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Article

A Bioeconomic Analysis of the Management Policies for the United States Gulf of Mexico Red Grouper Fishery

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Abstract : Since the red grouper was declared overfished, the Gulf of Mexico Fishery Management Council must prepare a rebuilding plan considering the following alternative management policies: a Total Allowable Catch (TAC), 5-month season closure, 1800-pound trip limit, and a 50-fathom longline boundary. This study was aimed at evaluating the effects of proposed policies for rebuilding the red grouper stock in a 10-year period by developing a bioeconomic model. Under the assumption that the recreation sector was held to its share of TAC (24% of the total quota), the target stock biomass goal was attained in all policies. The NPV was the largest in the 5-month season closure policy if the output price did not fall. There were distributional effects on the different components of the fleets in the 1800-pound trip limit and the 50-fathom longline boundary policy.

Key words : bioeconomic model, fisheries policy, total allowable catch, trip limit, season closure policy

1. Introduction

Under the U.S. Magnuson-Stevens Fishery Conservation and Management Act ("MSFCMA"), once a stock is declared overfished, the Regional Fishery Management Council has one year to submit a plan to the NMFS (National Marine Fisheries Service) to end overfishing and rebuild the stock to a level capable of supporting a maximum sustainable yield (MSY) on a continuing basis. When selecting a management alternative for the recovering of the stock, as National Standard Guidelines 1, 5 and 8 in the MSFCMA state, the Council is required not only to ascertain whether a management measure can rebuild the target stock size, but also carry out detailed economic impact analyses of management measures.[1] In addition, the recent court cases (North Carolina Fisheries Association v. Daley 1998; Blue Water Fisherman's Association v. Mineta 2000) have increased the importance of the economic impact of the management alternatives on the fishery participants.

A bioeconomic modeling is a useful tool for analyzing a combined biological and economic examination of fisheries utilization. It can predict the likely fishing mortality pattern and the likely economic effects on participants by analyzing the changes in economic benefits of participants that will result from a particular alternative. At the same time, it can compare alternative management techniques designed to achieve a desired fishing mortality pattern. For this reason, the bioeconomic models have been widely developed to investigate combined biological and economic

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[1]National standard 1 in the Magnuson-Stevens Fishery Conservation and Management Act: Conservation and Management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry. National standard 5: Conservation and management measures shall, where practical, consider efficiency in the utilization of fishery resources; except that no such measures shall have economic allocation as its sole purpose. And National standard 8: Conservation and management measures shall take into account the importance of fishery resources to fishing communities in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts in such communities.

utilization of the fisheries and to evaluate the effects of management measures implemented in many fisheries by the biologists and the economists (Lee *et al.* 2000; Eggert and Ulmestrand 2000; Thunberg *et al.* 1998; Danielsson *et al.* 1997; Yew and Heaps 1996; Polacheck 1990; Pikitch 1987; Murawski 1984).

The objective of this study is to develop a bioeconomic model for the red grouper fishery to evaluate the effect of management policies suggested by the Gulf of Mexico Fishery Management Council ("Council") for recovering the red grouper stock after it was initially declared overfished and undergoing overfishing measures adopted by the NMFS in October 2000. Management policies considered were a Total Allowable Catch (TAC), a 5-month closure period, an 1800-trip limit, a 50-fathom longline/buoy gear boundary and a recreational TAC (GMFMC 2002b). It is aimed to provide more useful policy implications to the Council in the selection of the preferred policies.

2. Red grouper fishery

In the U.S. Gulf of Mexico, red grouper (*Epinephelus morio*) is classified as the major component of the shallow-water grouper complex with gag and black grouper, with most of the fishery occurring within or immediately west of Florida's territorial sea.[2)] Although primarily fished along the inner to mid-continental shelf, the species ranges in depth from 2 to over 120 meters (65 fathoms), mainly inhabiting reefs and hard bottom areas (GMFMC 2002a).

Commercial landings of red grouper have been separated from other groupers since 1986. Before 1986, they were included with other grouper species as "unclassified groupers". Prior to the introduction of bottom longline gear to the U.S. commercial fleet in the early 1980s, landings of all groupers exhibited a slow decline from about 7.5 million pounds in 1962 to about 5 million pounds in the late 1970s. Handlines and power-assisted reels accounted for almost all the landings during this period. With the expansion of bottom longline gear in the early 1980s, total grouper landings increased sharply to about 12.5 million pounds in 1982 (Schirripa *et al.* 1999). However, as shown in Fig. 1, during 1986-1998, total landings have decreased. Since 1999, total landings have

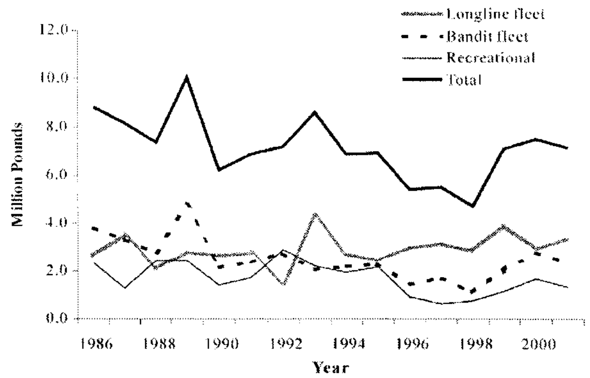

Fig. 1. Total landings of red grouper by mode (longline fleet, bandit fleet, recreational fishery, and total landings).

remained at about 7.1 million pounds per year.

Red grouper are commercially harvested with gears such as longline, bandit, fish traps, and spears throughout the Gulf of Mexico. However, most of the commercial harvests are caught primarily by the longline fleet[3)] and the bandit fleet.[4)] On the average, about 42% and 34% of the total red grouper landings are caught by the longline fleet and the bandit fleet, respectively. The remainder, about 24%, is harvested by the recreational fishery (Fig. 1).

Historically, conservation measures were instituted in Florida in 1985 and in the EEZ in 1990. The 1985 Florida action was an 18-inch minimum size and did not extend to the EEZ. The 1990 measures adopted by the Council included a 20-inch minimum size, 5-fish aggregate grouper bag limit for recreational fishermen, and a commercial grouper quota. The quota was set as an aggregate grouper quota in which a 11.0 million-pound limit was set as the commercial quota for groupers, with the commercial quota divided into a 9.2 million-pound shallow-water grouper quota and a 1.8 million-pound deep-water grouper quota. The quota for red grouper was included in the shallow-water grouper quota.

Since the 1990 amendment, 17 amendments have been made. However, red grouper has been only regulated by the aggregate shallow-water grouper quota and the size limit regulation. In the 1999 red grouper stock assessment, the stock was initially determined to be overfished and

[2)]Waters (1996) showed that 94% of the grouper landings at the U.S. ports in the Gulf of Mexico between 1960 and 1998 were landed in Florida and red grouper has accounted for approximately 60% of the total landings.
[3)]The longline gear is a line, which is over 440 yards long. Hooks are attached to the line. It is deployed horizontally and it is retrieved by an electric hauler.
[4)]The bandit gear is vertical hook and line gear with rods attached to a vessel with no more than two hooks per line. It is retrieved by electric reels.

overfishing was occurring. Therefore, the Council must propose management alternatives for recovering the red grouper stock within a 10-year recovery period according to the obligation of the fisheries act.

3. Red grouper bioeconomic model

The red grouper bioeconomic model I constructed in this study is an extension of the LEM (Lee, Emiko, and Maryjane) model developed by Anderson (2000). The LEM model is based on an age-structured biological model and it analyzes the joint commercial and recreational exploitation of a fish stock with 12 age structures. The necessary data to run the model are the initial stock size and composition, the initial number of vessels and recreational participants, the coefficients of the recruitment and individual growth equation, the age of sexual maturity, the fecundity at age, the catchability and natural mortality coefficients by cohort, and the values for prices and costs.

Table 1. A Glossary of symbols used in the model.

Variables:	
N	Stock Number of Red Grouper at age
F	Red Grouper Instantaneous fishing mortality rate
M	Red Grouper Instantaneous natural mortality rate
SSB	Spawning Stock Biomass
SS	Spawning Stock
C	Catch at age in Numbers
WC	Weight of Catch at age
TR	Total Revenue
TC	Total Cost
TVC	Total Variable Cost
TFC	Total Fixed Cost
p	Red Grouper Ex-vessel Price
NPV	Net Present Value of Returns
R	Stock Recruitment
TTC	Trip Cost
Trips	The Number of Trips
Parameters:	
α, β	Recruitment Coefficients
q	Catchability coefficient at age
Fe	Fecundity at age
w	Average weight (lb)
r	An annual discount rate
Indices:	
a	Red Grouper age in years (a = 1, 2, ….., 12)
t	Time in years (t = 1,2,….., 25)
i	Fleet (i = longline fleet, bandit fleet, and recreational sector)

For a detailed introduction of the red grouper bioeconomic model, the biological component of the model is explained first. Based on the red grouper stock assessment, the stock recruitment function and the estimation of the SSB are presented. Also, the mathematical equations for the changes of stock size and weight of catch are examined. In terms of the economic component, the equations that determine the total revenues and costs are explained. All variables, parameters, and indices used in the model are presented in Table 1.

Red grouper population dynamics

Stock-recruitment relationship

Recruitment is the amount of fish added to the exploitable stock each year. The number of fish that grow to become vulnerable to the fishing gear in a given year would be based on the recruitment to the fishable population in that year. According to the red grouper stock assessment, red grouper was estimated to be at the recruitment stage at age class 1 (N_1) and the deterministic Beverton-Holt recruitment function having the spawner-recruit steepnesses .7 was used as follows:

$$N_1(t) = \frac{\alpha \times SSB(t-1)}{\beta + SSB(t-1)}$$

The spawner-recruit steepness rate of .7 was estimated with non-linear regression using stock-recruitment data. The SSB is a spawning stock biomass that was estimated by multiplying the number of stocks at age and the average fecundity of individuals of that age, and summing up the over all ages. And α and β are the stock-recruitment parameters. For the steepness .7, the parameter estimates were $\alpha = 6{,}729{,}860$; $\beta = 150{,}428{,}000$ in the stock assessment.

Stock dynamics

The numbers of fish at the beginning of the age structure are reduced by the instantaneous natural mortality rate, M, and the fishing mortality rate by fleet i ($i = 1, .., 3$), $F_{a,i}$, during the fishing season. The equation of the change in stock numbers at age a between year t ($N_{a,t}$) and year $t+1$ ($N_{a+1,t+1}$) is:

$$N_{a+1,t+1} = N_{a \cdot t} \cdot e^{-\left(M + \sum_{i=1}^{3} F_{a,i}\right)}$$

As previously explained, because red grouper is primarily caught by the longline fleet, the bandit fleet, and the recreational sector, these three fisheries are considered major players in the model.

The NMFS provided the fishing mortality data for two commercial fleets (longline fleet and bandit fleet) and the recreational sector. In the NMFS stock assessment, red grouper is assumed to be composed of a 20-age structure. However, the 20 cohorts in the NMFS data were collapsed to 12 because that is all the LEM model could handle. The 12th cohort contains the NMFS cohort 12 through 20. The fishing mortality by fleet, average weight and fecundity coefficient at age has been changed to the weighted average with cohort size according to weights. The model works quite well this way. It was tested by using the constant f rates provided by the NMFS and it tracks the 10 year SS projections with errors of less than 1/2 of one percent. The instantaneous natural mortality, M, is assumed to be constant in all age classes (M = 0.2).

Weight of catch

From the equation of the change in stock numbers at age, the total loss in stock numbers at age a between year t ($N_{a,t}$) and year $t+1$ ($N_{a+1,t+1}$) is:

$$N_{a,t}-N_{a+1,t+1}=N_{a,t}-N_{a,t}\cdot e^{-\left(M+\sum_{i=1}^{3}F_{a,i}\right)}$$

$$=N_{a,t}\left(1-e^{-\left(M+\sum_{i=1}^{3}F_{a,i}\right)}\right)$$

Therefore, the total catch at age a in year $t(C_{a,t})$ is the proportion of the total losses due to fishing:

$$C_{a,t}=\frac{\sum_{i=1}^{3}F_{a,i}}{\left(\sum_{i=1}^{3}F_{a,i}+M\right)}\cdot N_{a,t}\cdot\left(1-e^{-\left(M+\sum_{i=1}^{3}F_{a,i}\right)}\right)$$

The weight of catch at age a in year t ($WC_{a,t}$) is simply calculated by multiplying the total catch at age a and the weight of fish at age a (w_a). And the total weight of catch in year t (WC_t) is obtained by summing up the weight of catch at age:

$$WC_i=\sum_{a=1}^{12}N_{a,t}\cdot\frac{\sum_{i=1}^{3}F_{a,i}}{\left(\sum_{i=1}^{3}F_{a,i}+M\right)}\cdot\left(1-e^{-\left(M+\sum_{i=1}^{3}F_{a,i}\right)}\right)\cdot w_a$$

Fishery economics

Total revenues

The total revenues in year t (TR_t) are calculated by multiplying the total weight of catch (WC_t) and the unit price of red grouper (p):

$$TR_t = WC_t \cdot p$$

An average price of red grouper (p) was obtained from the NOAA commercial landing and ex-vessel price data for 1986 through 2001. The price (p) averaged $2.25 per pound.

Total cost

Total annual cost in year t (TC_t) is the sum of total variable cost ($TVC_{i,t}$) and total fixed cost (TFC_i) by fleet i as follows:

$$TC_t = \sum_{i=1}^{3}(TFC_i + TVC_{i,t})$$

Total variable cost by the fleet i in year t ($TVC_{i,t}$) is assumed that it is a function of the number of trips by the fleet i ($Trips_{i,t}$) and the trip cost by the fleet i (TTC_i) is constant:

$$TVC_{i,t} = TTC_i \cdot Trips_{i,t}$$

The average trip cost by fleet i was constructed from the average vessel trip cost data surveyed in the Gulf of Mexico during 1996 (Waters 1996). However, because surveyed cost data was divided into trip cost data for high volume boats and low volume boats in each fleet, it was necessary to collapse high and low volume longline boats into one longline fleet sector and high and low volume bandit boats into one bandit fleet sector. Using a weighted average of the various sectors, the average trip cost and fixed costs by fleet were estimated. They are reported in Table 2.

Total profits

Total profits in year t (TP_t) are obtained by subtracting total cost (TC_t) from total revenues (TR_t):

$$TP_t = TR_t - TC_t$$

The net present value of returns to the fishery as a whole (NPV) is calculated by discounting with an annual interest rate (r):

$$NPV = \sum_{t=1}\frac{TP_t}{(1+r)^t}$$

Table 2. Number of vessels, trips, days per trip, and cost data by fleet.

	Fleets	
	Longline Fleet	**Bandit Fleet**
Vessels	105	200
Trips/year	10.15	18
Days/trip	12	7
Trip cost	$2,200	$650
Fixed cost	$29,139	$16,662

Fishing efforts

The average fishing effort by fleet was obtained from the NMFS Logbook data for 1999 through 2001. Focusing on the vessels that are harvesting red grouper more than 1,000 lbs per year out of all fishing vessels, the average number of vessels, number of trips per year, and days fished per trip were examined. The average fishing effort per fleet is summarized in Table 2.

An annual catchability coefficient at age a for fleet i ($q_{a,i}$) was calculated by dividing the fishing mortality rate at age a for fleet i by the average number of boats fishing per day. For example, the longline fleet had 12,792 boat days per year, which comes to a total of 35 per day. By dividing the annual catchability coefficient at age a by 365, the daily catchability coefficient at age a was calculated.

Due to the lack of data for the recreational fishery, it is very hard to measure the total effort of the recreational fishery. An actual recreational model should be set up to allow the known number of participants to change the number of trips it undertakes per year, given changes in catch per day and average fish size. However, there was not enough data to use this option. For this reason, the recreational fishery was assumed to comprise a constant number of recreational participants whose fishing activities were not influenced by the characteristics of the fish stock.

Model calibration and application

The model was calibrated to match the current catch for the year 2001. First, the commercial catchability coefficients were adjusted so that the model commercial catch equaled the actual commercial catch for 2001. The recreational sector was calibrated by changing the number of participants until the predicted recreational catch equaled the actual recreational catch for 2001. After the calibration, the model predicts the total catch that is within 3% of the actual total catch data where the recreational catch was adjusted to match accurately the actual catch, while the model showed a 5% difference between the actual commercial catch and predicted catch. Therefore, the model may predict a slightly higher level of the commercial catch and give a little bit more pessimistic assessment of the biological consequences of the management regulation.

The model was developed to evaluate the effects of management measures for red grouper on economic returns for the fleets and the change of stock, and especially to ascertain whether the regulation can allow the target SS goal (SS_{MSY}) to be achieved in a 10-year rebuilding period. The spawning stock (SS) was measured in terms of millions of grams in female gonad weight and it was used as a proxy for stock biomass. That is, a target goal SS_{MSY} is a proxy for a target stock biomass. As previously mentioned, recommended management policies such as TAC, five-month season closure, 1800-pound trip limit, 50-fathom line, and recreational TAC will be evaluated by the model.

A TAC policy is aimed at limiting the total catch to a maximum of red groupers that can be harvested by the fleets in the Gulf of Mexico for a year. When the actual catch reaches the annual allocated TAC, the fishery is closed for the season.[5)] A 5-month season closure policy prohibits fishing during the 5 months. It is often applied to protect resource stocks when and where they are particularly vulnerable, considered poor quality for market, and/or to protect young fish from being captured too soon.[6)] An 1800-pound trip limit policy is implemented to restrict the amount each vessel can land per trip. Its effectiveness is expected to increase the size of resource stock by reducing total landings and amount of effort per trip. And a 50-fathom longline/buoy gear boundary policy is aimed at banning the longline fleet's fishing within the 50-fathom line boundary. According to the recent analyses by the NMFS of Florida Trip Ticket Data 1998-2000, approximately 82-99% of the red grouper longline catch occurred in water depths of less than 50 fathoms. Therefore, under the 50-fathom longline boundary policy, the longline will lose a great opportunity for harvesting red grouper and

5)The implementation of a TAC policy usually results in a total catch below the initial capacity of the fleet. The greater the difference between pre-TAC landings and the TAC, the shorter the season stands to become.

6)Under the season closure policy, there is a possible problem that the commerce sector may lose some of its market because of the inability to provide continuous supplies and the subsequent increase in imports. This can result in a reduction in the ex-vessel price.

Table 3. The changed composition of the fleets and cost data under the 50-fathom policy.

	Vessels	Trips/year	Days/trip	Trip cost	Fixed cost
New bandit fleet (modified 70% of longline fleet)	74	12	12	$1,500	$29,139
Bandit fleet	200	18	7	$650	$16,662

consequently, their economic returns from catching red grouper will be reduced.

It is interestingly necessary to restructure the model in order to consider the 50-fathom policy. This management measure will ban all longline fleets but some of them may be modified to use bandit gear. This was handled by accommodating the longline fleet in the new bandit fleet. Therefore, it is necessary to determine how many will switch and what their costs and number of trips will be. Following the recommendation of the staff in the Council and participants at the bioeconomic modeling workshop (May 2002), it was assumed that 70% of the longline fleet would be transformed into the bandit fleet. In addition, it was assumed that the new bandit fleet would have the same catchability coefficient as the regular bandit fleet and the number of trips would be increased while days per trip would be the same. Also, the trip cost is expected to be lower than that of the longline fleet. The assumed composition of the fleets and cost data under the 50-fathom policy are summarized in Table 3.

4. Red grouper management policies and model results

The result for each management policy shows the change in the NPV of commercial fleets over a 25-year period, the percentage of the SS goals that are met by the 10th year of the rebuilding program, and the red grouper spawning stock in 25 years. Note that because the management policies that were not combined with a recreational hard TAC predicted that the target red grouper SS goal could not be achieved within the rebuilding period, it was assumed that the recreation sector was held to its share of TAC (24%) in all policies. The results of the models are summarized in Table 4.

Management policy (1): Status quo

The status quo policy was developed as the base policy with which the effects of other alternative management policies would be compared. The red grouper spawning stock decreases and reaches 74% of the SS_{MSY} in a 10-year period. As shown in Table 4, the NPV of the fishery as a whole is $100.7 (million dollars), while the NPV for the longline fleet and the bandit fleet is predicted to be $64.1 (million dollars) and $36.7 (million dollars), respectively.

Management policy (2): TAC

To allow for recovering the red grouper stock if the TAC policy is applied to the red grouper commercial fishery, the target SS goal will be easily achieved in 10 years. The commercial sector shows an increase in the NPV of returns over a 25-year period. The NPV of the fishery as a whole is increased by 18%, while the NPV of the longline fleet and the bandit fleet is increased by 16% and 21%, respectively. Net earnings are reduced in the first years of the recovery period due to the constraints of quotas, but, as the stock size improves, they increase later

Table 4. Management policies and model results.

	SS at 10 years[a]	SS[b] (After 25 years)	NPV[c] of Longline fleet	NPV of Bandit fleet	Total NPV
(1) Status Quo	74%	586	64.1	36.7	100.7
(2) The Commercial TAC	104%	983	74.5(16%)	44.4(21%)	118.8(18%)
(3) 5-month Season Closure	106%	919	76.3(19%)	45.5(24%)	121.8(21%)
(4) 1800-pound trip limit	107%	960	22.6(-65%)	69.7(90%)	92.3(-8%)
(5) 50-fathom program	109%	960	26.5(-59%)	72.4(98%)	98.9(-2%)

Note: Figures in parentheses are the Percentage change resulting from the Status Quo Policy.
[a]SS at 10 years denotes the percentage of the SS in the 10th year over the SS_{MSY}.
[b]The unit of SS after 25 years is Millions of Fish.
[c]The unit of NPV is a million dollars, and the 7% discount rate was used.

on more than compensating for these early losses.

One possible problem with the TAC policy is that the commercial sector may lose some of its market because of the inability to provide continuous supplies and the increase in imports. This can result in a reduction in the ex-vessel price. In the red grouper bioeconomic modeling workshop held on June 2002, the participants predicted the price would fall by approximately 33%. If there is truly a reduction in the price by 33%, the changes are very significant. Instead of a gain in NPV to the commercial fishery as a whole of 18%, it was predicted that there would be a loss of about 33%. Also, both fleets would suffer losses in that range. In order to investigate more potential effects of price reductions due to losses of markets, several more analyses were accomplished with different price reductions. The results are presented in Table 5.

The 5% reduction in price reduces the NPV by about 10% and the net earnings of the longline fleet and the bandit fleet by 9% and 12% respectively. If the output price falls by 15% or more, the NPV will be less than would have been earned under the status quo.

Also, there may be another possibility that if prices do not decrease, the increasing net returns could provide incentives for some fleet growth. It is estimated that if the fleet increases by only 1% per year, an increase in the NPV of 18% would be reduced to about 8%. It is hard to determine exactly how the fleet sizes will change as a result of the rebuilding plan, but even small changes can have significant negative effects on economic gains.

Management policy (3): 5-month season closure

Under the 5-month season closure policy, the SS goal is achieved (approximately 106%) in a 10-year rebuilding period. The net returns increase more than fully compensating for the original cut backs to allow the stock to grow. The NPV of the commercial fishery as a whole is increased by approximately 21%, while the longline fleet and the bandit fleet gains higher net earnings by 19% and 24% respectively.

Table 5. The changes in the NPV of the fleets due to a reduction in price under the TAC policy.

Price change	Change in total NPV	Net returns to the longline fleet	Net returns to the bandit fleet
None	18%	$74,472,374	$44,368,272
5% decrease	10%	$69,749,006	$41,205,457
10% decrease	2%	$65,148,668	$38,109,453
15% decrease	–5%	$60,548,330	$35,013,448
20% decrease	–13%	$55,947,991	$31,917,443
25% decrease	–20%	$51,347,652	$28,821,438

Table 6. The changes in the NPV of the fleets due to a reduction in price under the 5-month season closure policy.

Price change	Change in total NPV	Net returns to the longline fleet	Net returns to the bandit fleet
None	21%	$76,301,669	$45,509,985
5% decrease	13%	$71,704,976	$42,426,940
10% decrease	6%	$67,024,449	$39,289,355
15% decrease	–2%	$62,343,923	$36,151,769
20% decrease	–10%	$57,663,397	$33,014,184
25% decrease	–18%	$52,982,870	$29,876,598

As considered under the TAC policy, the 5-month season closure policy has the same potential problem in terms of market losses. If there is the same rate of price reduction, the changes are still very significant. Instead of a gain in NPV by the commercial fishery as a whole of 21%, there is a loss of about 30%. More analyses were performed to investigate more potential effects in terms of price reductions (Table 6).

The 5% reduction in price reduces the NPV by about 13% and the net earnings of the longline fleet and the bandit fleet by 12% and 16% respectively. As the same in the TAC policy, if the price falls by 15% or more, the possible gains in net earnings that could be achieved by the rebuilding program would be eliminated.

It is interesting to consider that if prices do not decrease, the increasing net returns could provide incentives for some fleet growth. As analyzed under the TAC policy, this will adversely affect the economic welfare of the fishery. It is predicted that if the fleet increases by only 1% per year, an increase in the NPV of 21% would decrease to about 14%.

Management policy (4): 1800-pound trip limit

It is predicted that the target SS goal would be achieved well within the rebuilding period (about 107%). Because the trip landings by the bandit fleet are not over 1800 pounds, only the longline fleet is constrained by this policy. As a result, there are losses to the longliners, but gains to the bandit fleet because of the reduced competition from the longline fleet. That is, the NPV of the longliners is 65% less than would have been earned under the status quo, while the NPV of the bandit fleet would increase by 90%. However, since the increase in net earnings of the bandit fleet does not compensate for the losses in the NPV of the longline fleet, the NPV of the fishery as a whole would be reduced by about 10%.

Management policy (5): 50-fathom policy

It is predicted that the target SS goal would be achieved in the rebuilding period. However, as with the 1800-pound trip limit policy, there are significant distribution effects on the different components of the fleet. While the regular bandit vessels gain higher net economic returns, the modified 70% of the longliners suffer a 59% reduction in net returns. It is interesting that, although both fleets are using the same bandit gear, their net returns are different, the modified longliners having lower returns. Apparently, boats designed for the longline fleet cannot operate bandit gear as efficiently as boats designed for the bandit fleet.

As analyzed under the 1800-pound trip limit policy, because the loss in the NPV of the longline fleet is greater than the increase in the NPV of the bandit fleet, the total NPV of the fishery as a whole is less by about 5% than that under the status quo.

The effect on the longliners which do not remain is uncertain. The NPV could fall to zero if they remain tied to the dock but otherwise it will depend upon what and where they fish.

5. Summary and conclusion

A bioeconomic model was developed to evaluate the biological and economic effects of alternative management policies recommended by the Council. The overall model simulation results indicate that the target SS goal (SS_{MSY}) will be achieved in all management policies within the rebuilding period.

However, as shown in Fig. 2, all policies that did not place a hard TAC on the recreational sector failed to achieve the target red grouper SS goad. This implies that the Council will have to take specific action on the recreational sector to ensure that it stays within its share of the TAC to accomplish the target SS goal. This does not mean the recreational sector must be subject to a hard TAC, but their harvest rates must be kept within those levels by some type of regulation.

It was predicted in the model that a higher NPV would be gained under the 5-month season closure policy and the TAC policy. However, under the 50-fathom policy and the 1800-pound trip limit policy, although the bandit boats would enjoy increases in the NPV in terms of returns, because the longliners would suffer significant decreases

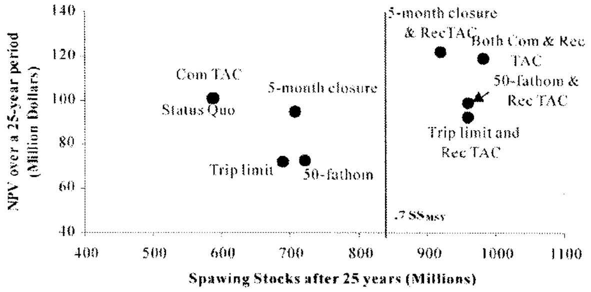

Fig. 2. The Results of the NPV over a 25-year period and for Spawning Stocks after 25 years Under Each Management Policy.

in the NPV, the economic returns to the fishery as a whole would be slightly less than those obtained under the status quo.

If there were reductions in output prices by 15% or more under the TAC policy and the 5-month season closure policy, the 50-fathom policy was estimated to be the preferred one among recommended policies. The 1800-pound trip limit policy was inferior to the 50-fathom policy in both biological and economic effectiveness.

Because of the nature of the biological information provided, which calculated catch and discard fishing mortality given the current size and creel limit, the current model could not analyze changes in creel and size limit. In addition, due to the unavailability of any relevant economic-based data on the recreational sector, this study cannot make any specific comments on the various alternatives for the recreational sector. If more data becomes available, the model can also provide useful policy implications for the recreational fishery. It is also important to note that the fleets that harvest the red grouper also catch other species at the same time. In response to the red grouper regulations, the fleets will change target species by shifting fishing efforts. This will adversely affect the other stocks and it will also change the economic welfare of the fleets. Therefore, the effects of the management policies for the red grouper fishery may be different from those evaluated by the single red grouper model.

As shown in this study, the bioeconomic model is useful to analyze the preliminarily effectiveness of fisheries policy before it is implemented. When setting up the management goal and selecting the policy that is able to achieve the goal, the bioeconomic model makes efficient use of the increase in fisheries policies. In order to utilize the bio-economic model, necessary biological and economic data must be attained. According to the level of available data, a few population dynamic models (for example, a surplus production model and an age-structured model) can be used in the bioeconomic model. Moreover, by developing a stochastic bioeconomic model, not only can uncertainties in predictions of the model be reduced, but also the environmental factors (climate change, biodiversity, etc.) can also be considered.

If continuing efforts to collect necessary biological and economic data and to improve the model specification is encouraged, the bioeconomic model will play an important role in fisheries management, which will have significant fisheries management policy implications.

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