

## STOCK ASSESSMENT OF THE WARTY SEA CUCUMBER FISHERY (*PARASTICHOPUS PARVIMENSIS*) OF NW BAJA CALIFORNIA

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### ABSTRACT

The catch of the warty sea cucumber *Parastichopus parvimensis* off northwestern Baja California declined since 1997 from 622 metric tons to almost one third through the last thirteen years, in a relatively stable harvest. The fishery employs 294 fishermen, with annual profits of \$243,000 USD. The goal of the study was to assess the stock biomass, the socioeconomic performance of the fishery, and to evaluate harvesting scenarios. A relative constancy of fishing mortality (F) and the stock biomass were observed the last thirteen years. Current profits per fisher are near the maximum the fishery can produce, which is profitable under a narrow combination of age of first catch and F. Fishermen seem to avoid unprofitable activity when fishing intensity increases, so there is an apparent tendency to reduce economic risk by exerting a low effort. Immature animals are exploited, but under the low F applied, the stock can withstand it without showing signs of depletion.

### INTRODUCTION

Holothurian fisheries are generally small scale and based on a few deposit-feeding species belonging to two families and five genera (Conan and Byrne 1993). *Parastichopus parvimensis* (Clark) is common from Baja California, Mexico, to Monterey Bay, California, USA, although only scattered individuals were reported to occur north of Point Conception, California. *Parastichopus parvimensis* is found mainly in low energy environments from the intertidal down to 30 m and can reach a maximum length of 30–40 cm (Bruckner 2006). These animals are an important component of benthic communities of the subtidal zone, recycling nutrients and cleaning the environment (Yingst 1982), being more commonly found on rocky and stony grounds from the low-tide level to >60-m depth (Woodby et al. 2000). They are dioecious and the gender ratio is 1:1 during the reproductive stage. Breeding season varies latitudinally along the west coast of Baja California, as in the stocks of Todos Santos Bay and El Rosario located in the northern peninsula, where it occurs in the spring-summer period, whereas in Isla Natividad and Bahía Tortugas, located off the center of the peninsula, it occurs in

winter-spring (Fajardo-León et al. 2008). Fully developed gonads were observed in individuals whose body weight ranges from 120 to 160 g (Pérez-Plascencia 1995, Espinoza-Montes 2000; Fajardo-León et al. 2008) and they begin reproducing when they are about two years old (Pérez-Plascencia 1995).

There is little information on the population dynamics of the warty sea cucumber. Muscat (1982) mentioned that recruitment is sporadic and that natural mortality is very high. Schroeter et al. (2001) found seasonal variations in the density of this species in California, USA, recording the highest values in spring and the lowest in autumn. Toral-Granda and Martínez (2007) describe the reproductive biology and population structure of the sea cucumber of the Galapagos Islands. The fishery of the warty sea cucumber in Baja California, Mexico, started formally in 1989, and is done mainly by the red sea urchin fishermen, who obtained fishing permits for its commercial exploitation, making this activity complementary and alternative to that of the sea urchin fishery. This activity takes place mainly when the red sea urchin fishery is closed from March to June each year. Currently, stakeholders are mostly red and purple sea urchin fishermen, who use the same fishing grounds, equipment, and capture system (hookah diving). Each team consists of a fishing boat with three crew members: the captain, the air provider, and a diver (Salgado-Rogel and Palleiro-Nayar, 2008). Fishing takes place along the Pacific coast of Baja California, from Ensenada, Baja California close to the US border, to Bahía Asunción, southern Baja California, in the middle of the peninsula. In the the state of Baja California Sur, the fishermen require special permits, whereas in Baja California (northern Baja) it is entirely commercial. In Mexico, *P. parvimensis* is exempt from the NOM-059-ECOL-2001, which includes species under special protection (DOF 2002); however the National Fisheries Chart (DOF 2004), the Mexican regulatory legal instrument, states that the sea cucumber fishery is deteriorating and that management guidelines should be based on the assignment of catch quotas, with the removal of 10% of the exploitable biomass. The warty sea cucumber fishery in Baja California is based on the catch of nearly 250 metric tons (mt)

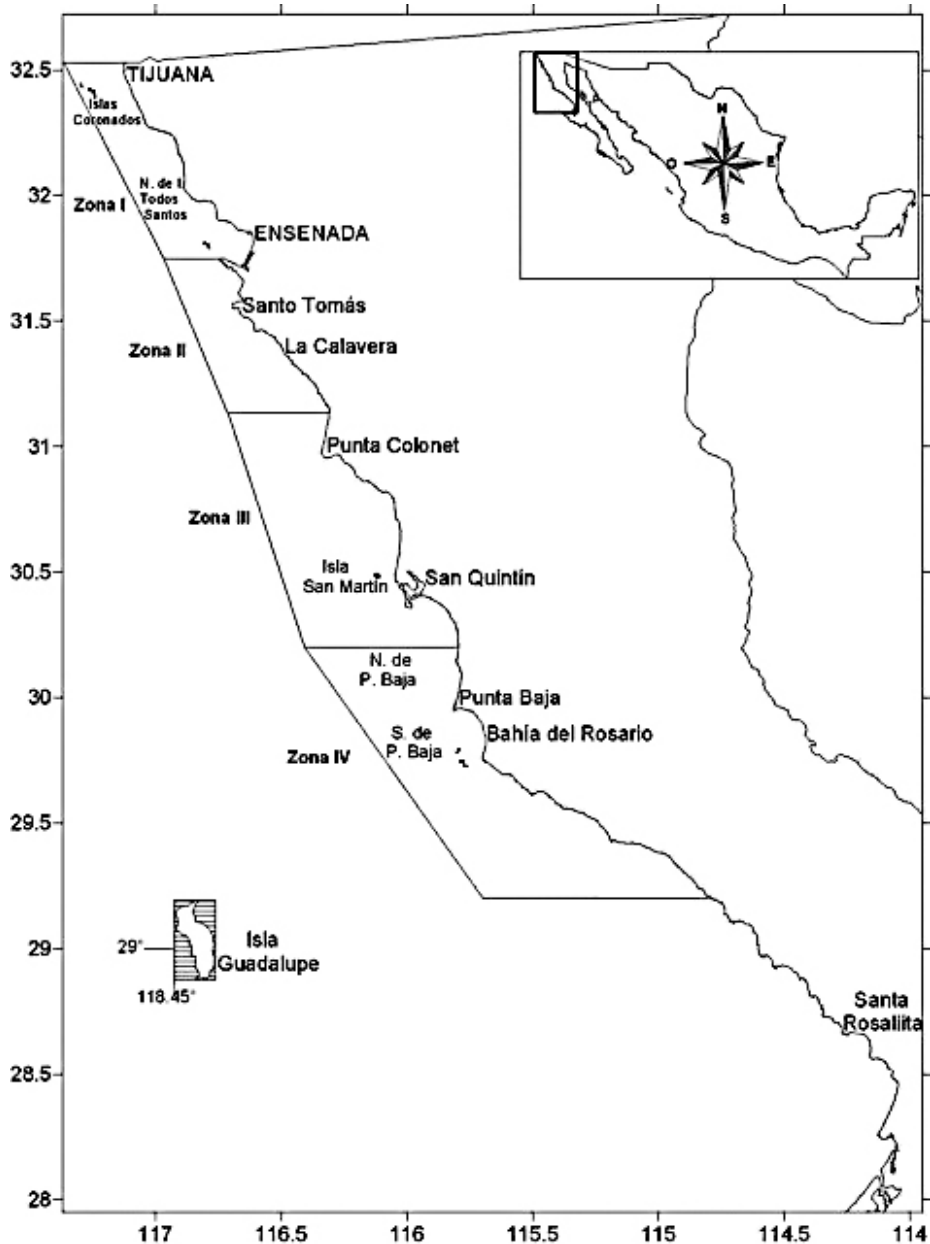


Figure 1. Fishing zones of the warty sea cucumber along the northwestern coast of Baja California, Mexico.

by 270 fishermen in 90 fishing boats allocated to four fishing zones (fig. 1), during a 55-day fishing season, and made at depths no deeper than 20 m.

The fishery takes place along the northern half of the western Baja California peninsula, between 29°2' and 32.5°N latitude. There is a high demand by the Asian market for the warty sea cucumber. This and the apparent scarcity of the product led to the assumption that the stock is overexploited and the need to assess this fishery with a socioeconomic diagnosis. For this reason, this paper provides some management options that are not considered in Mexican fishery regulations. The

stock is exploited in four fishing zones. The fishing zone I goes from the USA border to Punta Banda, zone II ranges from Punta Banda to Punta Colonet, zone III from Punta Colonet to El Socorro, and zone IV from El Socorro to El Rosario (figs. 1, 2).

Exploitation of the sea cucumber has become a productive activity for exporter countries to Asian markets, where the demand for this product seems to be constantly increasing. In consequence, some tropical producers, such as Mexico and Ecuador, have responded to this demand by exploiting their sea cucumber stocks to the point of depleting some populations, which are not

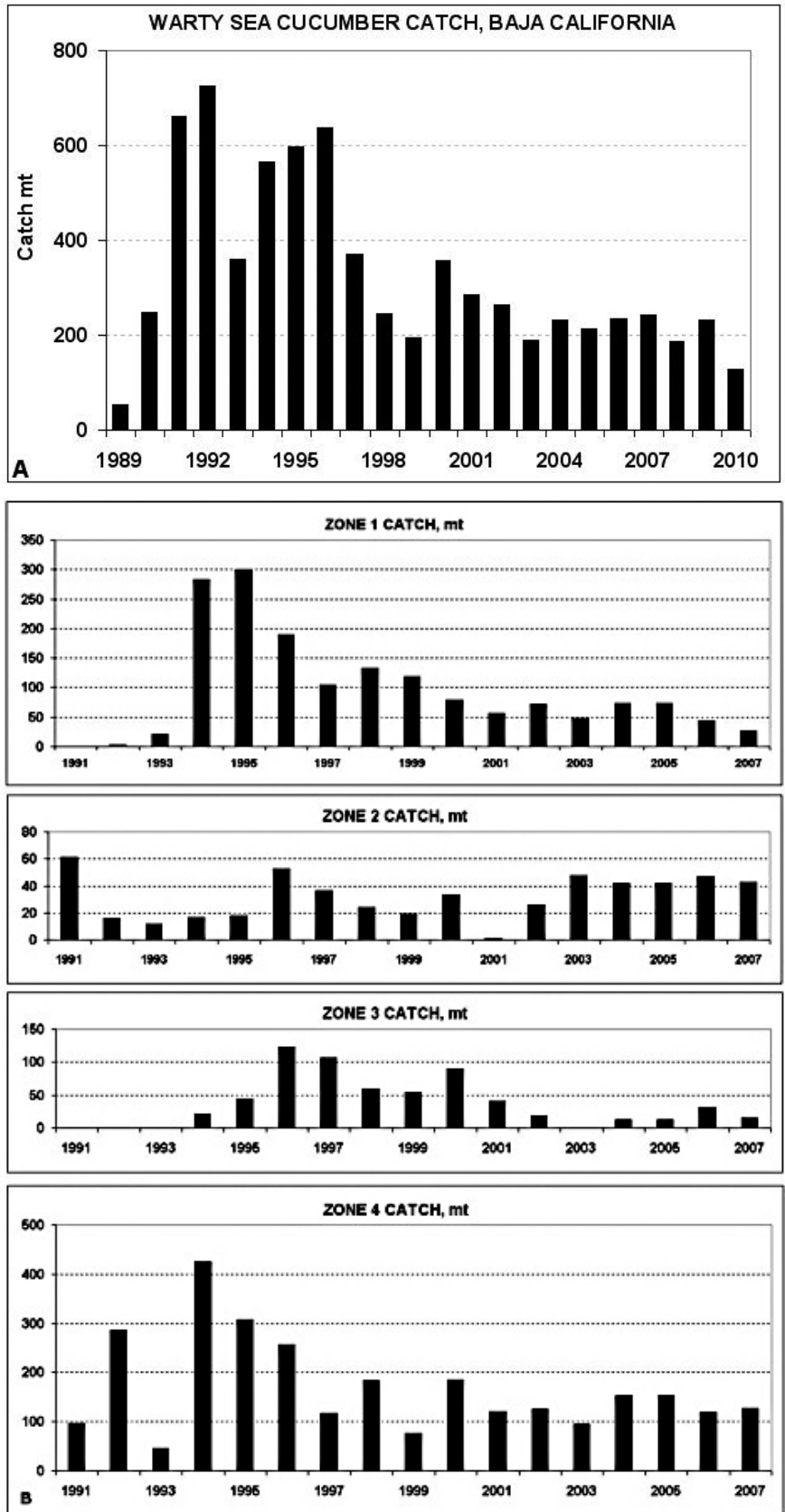


Figure 2. Catch records (t) of the warty sea cucumber exploited in all fishing zones (A) and in each of the four fishing zones (B) off the northwestern coast of Baja California, Mexico.

abundant and whose dynamics are characterized by being density-dependent, with a low recruitment rate, long lives, and consequently easily overexploited (Anonymous 2004; Toral-Granda and Vasconcellos 2008; Friedman and Gisawa 2010). Examples of this have been shown by the *Isostichopus fuscus* fisheries in the lower Gulf of California (Herrero-Pérezrul and Chávez 2005), Ecuador and the Galapagos Islands (Carranza and Andrade 1996; Anonymous 2000a), which were depleted, led the Mexican authorities to close the fishery during the late 1990s (Anonymous 1994; Anonymous 2000b; Sonnenholzner 1997) and reopen it in 2002 under strict control of the access to the fishing grounds.

The maximum catch of the warty sea cucumber was recorded in 1992, with 723 mt, but landings decreased to around 240 mt in recent years (fig. 2; Salgado-Rogel et al. 2009).

## METHODS

Monthly samplings were made on sea cucumber landings from all fishing grounds during the season. At each sampling, twenty kilos from each of two boats were taken and each sea cucumber was put in a plastic bag and weighed without water.

### Age and growth rate

A requirement for stock assessment is the knowledge of the age and growth rate of exploited stocks. This condition imposed the need of trying to evaluate the growth rate of the warty sea cucumber with sampling data and establishing the correspondence between length and weight. The lack of hard structures where growth rings are usually read led to the use of the analysis of this process by means of methods based on the indirect estimation of age based in the modal-progression analysis of size. First, the data from Pérez-Plascencia (1995) were reworked to obtain the parameters  $a$  and  $b$  of the exponential length-weight regression to transform the weight data into their corresponding lengths, because the software analyzing growth uses only length data. The power regression is

$$W = a \cdot L^b$$

The assessment of the stock was made using catch data for the last fifteen years. Changes in abundance over time were determined by using the catch data as a reference for estimating the population size. Population parameter values were determined by the use of the ELEFAN and Bhattacharya methods in the FISAT software package (Gayanilo et al. 1996). Before using these methods, it was necessary to transform weight data into their corresponding lengths. Weight-frequency values were obtained from samplings made on the catch (figures 3a, b).

Once the catch data and growth rate were known, with the aid of the FISAT software package, estimates

of the age composition of the catch were made and further analysis, including scenarios of feasible harvesting strategies, were evaluated with the aid of the simulation model FISMO (Chávez 2005). With these partial results the total mortality ( $Z_t$ ) could be determined with the exponential decay model as

$$N_{a+1} = N_a \cdot e^{-z_t} \quad (1)$$

where  $N_{a+1}$  is the number of warty sea cucumbers of age  $a+1$  and  $N_a$  is the number of warty sea cucumbers of age  $a$  in reconstructed age groups. With the numbers per age known, the use of the von Bertalanffy growth equation allowed the determination of their corresponding lengths at age. Time units are years.

In the virtual population reconstructed, the age structure for each year was estimated assuming a constant, natural mortality ( $M$ ). In the exploited age groups, the fishing mortality ( $F$ ) was added to  $M$  and so the total mortality was known,  $Z = M + F$ . For setting the variables of the initial state, the abundance per age-class ( $N_{a,y}$ ) was set using the age-specific abundance  $N_a / \sum N_a$  obtained from equation (1). In subsequent years, the age structure was defined after the estimation of the number of one-year-old recruits. These values were used to calculate catch-at-age as proposed by Sparre and Venema (1992) and were integrated into the simulation model as

$$Y_{a,y} = N_{a,y} \cdot W_{a,y} \frac{F_t}{(F_t + M)} (1 - e^{-(F_t + M)})$$

where  $Y_{a,y}$  is the catch-at-age  $a$  of each year  $y$ ,  $N_{a,y}$  is the number of warty sea cucumbers at age  $a$  in year  $y$ ,  $W_{a,y}$  is the warty sea cucumber weight equivalent to  $N_{a,y}$ ,  $F_t$  and  $M$  are as described. Given the initial conditions, the values of  $Y_{a,y}$  were adjusted by varying the initial number of recruits and linked to the equations described above until the condition of the following equation was fulfilled,

$$\sum_a^\lambda Y_{a,y} = Y_{y(\text{REC})}$$

where  $Y_{y(\text{REC})}$  is the yield recorded during the year  $y$ ,  $a = 2$  years, and  $t_\lambda = 3/K$  or longevity, where  $K$  is the growth constant of the von Bertalanffy growth equation and  $t_\lambda = 5$  years. The value of  $a$  was found by assuming that a reasonable life expectancy ( $L_{\text{max}}$ ) is when 95% of the population reaches 95% of  $L_\infty$ , the asymptotic length. Thus, by making  $L_{\text{max}} = 0.95L_\infty$  in the von Bertalanffy growth equation and finding the respective value of  $t$ , the longevity value was found. However, in the simulation, the model considers up to 20 age groups. Use of the catch equation was made for each year in the time-series analyzed.

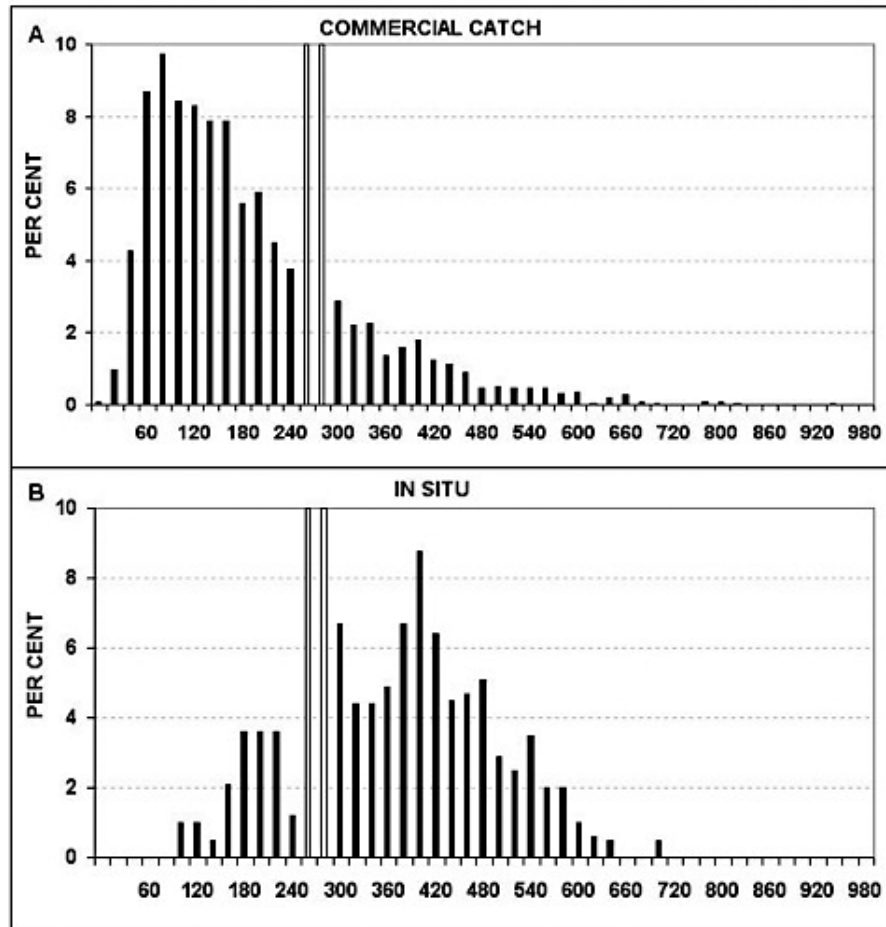


Figure 3. Weight-frequency distribution of the warty sea cucumber stock after samplings made in A, sampling of landings, and B, fishery-independent samplings. The weight at first catch is about 280 g, shown as two white bars, which also is the weight at first maturity.

### Mortality

For the estimation of the natural mortality ( $M$ ), the criterion proposed by Jensen (1996, 1997) was adopted, where  $M = 1.5K$ . For purposes of comparison, other  $M$  values were estimated by using methods proposed by other authors and are presented in Table 1. Estimations of the stock biomass and the exploitation rate  $E = [F / (M+F)]$  were made for each age-class in every fishing year analyzed by the model. These values were compared to the  $E$  value at the maximum sustainable yield level ( $F_{MSY}$ ), a special case, which is the maximum exploitation rate that a fishery should attain before the stock is overexploited. A diagnosis of which years of the series the stock was under- or overexploited was then made, providing a way to diagnose the status of the stock and to recommend either a further increase or decrease in  $F$  at the fishery.

The annual cohort abundance ( $N_{a,y}$ ) coming from ages older than age-at-maturity ( $t_m = 2$  years) was used to estimate the annual abundance of adults ( $S_y$ ) over the years, whereas the abundance of the one-year-old group was used as the number of recruits ( $R_y$ ). The

stock-recruitment relationship was evaluated by using a slightly modified version of the Beverton and Holt (1957) model in the form

$$R_{y+1} = \frac{a'S_oS_y}{S_y + b'S_o} ,$$

where  $R_{y+1}$  is the number of one-year-old recruits in year  $y+1$ ,  $S_y$  is the number of adults in year  $y$ ,  $S_o$  is the maximum number of adults in the population, and  $a'$  and  $b'$  are parameters modified from the original model where  $a'$  is the maximum number of recruits and  $b'$  is the initial slope of the recruitment line, which was constant through the simulation. The intensity of recruitment depends to a great extent on the stock size, as part of an ecological mechanism related to density dependence and carrying capacity.

### Model Simulation

The population parameters plus the catch and socioeconomic data were analyzed with the aid of the simu-



TABLE 1

Population parameter values obtained after the analysis of the length-frequency data used for the evaluation of the warty sea cucumber fishery. M values obtained after three other methods used for estimating M apart from  $M = 1.5K$  are also shown.

Parameter	Value	Units-Model	Source
K	0.6	Bertalanffy	This paper (ELEFAN)
$L_{\infty}$	50	mm, Bertalanffy	This paper (ELEFAN)
$W_{\infty}$ (g)	514	Live weight, Bertalanffy	This paper
$t_0$	-0.10	Years, Bertalanffy	This paper
a	0.4	Length-weight	This paper
b	1.83	Length-weight	This paper
Age of 1st catch	2	Years, both sexes	This paper
Maturity age	2	Years	Tapia et al. 1996
Longevity	5	Years	As 3/K, this paper
a'	0.29	Beverton & Holt S-R	After age structure
b'	3.16	Beverton & Holt S-R	After age structure
M	0.83	Instantaneous rate	Pauly (1980); Rikhter & Efanov (1976)
M	0.85	Instantaneous rate	Hoening (1983)
M	0.9	Instantaneous rate	As 1.5K (Jensen 1996, 1997)
$E_{max}$	0.25	$F_{MSY}/(M + F_{MSY})$	Exploit. rate at MSY, this paper
Phi'	3.2	$\log K + 2 \log L_{\infty}$	Growth performance, this paper

lation model FISMO (Chávez 2005). The weight at first maturity has been estimated to be at about 75 g eviscerated weight (Tapia-Vásquez et al. 1996) and after the analysis of weight-frequency of the landed catch and the estimation of growth rate, we found that the age of first capture is 2 years, which was maintained constant in the analysis of the catch records.

The model reconstructs the age structure over time and exploitation scenarios were simulated under different combinations of fishing intensities and the age-at-first catch to maximize the biomass, the profits, and the social benefits, as the number of fishermen in the fishery and the maximum profit per fisherman. For this purpose, analytical procedures adopting the concepts and views of Chávez (1996; 2005) and Grafton et al. (2007) were used.

The approach to the socioeconomics of the fishery was made through the explicit consideration of the costs of fishing per boat per fishing day (\$41.30), the number of boats (98), the number of fishermen per boat (3), and the number of fishing days during the fishing season (55). The catch value (\$2.00) is the price at the dock of the warty sea cucumber landed before adding value. The difference between the costs of fishing (C) and the catch value (the benefit, B) is known, so the value divided by the cost is the B/C ratio. In the simulation, the costs of fishing per day-boat and catch value were assumed constant over time. The information of the 2009 fishing season allowed us to reconstruct the economic trend of this fishery for the last fifteen years with the aid of the simulation model, using the estimates of fishing mortality over time as a reference and its correspondence to the economic variables. The changes in the population abundance using the number of survivors in each cohort were estimated. The initial condition is set by assigning a seed value to  $F_t$  usually choosing  $F_{MSY}$ , which at  $t_c = 2$

years, is  $F_{MSY} = 0.3$ , allowing an estimation of an initial recruitment number and then estimations of abundance for each cohort during each year.

### Model Validation

The model was developed with 15 years of catch data. In the validation process, the 15th year was left out of the direct evaluation and its value was simulated as if it were unknown. Then the model was fitted to the whole series of 15 years. The difference between the recorded and simulated values of this 15th year provided a way to evaluate the uncertainty in the assessment made for 2009, the last year of the catch records analyzed. The catch was displayed by the model, where the stock biomass and the fishing mortality for each year of the series were estimated.

### RESULTS

Evidence of overexploitation of recruits is shown in the weight-frequency bar graphs (figs. 3a, b) showing a remarkable bias towards the exploitation of juvenile sea cucumbers by the fishermen from samplings made of the catch landed, as compared to the weight-frequencies recorded from fishery-independent samplings. This is what is known in fishery biology as recruitment overfishing (Hilborn and Walters 1992).

For transforming weight (g) data into their corresponding lengths (cm), the parameters of the length-weight regression found are  $a = 0.4$  and  $b = 1.83$ . Then the Fisat software package by Gayanilo et al. (1996) was used, where the Battacharya method for extracting normal components from length-frequency data was used initially. Next, the routine named as Elefan method was used for the estimation of the growth parameter values. These and the other population parameter values found and used as input of the model are shown in Table 1.

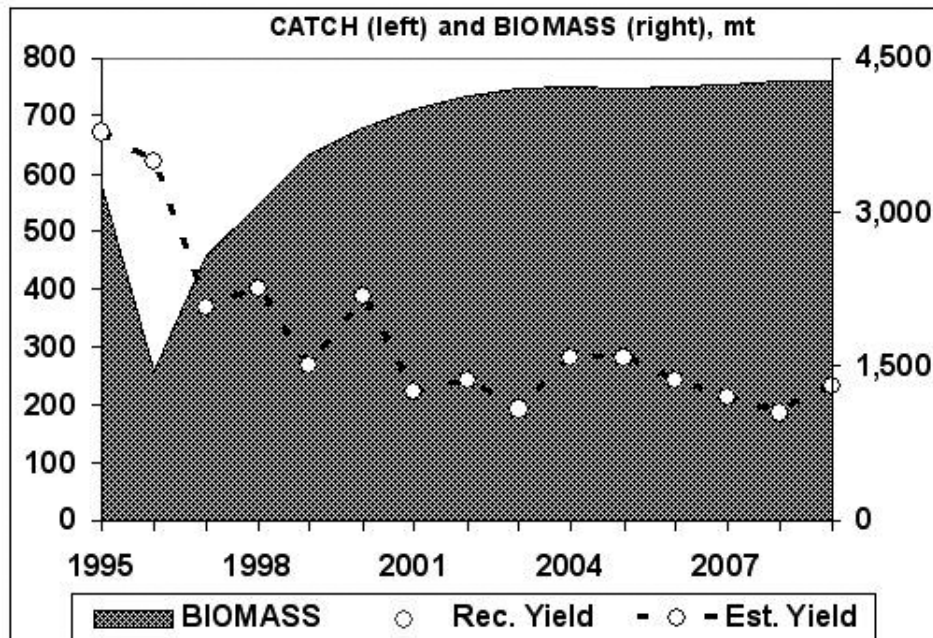


Figure 4. Stock biomass (left) and catch (right) in mt of the warty sea cucumber fishery off the northwestern Baja California peninsula.

### Condition of the Fishery

**Stock biomass.** The results show that the stock biomass had a declining trend since the beginning of the fishery and during the period of analysis since the first year (1995), when the catch was 671 mt. Through the 2000s, the catch has been low and relatively stable at low levels, probably caused by the low profits obtained during the years of high fishing intensity leading to a reduction of fishing effort. The maximum stock biomass of the years of analysis also is about 4,300 mt (fig. 4). The difference between direct estimations of catch and those obtained by simulation ranged between  $-5.9\%$  and  $+3.3\%$ , with a coefficient of variation of  $CV = 0.46$ .

The intensity of exploitation indicates that the fishery had a very high exploitation intensity during the second year. In an apparent consequence of this, the exploitation rate  $E$  in 1996 was almost twice the level of  $E_{MSY}$ , with a decrease in biomass, when the model output suggests that there were no profits. In an apparent response to this condition, the fishing effort was considerably reduced afterward and the catch decreased by nearly 50% for 1995 and 1996. Further reductions of catch took place thereafter ranging between 186 mt and 282 mt since 2001 (fig. 4). At first sight, this trend and the overexploitation of juveniles shown in Figure 3, led us to assume that the catch was reduced because the stock was over-exploited. However, after an initial decline in 1996, the analysis indicates that the biomass has been quite stable since 2000 and therefore a decline in the catch must have been generated by a different cause, not overfishing.

**Fishing intensity and exploitation rate.** After the estimation of the stock biomass, part of the diagnosis consisted in the estimation of  $F$  and  $E$  over time. For  $F$ , results show that excepting 1996, when the stock was clearly overexploited, in all other years the  $F$  values suggest that the fishery was underexploited and in ten of the fifteen years examined, the  $F$  values are below 0.1, indicating a condition of underexploitation, as compared to the  $F$  at the  $MSY$  level that is 0.3, as shown in Figure 5. The performance of the  $E$  values is consistent with those of  $F$  in 1996, when a strong overexploitation is evident. The exploitation rate suggests a condition of underexploitation, in particular through the last eleven years, when values range below 0.1, with the threshold or  $MSY$  level at  $E = 0.25$  (fig. 5; table 2).

### Bioeconomic Analysis

In 2009, the fishery provided jobs to 270 fishermen on 90 boats, each boat working 55 days per fishing season. The cost of each fishing-day per boat was \$41.30 USD and the total fishing effort was 5,390 days. The catch obtained was 233 mt with a value of \$466,000, producing profits of \$243,000 with a benefit/cost ratio of 2.1, which is twice the cost of fishing operations (fig. 6). These results indicate that with exception of 1996 and 1997, when apparently there were no profits, the fishery has been a profitable activity and stable economically.

To examine the stock response and its economic condition as a function of the fishing intensity, the simulation describes a series of curves, of which four were selected to display the potential socioeconomics of the

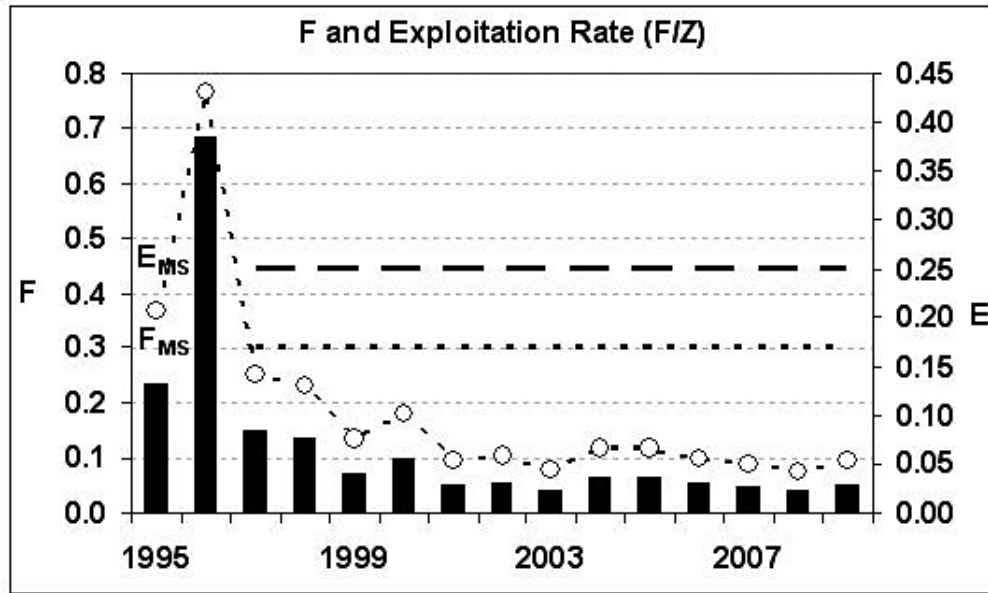


Figure 5. Exploitation rate (E) and fishing mortality (F) values of the warty sea cucumber stock, also showing the values of E and F at the MSY level (horizontal broken lines) over the fifteen years of analysis.

TABLE 2

Management scenarios for the warty sea cucumber fishery off Baja California. The condition for the 2009 fishing season is used as reference. The management options are  $F_{MSY} = F$  at the MSY level;  $F_{MEY} = F$  at the MEY level, both with a  $t_c = 1$  year. Costs and value are in USD. Yields are those to be obtained in the long term after the stock is restored. The fishing effort per boat was maintained constant in the 55 days per season, as recorded from the year 2009. Daily cost per boat is also constant at \$41.30, which per fishing season is \$9,587.00. C.V. is the coefficient of variation of recorded catch, 46.4%. Catch value is expressed in thousand USD. MS/Fisher is the condition of the fishery where profits per fisher are a maximum. EE = Economic equilibrium, when catch value is equal to the cost of fishing.

INDICATORS	2009	$F_{MSY}$	$F_{MEY}$	MS/Fisher	EE	Units
F (/y)	0.05	0.5	0.028	0.03	0.32	Rate
$t_c$	2	1	1	2	2	Years
E	5	36	3	3	26	Percent
CATCH	233	1,479	219	143	681	mt
VALUE	466	2,958	437	286	1,362	1,000 USD
FISHING DAYS	5,405	51,975	2,911	2,911	32,998	Per year
FISHERS	294	11,842	259	98	2,510	3/Boat
BOATS	98	3,947	86	33	837	
FLEET CAP	49	1,973	43	18	419	mt
TOTAL COSTS	223	2,146	120	120	1,362	1,000 USD
B/C	2.1	1.4	3.6	2.2	1.0	
PROFITS	243	813	317	148	328	1,000 USD
PROFITS/BOAT	2	0.2	4	4	0	1,000 USD
PROFITS/FISHER	827	69	1,225	1,521	0	USD

fishery. These are the yield, the profits, the number of fishermen, and the profits per fisher. In two of them (yield and fishermen), the maximum F value ( $F_{MSY}$ ) is at  $F = 0.35$  (fig. 7). At this fishing intensity, the maximum potential yield would be 685 mt, the number of boats required would be 846, providing employment to 2,538 fishermen. However, under this fishing intensity, the fishery is no longer profitable, because the  $B/C = 1$  is attained at  $F = 0.32$ . Therefore, the performance of the output variables imposes the need that  $F < 0.32$  for the existence of an economic activity. It is interesting to mention that if  $t_c$  is reduced to  $t_c = 1$ , then the poten-

tial yield at  $F_{MSY}$  would be 1,486 mt with a profitable activity, but if  $t_c = 2$ , the B/C value at the equilibrium would be attained at  $F = 0.317$  and the catch at  $F_{MSY}$  would be reduced to only 685 mt but the fishery would be not profitable. The F necessary for maximum profits is found at  $F_{MEY} = 0.028$  with  $t_c = 1$ , and the profits would be about \$317 million (M). However, to get to this condition, the fishing effort should be reduced from the current 5,405 fishing days to 2,911 (fig. 7; table 2), implying a reduction of the number of fishermen from 294 in the current condition to 259.

The  $F_{MSY}$  was used here as a reference point to evalu-



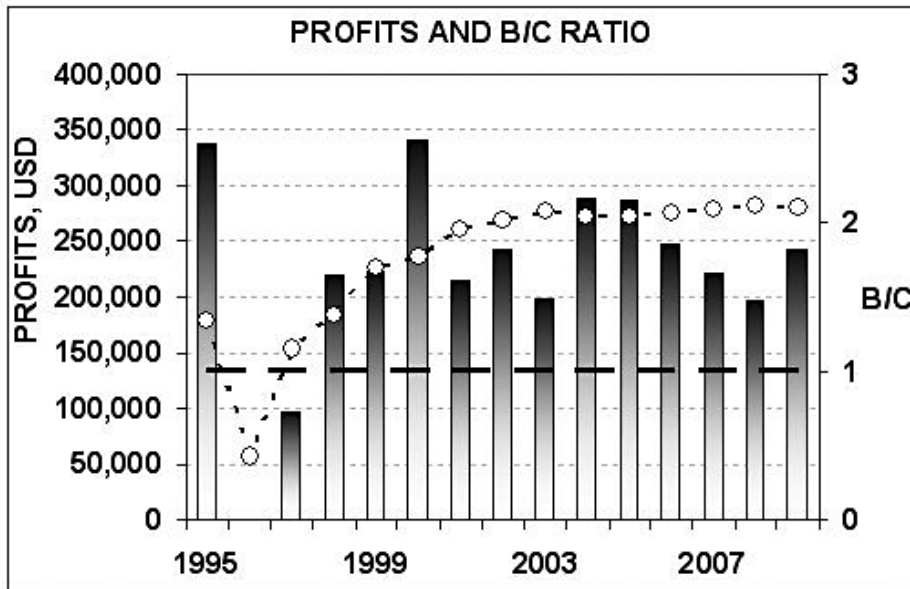


Figure 6. Reconstruction of total profits (bars, left scale) and the benefit/cost ratio (right scale) over fifteen years of the warty sea cucumber fishery off the northwestern coast of the Baja California peninsula. The horizontal broken line is the B/C ratio at the equilibrium level ( $B/C = 1$ ). When  $B = C$  the economic condition of the fishery is at equilibrium, meaning that the exploitation is not profitable, and when this occurs it means the beginning of a socioeconomic crisis.

ate the biological, economic, and social consequences of using the current fishing effort or other possible options, as shown in Table 2, where three different scenarios are compared to the current condition. The values of all other variables depend on  $F$  and  $t_c$ , so these should be considered as the reference or independent variables, and indicators in the output are the consequences of any strategy chosen. The maximum social benefit is derived from the number of boats fishing, so their maximum number is multiplied by the number of fishermen per boat and this is how the maximum social benefit is known. The economic-equilibrium level indicates the  $F$  value at the limit, where the fishing intensity cannot be increased because beyond that level it becomes unprofitable.

### MANAGEMENT OPTIONS

Trends in the fishing mortality ( $F$ ) over time and the estimates of the total stock biomass were examined. The criteria for evaluation of fishing scenarios were based on the  $F$  and the age of first catch at the maximum sustainable yield ( $F_{MSY}$ ) and at maximum economic yield ( $F_{MEY}$ ), and are shown in Table 2. If the fishing authorities decide to adopt any of these options, it would be convenient to examine in detail the best way to apply the chosen one in such a way that the fishery is sustained in the long term and the social problems are minimized.

With the aid of the simulation model, four possible options of  $F$  and  $t_c$  were explored and the most likely consequences of each one were evaluated: the condition under the  $F_{MSY}$ , the condition under  $F_{MEY}$ , the  $F$  producing the maximum profits per fisherman, and the state of

variables at the economic equilibrium ( $B/C = 1$ ). When the  $F_{MSY}$  is chosen as target of the fishery, at  $F = 0.5$ , the age of first catch must be reduced to  $t_c = 1$ . Here the catch would increase to more than six times the current value, but this is not a good option because it would not be profitable. After a review and evaluation of the current and other possible harvesting strategies, we concluded that as consequence of the narrow range of profitable  $F$  and  $t_c$  values, the current one is close to the most convenient option. In Table 2 the most likely results of the application of these management strategies are shown.

### DISCUSSION

World capture of sea cucumbers reached a peak of 23,400 mt in 2000, decreasing to about 18,900 mt in 2001 (Vannuccini 2004). The high economic value of the sea cucumber fisheries in the international market and their low biomass and low turnover rate are factors contributing to their vulnerability, making these stocks easily overexploited. However, apart from the belief of a depleted condition of the stock before this analysis, we concluded that the fishery is currently exploited very near to the level of maximum profit per fisher, which we believe is intuitively adopted by the fishermen. A possible explanation to this is that the fishery is profitable under a very narrow range of  $t_c$  and  $F$  values and therefore it is suspected that after an empirical knowledge of this from the fishermen's viewpoint, they may find it easier to exploit the stock under less risky conditions, leading to harvesting the warty sea cucumber within the

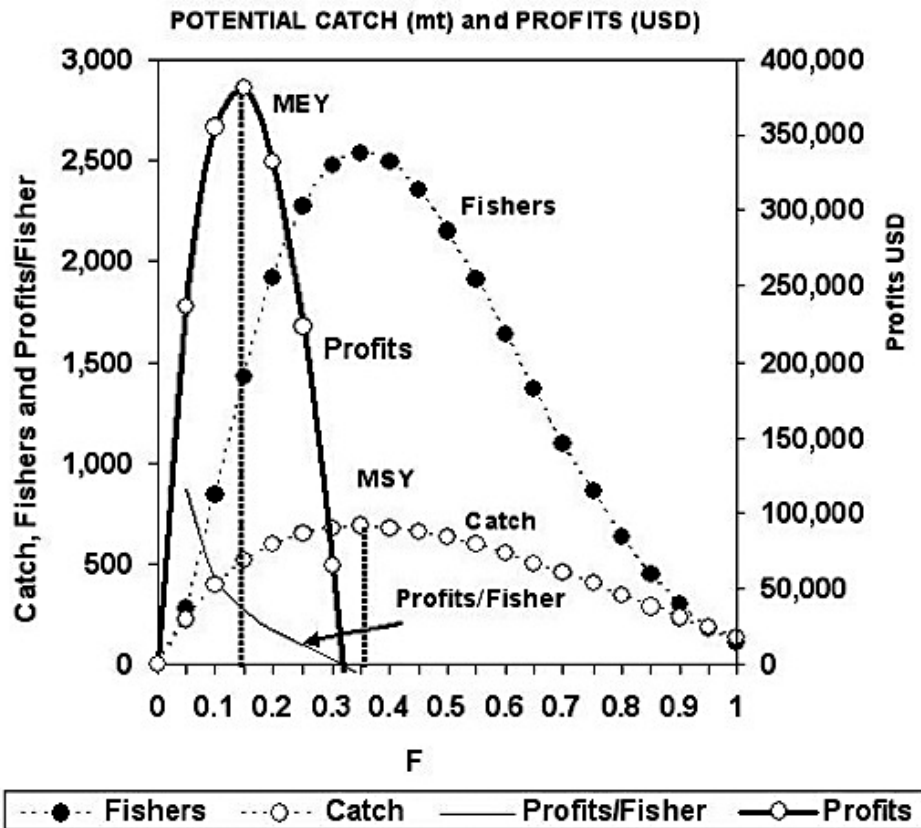


Figure 7. Bioeconomic stock response of the warty sea cucumber fishery off the northwestern Baja California peninsula, showing the trend of the potential yield, potential profits, the number of fishermen, and the potential profits/fisher, as a function of the fishing mortality,  $t_c=2$  years. The maximum profits (MEY) are attained at an  $F$  level lower than the one required for the MSY. The line describing the numbers of fishermen reaches its maximum at the same  $F_{MSY}$  value. The profits/fisher are positive at values  $F < 0.32$ .

most profitable range of age of first catch and fishing intensity such that it is exploited sustainably.

The dynamics of the sea cucumber fisheries are characterized by overfishing and depletion worldwide, and although the solution to restore the stocks seems to be a problem far from being solved, action is often taken after the stocks have been driven to low levels (Rosenberg 2003). Unfortunately, most of these stocks lack evaluation and rarely are under effective control and supervision, as stated in papers documenting overexploitation, overcapitalization, and threats to food security in general (Beddington and Kirkwood 2005; Bruckner 2005) and with the sea cucumber in particular (Conand and Byrne 1993; Lovatelli et al. 2004; Toral-Granda et al. 2008). The issues raised include whether restocking and stock enhancement should be used to manage the sea cucumber fisheries (Lovatelli et al. 2004). Unfortunately, most sea cucumber fisheries confirm the statement that they have rarely been “sustainable” (Pauly et al. 2002). The warty sea cucumber stock is under recruitment overfishing, which given the low intensity of its exploitation, it does not have a negative impact on the stock biomass nor on the stock recruitment process. Results presented

in this paper indicate that the exploitation of the warty sea cucumber stock in Baja California seems to be an exception to the most frequent condition seen in sea cucumber fisheries.

The lack of ability to gather the basic information needed for management plans, weak enforcement, the high demand from international markets, and the pressure exerted from resource-dependent communities are identified as the important factors responsible for the critical status of the sea cucumber fisheries worldwide (Carranza and Andrade 1996; Sonnenholzner 1997; Anonymous 2000a; 2004; Herrero-Pérezrul and Chávez 2005; Hearn and Pinillos 2006; Toral-Granda et al. 2008; Friedman and Gisawa 2010), leading to an increased concern for their management (Anonymous 1994; Richmond 1996; Salgado-Rogel et al. 2006; Rogers-Bennett and Ono 2001; Kaly et al. 2007; Friedman et al. 2008).

When a fishery is in a condition of severe exploitation, which is not the case of the warty sea cucumber, the obvious recommendation is to close it, because the conservation of the resource becomes a priority as compared to social or economic considerations and then rights-based management is probably not appropriate

for all fisheries (Hilborn et al. 2005). Under these circumstances, and if the depletion is not as severe, the key point is to find a way to constrain the access to the fishing grounds by minimizing the social impact, the number of jobs. This is not an easy task because the stock effect is a nonlinear function of yield and difficult to estimate with a high level of precision (Hannesson 2007). In overexploited fisheries, choosing the  $F_{MSY}$  or  $F_{MEY}$  as the target of the fishery, evidently would be a convenient option and any of these should be adopted once the stock is restored.

In many instances, a sustainable management of a fishery depends on reliable assessments of the stock. However, this is a necessary but not sufficient condition because an effective control of the access to fishing grounds and a sound and strict application of regulations are also indispensable conditions to guarantee a long-term exploitation.

Ecological extinction caused by overfishing precedes all the other pervasive human disturbances to the coastal ecosystems, but data also demonstrate achievable goals for restoration and management (Jackson et al. 2001). Unsuccessful systems have generally evolved from open access, attempts at a top-down control with a poor ability to monitor and implement regulations, or reliance on consensus (Hilborn et al. 2005). New definitions of sustainability will attempt to incorporate the economic and social aspects of the fisheries (Quinn and Collie 2005) and our work is an example of such an approach.

The profits of any fishery depend upon the cost of fishing operations and the catch value, such that even under the same fleet size, changes in catchability caused by seasonal changes in behavior or physiological condition, and accessibility of the stock to fishers may lead to a different catch per unit of effort even if the effort is relatively constant. These changes imply differences in costs and profits. In a well-managed fishery it is usually more convenient to adopt the  $F_{MEY}$  value as the target rather than the  $F_{MSY}$  because it implies a lower risk of overexploitation (Chávez and Gorostieta 2010). Appropriate control regulations are required to control the exploitation to maintain the warty sea cucumber fishery sustainable over time and space. The conversion of scientific advice into policy, through a participatory and transparent process, is at the core of achieving fishery sustainability (Mora et al. 2009) and it is hoped that the results given here can be used for a sustainable exploitation of the warty sea cucumber fishery off the Baja California peninsula.

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