a tendency for a size limit, at least on the margin, to increase fishing effort and discards. The biological impact of the policies combinations, therefore, is strongly influenced by release mortality. Since little is known about actual release-mortality rates, sensitivity analysis is carried out on these parameters over a range of possible values (Woodward and Griffin).

Figure 13 shows the trade-offs between the spawning stock in year 20 and the present value of consumer surplus (discounted at a 7% discount rate) assuming that release mortalities are very low (1%). If accurate, Figure 13 would suggest that a wide range of efficient policies are available: virtually all the points on the frontier could be reached by various combinations of size and bag limits. However, the shape of the policy frontier changes dramatically in Figure 14 where much higher levels of release mortality are considered. Here we see that size limits are relatively inefficient, leading to outcomes on the interior of the feasible set. For example, in this scenario when there is a bag-limit of 2 or 3 fish, an increase in the size limit not only reduces the fishery's economic value, but actually has negative consequences for the population as a result of the high discard rate. The contrast between Figures 13 and 14 demonstrates the importance of research to

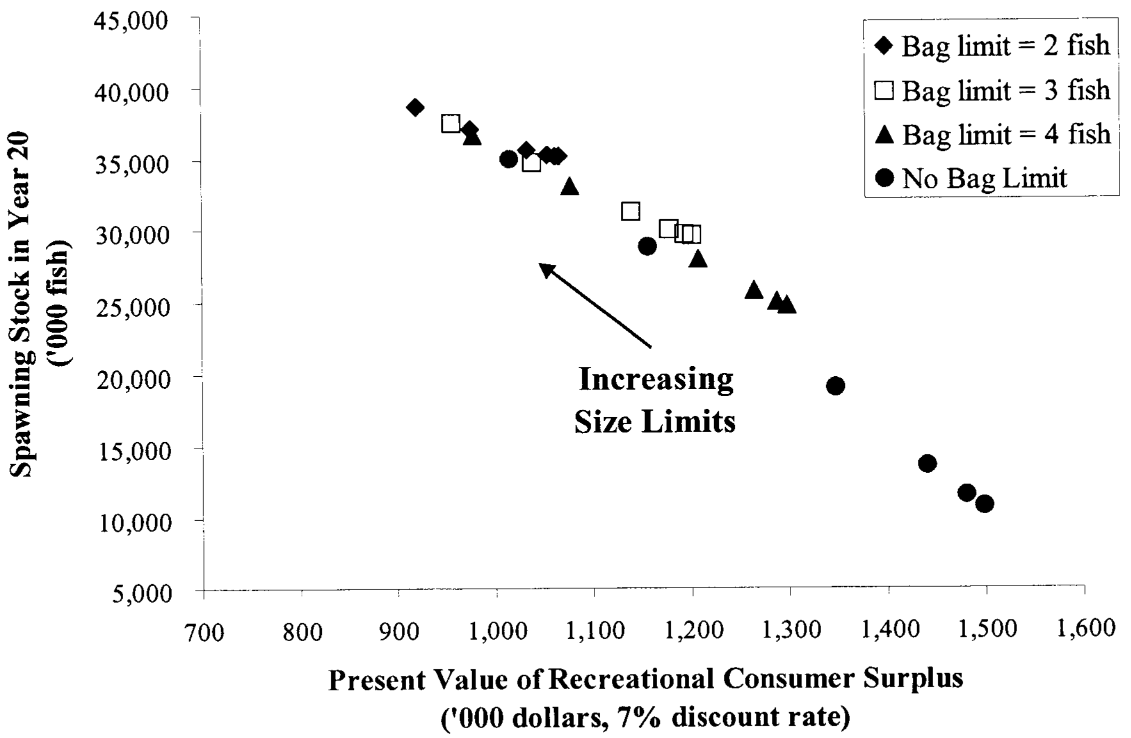

Figure 13: Consumer Surplus and Year-20 Spawning stocks under alternative policy options (discard mortality rates: 1%, 1% and 1%)[6] (Source: Woodward and Griffin)

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[6] Mortality rates for fish caught at 3 depths: 0-5 fathoms, 6-10 fathoms and more than 10 fathoms.

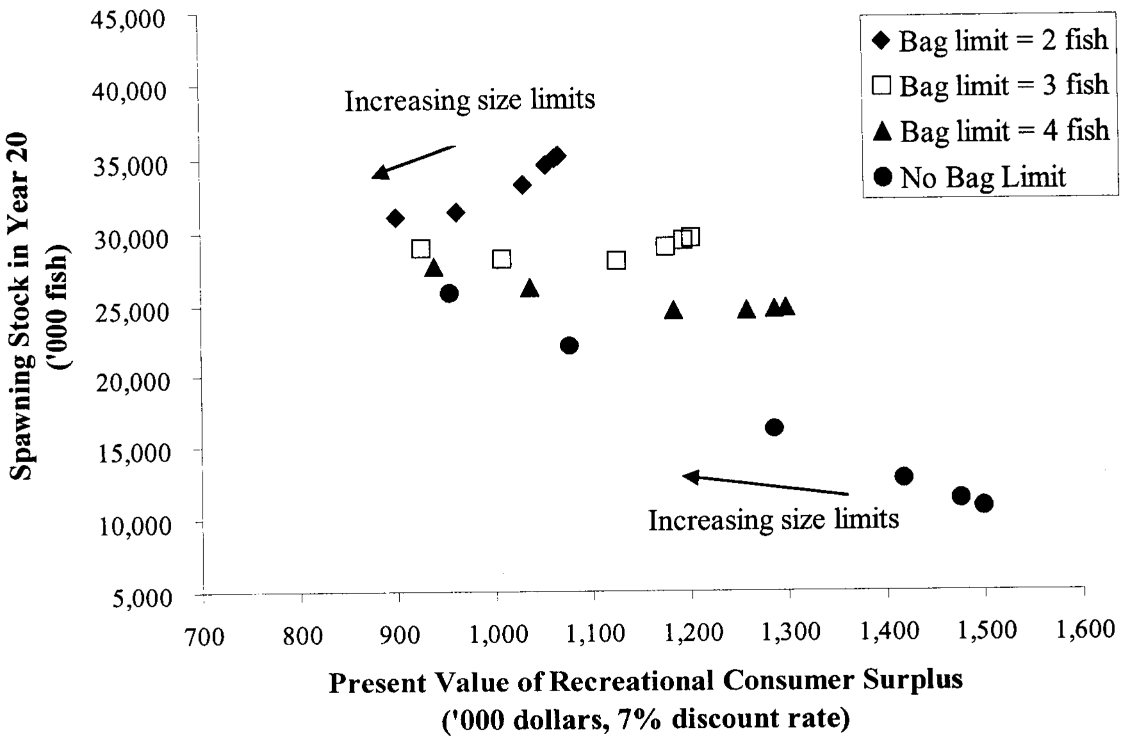

Figure 14: Consumer Surplus and Year-20 Spawning stocks under alternative policy options (discard mortality rates: 33%, 46%, and 59%). (Source: Woodward and Griffin)

improve our knowledge of release mortality and taking this variable into account when establishing fishery policies (Woodward and Griffin).

Conclusions

We evaluate alternative size- and bag-limit policies in the context of the Gulf of Mexico's red snapper fishery. The relative effectiveness of these policies is dependent on the rates of release mortality. When release mortality is high, size limits can be a very inefficient way to achieve either economic or biological goals. There remains, however, substantial uncertainty about release mortality rates and scientific study of this issue is needed to help identify the optimal policy mix.

We assume that anglers respond to bag limits through simple compliance, halting their fishing when their limit is reached. If anglers high grade, share their limit with other anglers or discard smaller fish during the day, then bag limits would lead to higher total catch and higher mortality. (Woodward and Griffin).

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Data Requirements for GBFSM

General Data Requirement For GBFSM

Length of fish are converted to weight using the coefficients in the following equation:

$$weight = VS(2,NSP)*(length)^{VS(3,NSP)}$$

VS(2,NSP) is the linear coefficient in length to weight equation.

VS(3,NSP) is the power coefficient in length to weight equation.

NMEASURE(2,NSP) is the conversion of fish to pounds. The user must be careful here. For example, fish may be grown in mm and then converted to weight which is in grams. This conversion would convert grams to lbs. Another example is that the fish may be grown in cm and then converted to kg by VS(3,NSP). Then this conversion would convert kg to lbs.

Nominal effort must be converted to real effort because vessels of different sizes, construction and gear type have different fishing powers per unit of nominal effort. Real effort is simply the product of relative fishing power and nominal effort. The fishing power of a given vessel is calculated as

$$P_{it} = e^{aD_{1t}} e^{bD_{2t}} e^{aD_{31}} D_{4t}^{d} D_{5t}^{f} D_{6t}^{g}$$

Where D_{1t}, D_{2t} and D_{3t} would be dummy variable (zero or one values) such as gear (hand line and long line) and D_{4t}, D_{5t} and D_{6t} are continuous variables such as vessel length, horsepower, length of gear, etc. The subscript *t* refers to the type of vessel, such as shrimp trawlers, red snapper commercial fishermen or red snapper recreational fishermen. The variables a, b c d f and g are coefficients derived through regression analysis. Relative fishing power (RFP_{it}) of the i^{th} vessel is calculated as

$$RFP_{it} = \frac{P_{it}}{P_s}$$

where, RFP_{it} is relative fishing power of the i^{th} vessel class of type *t*.

VS(1,NSP) converts whole fish caught to product sold at the dock. For example, fish may be gilled and gutted. VS(1,NSP) =0.62 would then be used to convert the weight of fish from a whole fish to gilled and gutted fish.

Biological Data Requirement For GBFSM by Species and Area Fished

A data set is required for each area/species combination. For example, if you have two areas and two species then four data sets are required. They are:

Data Set 1:	Area 1, Species 1
Data Set 2:	Area 1, Species 2
Data Set 3:	Area 2, Species 1
Data Set 4:	Area 2, Species 2

Recruitment Coefficients

ICOF(1,NA,NSP) is the gross recruitment rate that young fish are introduced into the fishery on a timestep (JTIME) basis.

SZR(2,NA,NSP,ND) is the factor to distribute recruited fish across depth zones. Factors across depth zone for a given species must sum to 1.0. In the following example all the new fish are recruited into depth 1.

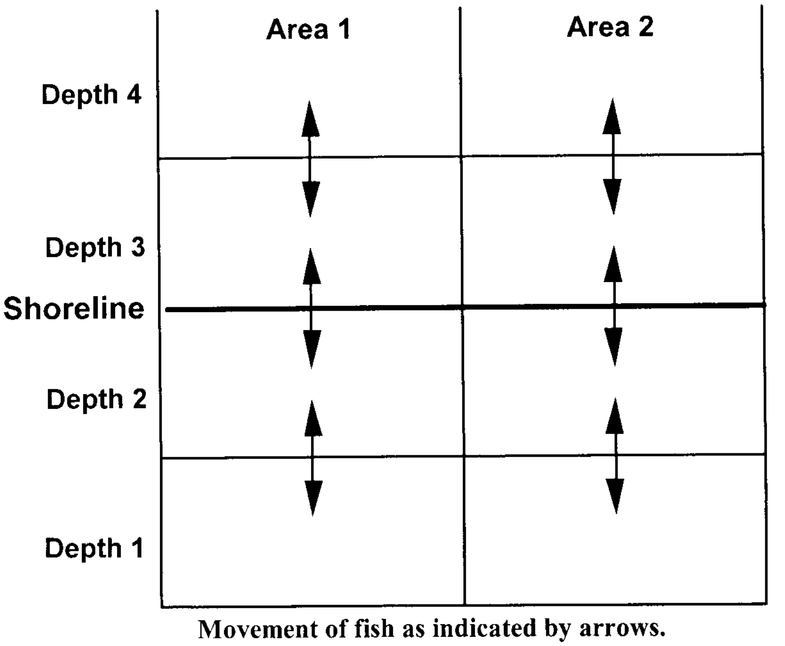
E(NA,NSP,NER) is the rate altering recruitment so that recruitment can vary on a seasonal basis. Total recruits for a given species in a given area for a given time step = ICOF(1,NA,NSP) *E(NA,NSP,NER). It is not necessary that the percentages add to one since it is just a seasonal adjustment factor.

ISZ(1,NA,NSP,NSX) is the initial length of new recruits . Length in mm, cm or inches.

Movement Coefficients

Movement across depth

ERT(1,NA,NSP,NSZ,ND) contains the percentage of individuals moving from a current depth to a greater depth on a timestep basis. That is, values in depth 1 control the movement between depths 1 and 2, values in depth 2 control the movement between depths 2 and 3, etc. This means that values in depth ND, the last depth, do not control anything. This variable is the net number entering and leaving from the current depth to the adjacent greater depth.

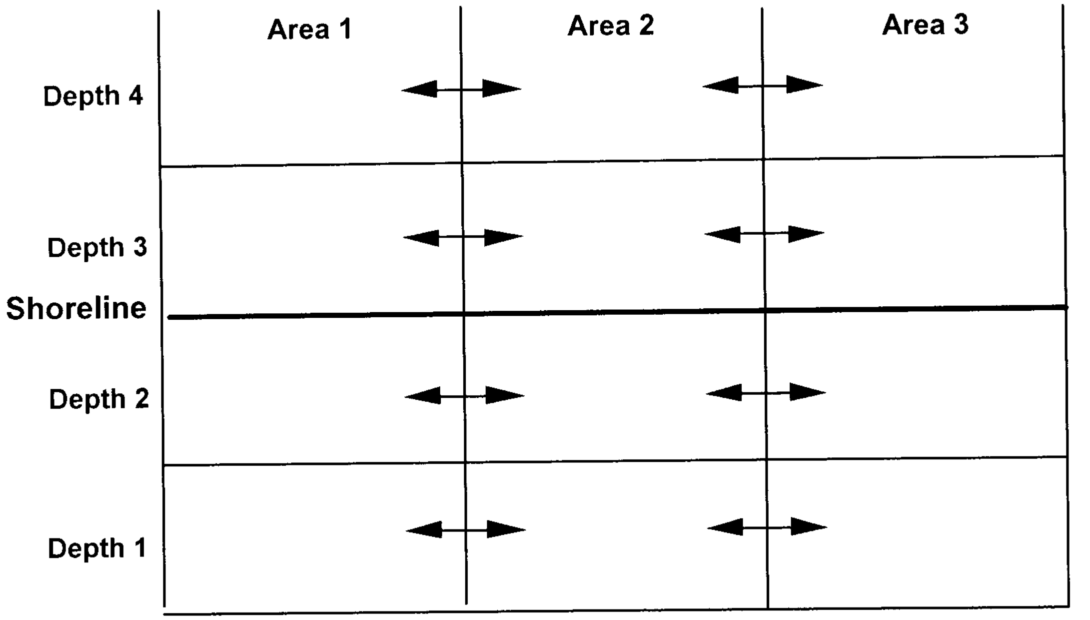


Movement of fish as indicated by arrows.

SZR(1,NA,NSP,ND) is the minimum size the fish reach before the fish moving from the current to the next greater depth or the non-fishing depth. It is calculated only when there is more than one depth.

Movement across area

ERT(2,NA,NSP,NSZ,ND) contains the percentage of individuals moving from current area to another area with the next highest index number on a timestep basis. That is, values in area 1 control the movement between areas 1 and 2, values in area 2 control the movement between areas 2 and 3, etc. This means that values in area NA, the last area, do not control anything. This variable is the net number entering and leaving from the current area to the adjacent area (area t to area t+1).



Movement of fish as indicated by arrows.

Net migration of fish from fishing grounds

NMCOFT(2,NA,NSP,ND,NS1) is the net migration of fish from fishing grounds by area, species, depth and size class.

Growth Coefficients

The von Bertelanffy growth equation is used to calculate the growth of fish and is represented by the following equation:

Growth = ISZ(3,NA,NSP,NSX) * GRT(NA,NSP,NPH) * [ISZ(4,NA,NSP,NSX)-current size)]

ISZ(3,NA,NSP,NSX) is the growth coefficient entered on a timestep basis.

ISZ(4,NA,NSP,NSX) is the upper asymptotic length for growth equation.

GRT(NA,NSP,NPH) is a factor used to alter growth on a seasonal basis. (Enter 1.0 for no effect.)

VASZ(NA,NSP,NSZ) is a factor to adjust growth rate by size class of fish. (Enter 1.0 for no effect.)

Natural Mortality Coefficients

NMCOFT(1,NA,NSP,ND,NSZ) is the natural mortality rates entered on a timestep basis.

SMOVE(1,NA,NSP,NM) is the adjustment mortality rate for NMCOFT(1, NA,NSX,NSP,ND,NC) by a seasonal factor.

Harvest Coefficients

There are 3 types of fisheries in this model: commercial, bait and recreational. Commercial fishing is always based on days fished. Bait and recreational fishing are treated as a mortality rate. Fishing, then, is on a straight percentage basis of population at a given area, species, depth and time step.

VAS(1,NA,NSP) is lowest catch rate size for bait harvest. Bait fishing is restricted to depth as defined by SZR(3,NA,NSP,ND).

VAS(2,NA,NSP) is lowest catch rate size for recreational harvest. Recreational fishing is restricted to depth as defined by SZR(4,NA,NSP,ND).

VAS(3,NA,NSP) is the bait harvest maximum catch rate size fish caught by bait fishermen.

VAS(4,NA,NSP) is the recreation harvest maximum catch rate size fish caught by recreationally fishermen.

VASM(1,NA,NSP,NM) is the bait fishing mortality coefficient .

VASM(2,NA,NSP,NM) is the recreational fishing mortality coefficient.

SZR(3,NA,NSP,ND) is the depths at which bait fishing can occur.

SZR(4,NA,NSP,ND) is the depths at which recreational fishing can occur.

VASV(1,NA,NSP,NVT) is the upper size bound for altered fishing mortality range.

VASV(2,NA,NSP,NVT) is the lower size bound for altered fishing mortality range.

VASV(3,NA,NSP,NVT) is the fraction of fishing mortality for fish killed between VASV(1,NA,NSP,NVT) and VASV(2,NA,NSP,NVT). To eliminate knife-edge effects in harvest, fish between VASV(1,NA,NSP,NVT) and VASV(2,NA,NSP,NVT) in size, generally smaller than legal catch size, are killed by the fraction VASV(3,NA,NSP,NVT) of fishing mortality. All organisms killed between the lower catch rate size and the lower legal size are counted as culls, except for a small percentage, which are counted in the smallest size class that can be harvest as legal commercial catch and are stored by depth, vessel class and size class.

SCATCH(1,NA,NSP,NVT) is the minimum size fish subject to the fishing gear. Fish are not subjected to the commercial nets below this size.

SCATCH(2,NA,NSP,NVT) is the maximum size fish subject to the fishing gear. Fish are not subjected to the commercial nets above this size. This is useful particularly with non-directed fish that can escape a trawl after they reach a certain length

VKIL(NA,NSP,ND,NLL,NVT) is the smallest size than can be legally landed. If the element VKIL(NA,NSP,ND,NLL,NVT), contains a size less than or equal to the lower limit of the smallest size class (SL), all the organisms killed are placed in the lower size class. If VKIL contains larger values, then culls can occur.

RELMORT(NA,NSP,ND,NVT) is the release mortality rate for discards.

CULL(NA,NSP,ND,NVC,NSZ) is the percent culls counted in legal catch.

FMAX(NA,NSP,ND,NM,NVC) is the density factor (q) for fishing mortality.

XCATCH(NVC) is the overall adjustment factor for FMAX(...).

CHADF(NA,NSP,NSZ,NVT) is the overall adjustment factor for fishing mortality based on the size class of the fish.

CHADFA(NA,NSP,NAGE,NVT) is the overall adjustment factor for fishing mortality based on the age of the fish.

CHADFI(NA,NSP,ND,NINCH,NVT) is the overall adjustment factor for fishing mortality based on the length of the fish in inches.

Nominal Effort

DFN(3,NR,NA,NSP,ND,NVC,JTIME) is nominal effort by region, area, species, area, depth, vessel class and time division.

Actual Landings to Calibrate GBFSM

CACT(IR,IA,IS,ID,IZ,IM) is the actual landings by region, area, species, depth, size of fish and month.

CACTV(IR,IA,IS,ID,IV,IM) is the actual landings by region, area, species, depth, size of vessel and month.

Parent Stock Recruitment Option

The equation to estimate annual eggs deposition of mature females fish as a function of length is

$$\text{Fec} = \left(aL^{b}\right)A$$

where a and b are estimated coefficients and L is the length of the fish. The equation in FORTRAN is

```
FEC = (VS(5,IS)*SZ(IA,IS,IX,IC)**VS(7,IS))*VS(7,IS)
```

where a = VS(5,IS),
b = VS(7,IS),
A = VS(10,IS),
L = SZ(IA,IS,IX,IC).

The number of spawners is defined as

$$\text{NumSpawn} = N^{*}\mu$$

where N is the number of fish of a given age that are mature,
μ is proportion of fish that are mature at that age level.

Therefore,

SSB = NUM(NA,NAP,NSX,ND,NC)* VAGE(NSP,NAGE)*FEC

where N = NUM(NA,NAP,NSX,ND,NC)
μ = VAGE(NSP,NAGE)

There are two types of recruitment equations to choose from. The first is Ricker and the second if Beverton and Holt.

The Richer model (see Ortiz pages 90-91 and 124)

$N_0 = \alpha * SSBe^{\beta * SSB} * AF$

where N_0 is the number of recruits,
α is the density independent parameter of the stock of recruitment relationship,
β is the density dependent parameter of the stock of recruitment relationship,
AF is an adjustment factor

The equation in FORTRAN is

RECRUI = {VS(8,NSP)*SSB*EXP[VS(9,NSP)*SSB]}* VAS(6,NA,NSP)

where N_0 = RECRUI
α = VS(8,NSP)
β = VS(9,NSP)
AF = VAS(6,NA,NSP)

The Beverton and Holt model

$N_0 = [\alpha * SSBe^{\beta * SSB}/(1 + \beta * SSB)] * AF$

The equation in FORTRAN is

RECRUI = [VS(8,NSP)*SSB/(1+VS(9,NSP)*SSB)] * VAS(6,NA,NSP)

The data needed is as follows.

VS(4,NSP) is the size (mm, cm, inches, etc.) at which a species of fish enter the parent stock.

VS(5,NSP) is the linear coefficient for the fecundity equation.

VS(7,NSP) is the power coefficient for the fecundity equation.

VS(8,NSP) is the density independent parameter of the stock of recruitment relationship.

VS(9,NSP) is the density dependent parameter of the stock of recruitment relationship.

VS(10,NSP) is the adjustment factor for fecundity by species.

VS(11,NSP) is the percent of the mature adult stock that is female and that spawn per year. If NSX=1, which means that males and females are grouped together, then enter a value less the 1,0; i.e., if 50% of the population are female and all spawn each year then enter 0.5.If only half the adults female spawn each year then enter 0.25. If NSX=1, which means that males and females are in separate groups, then enter a 1.0.

VAGE(NSP,NAGE) is the proportion of fish which are mature.

VAS(6,NA,NSP) is an adjustment factor for fecundity by area and species. This value adjusts recruitment between areas and should vary around 1.0.

Basic Economic Coefficients

This section contains all the economic information used in the model except for the price flexibility equations,

VB(9) is the discount rate.

HRV(42,NR,NVC) is the number of vessels in each class.

HRV(43,NR,NVC) is the crew number per vessel by vessel class.

HRV(44,NR,NVC) is the annual fixed cost per vessel by vessel class.

CF(NR,NA,ND,NVC) is the vessel owner's variable cost for vessels per nominal day fished by vessel class and depth.

CVCPDF(NR,NA,NVC) is the crew's variable cost per nominal days fished per vessel by vessel class.

HRV(45,NR,NVC) is the owner's annual opportunity cost per vessel by vessel class.

HRV(46,NR,NVC) is the crew's annual opportunity costs per vessel per crew member by vessel class.

HRV(47,NR,NVC) is the packing charge per pound of fish landed by vessel class.

HRV(48,NR,NVC) is the ownership of vessel. Enter a 1 if operator is the owner; enter 0 for non-owner operator.

HRV(49,NR,NVC) is the crew's percent share of landings by vessel class

PM(2,NR,NSP,NSZ,JTIME) is the ex-vessel price of fish by species, size class and division.

VB(11) is the inflation factor for cost.

VB(12) is the inflation factor for prices.

Costs for owner are kept separate from crew cost. Total cost for owners is calculated as

$$TC_O = CF(2,ND,NVC) * DFN + (HRV(44,NR,NVC) + HRV(45,NR,NVC)) * NV(1,NA,NVC) * \frac{DFN}{\Sigma DFN}$$

$$+ HRV(49,NR,NVC) * Landings * PMCS(2, NSP,NSZ,NM)$$

$$+ HRV(47,NR,NVC) * HRV(49,NR,NVC) * Landing$$

Notice that HRV(44,NR,NVC) and HRV(45,NR,NVC) are proportioned by nominal days fished. Total cost for the crew is calculated as:

$$TC_C = CVCPDF(NR,NA,NVC) * DFN + HRV(46,NR,NVC) * \frac{DFN}{\Sigma DFN}$$

Economic Impact Data

TOTMULT(1,NR) is the total income multiplier by region.

TOTMULT(2,NR) is the value added multiplier by region.

TOTMULT(3,NR) is the employment multiplier by region.

NAGGR is the number of groups to aggregated region. The regions can be combined in into groups, i.e., if there are 10 regions and you want to combine them into 2 groups you assign the value 2 to NAGGR.

NAGGRB(IR) is the beginning region to aggregate in group IR.

NAGGRE(IR) is the ending region to aggregate in group IR.

AGGRNAME(NR) is the path and filename of the groups of regions aggregated together. Enter NAGGR paths and filenames.

AGGRMULT(1,NR) is the total income multiplier by group of regions.

AGGRMULT (2,NR) is the value-added multiplier by group of regions.

AGGRMULT (3,NR) is the employment multiplier by group of regions.

Demand Equations

The flexibility option and data input can be included in the model analysis only if the model was first run with S(11)=TRUE to generate "NEW_LBS" file. Note: S(11) and S(12) cannot be TRUE at the same time.

N_FLEX is the number of price flexibility equations or groups to read. For example, if there are four species of fish of which three species are shrimp and one is red snapper then there would be two set or groups of price flexibility equations; one for shrimp and one for red snapper.

N_VAR(NSP) is the number of variables in each price flexibility equation.

N_SPEC(NSP) is the price flexibility equation number to which each species belongs. For example, if there are four species of fish with three species being shrimp and one being red snapper then there would be two sets of price flexibility equations. The shrimp flexibility equations could be 1 and the red snapper could be 2. Thus, the data would be entered as 1 1 1 2 implying that species 1 through 3 use shrimp flexibilities and species 4 uses red snapper flexibilities.

N_SIZE(NSZ,NSZ) is the subgroup size class to which each size class belongs to. For example, suppose there are 4 species of fish; 3 species of shrimp and one species if red snapper. And suppose there are 6 size classes of each species of fish. Also assume there are three sub sizes classes of shrimp and only one for red snapper. Now suppose that size classes 1 & 2, size classes 3 & 4 and size classes 5 & 6 belong to belong to subgroups 1, 2, and 3 respectively. Then for species 1, size class 1 enter a 1; for species 1, size class 2 enter a 1; for species 1, size class 3 enter a 2; for species 1, size class 4 enter a 2; etc.

FLEX (N_FLEX,N_SIZE,N_SIZE) is the price flexibility by size class of fish and cross flexibility between size class of fish with respect to a change in landings.

XBAR(NR,NSP,NSZ,JTIME)is the average landings by size class and by time step (these should be generated by the base simulation at equilibrium)

The price flexibility equation is:

$$\Delta P_i = (f_i)\,\frac{\Delta Q_i}{Q_i}(P_i) + \Sigma[(f_{i,k})\,\frac{\Delta Q_k}{Q_k}(P_i]$$

where ΔP_i is the change in the price of fish by the model; P_i is the price of fish in the same dollars as costs in Data Section 13; ΔQ_i is the change in landings of fish from the historical landings; and Q_k is landings of other size fish, which were generated by the model and written to file NEW_LBS. There are two recreational demand options. Option 1 uses elasticities to change the trips for next year. Option 2 reads the actual demand coefficient, mean for each variable, and the variation in catch.

Demand Equations for Recreational Fisheries

ELAST(1) is the catch elasticity and is used to estimate the number of trips recreational fishermen will take next year (i+1).

ELAST(2) is the expected consumer surplus rate per trip and is used to estimate consumer surplus generated by recreational fishermen.

Read in recreational demand coefficients and the means of the associated variables. This model assumes that you are using a double log model.

RECVAR is the variance of the catch variable.

ANGLER(NR) is the number of anglers by region. If you know the number of anglers in each region then you can read them in. However, if you do not know the number of anglers then you can let the model calculate for the first year of the simulation provided anglers are fishing for the entire season (i.e., a TAC does not close the fishery early during the first year of the simulation).

RECOEFF(1) is the constant coefficient
RECOEFF(2) is the coefficient for log(catch) = Log(CPUE)
RECOEFF(3) is the coefficient for log(catch))^2 =log(CPUE))^2
RECOEFF(4) is the coefficient for log(price) = log(total $ expenditures)
RECOEFF(5) is the coefficient for (Log(price))^2 = (log(total $ expenditures))^2
RECOEFF(6-35) are other coefficients in the demand model except state dummy coefficients.
RECMEAN(1) is set to 1
RECMEAN(2) is the mean value for log(catch)= log(CPUE): although you read in this value the simulation model will determine this value. Therefore you can enter a zero for this value.
RECMEAN(3) is the mean value for log(catch))^2 =log(CPUE))^2 (log(CPUE))^2: although you read in this value the simulation model will determine this value. Therefore you can enter a zero for this value.)
RECMEAN(4) is the mean value for log(price) = log(total $ expenditures)
RECOEFF(5) is the mean value for (Log(price))^2 = (log(total $ expenditures))^2
RECOEFF(6-35) are other mean values in the demand model except state dummy coefficient

If you have states in your data set for your demand analysis so that you have dummy variable and means, then enter a zero for RECSTATE(1,?) and RECSTATE(2,?), where ? represents the state number (region number) that is in the simulation but not in the demand model. The simulation model will use the average of the states (regions) that were in the demand model: AVERAGE = SUM[RECSTATE(1,IR)*RECSTATE(2,IR)] where IR=1:NR.

RECSTATE(1,NR) is the dummy coefficients for "state" in which the recreational fishermen fished.

RECSTATE(2,NR) is the mean value for "state" in which the recreational fishermen fished.

Q is the description card for BASELAND(I,NR,NSP).

BASELAND(I,NR,NSP) is the number of fish landed by recreational fishermen (I=1) and the number of fish caught by recreational fishermen (I=1) and the number of trips taken by recreational fishermen (I=2). Note the base year is always 1 therefore IY=1.

The number of trips next year (iy+1) that the recreational fishermen will take is calculated as follows.

PERCHA = [CPUE(current year) – CPUE(last year)]/ CPUE(last year)

where PERCHA is the percent change in the catch rate per trip in a given year and precious year.

CHATRIP = PERCHA * ELAST(1)

where CHATRIP is the change in trip rate for next year as compared to the previous year. Next year's trips by recreational fishermen is calculated as

DFN(2,IR,JIA,IS,ID,IV,ITIME+1) = DFN(2,IR,IA,IS,ID,IV,ITIME) * CHATRIP

where the vessel class (IV) is the recreational fishermen.

Recreational consumer surplus(RCS) for recreational fishermen if calculated as follows:

RCS = (Recreational trips)*ELAST(2)

TED/BRDs Parameters

TED(NA,NSP,ND,NVC,NM) is the rate of fish loss for using TEDs. Enter as 0.05 for a 5% loss of fish.

ADJTED(NSP,NSZ) is a factor that adjust TED(...) by species and size. For example, red snapper in the smallest size class may have TED(...)=35.82 and in the next smallest size class TED(...)=78.35. Then the adjustment factor would be 1.0 for the smallest size class and 2.187 (35.85=78.35/2.87) for the next smallest size class.

TLOSS(NSP,NVT) is the rate of survival or the fish loss for using TED/BRDs. Enter as 0.5 for a 50% survival of fish that are lost due to the TED/BRDs.

HRV(54,NR,NVC) Annual costs per vessel for using TEDs.

ALEARN(10,NSP,NVC) is the learning curve. If the fishermen loose twice the number of fish as shown in onboard observer program then enter a 1.0. Enter 0.0 for no effect.

PDFL(NR,ND) is the percent of tow time lost (percent reduction in days fished) due to using TEDs. This can occur due to unclogging nets; etc. Enter 5% as 0.05.

HRV(53,NR,NVC) is the percent of variable cost per day fished to use when they would normally be fishing but they are having to unclog their nets. Enter 40% as 0.40.