BIO-ECONOMIC ASSESSMENT OF A GREEN CRAB FISHERY IN BAJA CALIFORNIA SOUTH, MEXICO

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ABSTRACT

Optimum bio-economic harvesting strategies of the green crab *Callinectes bellicosus* (Stimpson) fishery of Magdalena Bay Mexico, were evaluated. The short life span implies high variability of the catch. The stock and its exploitation scenarios were evaluated with a simulation model. The stock biomass displays a slight decreasing trend over the second half of the 13 years of analysis, with a maximum of nearly 6,000 t. The fishing mortality and exploitation rate suggest that the stock was underexploited through all the period of analysis, except for two years (2009 and 2012). The profits have been over USD $200,000 for each of the last four years, whilst before then they were lower, and the efficiency of the fishery indicated by the benefit/cost ratio has been between 2 and 3. Three exploitation scenarios were evaluated, and compared to the current condition of the fishery, the maximum sustainable yield (MSY), the maximum economic yield (MEY), and the maximum economic benefit per fisher (MEBF). In order to do that, it was necessary to impose some constrains, like setting a maximum number of boats, to maintain the same number of fishers when the income per fisher was maximized, and setting a maximum age of first catch. The results with the scenarios MSY and MEY are the same with almost twice the current yield and profits. Those of the current scenario and that of MEBF also provided the same output values, meaning that the current condition almost provides the maximum benefit per fisher.

INTRODUCTION

Sixteen portunid crab species known as *jaiba* in Mexico and several Latin American countries, are distributed in the eastern tropical Pacific, and thirteen occur in western Mexico. Among these, the green crab *Callinectes bellicosus* (Stimpson 1853) is subject to exploitation in Bahía Magdalena on the west coast of Baja California South, whose catch amounts to 7.5 percent of total crab landings in northwestern Mexico (fig. 1), where the highest yields attained 17 thousand metric tons (t) in the year 2013; of which a little less than 400 t were caught in the study area. Other crabs from the same family with secondary importance as fishery resources in the region are *C. arcuatus* (Ordway 1893), and *C. toxotes* (Ordway 1983; SAGARPA 2013).

The fishery of *jaiba* (*Callinectes* spp.) in the Mexican Pacific began in 1980; its exploitation occurs mostly in the states surrounding the Gulf of California. *Jaiba* dwells in soft bottoms and sea grasses (Paul 1981; González-Ramírez 1996; Arreola-Lizárraga et al. 2003). The authorized gear in B. Magdalena is a Chesapeake type trap; there is a maximum of 8,000 authorized traps and the minimum legal size is 11.5 cm width. In the four states around the Gulf of California, total landings amounted to 17,046 t in 2013, of which 66% were caught in the state of Sinaloa at the eastern gulf (SAGARPA 2013).

Catch records display high variability, suggesting a strong influence of climate, often associated with short-lived species. In addition, the growing number of fishers creates a need for regulations, despite the scarce information on the life cycle and other aspects of the fishery, to control effort and ensure an equitable participation of the stakeholders under the stock conservation framework. The goal of this paper is to conduct a bio-economic assessment of the fishery by evaluating some exploitation scenarios intended to optimize yield, fishing effort, profits, and numbers of jobs. Maximum catch and maximum profit are different under the same level of fishing effort and in some cases a maximum value may conflict with another target of the fishery, such that some trade-offs must be critically examined in order to choose the most convenient option to consider in the decision-making process, where ideally fishers and authorities should be involved. Therefore, the purpose of the present paper is to carry-on a stock assessment involving its socio-economic aspects, in order to diagnose the condition of the fishery of Magdalena Bay, in the state of Baja California Sur, Mexico. The evaluation has the intention to provide pertinent recommendations addressed to choose the best scenarios of exploitation pursuing the maximum catch, the maximum profits, or the best social benefits under the framework of the conservation of the stock.

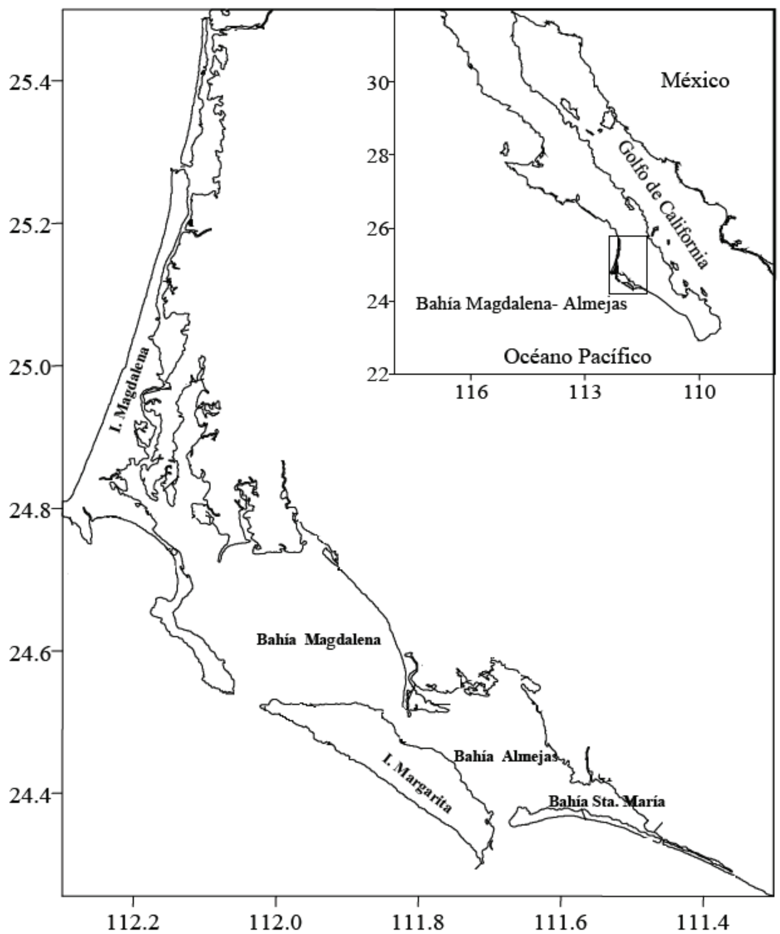

Figure 1. Magdalena Bay, Baja California South, México. Study site, where the green crab fishery takes place.

METHODS

Statistical data proceed from official catch records for the period 2001–13 (SAGARPA 2013). Population parameter values were obtained from published sources (see table 1). Some additional information, like costs and benefits of the activity, fishing days per season, number of boats, and number of fishers was obtained directly in Magdalena Bay. Some data were obtained directly by doing surveys in the study area.

Few papers provide biological data and population parameter values for *C. bellicosus* in northwestern Mexico (González-Ramírez et al. 1996; Escamilla-Montes 1998; Estrada-Valencia 1999; Molina-Ocampo et al. 2006; Huato-Soberanis et al. 2007; Hernández and Arreola-Lizárraga 2007; Rodríguez-Domínguez 2012; López-Martínez et al. 2014). A few other papers have also been produced, but they are mostly internal reports of restricted distribution.

The assessment of the stock was carried on by transforming the last thirteen years of catch data into the age structure of the population in numbers and weights per age class, with the use of the population parameter

TABLE 1

Parameter and other initial values of the *jaiba verde* (green crab), *Callinectes bellicosus* (Stimpson) of the Magdalena Bay fishery in west southern Baja California, used to feed the FISMO simulation model.

	Value	Source
Bertalanffy		
K	0.8/year	Escamilla-Montes 1998
L	16.9 cm	Hernández y Arreola-Lizárra 2007
W	465 g	This paper
to	–0.23 Years	Escamilla-Montes 1998
Length-Weight		
a	0.0706	Condition factor
b	3.11	Coefficient of allometry
Age of 1st catch	1 Years	Field samplings
Maturity age	2 Years	Field samplings
Longevity	4 Years	As 3/*K*
M	1.2	As 1.5**K*
Phi'	2.3589	Log *K* + 2 Log *L*
Value/Kg	1.6 US Dlls.	Landing site
Cost/Day	18 US Dlls.	Interviews
Num. of Boats	70	Interviews
Days/boat/season	141	Interviews
Num. of Trips	9,860	Interviews
Profits	112,873 US Dlls.	Subtracted from the costs
Benefit/Cost	1.64	Catch value/Total costs
Fishers/Boat	2	Interviews

values (table 1) and the FISMO simulation model (Chávez 2005, 2014). The model also has the capability to evaluate the economic performance of the fishing activity in the sea, before adding value to the landed catch. The socioeconomic values are part of the input and are linked into the model associating catch volume to catch value and fishing effort inferred from the fishing mortality to the cost of fishing and to the number of boats and fishers. All of these values are linked in the simulations and depend upon the biological output, so in some trials, a potentially high catch may be not profitable, or may require a high number of boats, which may be unreal for practical reasons; in these cases it was necessary to set three times the current number of boats (70), as the maximum number acceptable.

For the estimation of the numbers and weights of animals caught, the Baranov catch equation (Sparre and Venema 1992) is used. Here, the numbers in the exploited stock transformed into their weight are multiplied by the *F* estimated for that year; then, through an iterative procedure, an *F* value is found such that makes it equal to the catch each year of the series. Cohorts are followed over time with the aid of the Beverton & Holt (1957) stock-recruitment model, where the number of adults one year is the stock and the one-year-old juveniles next year are considered as recruits; this way it was possible to follow each cohort over time values year by year (Chávez 2005, 2014). Once changing *F*, until simulated catch attains the same value as the real data fits the model to real data, the user can explore fishing scenarios by just changing the fishing mortality (*F*), which is assumed directly proportional to the fishing effort, which is not known, and the age of first catch (*tc*). Here, all the variability of the fishery assumed caused by the *F*, such that in the process of fitting the model, recorded catch and simulated catch have essentially the same values. The model runs 30 years after the last one of real data, and a final tune up must be done for the simulation of exploitation scenarios, so that this fine tune-up reproduces the biological and socioeconomic variables of the last year of catch records. At this point, any fishing strategy as conceived by the user can be simulated on the basis that the only variables allowed to change are *F* and *tc*.

Socioeconomic variables as well as the status of the stock are linked in the spreadsheet, so that a change in *F*, in *tc* or both, cause changes in the catch and in the socioeconomic variables. The outputs are numerical and graphical, so it is possible to perceive any changes of the fishery and its internal biological and socioeconomic variables. For this part of the analysis, it is necessary to feed the model with the number of fishing days of an average season, the number of boats, and the number of fishers per boat. Total costs of the fishery are determined multiplying the costs/boat/day by the total number of boats. These values were obtained in the landing sites by interviewing the boat owners. Ideally, economic estimations are made after the examination of the logbooks. The catch value and the number of fishermen during the last fishing season are used to reconstruct the economic performance of the fishery. Economic benefits are determined by subtracting total costs from the catch value. All these values allow reconstruction of the fishery over time and on reconstructing the conditions of the last year is how the model simulates exploitation scenarios defined by the user.

RESULTS

The fisheries biology of the green crab

Catch and Stock Biomass. The first output of the model is the estimation of biomass over time. In Figure 2, the trend of the stock biomass, catch data, and simulated catch are displayed. The biomass is quite stable, ranging around 6,000 t, with a slight tendency to decline in the second half of the period. In contrast, the catch displays a tendency to increase almost from the first year, with a maximum of 379 t in the year 2009, and a drop to 234 t in 2013.

Fishing mortality (*F*) and exploitation rate (*E*). As a part of the assessment of the green crab fishery, values of these variables were estimated for the time series of the analysis (fig. 3). The variables display covariation, as expected. In this figure, two horizontal lines indicate the *F* at the maximum yield level (F_{MSY}) and the *E* at the same MSY level, allowing seeing at a glance, in which years the fishery was underexploited or overexploited. From here, it is evident that the fishery was underexploited through all the period of analysis, excepting the 2009 fishing season, when the stock was overexploited. This explains the reduction of the biomass estimated the following years, because the excess of fishing intensity began to have effect in the turnover capacity of the stock.

Economic variables, profits, and benefit/cost ratio

The performance of these variables indicates that the fishery has produced profits ranging from USD $58,930 in 2003 to USD $244,462 in 2006 being maintained in high levels (>$200,000) for the last six out of seven years, probably as a consequence of a high demand (fig. 4). The B/C ratio suggests that the economic efficiency of the green crab fishery has been high (above 2.0) throughout all the years, except in the years 2007 through 2010, when it ranged from B/C = 1.55 to 1.98; in this case, the relatively low efficiency of the activity was caused by an overexploitation of the stock, causing a decline in the biomass and therefore the high fishing effort led it to be less efficient.

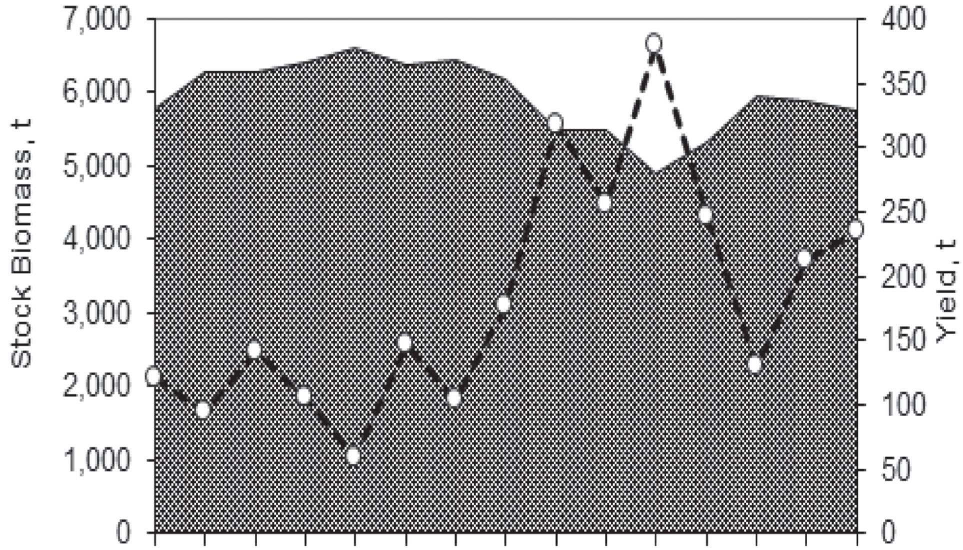

Figure 2. Stock biomass (shaded area), recorded yield (dots) and simulated yield (dotted line), fitted to catch records.

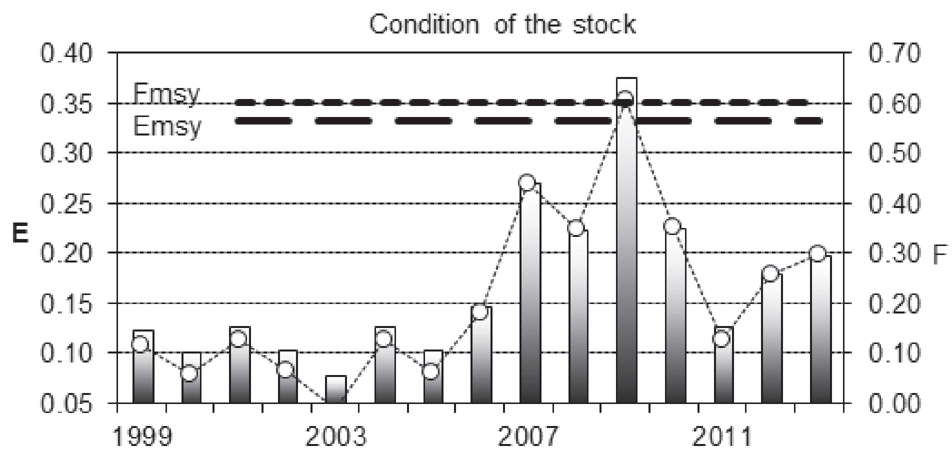

Figure 3. Fishing mortality (F), bars and exploitation rate (E), dotted line. F_{MSY} and E_{MSY} are the levels of these variables at the maximum sustainable yield and are represented as horizontal lines, as a reference to identify the fishing seasons where the fishery was under or overexploited.

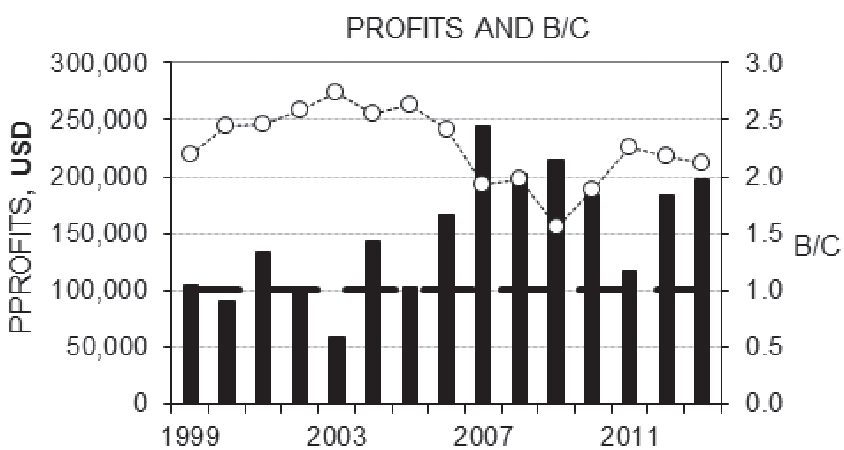

Figure 4. Economic performance of the fishery evidenced through the profits (bars, left side scale) and the benefit/cost ratio (dotted line, right side scale). The horizontal line corresponds to the economic equilibrium level = 1, when benefits and costs have the same value.

TABLE 2
Exploitation scenarios of the *jaiba verde* (*C. bellicosus*) of Magdalena Bay, Mexico. MSY: maximum sustainable yield, MEY: maximum economic yield, and MEBF: maximum economic benefit per fisher. Despite the model can find higher catch and higher profits than shown here, there were limits imposed to a maximum of 210 boats.

Management Scenarios				
Current Indicators	2012	MSY*	MEY*	MEBF*
Stock biomass t	6,769	6,663	6,663	5,769
F (/yr)	0.30	0.48	0.48	0.30
Exploitation Rate	0.20	0.29	0.29	0.20
Catch	234	405	405	234
CV	38.83	38.83	38.83	38.83
Value	374,400	648,480	648,479	374,400
Days/Boat/Season	9,864	16,031	16,031	9,864
Direct Jobs	145	425	425	145
Boats	70	210	210	70
Capacity	16,439	26,719	26,719	16,439
Days/Boat/Season	141	141	141	141
Costs/Boat/Day	18	18	18	18
Total Costs/Boat	2,535	2,525	2,535	2,535
Total Costs	177,544	288,562	288,561	177,544
Costs/Catch	759	712	712	759
B/C	2.1	2.2	2.2	2.1
Profits	196,856	359,918	359,918	196,856
Profits/Boat	2,812	1,714	1,714	2,812
Profits/Fisher	1,358	847	847	1,358
Age 1st Catch	1	3	3	2
Carapace width cm	10.6	15.6	15.6	14.1

*Selected by limiting the maximum number of boats as three times the initial number.
The model found higher values, but it was necessary to reduce the number of jobs, which was not acceptable.

Exploitation scenarios

Many exploitation scenarios can be selected; however, three options were chosen, because from the author's viewpoint, are the most evident for the stakeholders and are likely to be compared using the current condition of the fishery as reference; they are the MSY, the maximum economic yield (MEY), and the maximum economic benefit per fisher (MEBF). These targets of the simulation were evaluated in a process of dynamic optimization provided as the results of the simulation model. Numerical results of these exploitation scenarios are shown in Table 2, but in Figure 5, trends of these variables as function of F and tc are displayed.

By examining these results in Table 2, it is evident that there are many options derived from the combination of F and tc; however, numerical outputs do not discriminate social considerations to bear in mind. Therefore, it was necessary to set up some limits to the F in order to produce logical results, for instance, the maximum number of boats fixed a priori as a maximum socially acceptable of 210, was found at $F = 0.48$ (the F_{MSY} value). Another constraint imposed to the simulation was to not reduce the number of current jobs, because on the maximization search of the model, looking for the maximum total profits and per fisher, the simulation tended to reduce the number of fishers and this is considered not acceptable from the viewpoint of preservation the social value of the fishery.

By looking at results, it is remarkable to find out that within the framework of imposed constrains, the option MEBF has the same values as the current exploitation regime. In the two others (MSY and MEY), the results are coincident because of the same reason; however, without constraining the maximum number of boats, results would be quite different to each other, but not real. In conclusion, the current exploitation regime suggests that the fishermen display their activity intuitively such that they get the highest profits per fisher that the fishery can provide. As long as more fishers participate in the activity, the fishery would have to adapt to produce lower income per fisher, or they may be forced to change the fishing effort trying to maintain the current economic conditions as long as they can.

In the case of the MSY scenario, its adoption without any constrain implies a significant increase of the catch, from the current 234 t to 405 t. However, the size of first catch must be increased from 10.6 to 15.6 cm of carapace width; the profits would increase respecting to the current option, going from \$196,856 to \$359,918. In addition, it implies the benefit of three times more boats and the number of jobs would increase from 145 to 425. The MEY scenario shows the same values as the MSY (table 2), also by constraining the number of boats to a maximum of 210.

Data on Table 2 show specific results of the lines displayed in Figure 5a, c, corresponding to the current tc

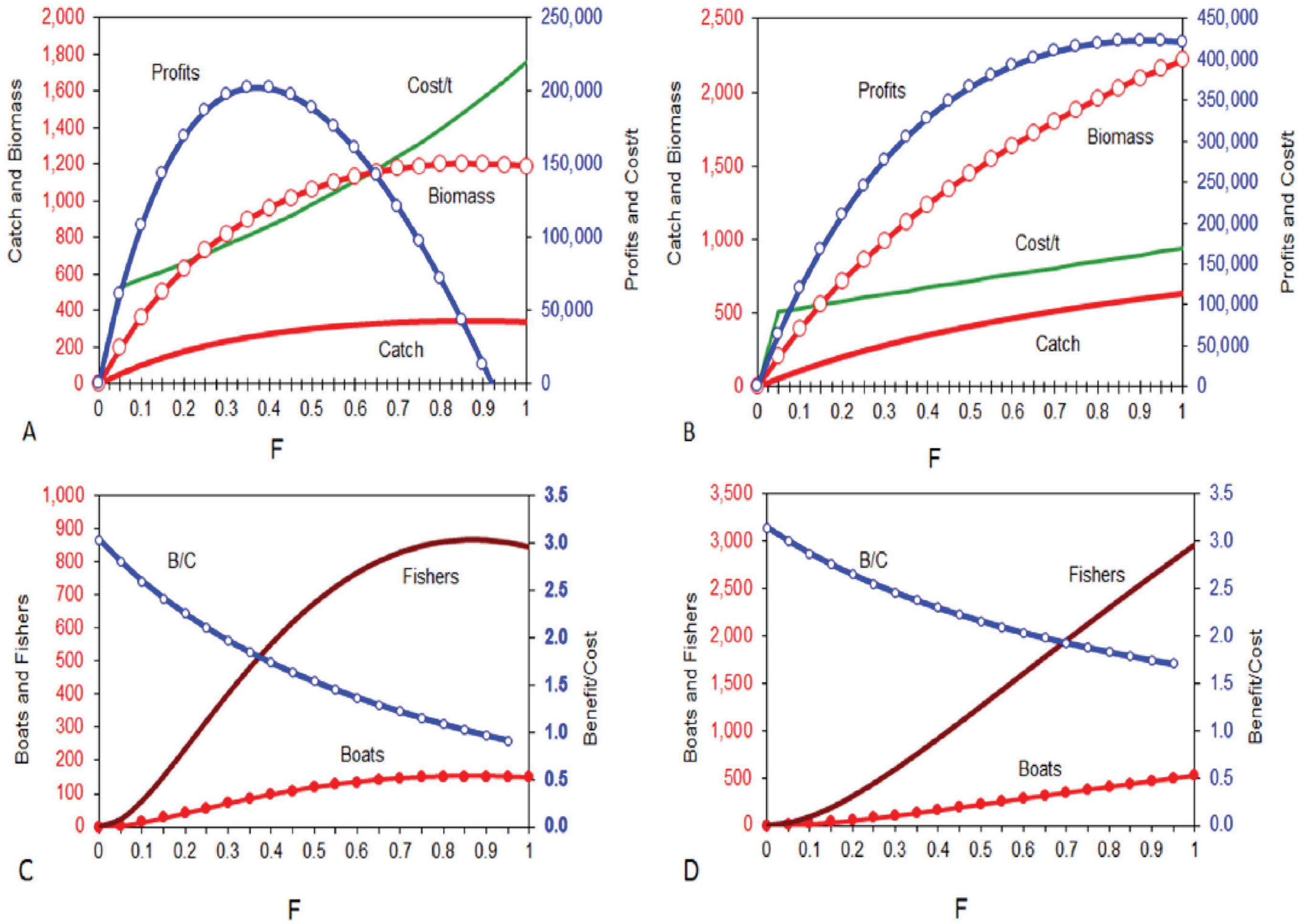

Figure 5. Display of exploitation scenarios showing the socioeconomic response of the fishery expressed as the variables catch, biomass, profits, benefit/cost, cost per t, number of boats and number of fishers under *tc* = 1 (10.6 cm, A, C left side) and *tc* = 3 (15.6 cm, B, D right side). Horizontal scale is *F*.

and they can be found by applying the value *F* = 0.48; however, in Figure 5 b, d, figures show different trend because *tc* = 3: A) trend of simulation with *tc* = 1 (carapace width = 10.6 cm); B) Same with *tc* = 3 (carapace width = 15.6 cm). The explanation of this is because when *tc* = 1 the potential production of the stock is constrained because a smaller number of crabs reaches the age of maturity, caused by the exploitation of juveniles. If *tc* = 3, a larger number of crabs is able to attain maturity age and for this reason their contribution to supply the population with more recruits may be much larger. In addition, the stock biomass is much higher than in the case when *tc* = 1 and the catch will be larger by applying the same *F*.

There are other important considerations pertinent to make by comparing these two scenarios. In reference to the economic variables, at *tc* = 1, the fishery would stop being profitable at *F* = 1. This is because the maximum stock biomass would be 1,200 *t* and the MSY = 345 t, and the cost to catch this volume is at *F* = 0.9 is $1,561. By contrast, with *tc* = 3, the stock biomass would be much higher, and at the maximum simulated *F* = 1.0, the stock biomass would be 2,221 t, but it would be not the highest one. This biomass would allow exploiting higher volumes with a lower effort at a lower cost, making the fishery more profitable with less risk of overexploiting the stock.

DISCUSSION

The model output provides estimates of the catch and other socioeconomic characteristics of the fishery, reconstructing the current conditions of the activity; afterwards the fishing mortality (*F*) and the age of first catch (*tc*) can be changed by the user to estimate the maximum yield, the maximum profits, the highest number of fishers under a profitable activity, the maximum economic benefit per fisher, and many other variables, just by changing *F* and *tc*. In addition to these, some options are able to maximize certain variables, but under non-profitable range, and the user is able to reject them; in other cases, it has been necessary to set up some limits, e.g. the maximum number of boats, as constrain for the estimation of the F_{MSY}, F_{MEY} or the F_{MEBF}, otherwise the output values would provide unrealistic numerical options.

The development of the green crab fishery in the Mexican Pacific is quite recent and apparently its exploitation was stimulated by the crisis of the blue crab fishery in Chesapeake Bay, and provides opportunity to shrimp fishermen in June and July when the shrimp season is closed. In west Mexico, most details of the life cycle of this crab are ignored. By contrast, it is known that in the Chesapeake Bay blue crabs move upstream and downstream separately, with marked seasonal cycles of abundance (Hines et al. 1987); recruits enter the estuary in late fall and spring, growing up to 100 mm the first summer, and by the second year they reach maturity. In the study area, adults mate from July to September whilst in the eastern coast of the Gulf of California, they mate from March through September (González-Ramírez et al. 1996).

Blue crabs are segregated by the habitat by size, sex, and molt stage (Hines et al. 1987). Nursery value of habitats is largely determined by the position of crabs in the landscape (Etherington and Eggleston 2003), and fecundity is significantly related to carapace width, with a mean ranging between 2.6 to 4 million eggs (Prager et al. 1990); fecundity and age of first maturity, and the potential for fisheries-induced sperm limitation (Jivoff 2003). In west Mexico, fecundity of *C. bellicosus* ranges from 1.3 to 2.7 million eggs per female (Cisneros-Mata et al. 2014).

Due to the marine nature of the habitat in Magdalena Bay, there may be some differences in the *C. bellicosus* stock respecting to *C. sapidus* (Rathbun 1896). Female blue crab in low salinity of estuarine regions move to high salinity areas near the sea to release larvae (Carr et al. 2004), feeding intensely and acquiring energy before migrating (Jivoff 2003). The lack of rivers in the Baja California peninsula determine that waters of the Magdalena Bay to be euhaline, and the life cycle of *C. bellicosus* occurs completely in this habitat. Population persistence depends upon various combinations of threats and management must recognize and address responses to these threats (Mizerek et al. 2011).

In the Magdalena Bay fishery, the green crab displays higher reproductive activity in April–May, and mainly in August–September, although males with mature spermatophore have been seen all year round (Cisneros-Mata et al. 2014), mating on several occasions, although it is known that in the blue crab, females mate only once in their lifetime, spawning several times during the year. Topics like a decrease of males causing a reduction in egg production and a decline in recruitment (Sharov et al. 2003) must be confirmed in the green crab fishery of Magdalena Bay, which is likely to occur.

A higher abundance of males to females should be the result of an adaptive process, rather than a factor induced by exploitation; in the case of *C. bellicosus*, there is a sex ratio of about one male to 2.4 females (López-Martínez et al. 2014). In addition, males reach larger sizes than females. If this is seen as a result of natural selection, it seems logical to expect that males, which mate several times in their lifetime, should reach greater sizes enabling them to produce large amounts of sperm, enough to fertilize as many females as possible. On the other side, females are able to spawn several million eggs, despite mating only once in their lifetime. These differences in sex proportion, size, and breeding behavior may be necessary to keep balance in a steady state population.

When more details are known like spatial dynamics and dispersal of the stock biology (Etherington and Eggleston 2003), preference of male capture (Costa and Negreiros-Fransozo 1998; Sharov et al. 2003); parasite prevalence (Messik and Shields 2000), etc., a more accurate knowledge will be available for an informed decision-making process. In this regard, the application of the stock-per-recruit approach may be a convenient option for assessing the stock (Bunnell and Miller 2005); however, the use of FISMO has other advantages, being able to simulate many more exploitation scenarios. It is pertinent to mention that the development of hatcheries for replenishment of a depleted stock may offer a convenient management option for stock enhancement of the green crab fishery (Davies et al. 2003; Zmora et al. 2005; Zohar et al. 2008).

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