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Optimizing yields of the king mackerel (*Scomberomorus cavalla*) fishery in the western and southern Gulf of Mexico*

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SUMMARY: The concept of optimum yield is applied to an age structured simulation model of the *Scomberomorus cavalla* (Mitchill) fishery in the western and southern Gulf of Mexico. Current yearly catch amounts to 2,600 tonnes and is part of a beach seine multispecies fishery yielding more than 10,000 tonnes annually. Cohort sizes and population parameter changes (fishing mortality and recruit numbers) were analyzed throughout a 39-year period. As a result of recruitment pattern, it was found that optimum yield can be attained when fishing mortality is F= 0.4, regardless of the population size. Hypothesizing that the stock fished along the Mexican coasts is independent from others of the same species caught elsewhere, it is concluded that the fishery has been overexploited since 1979. Yields obtained after simulations of the fishery applying several fishing intensities lead to the conclusion that the optimum yield level of about 3,000 tonnes could be achieved in the long term if the former fishing mortality value is applied, but this would imply a reduction of fishing effort to about 40 per cent below the current level.

Key words: Stock assessment, fisheries simulation, harvesting strategy, sustainable yield, delay-difference model, fishing mortality.

RESUMEN: RENDIMIENTO ÓPTIMO EN LA PESQUERÍA DE PETO (*SCOMBEROMORUS CAVALLA*) DEL SUR Y OCCIDENTE DEL GOLFO DE MÉXICO. – El concepto de rendimiento óptimo es aplicado a la pesquería del peto (*Scomberomorus cavalla*) del occidente y sur del Golfo de México en un modelo de simulación basado en la estructura por edades. La captura es del orden de las 2,600 toneladas y forma parte de una pesquería multiespecífica cuyos rendimientos anuales superan las 10,000 toneladas anuales. Se analizaron los cambios en los tamaños de las cohortes y en los parámetros (mortalidad por pesca y número de reclutas) durante un período de 39 años. Como resultado del patrón de reclutamiento, se encontró que el rendimiento óptimo se puede alcanzar cuando la mortalidad por pesca sea de F= 0.4, independientemente del tamaño de la población. Al considerar la hipótesis de que la población que se pesca en las costas mexicanas es independiente de otras de la misma especie que se explotan en otras áreas, se concluye que la pesquería ha estado sobre explotada desde 1979. Los rendimientos obtenidos mediante simulaciones de la pesquería al aplicar varios valores de la mortalidad por pesca, conducen a la conclusión de que el nivel de rendimiento óptimo cercano a las 3,00,0 toneladas, podría obtenerse sostenidamente si se aplica el valor de la mortalidad por pesca antes mencionado, pero esto implicará una reducción en el esfuerzo de pesca cercana al 40% por debajo del nivel actual.

Palabras clave: Evaluación del recurso, simulación pesquera, estrategia de explotación, rendimiento sostenible, modelo de diferencias finitas con retraso, mortalidad por pesca.

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INTRODUCTION

Beach seine fishery in the western and southern Gulf of Mexico exploits two mackerel species as main targets, the Spanish mackerel *Scomberomorus maculatus* (Mitchill) and the king mackerel *S. cavalla* (Cuvier). The first one is the most important, yielding abou t 6,500 tonnes annually. The catch of the second species is about 2,600 tonnes annually. For years it has been argued whether or not northern Gulf of Mexico stocks are the same as those exploited in Mexican waters. Recent findings (JOHNSON, 1994) suggest that in the northern Gulf there can be more than a single stock. Hence, for ppractical reasons it was considered that the stock here analyzed is different to that on the American side, and therefore extension of conclusions is limited to the source of the statistical information, this is, the Mexican coast. The goal of present study is to contribute to the management of king mackerel stock, based on the principles of its population dynamics integrated in a simulation model, and developed to understand subjacent mec hanisms ruling the fisheries dynamics and to draw some guidelines for its management. The simulation is designed to address an answer to the following questions: What is the stock size? How intense is the fisheries impact on population? and, What is the maximum yield level? Once all these questions are solved it will be possible to answer the following one: What level of exploitation will produce maximum yield in the long term, after its adoption as management strategy?

The fishery

Artisan fisheries of tropical America are typically multispecies often yielding relatively low catch volumes per stock. In case of the highly migratory king mackerel species, as well as in the case of the Spanish mackerel, the extent of the distribution range of their populations is in doubt, and the possibility that same stock being exploited on the American and Mexican coasts of the Gulf of Mexico is in question. The shorelines of the Gulf are quite homogeneous, being composed mostly of sandy beach, leading to a habitat with a low degree of heterogeneity. On the Mexican side, however, temperatures are tropical (20.0°C to 29.7°C), while in the American waters a warm-temperate climate prevails (HEDGPETH, 1953). The continental shelf is narrow in most of its northern half and widens at the Campeche Bank which apparently is the southern limit of migrating route of Gulf stocks. Fishing activities take place mostly by using beach seines. Fishing boats used are about 33 feet-long with two outboard motors and a crew of nearly 15 fishermen (DOI and MENDIZÁBAL, 1979; CHÁVEZ, 1981). Fishing trips take several hours during the day, and fishermen follow the stocks along their pathway before towing their nets; fishing grounds are spread over a wide space along the shore line. Catch records (Fig. 1), show that yields range from 194 tonnes in 1955 to 5,894 tonnes in 1982, decreasing to 2,676 tonnes in 1990.

Previous assessments of the mackerel stock of Mexican waters have been conducted; by means of cohort analysis (DOI and MENDIZÁBAL, 1979), by application of an age structured simulation model (CHÁVEZ, 1981), and by a system of equations based upon Lotka and Volterra's predator-prey system (ARREGUÍN-SÁNCHEZ *et al.*, 1992). In the first case, a stock assessment of Spanish mackerel indicates that the optimum yield is 1,000 tonnes and in the second case one it ranges from 4,000 to 5,000 tonnes (in this instance a three-species set is considered, where *S. cavalla* represents about 30 per cent of yield). In the third case, an estimate of maximum yield is in the range of 4,000 to 5,000 tonnes, under fishing efforts prevailing at the sixties when the king mackerel represented about 20 per cent of total yield.

METHODS

Data include commercial catch and age composition. Additional data pertinent to the dynamics of the king mackerel population were taken from the references cited above as well as from further sampling of landings made on the coast of Veracruz. Age structure of the population in 1978, expressed in numbers as well as in weight, was used as the reference year to define population structure throughout the period ranged by the catch data (1952-1990). Parameters of the von Bertalanffy growth model were derived after application of the Fisat software package (PAULY and SPARRE, 1991), whose values are as follows: k= 0.1658; t_o= 0.256; L= 115 cm. In order to establish the relationships between length and weight data ($W= aL^b$), the regression parameter values are a= 0.0000131 and b= 2.9128; additionally, asymptotic weight is W= 10.29 Kg. A life-span of 18 years was considered (t_T= 3/k, k from the von Bertalanffy growth model), by assuming that at least 95 per cent of the stock attains 95 per cent of asymptotic length). Natural mortality (M) was deter-

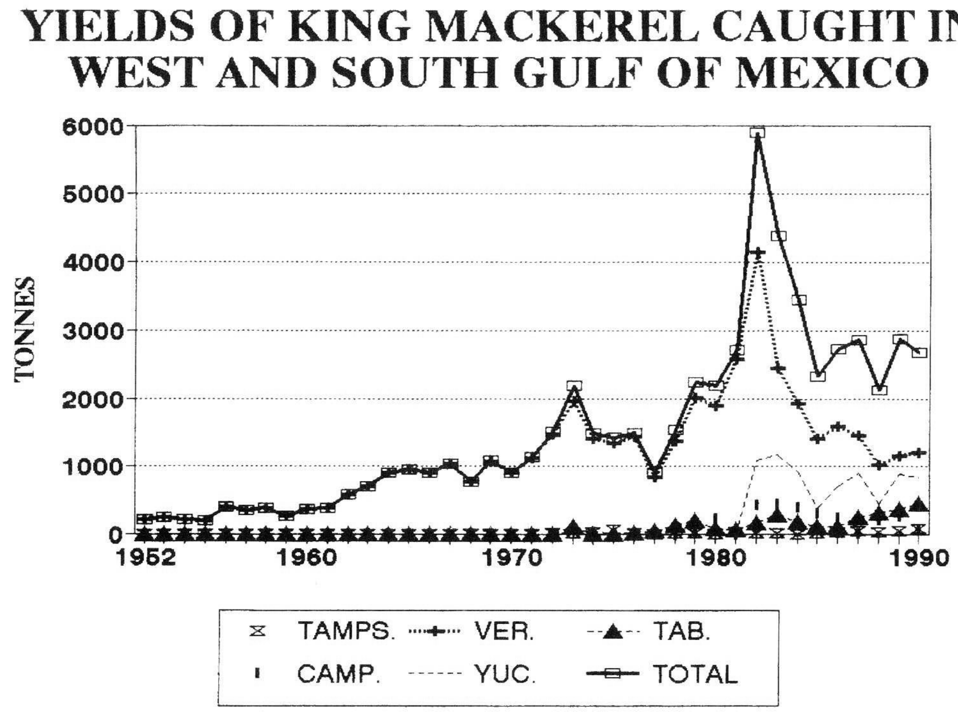

FIG. 1. – Yields of king mackerel exploited in Mexican waters for the years 1952-1990. Camp: Campeche; Tab: Tabasco; Tamps : Tamaulipas; Ver: Veracruz; Yuc: Yucatán; Tot: Total.

mined following Chávez (in press), by considering that at least 5 per cent of the stock survives to maximum longevity and thus M= k.

Reconstruction of the age structure was based upon natural mortality (M= 0.1658, yearly time units). Number of one-year old recruits was estimated year-by-year on the basis of maximum likelihood until the number of remaining age classes gave a catch value equal to the one recorded by the statistics each fishing season; estimates were obtained by means of the Baranov's catch equation (RICKER, 1975). Age of recruitment to fishery is 2 years-old and was assumed to be constant through time. With the fishing mortality (F) value previously determined for the year 1978 where effort was measured directly in the field, an estimate of Catchability coefficient q= $2.8*10^{-6}$ was derived from equation F= qf (RICKER, 1975; PAULY, 1980). Effort values (f) for most of the period (1955-1979), were taken from ARREGUÍN-SÁNCHEZ *et al.*, (1992).

Estimates of fishing mortality (F) were obtained through each year when catch records were available, that is, from 1952 to 1990 (Table 1). For the period mentioned, F values range from 0.09 (1952) to 0.75 (1985). In the same table, values for exploitation rate (E, the proportion of the stock that is caught) are also shown, which range from E= 0. 73 in 1973 to 0.458 in 1985 evidencing a progressive increment in intensity of exploitation. Particularly after 1980, when 2,200 tonnes were caught (F= 0.71 and E= 0.4412), the optimum yield value (F= 0.4) was exceded. Once the one-year old cohort was recruited to each year's population and adult numbers (ages 3 and over) were known, stock-recruitment relationship was analyzed.

Once all the previous data were defined, an age-structured simulation model based upon difference equations was developed in spread-sheet form. This lead to an experiment in management, to test the response of stock under different management options of fishery and to identify the best one after adopting a particular optimum management strategy. All management simulations were carried out after the validation process followed, finding the maximum likelihood of catch estimates respecting to observed ones after the 3 9-year data series. Sensitivity analysis shows that the recruitment model chosen and one of its parameter values are key factors required for a good fit of simulation outputs as compared concerning to real catch records.

Simulating the fishery

Age structure and stock-recruitment

The establishment of a parent-recruit relationship allows simulation of the population beyond the time period of catch records. Thus, the model can be used for advising fisheries managers on choosing the best harvesting strategy for the next fishing season. Hence, population number and biomass were assessed for each cohort at yearly intervals. To determine correspondence of stock size and structure in succeeding years, a stock-recruitment relationship was found, as shown in Fig. 2, where the success of

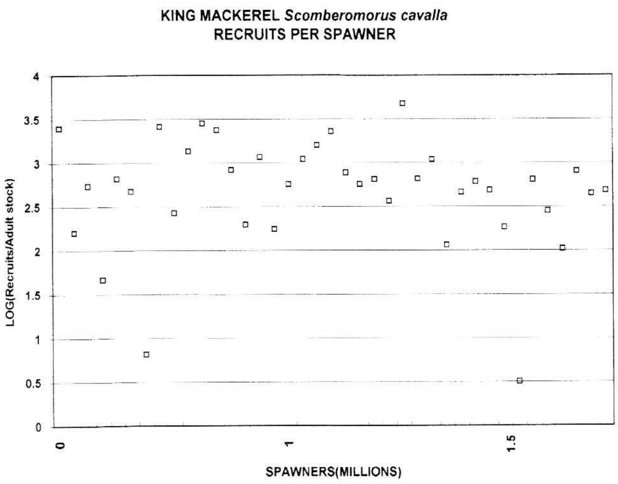

FIG. 2. – Pattern of recruit numbers per spawner displayed by the Mexican stock of king mackerel.

reproduction is expressed as number of recruits per spawner, as a function of spawner stock size. Although number of recruits per spawner tends to decrease at larger spawner sizes, the conclusion derived from the scatter of values of that figure is that recruitment seems to depend more on environmental factors than on stock size.

Yield observed for the period 1981-1984 indicates extraordinary increments in recruitment success. A possible explanation can be found on examining Fig. 1, where a significant increment of yield in the Yucatán fishery is evident in the same period. This increase would affect the recruitment pattern previously observed with additional recruits which probably belong to a different stock from other parts of the fishing grounds, where those exploited along the Veracruz shores are the most significant. This finding should to explaind in a reasonable way the adult numbers and their corresponding one-year old descendants in the next fishing season during the entire time period of catch records. The best fit of stock-recruitment data was with the Ricker model (1954): $R = A\alpha e^{\beta A}$, where R represents mean number of recruits (one-year old) produced by adult stock and A is the number of adults each year. Parameter associated with density-dependent mortality is $\beta = 0.000802$. In the case of the other parameter, which is linked to mortality associated to environmental factors, its value had to be changed in several periods in order to give a better fit to the simulated catch, thus, from 1952 to 1970 it was $\alpha = 0.9492$, from 1971 to 1978 it was $\alpha = 1.5187$, in 1979 and 1980 its value had an abrupt increase to $\alpha = 7.4$, dropping to $\alpha = 3.7$ the years after.

On examining time distribution of recruitment, it was found that in 1980 the one-year old recruit value was almost twice that observed on 1979 when it was 1.08 million and had an effect in catch records three years afterwards. These values were much higher than those observed the previous years. In addition, the remarkable increment in recruitment rate recorded in 1979 and 1980 coincides with a large reduction in adult stock of about 20 per cent under value for 1978. This reduction can not be explained even after consideration that fishing mortality was twice as high as before, as it was done on restructuring the virtual population. Thus, a factor external to the fishery probably was responsible for determining these anomalies. A possible explanation to this can be found in the Ixtoc-I oil spill, which for about six months spilled about 3 million barrels into the south Gulf of Mexico, thus inducing profound pertur bation in marine communities of the area as was documented for the zooplankton by GUZMÁN del PROO *et al.*, (1986). By considering the habitat of mackerels, it is suggested that the effects of the oil pollution may have had a deleterious impact on adult stock, but once these effects ceased an abrupt increment of recruitment rate may have occurred as a result of a possible competitive advantage through opportunistic exploitation of the resources of the environment once the perturbing factor stopped. Consequently, high values of the (parameter observed after 1980 may thus correspond to a new level of equilibrium reached by the king mackerel stock, which then was maintained throughout the last years of catch records.

Estimates of simulated biomass of each cohort are shown in Fig. 3. A sudden increase of catch is evident after 1981 and as it was formerly stated, it is

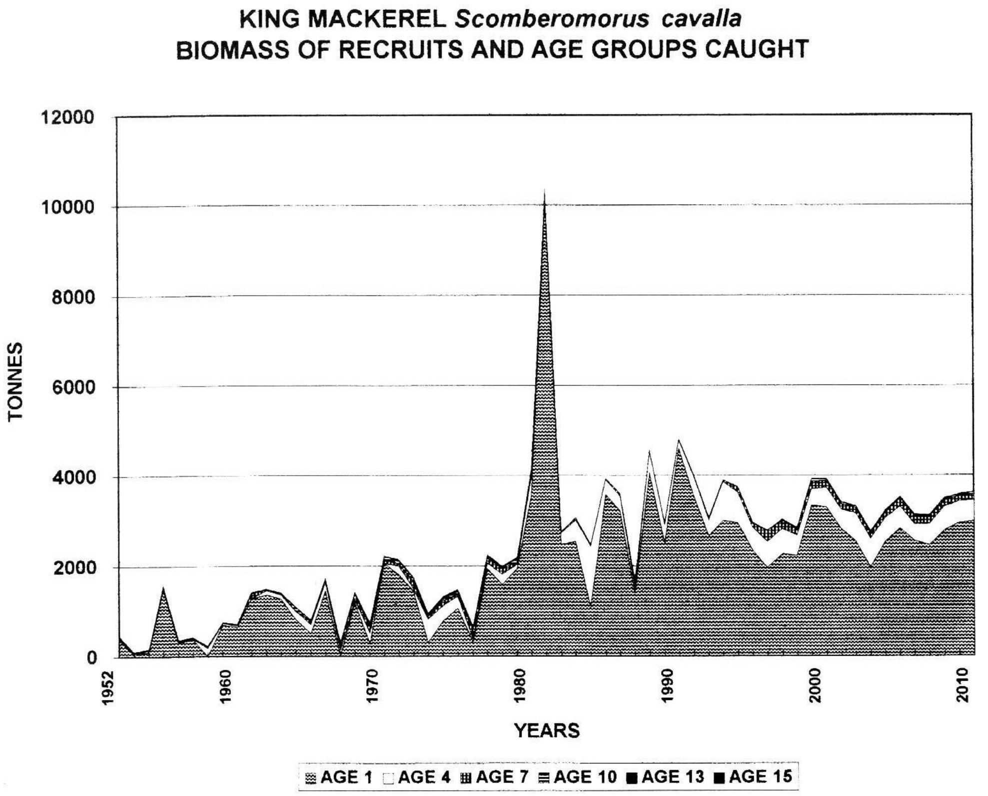

FIG. 3. – Biomass of age groups of king mackerel stock.

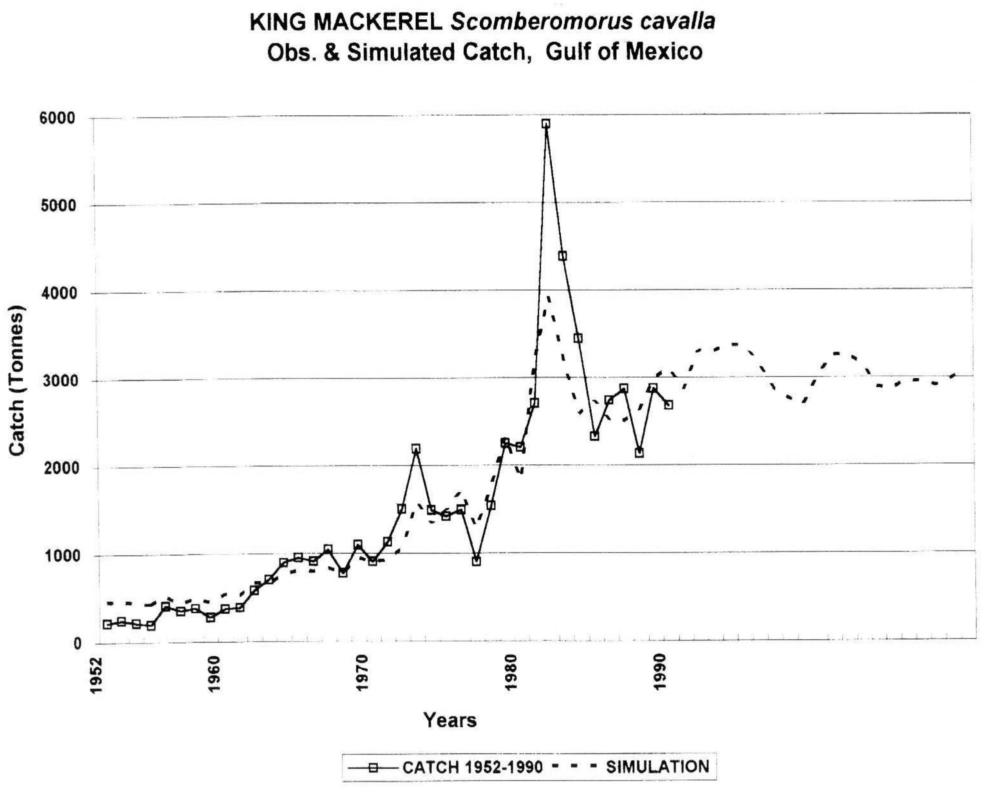

FIG. 4. – Catch records of king mackerel fishery 1952-1990, and simulated catches for a period 20-year longer. Fishing mortalities after 1990 are F = 0.4, other values are shown in Table 1.

determined by a higher recruitment rate probably caused by the reasons already given in addition to the opening of new fishing grounds along the shores of the Yucatán peninsula. In order to cope with these circumstances, evidently a good management strategy should imply a permanent assessment of the stock in order to closely follow any unforeseen changes in stock size and in the recruitment pattern, and in this way to apply at timely intervals any regulations addressed to optimize exploitation regime.

Optimum Harvesting Strategy

For practical use of the model, the last year of simulated values considered were the real number of one-year old recruits, rather than the value obtained after simulations enabling a more accurate identification and evaluation of exploitation policies after the last year of data records. Catch obtained by simulations was plotted (Fig. 4). In addition, catch re cords, total mortalities (Z), fishing mortalities (F), exploitation rates (E), one-year old recruits' estimations and adult number for each year over the 1952-1990 period are given in Table 1.

Once assessment of any fishery is performed, the goal of the process is to determine optimum yield. There are at least two views regarding the concept of maximum sustainable yield (MSY). The most traditional is expressed in terms of maximum biomass that can be extracted from the stock in the long term. Another view, as stated by HILBORN and WALTERS (1992), is opposed to the former one, arguing that the concept fails because once maximum yield is achieved, it is not sustainable, and besides, in order to determine the maximum yield value it is necessary to over exploit the fishery which is undesirable.

TABLE 1. – Catch data, total mortalities (Z), fishing mortalities (F), exploitation rates (E), recruits (R), and adult stock (both in thousands) of king mackerel, considered for the period 1952-1990.

YEAR	Catch (Tonnes)	Total Mortality	Fishing Mortality	Exploit. Rate	Recruit Numbers	Adult Stock
1952	212.012	0.1	0.1	0.095163	220	767.9499
3	242.661	0.105	0.105	0.099675	22	865.6749
4	211.663	0.101	0.101	0.096067	60	778.6219
1955	194.481	0.1	0.1	0.095163	830	735.0396
6	406.386	0.123	0.123	0.115736	170	1360.671
7	349.493	0 101	0 101	0 096067	210	1360 .412
8	377.357	0.105	0.105	0.099675	5	1390.783
9	275	0.09	0.09	0.086069	390	1252.32
1960	368	0.1	0.1	0.095163	355	1462.703
1	385	0.095	0.095	0.090627	707	1629.524
2	578	0.115	0.115	0.108634	755	2059.601
3	701	0.115	0.115	0.108634	707	2486.087
4	897	0.13	0.13	0.121905	453	2781.754
1965	953	0.135	0.135	0.126284	278	2804.935
6	913	0.135	0.135	0.126284	808	2673.021
7	1042	0.141	0.141	0.131511	5	2982.676
8	775.065	0.135	0.135	0.126284	660	2606.444
9	1095.532	0.165	0.165	0.152106	150	2759.53
1970	907.469	0.157	0.157	0.145296	1151	2355.232
1	1127.973	0.161	0.161	0.148708	1008	2958.887
2	1504.208	0.195	0.195	0.177165	801	3234.923
3	2186.829	0.305	0.305	0.262877	170	2974.405
4	1488.839	0.25	0.25	0.221199	431	2411.071
1975	1415.894	0.27	0.27	0.236621	591	2140.555
6	1495.936	0.316	0.316	0.270941	175	1945.125
7	900.953	0.22	0.22	0.197481	1081	1656.885
8	1534.847	0.33	0.33	0.281076	879	1934.68
9	2249.837	0.61	0.61	0.456649	1082	1515.474
1980	2199.838	0.71	0.71	0.508356	1979	1272.426
1	2703.572	0.7	0.7	0.503415	5589	1606.999
2	5893.577	0.7	0.7	0.503415	1374	3573.401
3	4383.678	0.71	0.71	0.508356	1413	2430.361
4	3445 586	0.71	0.71	0.508356	611	1889.302
1985	2323.399	0.75	0.75	0.527633	1992	1179.941
6	2735.007	0.73	0.73	0.518091	1793	1528.033
7	2870.789	0.73	0.73	0.518091	776	1600.178
8	2130.527	0.73	0.73	0.518091	2263	1145.066
9	2875.417	0.7	0.7	0.503415	1396	1692.337
1990	2675.612	0.7	0.7	0.503415	2559	1533.571

Therefore they suggest that it is preferable to refer to optimum harvesting strategy, which is determined by recent history of yields and exploitation policies, and which may change year after year. With these criteria in mind, further analysis of the fishery was conducted.

When stocks are under increasing intensity of exploitation, the number of age groups decline and the oldest animals in the catch are younger than those in the virgin stock. In this case, biomass of exploited stock is smaller than that of the unexploited one. The model simulates these changes under variable intensities of fishing effort and allows the estimation of population sizes under different fishing intensities and the determination of a combination of values such that yield estimates are the highest in the long term. Throughout the tuning up process of the model, many F values were tested, finding that maximum yield values were obtained at F= 0.4, regardless population size (Fig. 4). A similar behavior of exploited stock was found in the case of simulations made with the queen conch (CHÁVEZ and ARREGUÍN-SÁNCHEZ, 1994) and with three stocks of snapper (CRUZ-ROMERO *et al.*, in press), with the difference that in those cases maximum yield was obtained with F= 0.7, and thus it is concluded that optimum value depends upon the type of stock-recruitment process. At this point, the king mackerel fishery was simulated through the 39-year periods plus an additional 20 years departing from catch values for the year 1991 in order to make the best choice for the exploitation regime in the following season.

Simulation shows that an optimum harvesting strategy may be achieved by applying a fishing mortality of F= 0.4. These results are coincident with optimum value found after the application of a surplus yield model to historic data (not included in this paper). This is remarkable, because of dramatic changes in population size that occurred before and after the oil spill, when the fishery passed from an unexploited stage before 1979 to another of overexploitation afterwards. LUDWIG and WALTERS (1985) state that the best choice between a surplus production model and a simulation age-structure depends on how much contrast has occurred in historical effort and in performance of catch per unit of effort data.

Yields obtained by simulation after the last year of data records (1990), by applying different F values, determined that optimum yield can be obtained by a reduction of current effort to maintain F= 0.4. This would imply a reduction in the intensity of fishing effort to about 60 per cent of the current level. If this exploitation strategy where adopted, annual yields would be around 3,000 tonnes (value obtained as average of the last ten years of simulation), as compared to current levels when yields are about 2,600 tonnes. Should other F values be adopted, then yields would be lower than optimum in the long term (Fig. 4). This is why it is advised that the optimum harvesting strategy is adopted as far as population structure, size and recruitment pattern persist.

Criteria for fisheries management

Resource management of fisheries should guarantee the activity in a sustainable and profitable way. If a consideration of potential development of fishery is made upon the premise that exploitation of *S. cavalla* is based upon a stock (or stocks) restricted to Mexican waters only, then it is concluded is that current levels of fishing mortality have been overexploiting it since 1979. A drastic reduction of fishing effort as result of the conclusion arrived at in this paper would imply a severe social impact because about 40 per cent of the current number of fishermen would have to stop fishing. Unfortunately, the consideration of maximum social benefit as a feasible goal for the management of this fishery it is not congruent with the idea of sustainability of the resource, nor with maintenance of the fishery as an economic activity.

CONCLUSIONS

1. The king mackerel fishery exploited in Mexican waters along the west and south Gulf of Mexico is overexploited and thus a reduction in about 40 per cent of fishing effort with respect to the current level is advised.
2. The fishing mortality value recommended for an optimum harvesting strategy, F= 0.4, would ensure high sustainable yields (about 3,000 t). This implies a severe reduction in employment, but is a condition necessary for the conservation of the resource.
3. A collapse in the fishery may occur if further increase of effort is allowed.

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