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## Chapter

# Estimation of the Maximum Sustainable Yield and the Optimal Fishing Effort of the Blue Crab (*Callinectes sapidus*, Rathbun 1896) of Laguna Madre, Tamaulipas, Mexico

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## Abstract

The fishery of the blue crab (*Callinectes sapidus*) in Laguna Madre (LM), Tamaulipas, Mexico, with an average annual catch of 3307 tons, is of great importance economically and socially. The objective of this research was to estimate the carrying capacity ( $K$ ), the catchability coefficient ( $q$ ), the maximum sustainable yield (MSY) (tons), and the optimal fishing effort ( $f_{MSY}$ ) (traps). For this, a time series from 1998 to 2012 was used for the catch and number. The Fox (1970) and Schaefer (1954) models included in A Surplus-Production Model Incorporating Covariates (ASPIC) software were employed for this study. A set of statistical variability estimators and the Akaike's, Bayesian, and Hannan-Quinn information criteria were used for the selection of models. The results obtained by the fox model were  $K = 54,000$ ,  $q = 0.00008798$ ,  $MSY = 2567$  and  $f_{MSY} = 146,900$  traps, whereas for the Schaefer model, the results were  $K = 28,370$ ,  $q = 0.00002425$ ,  $MSY = 2008$ , and  $f_{MSY} = 58,390$ . The model with the best adjustment was that of Schaefer. It is concluded that the fishing resource has been overexploited during the period 2003–2011, with an average annual surplus of 670 tons and 25,000 traps. It is recommended to consider the MSY and  $f_{MSY}$  values of the Schaefer model for the National Fishing Charter (NFC).

**Keywords:** *Callinectes sapidus*, blue crab, Laguna Madre, Mexico, maximum sustained yield, ASPIC

## 1. Introduction

In 2017, a total of 48,602 tons of blue crab was captured in Mexico, 4033 of which came from the State of Tamaulipas. Such state capture allows the State to

occupy the fifth place at a national scale, thus taking the fifth place among the nine main fisheries of the State, according to the definition of the Yearbook of Fishery and Aquaculture Statistics 2017 [1]. An estimate of 3307 tons from the capture the State of Tamaulipas comes from Laguna Madre (LM). This goes in accordance with the proportion of 0.82 that corresponds to LM from the total capture of the blue crab in Tamaulipas, according to Rodríguez-Castro et al. [2]. In economic terms the value (in Mexican pesos and its equivalent in US dollars) of the capture of the blue crab, corresponding to the year 2017, was 51.26 million pesos (2.44 million US dollars) for the Laguna Madre; 62.51 million pesos (2.98 million US dollars) for the State of Tamaulipas; and 753.33 million pesos (35.87 million US dollars) for the country.

The SEMARNAT [3] indicates that the blue crab fishery of LM forms part of the group of fisheries that concurs in the natural protected area, named as *Área de Protección de Flora y Fauna Laguna Madre y Delta del Río Bravo*, and thus is an important economic source in the zone. Furthermore, the SEMARNAT recognizes the need for generating biological reference points such as catch limits and optimal fishing effort ( $f_{MSY}$ ), among others, in order to manage the fisheries.

Nevertheless, and despite of the economic and social importance of this fishery resource, the normative of this is limited in terms of the specifications required in order to achieve its sustainable use. Certain regulatory guidelines specific for the Gulf of Mexico (e.g., National Fishing Charter (NFC)) are at disposal and used to administer its management [4]. However, the scope of the guidelines is limited given that these do not provide management specifications for the State of Tamaulipas. In part, this is due to the fact that the scientific reports for this fishery resource are scarce. Furthermore, those few reports are mainly focused on capture size analysis rather than management [5–7]. In sum, no scientific research has been made regarding the management of the blue crab in LM as a fishery resource. Particularly for the coast of the State of Tamaulipas, the NFC establishes that the annual maximum catch limit is 2100 tons per year and that the maximum fishing effort consists of 47 permits, 11,802 hoops, 35,200 traps, and 641 vessels. The NFC also mentions that this fishery is “exploited to its sustainability maximum.” This yearly allowed catch limit pertains to an average of the annual catch of the period from 2000 to 2007, and not to the maximum sustainable yield (MSY).

The estimation of the maximum sustainable yield from the surplus production models has been a popular goal in fisheries management even though it has been questioned regarding its supposed equilibrium [8–13]. On the other hand, the conceptualization of this reference point has transitioned from being a target goal into a target limit. Given the overexploitation status of the majority of fisheries in the world, in terms of fisheries management, the fisheries science seeks to minimize the probabilities of exceeding the limit of the MSY (fishery risk) or of the biomass declining beyond the level of natural renewal (stock risk) [14]. With this in mind, in the effort of minimizing probabilities, the precautionary approach in the fisheries management is implicitly included, represented by the fisheries biological reference points (e.g., MSY, maximum sustained effort or  $E_{MSY}$ ) or those based on the fishing mortality (e.g.,  $F_{MRS}$ ,  $F_{0.1}$ ) [14, 15].

In the context of fisheries management, the line of research regarding the estimation of some fisheries reference points has currently resurfaced in the Middle East, primarily MSY and  $f_{RMS}$  [16–24], by means of the adjustment of the Fox, Schaefer, and Pella-Tomlinson models, which are included in some computer packages such as A Surplus-Production Model Incorporating Covariates (ASPIC) [25], which in turn is a stock production model that incorporates the covariance of the parameters. On the other hand, on the topic of model selection, the flow of use of the information criteria (IC) reaching up to multimodel inference, within the framework of the information

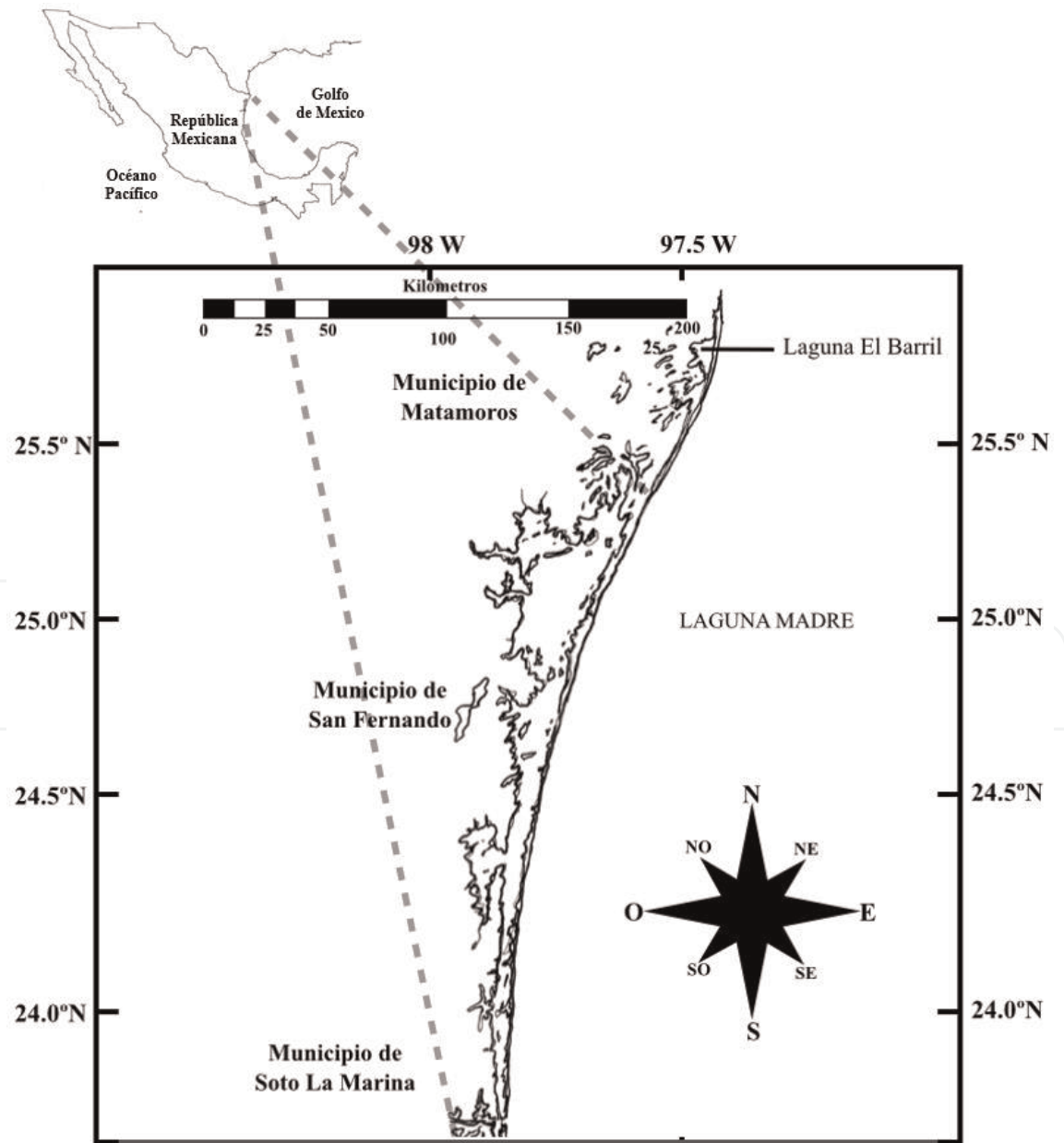
theory, arose in parallel. The model selection based on the information theory is a relatively new paradigm in biological sciences and is very much different from the classical method based on the null hypothesis test [26–29].

Therefore, the objective of this research is to estimate fisheries reference points of the blue crab (*Callinectes sapidus*) of the Laguna Madre, Tamaulipas, Mexico, that can be employed to make decisions in the management of this resource.

## 2. Methods

### 2.1 Study area: Laguna Madre, Mexico

Laguna Madre is located north of the State of Tamaulipas ( $23^{\circ}48'25''30''$  N y  $97^{\circ}23'97'52''$  W) (**Figure 1**). The northern part of the lagoon is delimited by Río Bravo in the municipality of Matamoros and in the southern part by the Soto la Marina River in the municipality of Soto La Marina [30]. Its surface has an area of  $2000\text{ km}^2$ , with an average depth of 0.7 m. It is separated from the Gulf of Mexico



**Figure 1.**  
*Laguna Madre, State of Tamaulipas, Mexico.*

by a straight and uniform coastal barrier located windward and irregular towards the continental edge. The depression of the lagoon is partially filled by supply of the San Fernando River, thus being divided into two basins: northern and southern [31]. LM has a type BS1 (h') climate which is semiarid with rainfall in the summer though scarce throughout the year, with a winter precipitation between 5 and 10.2% [32]. The surface water of LM has a wide range of salinities, from 21.0 to 51.0 with euryhaline conditions during October (35.0–38.0 psu), poly-euhaline in January (21.0–36.0 psu), and eu-hyperhaline in May and July (33.0–46.0 and 36.0–51.0 psu, respectively) [30].

2.2 Data

The annual historical record of the catch measured in tons of the blue crab and the fishing effort (f), this last one represented by the number of traps (NT), were used for a time series of 14 years, corresponding to the period from 1998 to 2012 (Table 1). This information was provided in 2013 by the Fisheries Sub-delegation in Tampico, Tamaulipas, of the delegate of SAGARPA in Tamaulipas. The fishing effort was not standardized for the following reasons: (1) the blue crab fishery in LM is monospecific, (2) the extractive activity of this resource is carried out in a single zone during a single period of the year, and, (3) since the beginning of the fishery, the artisanal fishing fleet has remained technologically stable.

2.3 Models

Both the Schaefer [33] and the Fox [34] models were the two surplus production models (or dynamic biomass models) employed in this study using the following

Years	Catch (tons)	Effort (number of traps)	CPUE
1998	2498	28,500	0.088
1999	2302	45,600	0.05
2000	1103	45,600	0.024
2001	1318	45,600	0.029
2002	1432	25,420	0.056
2003	2699	25,420	0.106
2004	2971	32,600	0.091
2005	3462	32,600	0.106
2006	2140	25,420	0.084
2007	2097	83,450	0.025
2008	2433	92,680	0.026
2009	2362	92,680	0.025
2010	2940	83,450	0.035
2011	2967	73,836	0.04
2012	1927	73,836	0.026

CPUE, Catch per unit effort.

**Table 1.**  
*Catch, fishing effort, and catch per unit effort of the blue crab (Callinectes sapidus) in Laguna Madre, México, during the period 1998–2012.*



algorithms:  $\frac{dB}{dt} = rB(B_{\infty} - B)$  [33] and  $\frac{dB}{dt} = rB(\ln B_{\infty} - \ln B)$  [34], where  $B$  is the biomass of the stock,  $t$  is the time measured in years,  $B$  ( $K$ ) is the carrying capacity,  $n$  is the inclination measure of the curve, and  $r$  is the intrinsic rate of population increase. In order to run these models, the ASPIC Version 5.0 computer package [25] was used. This software incorporates the values of the initial proportion, which correspond to the relative catch value of the first year of the time series, concerning the catch of the year with the highest catch value from the same time series. In addition to the variability estimators such as the coefficient of determination ( $r^2$ ) and the coefficient of variation (CV), the outgoing parameters (management quantities) are the carrying capacity ( $K$ ), the catchability coefficient ( $q$ ), the maximum sustainable yield, and the optimal fishing effort ( $f_{MSY}$ ) (i.e., the maximum number of traps that the body of water can withstand without affecting the stock renewal). The management quantities were obtained by using two types of residual errors: the additive error and the multiplicative error. These types of errors of residual

variance were calculated using  $\sigma^2$ , with additive error  $= \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n}$ , and  $\sigma^2$ , with multiplicative error  $= \frac{\sum_{i=1}^n \left( \ln \left( \frac{y_i}{\hat{y}_i} \right) \right)^2}{n}$ , where  $\sigma^2$  = variance,  $y_i$  = observed value,  $\hat{y}_i$  = estimated value, and  $n$  = number of data. Also, confidence intervals of the outgoing parameters were estimated at a confidence level of 95% ( $\alpha = 0.05$ ), according to Sparre and Venema [35]. This was carried out using the following algorithm:

$CI = \bar{X} \pm t_{n-1} \left( \frac{\sigma}{\sqrt{n}} \right)$ , where  $CI$  = confidence interval,  $t_{n-1}$  = percentiles of Student's t-distribution,  $\sigma$  = standard deviation, and  $n$  = number of data. In this study,  $t_{n-1} = 2.5$ , as gathered from the t-distribution table. Given the confidence level of 95%, this percentile was searched in the table and used for the obtaining the t-distribution with  $n - 1 = 14$  degrees of freedom.

## 2.4 Model selection

The information criteria were used for the selection of the model with the best adjustment. These were (a) the Akaike information criterion (AIC) [36], as in the corrected Aikake's information criterion (AICc) [37], given that  $n/k < 40$  [26] ( $AIC_c = AIC + \frac{2k(k+1)}{n-k-1}$ , where  $AIC = n\hat{\sigma}^2 + 2k$ ) [39]; (b) the Bayesian information criterion (BIC) ( $BIC = -2\hat{\sigma}^2 + kn$ ) [39]; and (c) the Hannan-Quinn information criterion (HQIC) ( $HQIC = -2\hat{\sigma}^2 + 2kn$ ) [40]. From the shown equations,  $\hat{\sigma}^2$  = residual variance,  $k$  = number of parameters, and  $n$  = number of data.

Once the values of the outgoing parameters and the IC were known, the statistical support was assessed, followed by the quantification of evidence from each model by estimating the differences ( $\Delta_i$ ) and the plausibility (i.e., the weight of the evidence in favor of the model  $i$ ) of each ( $w_i$ ), according to the criterion set by Burnham and Anderson [26]. For the estimation of  $\Delta_i$ ,  $\Delta_i = IC - IC_{min}$  was used, where  $IC$  = AICc, BIC, or HQIC and  $IC_{min}$  = model with the lowest value of AICc, BIC, or HQIC. According to Burnham and Anderson [26], the scale of  $\Delta_i$  is described as follows: if  $\Delta_i > 10$ , it shows that the candidate models lack statistical support and thus should not be taken into account; if  $\Delta_i < 2$ , the candidate models have high evidence as alternative functions; and if  $4 < \Delta_i < 7$ , the candidate models can be taken into account, although they count with less statistical support than the previous ones. The  $w_i$  were calculated using  $w_i = \frac{\exp(-\frac{1}{2}\Delta_i)}{\sum_{K=1}^K \exp(-\frac{1}{2}\Delta_i)}$ , where  $\Delta_i$  = AICc, BIC, or HQIC difference and  $K$  = number of parameters.

3. Results

3.1 Maximum sustained yield according to the initial proportion

The values of  $K$ ,  $q$ ,  $MSY$ ,  $f_{MSY}$ ,  $CV$ , and  $R^2$  of the Fox and the Schaefer models are presented in **Table 2**. Based on the results of the management quantities ( $B_1/K$ ,  $K$ ,  $q$ , and  $MSY$ ) of every IP value (from 0.1 to 0.9), the model with the best adjustment was the Fox model, according to  $r^2$ , whereas the Schaefer model had the best adjustment, according to the CV (**Table 2**). However, considering the management quantities only for  $IP = 0.7$  and based on the CV (**Table 3**), the regression estimator ( $r^2$ ), the variability estimators ( $r^2$ ,  $CV$ ,  $\sigma^2$ ,  $\sigma$ ), and IC (AICc, BIC, and HQIC), the selected model was the Fox model (**Table 4**).

**Table 3** shows the punctual estimations and the confidence intervals of the management quantities ( $K$ ,  $q$ ,  $MSY$ , and  $f_{MSY}$ ) calculated by both models, Fox and Schaefer, according to the type of error in the residual variance and based on the  $IP = 0.7$ . Based on the standard deviation, the sizes of confidence intervals are in the following ascending order: Fox (multiplicative), Schaefer (multiplicative), Fox (additive), and Schaefer (additive), respectively. The punctual values of the management measures varied between models, but not between types of error of residual variance.

Model	IP	$B_1/K$	$K$	$q$	$MSY$	$f_{MSY}$	$CV$	$r^2$
Fox	0.1	0.1337	53,990	0.00008798	2567	146,900	0.3318	0.803
	0.2	0.1337	53,990	0.00008798	2567	146,900	0.3175	0.803
	0.3	0.1337	53,990	0.00008798	2567	146,900	0.342	0.803
	0.4	0.1337	53,990	0.00008798	2567	146,900	0.3166	0.803
	0.5	0.1337	53,990	0.00008798	2567	146,900	0.337	0.803
	0.6	0.1337	54,000	0.00008798	2567	146,900	0.3186	0.803
	0.7	0.1337	54,000	0.00008798	2567	146,900	0.3472	0.803
	0.8	0.1337	53,990	0.00008798	2567	146,900	0.3272	0.803
	0.9	0.1337	54,000	0.00008798	2567	146,900	0.3329	0.803
Logistic (Schaefer)	0.1	1.098	26,850	0.00002528	2006	58,960	0.235	0.517
	0.2	1.098	27,440	0.00002488	2006	58,760	0.205	0.517
	0.3	1.098	27,850	0.00002459	2007	58,610	0.2099	0.516
	0.4	1.098	28,060	0.00002444	2007	58,520	0.2585	0.516
	0.5	1.098	28,200	0.00002435	2008	58,470	0.2079	0.516
	0.6	1.098	28,300	0.00002429	2008	58,430	0.2345	0.516
	0.7	1.098	28,370	0.00002425	2008	58,390	0.2117	0.516
	0.8	1.098	28,420	0.00002422	2009	58,370	0.2273	0.515
	0.9	1.098	28,460	0.0000242	2009	58,350	0.2074	0.515

*IP = initial proportion,  $B_1/K$  = initial biomass divided by carrying capacity,  $K$  = carrying capacity,  $q$  = catchability coefficient,  $MSY$  = maximum sustained yield,  $f_{MSY}$  = optimal effort,  $CV$  = coefficient of variation, and  $r^2$  = coefficient of determination.*

**Table 2.** Management quantities ( $B_1/K$ ,  $K$ ,  $q$ , and  $MSY$ ) and variability estimators ( $CV$  and  $r^2$ ) according to the Fox and the Schaefer models, in function with the initial proportion of the biomass ( $IP$ ), of the fishery of the blue crab (*Callinectes sapidus*) in Laguna Madre, Mexico, during the period of 1998–2012.

Parameters and confidence intervals	Type of error of residual variance			
	Additive		Multiplicative	
	Models		Models	
	Fox	Schaefer	Fox	Schaefer
$K$	54,000	28,370	54,000	28,370
ILCI ( $P < 0.05$ )	53,547	27,559	53,781	28,012
SLCI ( $P < 0.05$ )	54,453	29,181	54,219	28,728
$q$	0.00008798	0.00002425	0.00008798	0.00002425
ILCI ( $P < 0.05$ )	0.00008753	0.00002344	0.00008776	0.00002389
SLCI ( $P < 0.05$ )	0.00008843	0.00002506	0.00008820	0.00002461
RMS	2567	2008	2567	2008
ILCI ( $P < 0.05$ )	2114	1197	2348	1650
SLCI ( $P < 0.05$ )	3020	2819	2786	2366
$f_{\text{RMS}}$	146,900	58,390	146,900	58,390
ILCI ( $P < 0.05$ )	142,370	57,579	144,710	58,032
SLCI ( $P < 0.05$ )	151,430	59,201	149,090	58,748

$K$  = carrying capacity,  $q$  = catchability coefficient,  $MSY$  = maximum sustained yield,  $f_{\text{MSY}}$  = optimal fishing effort, ILCI = inferior limit of the confidence interval, and SLCI = superior limit of the confidence interval.  
The initial values of the management quantities were estimated using the A Surplus-Production Model Incorporating Covariates (ASPIC) software with 0.7 as the initial proportion, considering the additive and multiplicative errors of the residual variance.

**Table 3.**  
Average values and confidence intervals of the management quantities ( $K$ ,  $q$ ,  $MSY$ , and  $f_{\text{msy}}$ ) generated by the Fox and logistic (Schaefer) models for the fishery of the blue crab (*Callinectes sapidus*) in Laguna Madre, Tamaulipas, Mexico.

Selection criteria	Types of error			
	Additive models		Multiplicative models	
	Fox	Schaefer	Fox	Schaefer
$r^2$	0.813	0.516	0.813	0.516
$\sigma^2_{\text{residual}}$	665,217	2,132,349	0.1560	0.4148
$\sigma$	816	1460	0.3950	0.6441
$k$	3	3	3	3
AIC	9,978,258	31,985,238	8.34	12.22
AICc	9,978,256	31,985,235	5.94	9.82
BIC	9,978,297	31,985,277	47.34	51.22
HQIC	9,978,342	31,985,322	92.34	96.22

The initial values of the management quantities were estimated by means of the A Surplus-Production Model Incorporating Covariates (ASPIC) software with 0.7 as the initial proportion, considering the additive and multiplicative errors of the residual variance.

**Table 4.**  
Residual variance ( $\sigma^2$ ), standard deviation ( $\sigma$ ), number of parameters ( $k$ ), and the corrected Akaike's information criterion (AICc) as well as the Bayesian (BIC) and the Hannan-Quinn (HQIC) information criteria for each model (Fox and logistic), of the management quantities ( $K$ ,  $q$ ,  $MSY$ , and  $f_{\text{MSY}}$ ), for the fishery of the blue crab (*Callinectes sapidus*) in Laguna Madre, Tamaulipas, México.

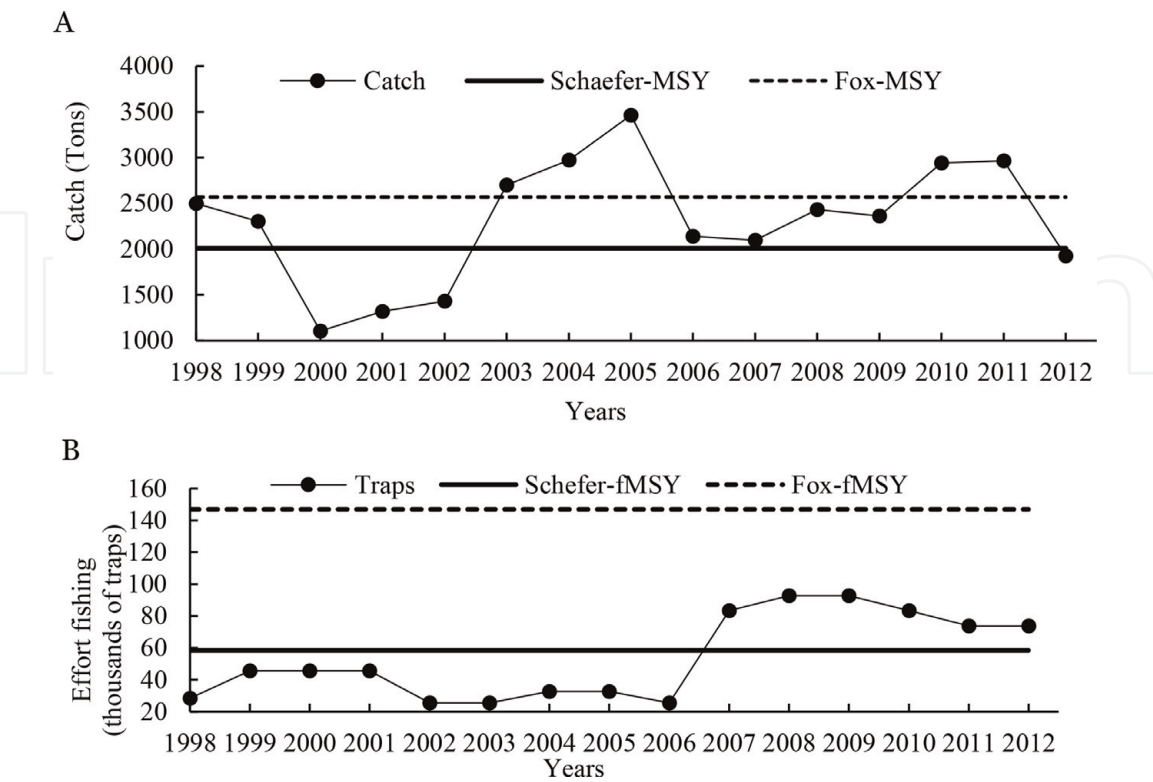


3.2 Model selection

The values of the parameters  $r^2$ , CV,  $\sigma^2$ ,  $\sigma$ , and those of the IC (AICc, BIC, and HQIC), which correspond to the Fox and Schaefer models and according to the type of error of residual variance, are presented in **Table 4**. The lowest values of those estimators pertain to the Fox model in both types of errors. Nevertheless, the values of the management measures obtained from this model (Fox) are far from reality, particularly the optimal fishing effort (number of traps).

**Figure 2A** shows how the fishing catch developed through time as well as the obtained MSY from the models (Schaefer and Fox). It can be observed that, according to the Schaefer model, during the period beginning from 2003 up to 2011, the fishery resource of the blue crab in LM became overexploited. During this period, approximately 24,000 tons of blue crab were captured, with a surplus of 6000 tons as defined by the function based on the difference in tons of catch with the MSY (2008 tons). Regarding the number of traps ( $f$ ), the  $f_{MSY}$  was exceeded from 2007 to 2012 (**Figure 2B**). During this mentioned period (2007–2012), approximately 500,000 traps were registered, with a surplus of 150,000 traps.

As for the Fox model, the results indicate that the resource was overexploited during only 5 (2003, 2004, 2005, 2010, and 2011) out of the 14 years that make up the time series of this study. During these years of overexploitation, the catch should have not exceeded 12,835 tons; but 15,039 tons were gathered instead. This shows a surplus of 2204 tons. In this period of overexploitation, 132, 404, 895, 373, and 400 tons were overfished in the years 2003, 2004, 2005, 2010, and 2011, respectively. This is the equivalent of an overfished resource by 5%, 14%, 26%, 13%, and 13%, respectively. In terms of fishing effort (number of traps), the  $f_{MSY}$  was surpassed (14,690 traps) by 40 up to 85% within the whole time series, according to the Fox model.



**Figure 2.** Fishing catch development through time of blue crab from 1998 to 2012 in Laguna Madre, Tamaulipas, Mexico, with the maximum sustained yield (A) and the number of traps and the optimal number of traps (optimal fishing effort) during this period (B).

## 4. Discussion

This is the first time that management quantities have been estimated for the fishery of the blue crab (*Callinectes sapidus*) in Laguna Madre, Tamaulipas, Mexico. Furthermore, this is the first work carried out for aquatic organisms on the coast of Tamaulipas, Mexico, in which the information theory is applied with the purpose of selecting models by means of the IC, using the corrected Akaike's information criterion [41] (AICc) (which is used for small samples), the Schwarz or Bayesian information criterion [39] (BIC) and the Hannan-Quinn information criterion (HQIC).

### 4.1 Management quantities

Fisheries research investigations that deliver fishery management measures through application software programs such as ASPIC and CEDA (catch effort data analysis) to mention some, which include the adjustment of the Fox, Schaefer, and Pella-Tomlinson models, have recently resurfaced [16–24]. However, in this resurgence, there has been an underutilization of the management measures delivered by these software programs given that these only give even more emphasis to the MSY and the  $f_{MSY}$ , thus leaving both  $K$  and  $q$  unused. Both  $K$  and  $q$  are parameters relative to the initial biomass and the catchability of the fishing gear and, hence, can be used to generate management measures.

The results presented in this study for the two main reference points were  $MSY = 2567$  tons and  $f_{MSY} = 146,900$  traps, from the Fox model, and  $MSY = 2008$  tons and  $f_{MSY} = 58,390$  traps, from the Schaefer model. The model with the best delivered adjustment was the Fox model, according to  $r^2$ , CV, and the information criteria. As for the MSY, the Schaefer model presented a result (2008 tons) that was a little more conservative than the one delivered by the Fox model (2567 tons). The difference between both results was of 22%. However, the values of the management measures obtained from this model (Fox model) were far from reality, for the optimal fishing effort (number of traps) particularly. By accepting this model could mean allowing an increase of more than 170% of the fishing effort (number of traps) which in turn could imply an increase of overfishing risk in the short term, whereas, to accept the Schaefer model ( $f_{RMS} = 58,390$ ), which is a more conservative proposal, could imply the sustainability fortification of this fishery resource. With the Schaefer model, and in relation with the average number of traps from the last 6 years of the time series, the use of about 25 traps (the equivalent of a 30%) would be restricted. This also means a lower social impact without affecting the sustainability of the fishery resource.

### 4.2 Fishing effort measure

The definition of the fishing effort measure always represents a challenge for fisheries research, given the need for seeking the measure that can best explain the variability of fisheries catch. In this study, the number of traps was used as the measure of fishing effort, assuming that this measure of fishing effort delivers better adjustments to the models than the number of fishermen and vessels can do. Yet, it remains the assessment of the best adjustment of these management measure units for this fishery. A better measure would probably be the time length on which a trap remains underwater; this will also be a pending challenge. The same situation is presented by the shrimp fishery in the Gulf of California, where the approach of using engine power (horsepower) as a measure to normalize fishing power has been

attempted [42]. Nevertheless, it has been considered that this measure does not properly represent the variation of the applied fishing effort since trawls use a speed of 3 knots for efficient fishing [43]. Instead, Morales-Bojórquez et al. [43] suggest that the best measure for this crustacean is the drag time; also, they indicate that the number of vessels is a good measure of fishing effort, which Altran and Loesch suggest as well [44].

The fishing effort (number of traps) in this study is expressed in absolute values and was not normalized by any technique, given that (1) the fishery of the blue crab in Laguna Madre is monospecific, (2) the fishing season is the same throughout LM during the year, and (3) the fishing gear has remained technologically stable since the beginning of the fishery. It is important to properly identify the need for normalizing the fishing effort, or not, given that the results may vary according to the unit of the measure of fishing effort and that the results of some measures could be less realistic. Morales-Bojórquez et al. [43] standardized the number of vessels for the yellowleg or brown shrimp (*Farfantepenaeus californiensis*) fishery in the Gulf of California considering methods of using average efforts. However, the results were not successful [43]. Using average efforts can lead to poor results [45].

### 4.3 Model selection

In a large number of research publications, the values of the coefficient of determination ( $r^2$ ) and the coefficient of variation (CV) are established as selection criteria between different candidate models of individual growth [46]. The selection criterion consists of the process of identifying the candidate model with both an  $r^2$  value closest to 1 and the lowest CV. According to Burnham and Anderson [26],  $r^2$  is a measure of the description and variation of the adjustment of the model to fit the data. Regardless of this, it is not a useful criterion to select models that compete to describe the observed data [26]. Because of this, the use of the information criteria is recommended to align with the theory of information [26].

The AICc, BIC, and HQIC have as their foundation the Kullback–Leibler distance, which measures the approximation of the calculated model with the real data; this way, the best candidate model is selected [27, 47]. The information criteria rank the models according to the lower values of these information criteria, so that the models with the lower values of AICc, BIC, and HQIC will be considered as the best models [48–50]. The most important premise on the IC method is to penalize the number of parameters from each model based on the principle of parsimony [46]. In other words, there is a criterion based on the goodness of fit (adjustment) of the model to the data defined by the objective function of maximum likelihood or residual sum of squares (RSS) [46]. At the same time, there is a penalization associated with the total amount of parameters of the model [46].

The NFC establishes that capture over 2100 tons per year should not be allowed. Additionally, it indicates that this fishery is in a state of “exploited to its sustainable maximum.” In this study, the model with the best adjustment, according to both the scientific criteria and reality, was the Schaefer model ( $MSY = 2008$  tons per year). Following this criterion, the maximum catch recommended by the NFC represents the overexploitation of the blue crab as a fishery resource, given a surplus of 90 tons per year on average.

### 4.4 Decision criteria

The model selection based on the information theory is a relatively new paradigm in the biological sciences and is very different from the classic method based on null hypothesis testing [26–29]. In this study, the estimators of the coefficient of

determination, standard deviation, and the IC used (AICc, BIC, and HQIC) delivered the same results with respect to the selection of the model with the best adjustment. However, it has been shown that the criteria based on the information theory in the adjustment of the models are those that deliver values with greater certainty for their particular properties according to Burnham and Anderson [26].

## 5. Conclusions and recommendations

- a. Despite the economic and social importance of the crab fishery from Mexico, and in particular the blue crab (*Callinectes sapidus*) on the coast of the Gulf of Mexico, specifically in the Laguna Madre, Tamaulipas, the official measures of fishing management are insufficient and outdated, while those corresponding to unofficial scientists are nonexistent. On the Pacific Ocean side, several species of the genus *Callinectes* concur for which certain regulations (Official Mexican Standard) and planning (Regional Fisheries Management Plan) applicable to fisheries regulation are available. In the specific case of Laguna Madre, Tamaulipas, there is currently no specific regulation or regional fisheries planning; this is the first work that delivers some fisheries management measures such as MSY and  $f_{MSY}$ , mainly and specifically for the fishing resource of the blue crab *Callinectes sapidus* in the Laguna Madre, Tamaulipas. Consequently, the comparative analysis of fishery management measures of this species is only carried out between those officially indicated and those thrown by this study, and in particular, these measures are only the MSY and  $f_{MSY}$ .
- b. The scientific publications on the blue crab *Callinectes sapidus* of the Laguna Madre, Tamaulipas, and the State of Tamaulipas are scarce; the existing ones deal mainly with growth issues and are located in gray literature, with little access. On the contrary, for this same species, in other regions of the Atlantic, such as the Chesapeake Bay, USA, and Lake Maracaibo in Venezuela, there is research on the estimation of fishery management measures, located both in gray literature as in published literature, but infrequent and outdated.
- c. According to the results presented in this study, and considering the period analyzed (1998–2012), the fishery resource of the blue crab (*Callinectes sapidus*) of the Laguna Madre, Tamaulipas, was under-exploited for the first 5 years, and subsequently, the last 10 years, an overexploitation is recorded according to the RMS obtained in this same study.
- d. It is recommended to use the fishery management measures thrown in this study for blue crab (*Callinectes sapidus*), in particular those corresponding to MSY and  $f_{MSY}$  (MSY = 2.008 ton and  $f_{MSY}$  = 58.390 traps), specifically for the Laguna Madre, Tamaulipas. It is necessary to incorporate these measures into the applicable regulations in force or add them to the NFC, as well as include them in the Fisheries Management Plan that is being prepared for this purpose. These actions would be in order to contribute to fisheries regulation, and, consequently, to the conservation of the fishery resource.
- e. The use of the information criteria (Akaike, Bayesian, and Hannan and Quinn) is proposed to select, according to the best fit, the dynamic biomass models of Schaefer and Fox, since they increase the certainty during the selection process.



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