Optimum fishing strategies for *Isostichopus fuscus* (Echinodermata: Holothuroidea) in the Gulf of California, México

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Abstract: The *Isostichopus fuscus* fishery in Mexico was heavily exploited until 1994, when it was closed due to overfishing. However, no information existed on the *status* of the populations. The fishery was evaluated through an age structured simulation model, and according to our analysis of the stock, the fishery can be feasible and sustainable as long as fishing mortality and age of first catch are optimized. In order to evaluate exploitation strategies, several scenarios were simulated considering different combinations of fishing intensities and ages of first catch. Input data for the model included population parameters, commercial catch and costs and benefits of the fishing operations. Yield production was strongly influenced by the fishing pressure and by the age of first capture. When the first one increased, significant decreases in yield and profits occurred. The best exploitation strategy was with these parameters: fishing mortality level F= 0.15, age at first capture t_c= 4 years, and yielding of ~ 430 tons. However, since the species reproduces for the first time at 5 years, extracting younger specimens would collapse the population. The critical value of fishing mortality was detected at F_c= 0.25. If exceeded, the population tends to exhaustion and the fishery is no longer profitable. In conclusion, *I. fuscus* fishery is highly vulnerable to overfishing and age of catch. It must be taken into account that the management policies should be considered as pilot and used on a regional basis. Continuous monitoring of the stock, control of the number of fishing licenses and extracting only specimens 5 yeasr-old and older (around 20 cm and >400 g), will allow the populations to recover from fishing activities. Rev. Biol. Trop. 53(Suppl. 3): 357-366. Epub 2006 Jan 30.

Key words: *Isostichopus fuscus*, population dynamics, fisheries simulation, harvesting strategies, Gulf of California, México.

Sea cucumbers or holothurians have been fished since ancient times in China, Japan and in many other countries. There is an antique tradition in the consumption of these organisms as Bêche-de-Mer or trepang (common name for dried or smoked holothurians) and as fermented beverages. Holothurians are also well known for their curative properties (Conand 1990, Baine and Poh Sze 1999, Reichenbach 1999, Levedeb 2000).

In México, the holothurian fishery is a recent activity (about 10 years). The Gulf of California was the main source and the first recorded catch dates from the late 1980's. The target species was the aspidochirote *Isostichopus fuscus* (Ludwig, 1875). The maximum recorded catch occurred in 1991, with 1800 tons but mean annual catch was around 300 tons. This sea cucumber is well accepted in the international market because of its large size and body wall properties (Fajardo León and Vélez Barajas 1996, Ramírez Soberón 2001), and yield is similar and sometimes higher than those reported for other commercial holothurians (Baine and Forbes 1998, Trianni 2002).

México and Ecuador were (and still are) the main exporters of this species to Asian markets, but in the early 1990's both countries closed the fishery due to over-fishing (Anonymous 1994, Sonnenholzner 1997). It is important to notice that no regulations existed for the fishery at the time and that there were high levels of poaching or illegal capture (Fajardo León and Vélez Barajas 1996, Sonnenholzner 1997, Gutiérrez García 1999, Anonymous 2000a). However, the fishery reopened in the year 2000 and it is still going.

The holothurian *I. fuscus* inhabits shallow waters (0-40 m depth) on the tropical Pacific coasts of Mexico (including the Gulf of California) to Ecuador (Maluf 1988). It is usually found associated with corals and rocky-sandy bottoms. To date, *I. fuscus* is still under protection, but permits for the fishery may be granted when the surveys prove that a portion of the stocks can be exploited under controlled conditions (Anonymous 2000b).

Although literature (about biology, population dynamics, fishery analysis, etc) of this sea cucumber is scarce (Fajardo León *et al*. 1995, Martínez *et al.* 1996, Herrero Pérezrul *et al*. 1999, Jenkins and Mulliken 1999), the information available is good enough to establish basic regulation measures as minimum size, reproductive ban, etc. In this study the information available plus additional data, was analyzed and served as a basis to identify optimum harvesting strategies. The goal of this paper is to evaluate the stock biomass, to diagnose the status of exploitation and the effect of different patterns of exploitation on a surveyed stock of *Isostichopus fuscus* in the southern Gulf of California, Mexico.

MATERIALS AND METHODS

An analysis based upon an age-structured model was used to evaluate and simulate the fishery of *I. fuscus* under different levels of fishing mortality (F) and the age of first catch. The model was developed in a spreadsheet and its guidelines are described by Chávez (1996, 2001).

Data for the model included commercial catch and effort (from the local Fisheries Office in Baja California and Baja California Sur, México) for the six-year fishing period before it was banned (1989-2001). The model also includes the population parameters (obtained from Herrero Pérezrul *et al.* 1999) of a non-exploited population of *I. fuscus* at Isla Espíritu Santo in the southern Gulf of California, México (24°30’ N; 110°15’ W) (Herrero Pérezrul *et al.* 1999). These data were used to calculate the age structure of the population using the von Bertalanffy growth model (Ricker 1975, Conand 1988), and the natural and fishing mortality coefficients. The length-weight ratio, natural mortality coefficient and individual growth rate parameters are shown in Table 1. The costs and benefits of fishing operations were obtained from Fajardo León and Vélez Barajas (1996).

A lifespan (t_T) of 17 years was estimated using t_T = 3/K, where K is the growth rate coefficient from the Bertalanffy growth equation and assuming that at least 95% of the stock survives to attain 95% of the asymptotic length. Natural mortality was calculated according to the Beverton invariants, thus M =1.5 K (Jensen 1996, 1997).

Once the age structure was reconstructed (Table 2), and population size and exploitation rates were determined for each year of the study period, the Baranov’s catch equation (Beverton and Holt 1957, Ricker 1975) was used on the fishery data to evaluate fishing mortality values each year. On fitting the model, the number of recruits was estimated year by year until the number of remaining age classes gave a catch value equal to the one recorded by the statistical records of the fishing season.

The parameters α and β of the stock-recruitment model by Beverton and Holt (1957) were calculated using the mean size of adult population and based on the age structure of the last three years of captures.

The model used is

$$[R= ßxA_dxA_{max}/(A_d+(\alpha xA_{max}))].$$

The parameters α and ß have no biological meaning, they fit the observed data to the stock-recruitment model (Beverton and Holt 1957). During the fifteen-year study period, maximum yield was used as a reference because ß strongly depend on the reconstructed stock size. A_d is the number of adults and A_{max} is estimated maximum number of adults (Table 1).

The model assumes that each stock is in a steady state and that recruitment is relatively constant during the eight years of catch data. However, considering that in echinoderms recruitment is variable (Lawrence 1987), a stochastic function was added to this model in order to obtain variability in the estimations of recruitment. The number of each cohort over time is determined by difference equations.

Estimates of F were obtained for each fishing season. Long-term effects on the population were evaluated using the average values of the last three years of the catch records. When

TABLE 1

Population parameters of I. fuscus *used as input to feed the simulation model. Most values were obtained from Herrero Pérezrul* et al. *(1999). Natural mortality (M) was calculated following the Beverton invariants (Jensen 1996, 1997). N = 1446. Estimates of other pertinent values for the analysis of the fishery are shown*

CUADRO 1

Parámetros poblacionales de I. fuscus *utilizados como datos de entrada para alimentar el modelo de simulación. La mayoría de los valores fueron obtenidos de Herrero Pérezrul* et al. *(1999). La mortalidad natural (M) fue calculada siguiendo las invariantes de Beverton (Jensen 1996, 1997). N = 1446. Se muestran las estimaciones para otras variables pertinentes para el análisis pesquero*

Population parameter	Values
Individual annual growth rate (K)	0.18 $\pm$ 0.044
Asymptotic length (L_{asint}) (cm)	36.1 $\pm$ 0.244
Asymptotic weight (W_{asint}) (g)	815.5 $\pm$ 5.509
a (from length-weight relationship)	1.142 $\pm$ 1.100
b (from length-weight relationship)	1.83 $\pm$ 0.003
Natural mortality (M)	0.27 $\pm$ 0.03
Age of first capture (tc), years	4
Age of first maturity (tm), years	5
Theoretical age when length is zero (t_0)	-0.024
Longevity (as 3/K, years)	17
Growth performance ($\phi' = \text{Log}(K) + 2\text{Log}(L_{asint})$)	2.4
α (recruitment)	0.25
β (recruitment)	3.45
Cost per trip (USD)	$ 387.00
Catch value per Kg (USD)	$ 6.00
Catchability coefficient ($q = F_{1994}/f_{1994}$)	0.00006
Total profits (USD)	$ 3 341 445.00
Number of boats (1994)	61
Number of daily trips (1994)	618
Benefit/Cost ratio (1994)	8.2

TABLE 2

Age frequency at length and weight of I. fuscus *from the southern Gulf of California. Estimates of size and weight were obtained using the parameter values of Table 1. Sample size = 1 446 specimens (* is the age at first maturity)*

CUADRO 2

Frecuencia de edad para el largo y el peso de I. fuscus *en el sur del Golfo de California. Las estimaciones de talla y peso fueron obtenidas utilizando los valores de los parámetros del cuadro 1. Tamaño de la muestra = 1446 especimenes (* es la edad de la primera madurez).*

Age (years)	Frequency	Length (cm)	Weight (g)
0	0	-0.2	0
1	2	5.8	28.80
2	19	10.8	89.6
3	55	15.0	162.8
4	141	18.5	238.7
*5	245	21.4	312.2
6	259	23.8	380.3
7	252	25.8	441.5
8	205	27.5	496.4
9	86	29.0	543.6
10	93	30.1	585.0
15	71	33.7	717.7
20	14	35.1	775.0
25	0	35.7	799.4
30	0	36.0	808.4
35	3	36.0	812.4
40	1	40.0	830.0

using all the required parameters, the model was run in the long term to forecast the consequences of different management options.

Several scenarios were simulated by testing different fishing mortality values and age of catch. For the analysis of exploitation scenarios, only the group of recruits of three years and older were considered, because younger specimens are never part of the fishery (Fajardo León and Vélez Barajas 1996, Herrero Pérezrul *et al*. 1999).

To determine optimum yields, different combinations of age at first capture (t_c=3, 4, 5, 6 and 7 years old) and different F values were tested for evaluation of the stock response. Estimates of the potential yield varied from F = 0.1 to 2.0, which includes the observed range of the current exploitation pattern (F = 0.1 to 0.5).

Costs (C) and benefits (B) of fishing activities allowed to determine the profits by just subtracting B from C. Costs per trip were considered constant regardless the stock size. Implicitly, the catchability also was considered constant. This way, economic performance of the fishery could be analyzed through time and the Maximum Economic Yield (MEY) as well as the economic equilibrium limit as a function of fishing intensity could be evaluated.

RESULTS

Catch records evidencing the stock depletion are shown in Fig. 1, where yields and F values through time are displayed. The stock-recruitment analysis suggests that the stock is quite sensitive to over fishing. When F is lower than 0.25 the stock seems to be able to withstand a sustainable exploitation. However, this fishing intensity is at the threshold of over fishing and any increase would deplete the population (Fig. 2a, b).

In addition, uncertainty of recruitment (*e.g.* by climate events), may lead to over fishing under the same level of the effort (the one required for F = 0.25) from one fishing season to the next one, just because recruitment rate may be poor and consequently fishing mortality

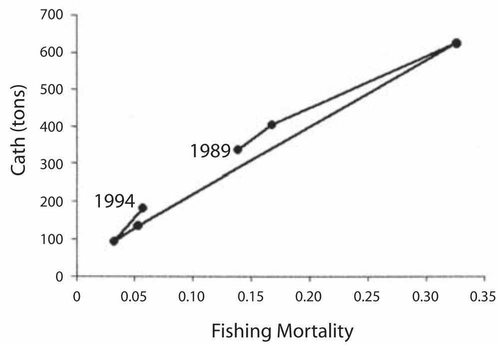

Fig. 1. Record of Catch and fishing intensity of the *Isostichopus fuscus* fishery in the southern Gulf of California through the six-year period of exploitation leading to its depletion.

Fig. 1. Récord de la captura e intensidad de la pesca de la industria pesquera de *Isostichopus fuscus* en el sur del Golfo de California a través de un periodo de seis años de explotación que condujo a su agotamiento.

would exceed F $\geq$ 0.25. Therefore, the turnover rate of the stock would not be capable to restore a steady state as result of reproduction and depletion may be imminent.

Results of the model indicate that it is possible to maximize the fishery in the Southern Gulf of California to ~430 t•year^{-1} by means of a management strategy that assumes low rates of fishing mortality (F= 0.15) and an age of first capture t_c= 4 years (Fig. 3). However, increasing t_c= 5 years produced lower yield and profits, but for longer time.

From the several tested combinations of F and t_c, three main scenarios were simulated to evaluate the optimum fishing strategy. Simulations were made immediately after the last year of catch records and maintaining constant the fishing strategy chosen, for thirty additional years. Results were evaluated as the mean of the last five years of simulation. The first scenario detected the critical or threshold value of fishing mortality (F_{MY}), coincident with the maximum yield (Fig. 4). The second scenario showed the exhaustion of the fishery when F > 0.25. The third scenario used the F value required for MEY (F_{MEY}), as a management strategy suggested for adoption.

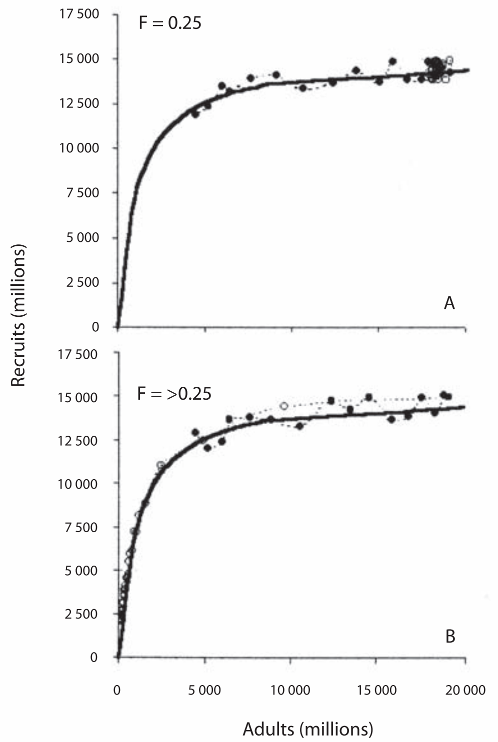

Fig. 2. Tendency of the stock-recruitment relationship according to the Beverton and Holt model and distribution of the values of recruitment in the *Isostichopus fuscus* restructured stock. Simulated recruitment is shown as empty. Values are subjected to stochastic variation. a) Stock response under a low fishing intensity ($0.15*F_{max}$). b) Potential overexploitation of stocks under a fishing intensity value of F = 0.70.

Fig. 2. Tendencia de la relación parentela progenie de acuerdo al modelo de Beverton y Holt y distribución de los valores de reclutamiento de las existencias reestructuradas de *Isostichopus fuscus*. El reclutamiento simulado se muestra con círculos vacíos. Los valores están sujetos a variaciones estocásticas. a) Respuesta de las existencias bajo una baja intensidad de pesca ($0.15*F_{max}$). b) Potencial de sobreexplotación de las existencias bajo una vlor de intensidad de pesca de F = 0.70.

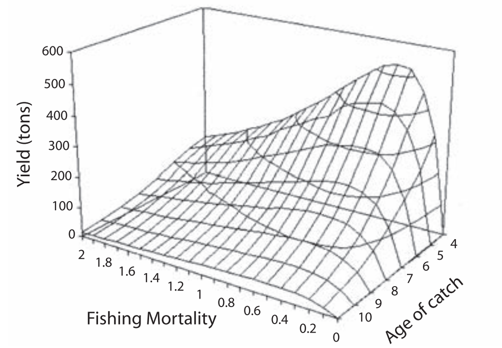

Fig. 3. a) Yield response (tons) and b) Economic yield (USD) as effect of the F and age of first catch of *Isostichopus fuscus*.

Fig. 3. a) respuesta de producción (toneladas) y b) producción económica (USD) como efecto de F y la edad de la primera pesca de *Isostichopus fuscus*.

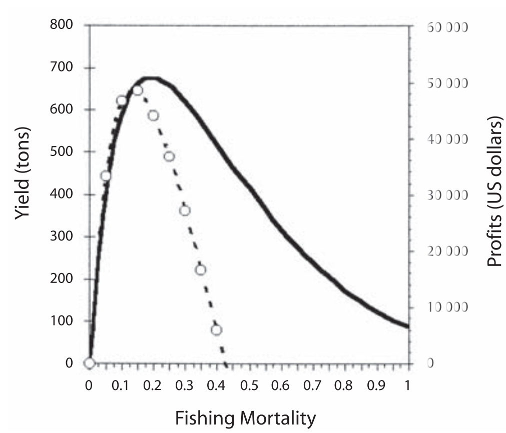

Fig. 4. Potential yield (tons) and economic yield (USD) of the *Isostichopus fuscus* fishery in the southern Gulf of California showing the stock response as a function of the fishing mortality. The optimum age of first catch is four years.

Fig. 4. Potencial de producción (toneladas) y producción económica (USD) de la pesquería de *Isostichopus fuscus* en el sur del Golfo de California mostrando las respuestas de las existencias como una función de la mortalidad. La edad óptima de la primera captura es de cuatro años.

First scenario: Threshold fishing mortality (F_{MY})

The stock response shows that the maximum yield, near to 430 t•year^{-1}, may be attained at F = 0.25 and an age of first catch of 4 years; however, it may not be sustainable because of the uncertainty associated to recruitment (Fig. 4). This is the threshold level after which the stock starts being overexploited, although it may not be evident at initial levels of overexploitation (Table 3).

TABLE 3

Fishing intensities of I. fuscus *calculated for three harvesting strategies: Threshold (F_{MY} = 0.25), Over fishing ($F_{>MY}$ = 0.7), and Maximum Economic Yield (F_{MEY} = 0.15), and different ages of first capture (t_c). B/C is the benefit/cost ratio. Y_o = Yield, t. Profits are given in USA dollars (* is the age at first maturity)*

CUADRO 3

Intensidad de pesca de I. fuscus *calculada para las tres estrategias de captura. Umbral (F_{MY} = 0.25), sobrepesca ($F_{>MY}$ = 0.7), y producción económica máxima (F_{MEY} = 0.15), y diferentes edades para la primera captura (t_c). B/C es la tasa de beneficio/costo. Y_o = Yield, tons. Los beneficios están dados en dólares de EUA (* es la edad de la primera madurez)*

	F_{MEY} = 0.15			F_{MY} = 0.25			$F_{>MY}$ = 0.70		
t_c	B/C	Y_o	Profits	B/C	Y_o	Profits	B/C	Y_o	Profits
3	1.32	456.7	10 906	2.17	500.8	26 585	0.53	303.3	-26 849
4	3.60	414.6	29 443	2.21	508.4	27 337	0.62	360.0	-21 275
*5	3.33	384.2	26 454	2.11	485.8	25 106	0.69	396.4	-17 691
6	3.06	352.8	23 363	1.96	451.7	21 753	0.69	399.4	-17 398
7	2.70	310.6	19 218	1.78	411.0	17 755	0.66	382.5	-19 061

Second scenario: Exhaustion of the fishery $F_{>MY}$

With fishing intensities over the critical value of fishing mortality (F = 0.7), the stock is unable to be restored as result of reproduction. The fishery stops being profitable at F = 0.375, a moderate level of overexploitation (Fig. 2b). Under this regime of exploitation, the profits may be still high shortly after the last year of catch records, but for only a couple of years. After the third year of simulation, a sharp decline in the population numbers may occur because the remaining adult stock is not large enough to restore the population in subsequent years. Yield is reduced when the age of first capture is increased. The F_{MY} value signals the threshold of stock over fishing. If increased, the collapse of the fishery was imminent (Table 3).

Third scenario: F_{MEY}

Under the conditions of F= 0.15 and t_c= 4 years, a long term and profitable fishery can be achieved (Fig. 2a, 4), because the number of recruits remains high and the stock can be restored every year. Yields are sustained at a level near to 475 tons at the most profitable level, with annual returns near to USD $ 30 000.00 (Fig. 4, Table 3).

DISCUSSION

During the fishery period (1989-2001), stock response shows that yield was strongly influenced by variations in the rate of fishing mortality. Although maximum potential yield was calculated at ~500 t•year^{-1} with a fishing pressure of F = 0.25, this value turned out to be critical. It signaled the threshold of the population numbers and yields (Fig. 4). When exceeded, the collapse of the fishery was imminent.

The chosen target of the fishery may be attained by means of a limited number of fishing permits and boats during a three or four-month fishing season every year. In addition, a close inspection of landings to ensure that the minimum legal size and expected yields per boat are accomplished should be mandatory and enforced.

The annual yield of sea cucumbers worldwide in recent years was around 60 000 to 120 000 tons of fresh weight. A substantial portion comes from countries which export their whole production to Asian markets (Conand

1990, Woodby *et al.* 1993, Fajardo León and Vélez Barajas 1996, Conand 1997, Conand *et al*. 1998, Lebedev 2000).

At high fishing intensity (F_c= 0.50), the recruits decrease noticeably (Fig. 2b), so the fishery is no longer profitable and extinction of the exploited stock is prompt to occur. The number of recruits-per-adult tends to decrease at older ages as occurs in other exploited stocks.

The parameters of the von Bertalanffy growth model and the length-weight relationship used to feed the model (Table 1) are not too different from those estimated for other commercial holothurians (Ebert 1978, Shelley 1985, Conand 1988). Although several approaches have been tried to estimate growth in these organisms, there are some constraints in their use (Ebert 1978, Conand 1988, Hamano *et al.* 1989). For instance, sea cucumbers usually expel tags causing necrosis, and using radioactive stains implies the sacrifice of the organisms (Conand 1990). Despite these constraints, the use of length frequencies to study growth to infer an age-structure in holothurian stocks has been favored (Ebert 1978, Conand 1988, Herrero Pérezrul *et al.* 1999).

Estimates of age at first sexual maturity in holothurians are scarce. For *I. fuscus,* it was calculated to be 5 years, which corresponded to a length of ~20 cm and a drained-weight of 367 g (Table 2), and individuals between 4 and 6 years are the most abundant in the population (Herrero Pérezrul *et al.* 1999). Other aspidochirotes showed first mature individuals in a range from 160 g to > 500 g (Conand 1990, Pérez Plascencia 1995).

The stock response shows that the population is most productive at an age of 4 years according to the model (Fig. 3a) and predicts that the remaining younger individuals will support the fishery with further generations when they attain maturity. However, on the long term simulation (> 10 years) the fishery and the population will collapse. Therefore, authorities should take this in consideration, because *I. fuscus* reproduces at an age of 5 years (Herrero Pérezrul *et al.* 1999).

Reliable estimates of natural mortality are required for assessments of the stocks; this parameter was originally determined through Hoenig (1983), Alagaraja (1984) and Chávez (1995), assuming that at least 5% of the stock survives to reach maximum longevity, where M = K; however, it is felt that when it is calculated according to the Beverton invariants, as M =1.5 K (Jensen 1996, 1997) the estimates may probably be more accurate.

To define the stock-recruitment relationship amongst cohorts through time, the use of the Beverton-Holt model for many exploited stocks has proven to provide reasonable results describing the relation between adult and recruits, despite the undesirable high uncertainty always present. A stock-recruitment model should describe this relationship as accurately as possible, when reliable data on the age structure through a long enough series of years are available. This is not the case with sea cucumbers, whose population dynamics is at an early stage of knowledge. Only when a long series of observations on the recruit numbers and the breeding stock has been recorded it is worth trying to explore other stock-recruitment models and to choose the most suitable. Meanwhile, derivation of a robust stock-recruitment relationship is undoubtedly one of the most significant problems modeling exploited stocks (Medley and Nimes 1997).

The main life history traits of holothurians suggest that they constitute fragile stocks. For instance, they are big, slow growing organisms which hardly move (therefore easily detected by divers), and reproduction occurs until the age of 5 years, so over fishing is likely to occur due to their high vulnerability (Bakus 1973, Conand 1990, Conand *et al.* 1998, Herrero Pérezrul *et al.* 1999). Signs of over-exploitation in holothurian fisheries have been frequently reported in the last few years (Woodby *et al.* 1993, Fajardo León and Vélez Barajas 1996, Conand *et al*. 1998, Morgan 2000).

The traditional extracting of Bêche de Mer is done in two principal ways: by walking, where recollection is done by hand or using harpoons or poles with a hook tied to one end. The other one is by using different types of dredges. These methods are considered of no harm to the stock numbers, since only adult animals are caught, so juveniles have the opportunity to grow and reproduce (Lebedev 2000). Although in some places the extraction is still done in the traditional ways (Baine and Poh Sze 1999), at this time and age, the introduction of new technology developed a new way of extraction: by diving and with motor boats. This method implies an exhaustive search of the specimens, including younger ones (Fajardo León and Vélez Barajas 1996, Sonnenholzner 1997) and the divers can deplete holothurian populations in the short term (Lebedev 2000).

Beside this, a continuous increase in fishing effort, the lack of studies on the species of interest (especially those of artisan value), the misreporting of catch, infringements of the established quotas and poaching are other major problems to solve. The collapse of fisheries worldwide indicates an urgent need to avoid the exhaustion of the over-exploited resources. Several approaches have been made in order to create general guidelines to manage fisheries. However, trying to combine the different groups involved in the fishery, such as fishery scientists, economists, ecologists and fishermen is a very difficult task.

According to simulations, whose results are summarized in Table 3, the most profitable option is the F_{MEY} and tc = 4 years as a goal, although this implies catching juveniles. However, the analysis suggests that the fishery may still be sustainable. Therefore, by following the principles stated by fisheries management, corresponds to the authority to take the decisions in this respect, by assuming that they will take into consideration all the biological, economical and social factors under the current political conditions over the fishery.

When the F_{MEY} is chosen as target, the activity is not as profitable as in the former case, although yields are considerable higher. These two targets lead to the trade-off of decision on what may be the most convenient option to adopt as goal for management. Adoption of the F_{MEY} as target may look as a convenient one because implies the possibility to provide up to 66% more jobs than the F_{MEY} target; however, exploiting any stock at this level implies taking the chance to cope with a high risk of unfavorable conditions for recruitment, because carrying capacity of environment is not constant and therefore is subjected to random changes caused by conditions unfavorable to survival of recruits. Betting with uncertainty may be very difficult in cases of a low survival of recruits (from the social point of view), because there would be no catch enough to sustain all the fishermen that the stock could maintain under a stable condition. For this reason, choosing the FMY as target could provide a better chance to cope with uncertainty in conditions of poor survival of recruits; this way, there would be less chance to face extreme environmental conditions than in the former case and therefore the FMY option would provide a safer social margin.

In the particular case of holothurian fishery, some proposals of pre-requisites for management have been discussed (Conand *et al.* 1998). Their main steps are summarized as follows:

- Studies on the biology and population dynamics of the species
- Stock assessment and continuous monitoring
- Analysis of catch and statistics available
- Creation of a quality manual
- Farming

The results obtained here by the model and the information available, will allow to establish management and conservation regulations for this holothurian stock in the southern Gulf of California, extracting animals only 5 year-old and older (around 20 cm and >300 g), control of the number of permits and continuous monitoring of the stocks. It must be taken into account that the management policies should be considered as pilot and used upon regional basis.

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RESUMEN

La pesca de *Isostichopus fuscus* en México fue altamente explotada hasta 1994, cuando fue clausurada por sobrepesca. Sin embrago, no existe información sobre el estado de sus poblaciones. La pesquería fue evaluada a través de un modelo de simulación de estructura por edades, y de acuerdo a nuestro análisis de sus existencias, la pesquería puede ser realizable y sostenible siempre y cuando la mortalidad y la edad de la primera captura en la pesca sean optimizadas. Para poder evaluar las estrategias de explotación, varios escenarios fueron simulados considerando diferentes combinaciones de intensidades de pesca y edades de primera captura. Los datos de entrada para el modelo incluyeron parametros poblacionales, capturas comerciales y costos y beneficios de las operaciones de pesca. La producción está fuertemente afectada por la presión de pesca y por la edad de la primera captura. Cuando la producción se incrementa, disminuciones significativas ocurren en la producción y en los beneficios. La mejor estrategia de explotación fue estimada con un nivel de mortalidad de pesca de F = 0.15, una edad de primera de captura t_c= 4 años, y una producción de ~ 430 toneladas, sin embrago debido a que la especie se reproduce por primera vez a los cinco años, extraer especimenes jóvenes haría colapsar a la población. Los valores críticos de mortalidad por pesca fueron detectados a F_c= 0.25. Si se excede, la población se agotaría y la pesquería no seria aprovechable. En conclusión, la pesquería de *I. fuscus* es altamente vulnerable a la sobrepesca y la edad de captura. Se debe tomar en cuenta que las políticas de manejo deben considerarse como pilotos y utilizadas a nivel regional. El continuo monitoreo de las existencias, del control de las licencias de pesca y extraer solamente especimenes de 5 años de edad y mayores (alrededor de 20 cm de largo y > 400 g), permitirán a las poblaciones recuperarse para retomar las actividades pesqueras.

Palabras claves: *Isostichopus fuscus*, dinámica de la población, simulación de pesquerías, estrategias de explotación, Golfo de California, México.

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