EVALUATION AND ESTIMATION OF REFERENCE POINTS FOR THE BLUE CRAB STOCK (*Callinectes sapidus*) FROM THE MEXICAN GULF OF MEXICO

AUTHORS

Alejandro Balmori-Ramírez

Rufino Morales Azpeitia

Andrés Antonio Seefoo-Ramos

February 2021

SUMMARY

Blue crab (*Callinectes sapidus*) has a broad latitudinal distribution, from Nova Scotia, to northern Argentina. In Mexican waters, the fishery occurs in 5 states: Tamaulipas, Veracruz, Tabasco, Campeche and Yucatan, where crabs are an important commercial resource placed among the ten most important fisheries in value for the country. Despite its socioeconomic relevance, the blue crab in the Gulf of Mexico, is considered a resource that has little information compared to other important economic resources, such as octopus or red grouper, therefore, the stock health as well as the environmental and socioeconomic impacts of the fishery are unknown. Fishery management generally involves decision-making based on the evaluation of the population size (biomass) and population dynamics, in order to maintain desired levels of exploitable biomass over time; in small scale fisheries, the information needed to make such estimates is often difficult to obtain. Biological reference points to inform management are usually derived from models that are difficult to understand and often require a large amounts of input data. The Catch-Maximum Sustainable Yield (C-MSY) method allows estimation of reference points that can be used for management of a fishery, such as catch at maximum sustainable yield (MSY), biomass associated with MSY (B_{MSY}) and mortality associated with MSY (F_{MSY}) using limited data. The objective of the present work was to determine the level of exploitation of the crab resource in the Gulf of Mexico using official catch data from 1980 to 2018. The values of MSY and B_{MSY} found by the C-MSY method were 16,491 t and 27,687 t, respectively. The F_{MSY} value was 0.596, with a k value of 55,374 t, varying between 33,842 and 90,604 t. The highest viable *r* value of maximum net productivity was equal to 1.19. The results indicate that the Mexican blue crab (*C. sapidus*) fishery within the Gulf of Mexico is at healthy levels and is at maximum levels of exploitation. To maintain the stock status, it is recommended that catches do not exceed a catch equal to 14,842 t (0.9 MSY) and/or fishing mortality equal to 0.8 F_{MSY}.

1. Introduction

Swimming crabs of the *Callinectes* genus are known in Mexico as “jaibas,” they are widely distributed in the Gulf of Mexico and the United States coastal zone of the Atlantic Ocean. They have been documented from the states of Maine and Massachusetts in the United States to the coast of Uruguay, including the archipelagos of Bermuda and the Antilles (Williams 1974).

These crustaceans are a fishing resource of high economic value, especially in small/medium-scale estuarine fisheries, and to a lesser extent, in industrial shrimp fisheries, where they form part of the retained bycatch and are used by ship owners and/or crews; however, the information about their respective composition, volume and landings has been poorly studied.

Six species of swimming crabs of the *Callinectes* genus are reliably identified in the Gulf of Mexico: blue crab (*Callinectes sapidus*), Bocourt swimming crab (*C. bocourti*), Dana crab (*C. danae*), sharp tooth crab (*C. rathbunae*) and lesser blue crab (*C. similis*) and swimcrab (*C. ornatus*).

Blue crab can be considered the main species and inhabits the entire coastal strip of the Gulf of Mexico, the main producing states are Tamaulipas (30.23%), Veracruz (32.51%), and Campeche (26.05%); together they account almost 90% of the crab biomass of the Gulf of Mexico. In a lesser extent, Tabasco (10.60%) and Yucatán (0.61%) complete the total production of *C. sapidus* (Rathbun, 1896) and *C. rathbunae* (Contreras, 1930) that support the fishery in these states (SAGARPA 2013). Due to its abundance and culinary appreciation, *C. sapidus* has economic importance in North America, especially in Mexico (Soto, 1979; Ramírez & Hernández, 1988) and in the United States, which is considered the world's leading producer (Williams, 1974; Villasmil & Mendoza, 2001). Small-scale fishing is a very important activity from the social perspective, since it provides excellent food in the coastal areas, reaching major cities, as well as rural areas adjacent to the coast. This makes the blue crab an important element for the food production reasons for the inhabitants of these regions.

Fisheries management generally involves decision making regarding fishing effort based on the evaluation of the population size and population dynamics, in order to maintain the desired levels of exploitable biomass over time (Anderson and Seijo, 2010; Hilborn and Walters, 1992). Among the disadvantages of this approach, especially in small scale fisheries, is that the information necessary to make these estimates is very difficult to obtain or there are no adequate population assessments (Martell and Froese, 2012), and implemented management strategies frequently ignore the responses from fishers to changes in abundance and self-management over time (Hilborn and Walters, 1992).

The official document that defines the status of fisheries in Mexico is the National Fisheries Chart, NFC (DOF, 2010, 2012, 2014, 2018), which is the instrument, with technical and scientific bases, of a legal nature that serves as a reference to the Federal Government to establish the condition of the fisheries in the country, and from there formulate actions for the administration of the fisheries.

In this context, it should be noted that the scientific information that supports the diagnosis of the status of fishery resources and also supports the NFC in Mexico, is very detailed and synthesized, is the so-called “Libro Rojo" Sustentabilidad y Pesca Responsable en México, under the responsibility of the National Fisheries Institute (Arreguín-Sánchez *et al.* 2006)

However, the NFC does not contain any relevant management reference points to guide the exploitation of the Gulf of Mexico blue crab resources, and there is no evaluation of the risks and best management options for this fishery, as recommended by Hilborn and Walters (1992) and Caddy and Mahon (1995).

A biological reference point (BRP), in its most generic form, is a standard or benchmark against which to measure of the state of the stock from a biological perspective. A BRP often reflects the combination of several components of stock dynamics (growth, recruitment, and mortality, generally including fishing mortality) into a single number. This number is generally expressed as an associated fishing mortality rate or a biomass level (Gabriel and Mace 1999).

In general, BRPs are often derived from models that are difficult for non-modelers to understand, with the models often requiring a large amount of input data.

To estimate the optimal levels of allowable catches it is necessary to have as much information as possible; to be able to establish an adequate management of the target resources, it is necessary to know the behavior of the fishers, their catch statistics, and the fishing effort applied. It is also essential to know the fundamental biological aspects of the most commercially important species along the coast, which should also consider associated species.

In Mexico, the vast majority of fisheries and the resources on which they depend are data poor due to a lack of funds for research and a lack of support for monitoring and analyses. Many of these fisheries are important for socio-economic and for food reasons and/or because they affect vulnerable ecosystems or vulnerable populations. However, it is important to assess and manage the fisheries, even when little data are available. Fortunately, there are methods for assessing the stock status and identifying management reference points for fisheries that have scarce information. Methods exist that can be used to prioritize fisheries for research and management, as well as to estimate overfishing thresholds, biomass levels, stock status, catch or effort (Honey *et al*, 2010). In this sense, the reference points can be direct estimates, or proxies for direct estimates, depending on the sufficiency of the available data. There are also approaches used that set default, precautionary, management reference points in the absence of specific stock or species information (MFNZ, 2008; DAWE, 2018).

2. Background

In 2004 Díaz de Leon *et al.* analyzed the health status of 28 fishery management units in the Gulf of Mexico determining that 79% were overexploited and that 25% required urgent attention, including the blue crab fishery in Campeche.

Guerra-Jimenez *et al*. (2018), applied the Martell and Froese (2012) method to the Campeche blue crab fishery and estimated an MSY of 3,350 t. They concluded that the fishery is exploited at the maximum sustainable level with some indication of overexploitation.

Rodríguez-Castro *et al*. (2017), applied different adjustments to linear and nonlinear mathematical functions to the captures reported in Laguna Madre, Tamaulipas during the period 1998-2012, and concluded that the fishery experienced six capture periods and two lifecycles and resulted in a a fishery that had been severely overfished.

Palacios-Fest *et al.* (2000), determined that the species of the Callinectes genus in the Alvarado lagoon in Veracruz, Mexico are overexploited with exploitation rates values (E) above 0.60.

Villegas-Hernandez, *et al.* (2017), through a short-term Jolly–Seber mark-recapture model experiment estimated the catch-per-unit-effort (CPUE) and the catchability coefficient (q) of the blue crab (*C. sapidus*) in the fishing port of Sisal, Yucatan, Mexico.

Other research reports for the blue crab in the Mexican coastal Gulf of Mexico have been focused on determining population parameters and ecological aspects, including Chávez *et al* (2019); Leo-Peredo y Enrique-Conde(2014); Rodríguez-Castro *et al.* (2016); Rosas-Correa and Navarrete (2008).

Based on genetic and phylogenetic analyses, it is considered that there are two stocks of blue crab in the US Gulf of Mexico (GDAR, 2013). The NE Gulf of Mexico stock along Florida state coast up to the Apalachee Bay, and a NW Gulf of Mexico stock occurring from Apalachicola Bay, Florida, to the west of the gulf. However, the connection between the western US Gulf of Mexico stock and the southern distribution in Mexican waters is uncertain (GDAR, 2013).

The Catch-MSY (C-MSY) method described by Froese *et al*. (2017) has gained importance since it allows estimating the main exploitation parameters (reference points) of fisheries with limited data. Rosenberg *et al* (2014), for the single-stock status work, developed a fully factorial simulation testing framework to assess four potential data-limited models. The results suggest that Catch-MSY, a catch-based method, was the best performer, although the different models performed similarly in many cases. ICES (2014), applied the C-MSY method to 17 stocks including fully evaluated populations, populations with limited data and simulated populations. The results indicated that the C-MSY method produces reasonable predictions for the relative biomass and the relative exploitation rate compared to the fully evaluated populations, the simulated populations and the populations with limited data for which CPUE data were available.

Considering the above, and given that crab populations are very dynamic and can change size rapidly, as well as the improvement of population assessment methodologies over time, the present study aims to determine the health status of crab population in this area and estimate candidate reference points for these fisheries.

3. Objectives

- To assess the health status of the blue crab (*C. sapidus*) stock in the Mexican Gulf of Mexico.
- To estimate appropriate candidate reference points for the Mexican blue crab (*C. sapidus*) fishery in the Gulf of Mexico.

4. Area of Study

The study area includes the coastal Gulf of Mexico in Mexico, which includes the states of Tamaulipas, Veracruz, Tabasco and Campeche, Yucatán and Quintana Roo, where the main catches of this species are made (Figure 1).

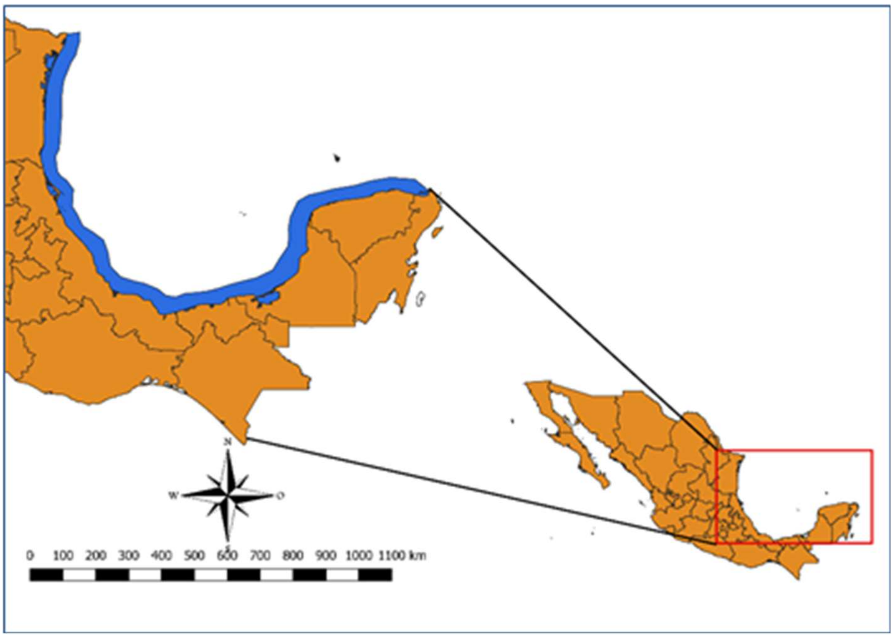

Figure 1. Study area for *C. sapidus* in the Mexican Gulf of Mexico

5. Methods

One part of the methodology consisted of the analysis of the historical official landings records (t/year) and another of the application of the C-MSY method described by Froese *et al.* (2017).

Catch and Effort Trends

The live weight information was taken from official crab landings records from the Statistical Fishing Yearbooks during the period of time from 1980 to 2018[1]. In this data base, all of the species of the Callinectes family that share the common name crab were grouped and later they were disaggregated by species, based upon information provided by producers and processors interviewed for this study. According to the answers provided, blue crab landings represent 95% of

---

[1] https://www.gob.mx/conapesca/documentos/anuario-estadistico-de-acuacultura-y-pesca

the total. The remaining 5% is comprised of the other crab species in the region, which are largely sold as bait while blue crab is entirely oriented for direct human consumption (Pesca Responsable y Comercio Justo, *pers. comm.* 2020).

In order to understand how the fishing effort has changed in the last decade, the fishing effort data published in the NFC, together with CONAPESCA fishing license databases and the fishing license database published in the www.pescandodatos.org platform were analyzed.

Stock Assessment, Limit Reference Points (LRP), Target Reference Points (TRP) Fishing Mortality (F)-based Reference Points.

For the evaluation of the blue crab stock and the estimation of the different reference points, the species was considered as a single stock for the Mexican Gulf of Mexico (BC_GM).

The C-MSY method described by Froese *et al.* (2017) was applied. This, through the Monte-Carlo method, estimates the reference points of the fishery (MSY, F_{MSY}, B_{MSY}), as well as the relative size of the population (B/k) and the exploitation rate (F_t/F_{MSY}). The method requires the definition the stock biomass at the beginning and end of the time series, expressed as intervals of proportion of virgin biomass (k or carrying capacity); to define these intervals of the state of the stock (B/k), the authors of the method propose a range of values both initial (λ_{i1}, λ_{i2}) and final (λ_{f1}, λ_{f2}), based on the proportion of catches at the beginning and end of the time series, relative to the maximum recorded catch.

This method also requires the general background of resilience and productivity (*r*) to be known. The same authors propose values of *r* based on the level of resilience of the species, in case there is no previous value of resilience.

Another important feature of the C-MSY is that it differs from an earlier version of the Catch-MSY method (Martell and Froese, 2012) by searching for the most probable r not in the center but rather in the tip of the triangle. This is based on the underlying principle that defines *r* as the maximum rate of increase for the examined population, which should be founded among the highest viable *r*-values, i.e. *r* is defined as maximum net productivity.

Part of the C-MSY package is a Bayesian state space implementation of Schaefer's surplus production model (BSM). The main advantage of BSM compared to other surplus production model implementations is the focus on informative background and data acceptance brief and incomplete (fragmented) abundances (Froese *et al*. 2017), the initial biomass was calculated as:

$$B_0 = \lambda_{i1} k * \exp(\upsilon t) \qquad \text{Eqn 1}$$

and the biomass of the following years as:

$$B_{t+1} = \left[B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t\right] * \exp(\upsilon t). \qquad \text{Eqn 2}$$

Where:

B_t = Biomass at time t

B_{t+1} = Biomass one year after t

C_t = Capture at time t, and

exp (υt) = process error. If the process error is equal to 0, it is considered a deterministic model and if it is equal to 1, it is considered an observation error (uncertainty).

To account for reduced recruitment at severely depleted stock sizes (depensation), such as predicted by all common stock–recruitment functions (Beverton and Holt 1957; Ricker 1975; Barrowman and Myers 2000), this method incorporates a linear decline of surplus production, which is a function of recruitment, somatic growth and natural mortality (Schnute and Richards 2002), when biomass falls below ¼ k (Equation 3).

$$B_{t+1} = \left[B_t + 4\frac{B_t}{K} r\left(1 - \frac{B_t}{K}\right) - C_t\right] * \exp(\upsilon t) \qquad \text{Eqn 3}$$

It was assumed that, at the beginning of the time-series, the biomass of the blue crab stock varied between 50 and 90% (B/k = λ_{i1}, λ_{i2}) of its carrying capacity (k), and in last year between 30 and 70% (B/k = λ_{f1}, λ_{f2}). The biological plausible range for r for species with high resilience (0.6 < r <1.5 Froese *et al*. 2017) was considered appropriate for BC_GM stock.

To note a key uncertainty, there are many catches that are not correctly recorded, mainly when it comes to small-scale fisheries. The lack and low precision of information is usually considerably greater for the small-scale fleet than for the industrial fleets (Arreguín-Sánchez & Arcos-Huitrón, 2006), as some crab is not sold and therefore goes unrecorded in the official capture statistics. To address this, the input values of CV and process error used in the method were 0.2 (20%) and 0.1, respectively. In all cases, 30,000 MCMC iterations were performed.

The parameter estimated by C-MSY and BSM relate to standard fisheries reference points, such that

$$\mathrm{MSY} = r\ \mathrm{k}/4, \qquad \text{Eqn 4}$$

$$\mathrm{B}_{\mathrm{MSY}} = 0.5\ \mathrm{k}, \qquad \text{Eqn 5}$$

$$\mathrm{F}_{\mathrm{MSY}} = 0.5\ r, \qquad \text{Eqn 6}$$

If the reduction in recruitment at very slow stock sizes ($B/k < 0.25$), instead

$$\mathrm{F}_{\mathrm{MSY}} = 0.5\ r\ 4\ \mathrm{B/k}. \qquad \text{Eqn 7}$$

The version of the R script of the C-MSY method used here (MSY_O_7q.R), is newer than that used in Martell and Froese (2012).

Equilibrium Curve

Using the equilibrium curve graph (Equation 3), the relation of the population relative biomass (B_t/k) against the relative catch (C_t/MSY) is shown, and allows visualizing the behavior of the respective rates with respect to the carrying capacity (k) or virgin biomass.

Crab Production Rates

According to the Schaefer model, the net surplus production in a period of time t of a population subject to fishing is defined as (Anderson and Seijo 2010, Seijo *et al.* 1998):

$$SPt = rBt\left(1 - \frac{Bt}{k}\right) \qquad \text{Eqn 8}$$

Where *r* is the intrinsic rate of population growth, B is the biomass at time t and k is the carrying capacity of the stock.

In the case of exploited stocks, the annual biomass (B_t) can be estimated by relating it to the instantaneous rate of population growth (ρ_t) (Jacobson *et al*. 2001):

$$\mathrm{B}_{t+1} = \mathrm{B}_t e^{\rho_t - \mathrm{F}_t} \qquad \text{Eqn 9}$$

where F_t is the instantaneous fishing mortality rate defined as the ratio between the accumulated catch in a fishing period and the average biomass in the same period, or $F_t = C_t/B_t$ (Jul-Larsen *et al.* 2003). So,

$$\rho_t = \ln\left(\frac{B_{t+1}}{B_t}\right) + F_t \qquad \text{Eqn 10}$$

Furthermore, ρ_t is related to the annualized surplus production of the stock (SP) as follows (Jacobson *et al*. 2001):

$$\rho_t = \ln\left(\frac{SP_t+B_t}{B_t}\right) \qquad \text{Eqn 11}$$

Units are by time and measures the instantaneous population growth rate due to individual growth, recruitment, fishing mortality, and natural mortality. This standardized formulation makes it possible to compare the productivity of different stocks or to relate it to either environmental or biological indices.

A Kobe plot was constructed (Aires-da-Silva and Maunder, 2011, Schirripa, 2016), which allows a plot of assessment from the perspective of the exploitation rate (F_t/F_{MSY}) and the relative biomass (B_t/B_{MSY}), and summarizes stock status by plotting points by colored quadrant: green quadrant (not overfished, no overfishing), yellow and orange quadrant (overfished or overfishing), and the red quadrant (overfished and overfishing). It can also be used to guide the choice of reference points for use as part of a standard management strategy (Laurence *et al* 2014).

Candidate Reference Points

There is no universally recognized best method for setting fisheries targets and limits, however, the establishment of reference points is intended to guide a possible standard management strategy that results in long-term sustainability of the target fishery, benefitting both the fishers and the target fish population. These population biomass should be managed to fluctuate around a target reference point (TRP) compatible with MSY (MFNZ, 2008), but not generally be allowed fall below the limit reference point (LRP).

As is traditional, we suggest that the biomass TRP is established as equal to the B_{MSY}. A threshold around 0.5 B_{MSY} has been widely adopted as a biomass LRP to prevent recruitment overfishing (Froese *et al*. 2017; Haddon *et al.* 2012; Carruthers *et al.* 2014; Froese *et al.* 2015). Additionally, we recommend a fishing mortality limit reference point at the value of F_{MSY} produced by the model, such that any value above this is considered overfishing. In summary, the advised candidate reference points are:

$$TRP_{BMSY} = B_{MSY} \quad \text{Eqn 12}$$

$$LRP_{BMSY} = 0.5\ B_{MSY} \quad \text{Eqn 13}$$

$$LRP_{FMSY} = F_{MSY} \quad \text{Eqn 14}$$

With the information generated by the C-MSY method, candidate values for appropriate TRP and LRP were established. Kobe plots were constructed to show the evolution of the stocks relative to the candidate target and limit reference points and provide information on the stock status and exploitation rate. Likewise, it allowed evaluating the uncertainty of the current status by establishing the variation of these results.

To test the effect of the establishment of possible standard management strategies of limiting catch or fishing mortality, and evaluate their effect on the trend of the stock biomass, the Schaeffer model (constant captures) was used. For catch limits, the values tested were the TRP_{MSY} and the LRP_{MSY} as well as several values in between. For fishing mortality limits the values tested were F_{MSY} as well as 0.9, 0.8 and 0.7 F_{MSY}. Additionally the exploitation rate and relative biomass were calculated and plotted in a Kobe plot to show their evolution projected to the year 2025.

Management Options Outcome Analysis

An analysis was carried out to evaluate stock and fisheries outcomes using a range of different constant catch limits as the key management measure, projecting biomass to the 2025 season. From this analysis we can evaluate the probability that the biomass of the stock will be above the candidate TRP_{BMSY}, between the candidate TRP_{BMSY} and LRP_{BMSY}, or below the candidate LRP_{BMSY} in 2025.

A similar analysis was also completed where the key management measure was one of a range of constant fishing mortality limits.

6. Results

a. Fishery Indicators

Capture Behavior

With the data from the base of the statistical fishing yearbooks (1980-2018), Figure 2 was elaborated. This shows the time-series of annual landings of swimcrabs from the Mexican waters of the Gulf of Mexico. During this period of time annual landings have averaged 10,054 t, with a decrease in catch early in the time series, reaching the lowest value (5,188 t) in 1986, followed by a generally increasing trend reaching a maximum value of 17,903 t in 2016. The annual average of the catches of the last 5 years (2014 to 2018) was 15,953 t, one and a half times more than the overall timeseries average.

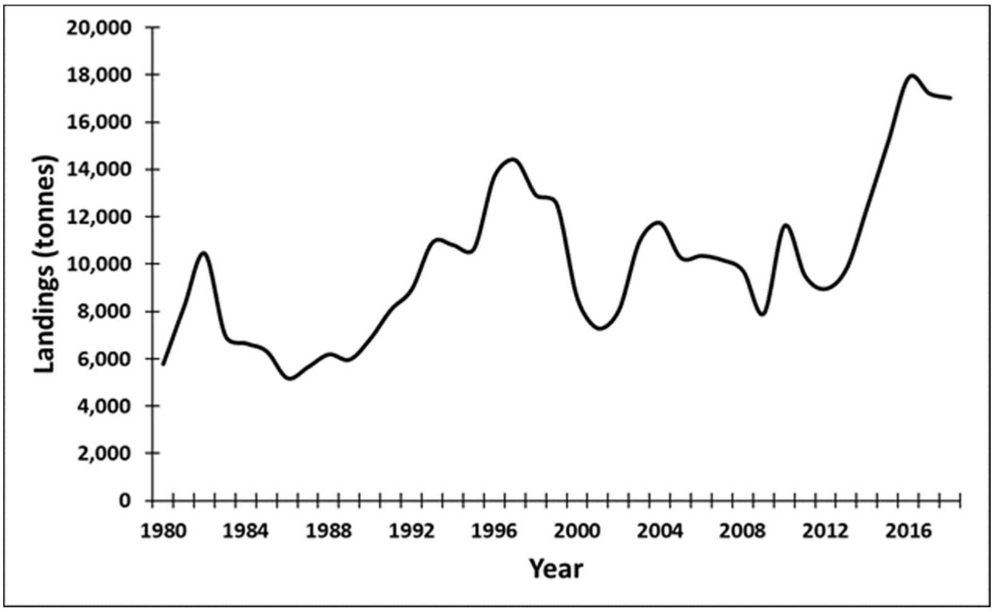

Figure 2.- Annual crab landings (tonnes) in Mexican waters of the Gulf of Mexico from 1980 to 2018. Source: CONAPESCA Statistical Fisheries Yearbooks.

Figure 3 shows captures by state. Throughout the analyzed period Tamaulipas, Veracruz and Campeche contributed 87.9% of the total crab production. The trend of increasing crab production in the state of Campeche is notable, accounting for 42.3% in the last year of the analyzed period (2018), followed by the states of Tamaulipas and Veracruz (28.9% and 20.6%, respectively).

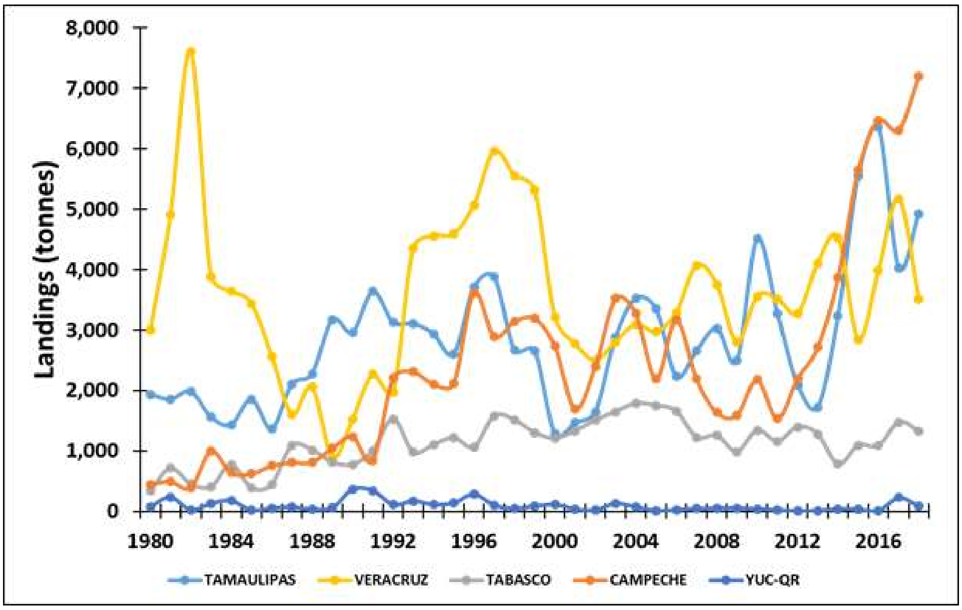

Figure 3.- Annual crab landings (t) by state in Mexican waters of the Gulf of Mexico from 1980 to 2018. Source (CONAPESCA. Statistical Fisheries Yearbooks).

Effort

According National Fisheries Chart (SAGARPA 2018), in 2017 there were 452 authorized crab fishing licenses along the Mexican Gulf of Mexico covering 3,369 small scale vessels and 324,978 fishing instruments (number of traps, rings and scoops). However, there is no available number of small scale vessels in the Tabasco State and the number of fishing instruments in the Campeche State.

Recently, the www.pescandodatos.org platform published, based upon CONAPESCA databases, the updated (Nov. 2020) number of licenses, small scale vessels and authorized fishing instruments per small scale vessel for all the states and fisheries in Mexico. The platform indicates that, in November 2020, 175 fishing licenses existed for the Mexican crab fishery in the coastal Gulf of Mexico, which include 2,120 small scale vessels and 191,419 fishing instruments.

Analyzing the information on landings and authorized fishing effort, it is clear that there are major issues with non-authorized participants in the fishery. The State of Campeche situation is notable. While there are only 3 fishing licenses for 4 vessels and 450 fishing instruments (ring nets), annual landings average 4 thousand tonnes for the last 10 years (Pescando Datos 2021).

b. Stock Assessment and Status

The results of the application of the C-MSY method for estimation of *r* and k, through the Monte Carlo method, with the information of the catches and the previous input assumptions, are presented in Table 1. Figure 4a shows the most viable *r*-k pair values. The model yielded 90,154 trajectories of possible combinations of *r*-k; 11,147 were viable. Through the underlying principle that defines *r* as the maximum rate of increase for the examined population, among the highest viable *r* values, the model yielded a value of maximum net productivity of *r* equal to 1.190 with confidence intervals of 0.957 to 1.480. Figure 4b shows the biomass relative to the carrying capacity (k) of the population in the time analyzed. The relative biomass in the last year was 0.594k, with confidence intervals between 0.327 and 0.696. Figure 4c shows the exploitation rate of the stock. In the last year the exploitation rate was 0.87 with confidence intervals of 0.742 to 1.580.

Table 1. – Assumed parameter and output results C-MSY method for the stock of blue crab (*Callinectes sapidus*).

Stock	Prior range values				Carrying capacity Median (IC = 95 %)	
	Initial relative biomass λ_{i1} - λ_{i2}	Final relative biomass λ_{f1} - λ_{f2}	r	k*i* (tonnes)	*r*	k (tonnes)
Blue crab	0.5 - 0.9	0.3 - 0.7	0.6 - 1.5	11,591 - 115,910	1.190 (0.957 - 1.480)	55,374 (33,842 – 90,604)

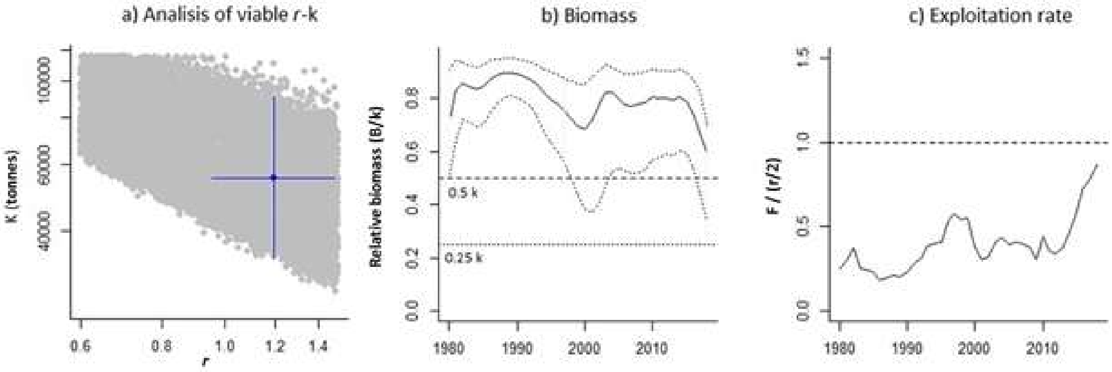

Figure 4.- Results of the C-MSY method for the Mexican blue crab (*Callinectes sapidus*) fishery in the Gulf of Mexico. a) Analysis of the most probable combinations of *r* and k. The viable *r*-k pairs that fulfilled conditions are show in grey. The blue cross, with approximate 95% confidence limits, marks the most probable *r*-k pair. b) Biomass relative to the carrying capacity of the population in the time analyzed with 2.5 and 97.5 percentiles. c) Exploitation rate of the stock.

Figure 5 shows the equilibrium curve (Equation 3) of the Schaefer model of C-MSY, relative to B/k and indented at B/k < 0.25, to explain the reduced recruitment at low stock sizes (right side of the parabola). Values of catch relative to MSY and biomass relative to k show a stock with high resilience and with a pattern of decreasing biomass, including the phases of decrease, increase and equilibrium, as shown by the location of the points below, above and near the equilibrium curve. It is observed that during the entire period, these were around the equilibrium curve with relative biomass values higher than 0.5 B/k indicating catches that will maintain the corresponding biomass. In recent years, the last three point values can be observed above and away from the equilibrium curve, suggesting a biomass decrease with relative values of catch/MSY > 0.9.

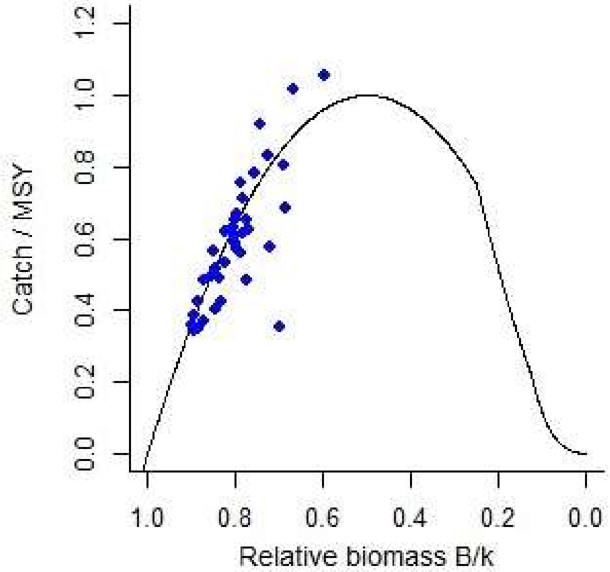

Figure 5.- Equilibrium curve of the Schaefer model to explain reduced recruitment at low stock sizes for the Mexican blue crab fishery in the Gulf of Mexico. The dots indicate values of catch relative to MSY and biomass relative to k.

Surplus Production and Instantaneous Rate of Population Growth

Figure 6 shows the surplus production (SP) (Equation 8) of Mexican blue crab stock of Gulf of Mexico, which varied between 6,088 t and 15,897 t. For the BC_GM stock an increase in the values of SP is observed at the end of the period, at which point the catch values are above the SP and the biomass shows a decrease.

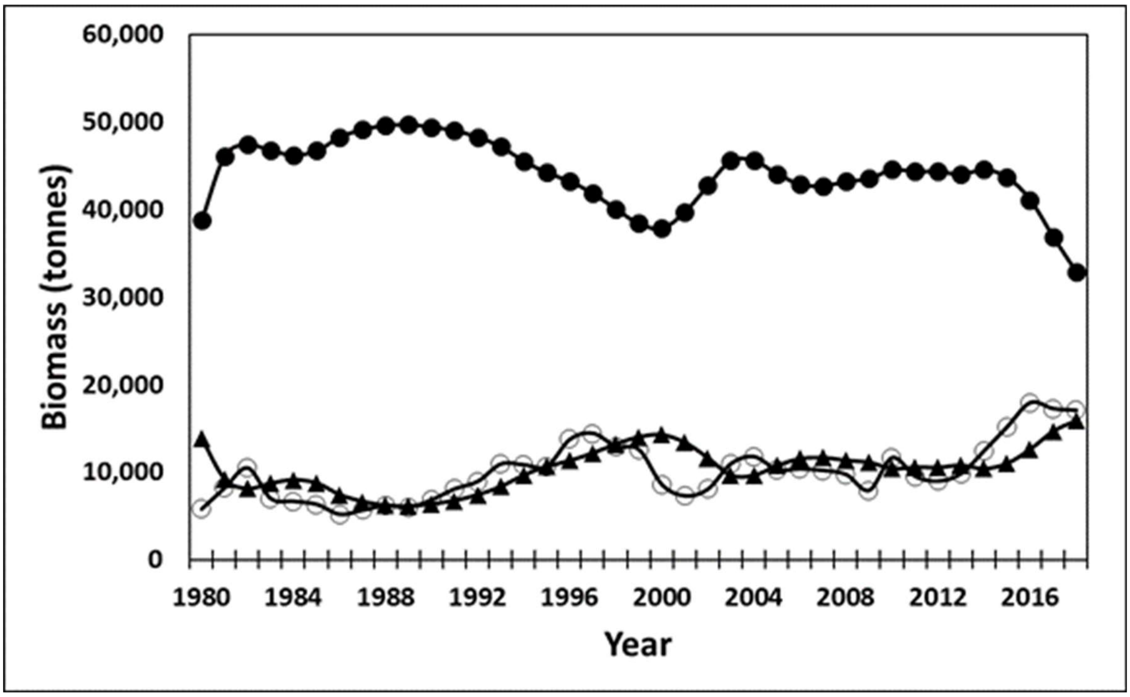

Figure 6. Annual surplus production (solid triangles), catch (open circles) and biomass (solid circles), for the Mexican blue crab stock in the Gulf of Mexico.

Figure 7a shows the SP and its corresponding biomass for consecutive years from 1980 to 2018. The lowest value of SP is located with the maximum biomass value at the beginning of the time period and, as time progresses, the annual SP values tend to approach values close to the B_{MSY}. Figure 7b shows the instantaneous rate of population growth (Equation 11) from 1980 to 2018, which varied between 0.11 year^{-1} and 0.39 year^{-1}. There was an initial decline in the instantaneous rate of population growth at the beginning of the period, reaching its lowest value in 1989. This was followed by a positive trend, observing two periods with a rapid growth (1988-2000 and 2014-2018) and an intermediate period of stabilization with values between 0.20 and 0.23 year^{-1}. The maximum value for the instantaneous rate of population growth was in 2018, the last year of the period.

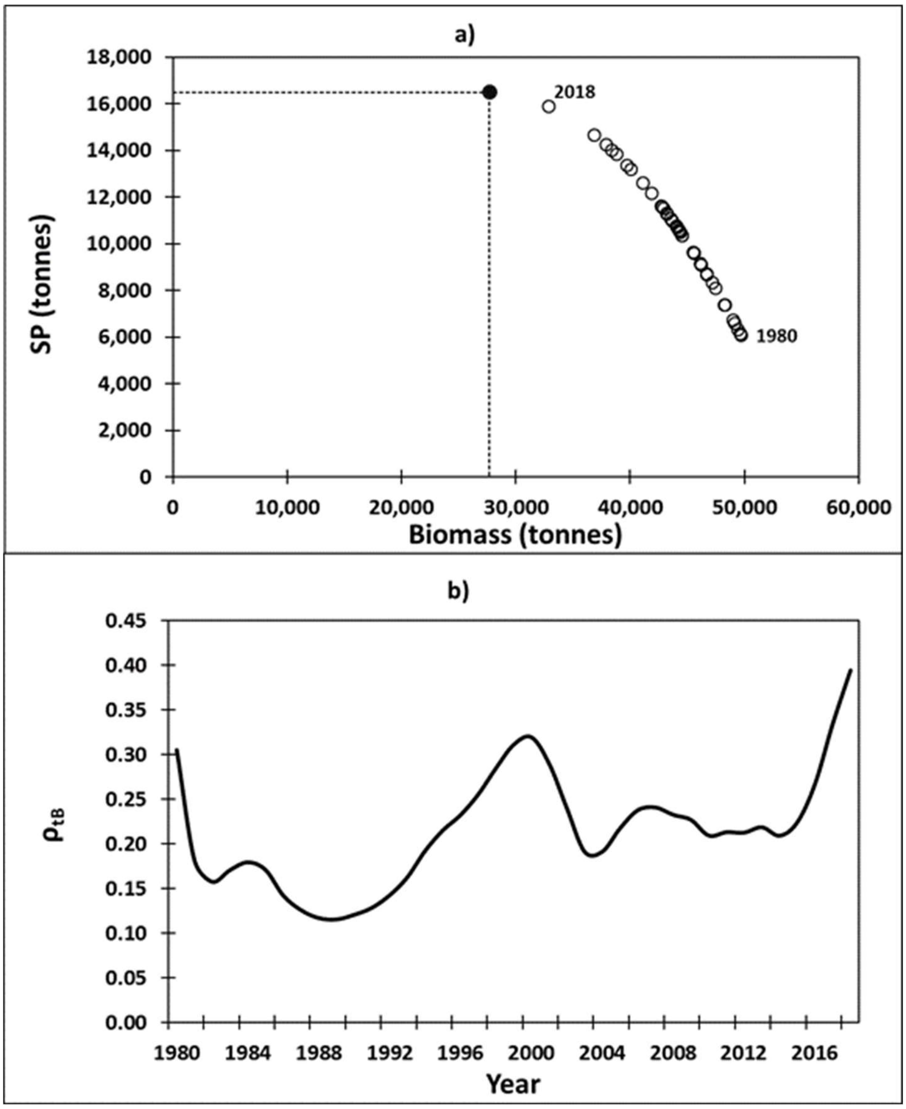

Figure 7.- a) Annual surplus production of the Mexican blue crab fishery in the Gulf of Mexico (the black dot shows the estimated B_{MSY} value). b) Annual instantaneous rate of population growth (PtB).

Estimation of Candidate Target and Limit Reference Points for Management

The reference points (RPs) estimated by the C-MSY method (MSY, B_{MSY} and F_{MSY}) through the Equations 3, 4, and 5 for the BC_GM fishery and the candidate reference points (Equations 12, 13 and 14) associated with these and proposed for management purposes are presented in Table 2.

Table 2. Reference points estimated by the C-MSY method and candidate reference points for management purposes for the Mexican blue crab fishery in the Gulf of Mexico.

Stock	Reference Points Estimated by C-MSY Method			Candidate Reference Points for Management		
	Median (IC = 95 %)			Target	Limit	
	MSY	B_{MSY}	F_{MSY}	B_{MSY}	0.5 B_{MSY}	F_{MSY}
	Tonnes			Tonnes		
BC-GM	16,491 (9,641 - 28,209)	27,687 (16,921 - 45,302)	0.596 (0.479 - 0.741)	27,687	13,843	0.596

The catch at the maximum sustainable yield (MSY) estimated by the model was 16,491 t. During most of the period the catches remained below this level with an increasing trend towards MSY until 2016, from which time catches have been above MSY, with a decreasing trend at the end of the period (Figure 8a). The biomass associated with the maximum sustainable yield, or TRP_{BMSY}, was estimated to be 27,687 t. Throughout the period analyzed, the biomass trajectory remained above the TRP_{BMSY}, though with a decreasing trend, and in the last three years this value showed a drastic decrease (Figure 8b). Figure 8c shows the fishing mortality (F) throughout the time-series compared to the LRP_{FMSY} of 0.590. The annual fishing mortality throughout most the time series is less than half of the LRP_{FMSY} value until 2014, after which it increased markedly, reaching its maximum value in the last year (2018) at 0.518. The exploitation rate for 2018 was 0.742.

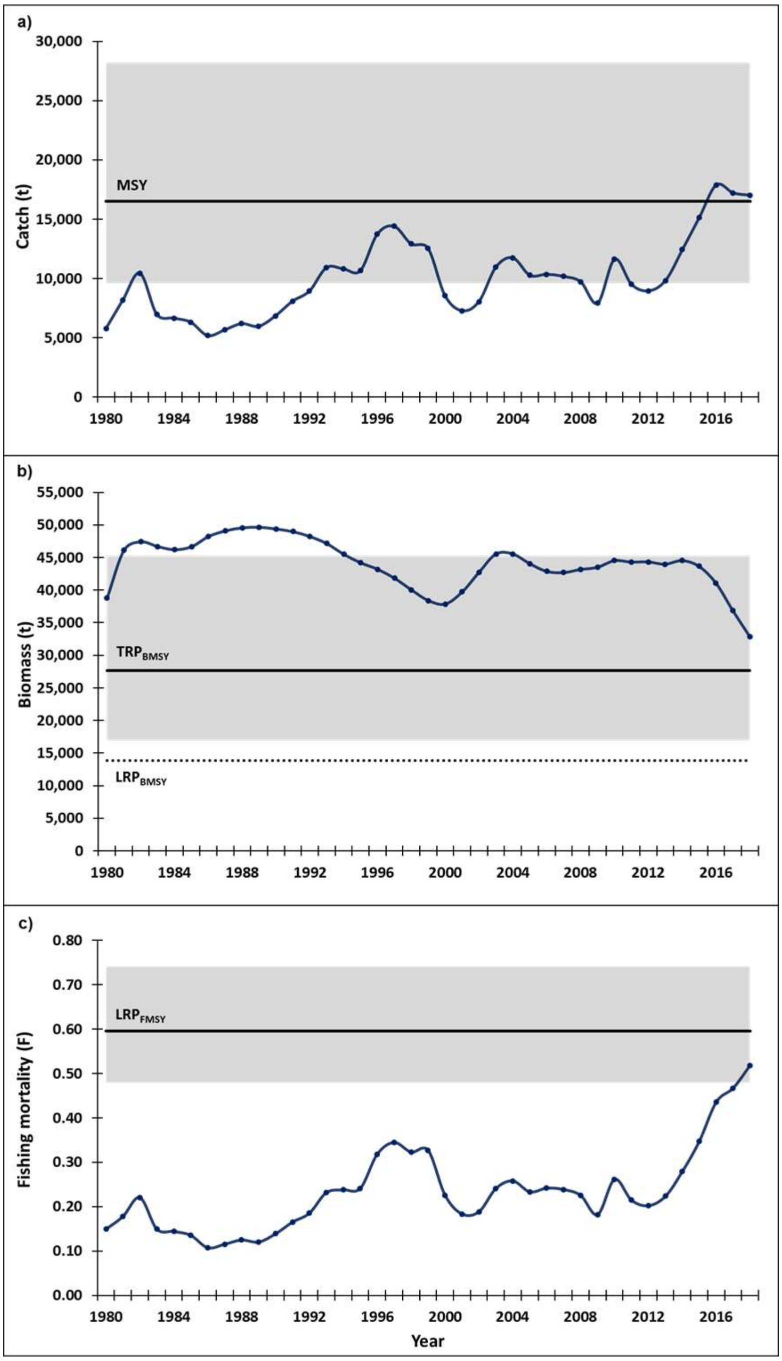

Figure 8.- Results of the C-MSY method for management purposes based on Monte Carlo evaluation for the Mexican blue crab (*Callinectes sapidus)* fishery in the Gulf of Mexico (BC_GM). a) Catch, MSY with 95% confidence interval (gray area). b) Biomass trajectory, TRP$_{BMSY}$ with 95% confidence interval (gray area) and LRP$_{BMSY}$ (dotted line). c) Fishing mortality and LRP$_{FMSY}$ with 95% confidence intervals (gray area).

The Kobe plot illustrates the evolution of the fishery over this period of time (Figure 9) and shows at the end of the period a healthy population with sustainable level of exploitation. The trajectory of the different points shows us how the population has evolved in the analyzed period, remaining in the course of time at healthy levels of exploitation (green quadrant), with a trajectory towards levels close to the candidate reference points determined in this research. This low information methodology tends to generate large overall uncertainty, as can be seen in the iso-probabilities covering all quadrants of the diagram. There is a 64.4% probability that the current status of the Mexican blue crab fishery is in the green quadrant (not overfished and not experiencing overfishing), and a 25.9% probability that the current status is in the orange quadrant, which denotes a population that is not overfished, but is experiencing overfishing. The probabilities that the stock is overfished but not experiencing overfishing (yellow = 3.4%) and overfished and experiencing overfishing (red = 6.3%) are relatively low.

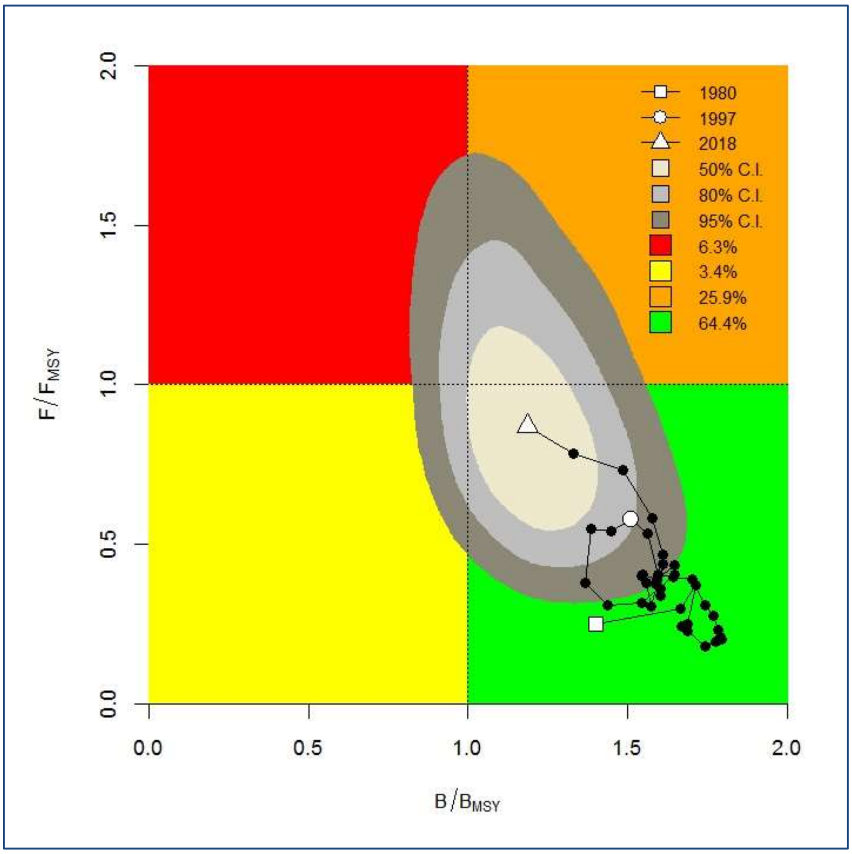

Figure 9.- Kobe plot using the method of Maximum Sustainable Yield (C-MSY) Froese *et al* (2017), for the Mexican blue crab fishery in the Gulf of Mexico. Gray areas indicate iso-probabilities.

Management Strategies

Figure 10 shows the projected biomass stock trajectory to 2025 for the Mexican blue crab fishery with the application of the Schaefer model (constant catch and constant fishing mortality) to evaluate the effect of implementing different reference values (Table 3) expressed as a percentage of the MSY and F_{MSY}. With a catch limit equal to the MSY, 16,491 t as a harvest strategy, the biomass tends to decrease (Figure 10a) but remains above TRP_{BMSY}. With harvests equal to lower percentages of MSY the biomass stabilizes at higher values, and with a harvest value equal to the lower confidence interval of MSY, 9,641 t the biomass reaches a value equal to the upper limit of the confidence interval of B_{MSY}.

Considering the limitation of fishing mortality as a second strategy, it can be seen that establishing the fishing mortality limit at F_{MSY} allows the biomass to decrease to a level equal to TRP_{BMSY} by 2025 (Figure 10b). With fishing mortality limited to lower percentages of F_{MSY}, the biomass stabilizes at slightly higher levels (Table 3).

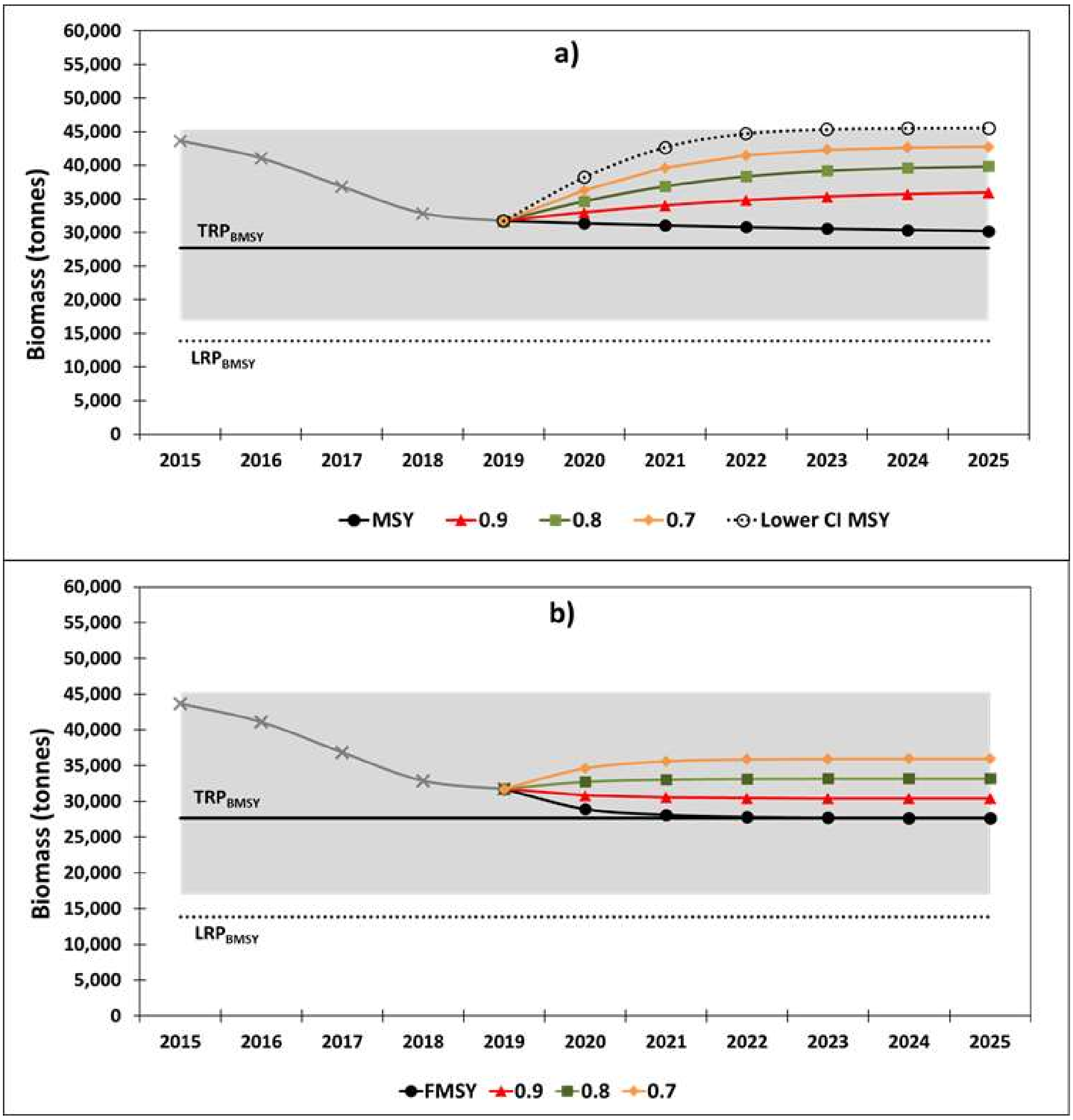

Figure 10.- Standard management scenarios projected to 2025 for the Mexican blue crab fishery in the Gulf of Mexico using different values of (a) constant catch relative to MSY, and (b) constant fishing mortality relative to F_{MSY}, as harvest strategies. The solid lines show TRP_{BMSY}. The dotted lines show LRP_{BMSY}. The gray area show 95% confidence intervals of B_{MSY}. Refer to Figure 8b to view the historic biomass trajectory (gray line).

Table 3. Results of projections from the Schaefer model (constant catches and constant fishing mortalities) for the evaluation of possible standard management strategies, considering the catch and fishing mortality as management parameters. Outputs are long-term averages.

		2018	**2025**								
			Harvest strategy (catch)					**Harvest strategy (Fishing mortality)**			
			MSY	**0.9 MSY**	**0.8 MSY**	**0.7 MSY**	**Lower CI MSY**	**F_{MSY}**	**0.9 F**	**0.8 F**	**0.7 F**
BC_GM	Catch (t)		16,491	14,842	13,193	11,544	9,641	16,481	16,315	15,823	15,002
	F	0.518	0.546	0.413	0.331	0.270	0.212	0.596	0.536	0.476	0.417
	B/B_{MSY}	1.190	1.091	1.299	1.439	1.545	1.644	1.000	1.099	1.199	1.299
	F/F_{MSY}	0.870	0.916	0.692	0.556	0.453	0.355	1.000	0.900	0.800	0.700

The values of relative biomass and exploitation rate resulting from the application of the different management strategies (catch and fishing mortality) were plotted in a Kobe plot to show the predicted status of the fishery in 2025 (Figure 11).

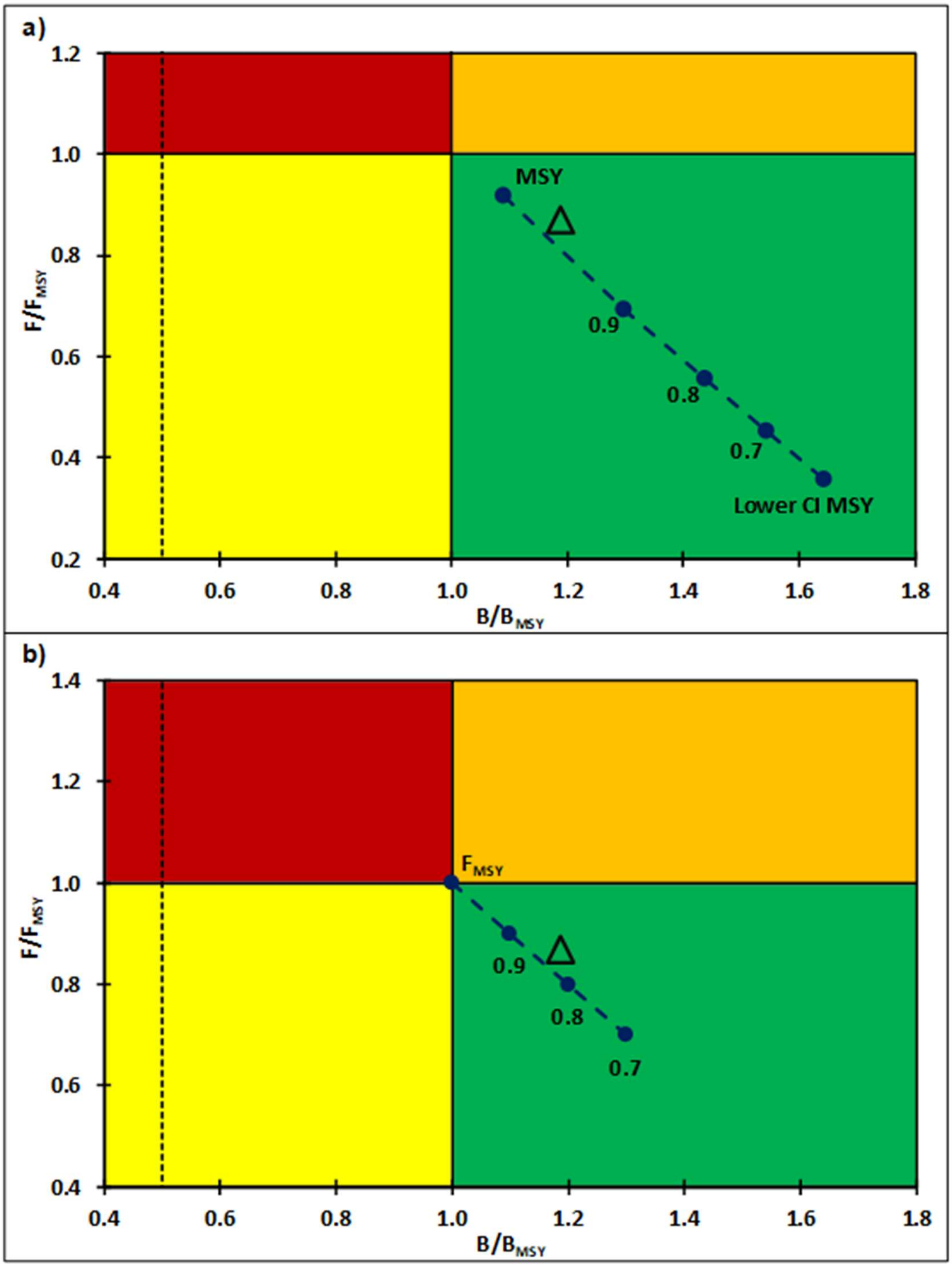

Figure 11.- Evolution of the Mexican blue crab (*Callinectes sapidus*) fishery in the Gulf of Mexico, projected to 2025, as a result of applying constant catch (panel a) or constant fishing mortality (*F*) (panel b) management strategies. The dashed line shows the LRP_{BMSY}. The open triangle show fishery status in 2018.

Management Options Outcome Analysis

The result of this analysis shows that the application of a range of constant catch limits as the key management measure does influence the outcome of fishery performance and stock status. With a constant annual catch equal to the estimated value of MSY (16,491 t), the probability that the stock biomass in 2025 falls below the LRP_{BMSY} is 0.39, noting that a probability of being below the LRP_{BMSY} of 0.39 represents a relatively high LRP-breaching risk. For constant catch equal to MSY, the probability of the stock being between the LRP_{BMSY} and TRP_{BMSY} is 0.10, and of being equal to or greater that the TRP_{BMSY} is 0.51 (Figure 12, Table 4). The outcome status of the stock projected to 2025 for a range of different levels of constant catch and constant effort in relation to MSY, are also shown in Table 4.

Table 4: The outcome status of the stock in 2025 given implementation of different constant catch or effort management options.

Constant management option	**Probability of being ≤ LRP_{BMSY}**	**Probability > LRP_{BMSY} and < TRP_{BMSY}**	**Probability of being ≥ TRP_{BMSY}**
Catch = MSY = 16,491 t	0.39	0.10	0.51
Catch = 0.9 MSY = 14,842 t	0.30	0.10	0.60
Catch = 0.8 MSY = 13,193 t	0.22	0.09	0.69
Catch = 0.7 MSY = 11,544 t	0.15	0.08	0.77
Catch = Lower CI MSY = 9,641 t	0.09	0.06	0.85
Effort = F_{MSY}	0.39	0.10	0.51
Effort = 0.9 F_{MSY}	0.38	0.10	0.52
Effort = 0.8 F_{MSY}	0.35	0.10	0.55
Effort = 0.7 F_{MSY}	0.31	0.10	0.59

Figure 12 can be used to help select reference points and an LRP breach risk that will enable managers to keep the stock in a healthy state. For example, the level of sustainable catch that can be taken for a range of LRP breach risk from, say 5% to 20% can be determined, noting that these are lower than the MSY estimated in this study. Managers will need to consider the uncertainties inherent in this low information assessment methodology against the risk of overexploiting the stock by setting reference points and thus catches too high.

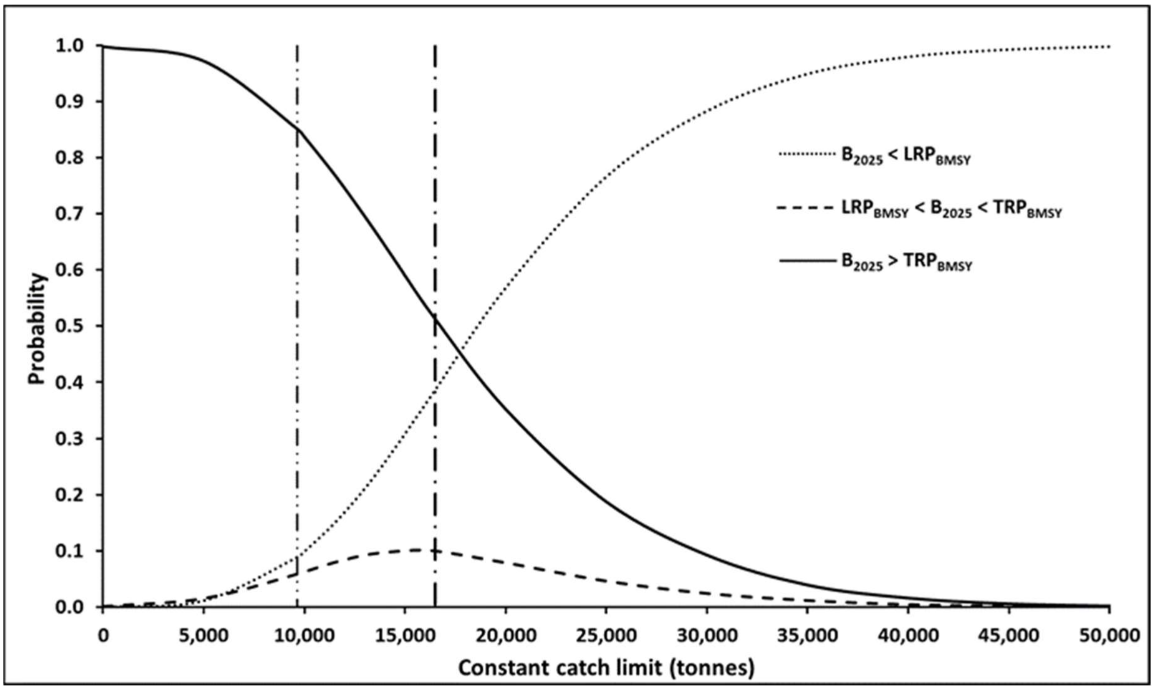

Figure 12.- Analysis assuming different values of a constant catch limit as the key management measure and the resulting probability on population biomass in the year 2025 falls below the LRP_{BMSY} (dotted line), remains between the LRP_{BMSY} and the TRP_{BMSY} (dashed line) and above TRP_{BMSY} (solid line) compared to candidate reference points. The vertical lines show the value of MSY (dash dot line) and the lower CI MSY (dash dot dot line).

7. Conclusions

The C-MSY method determines the most viable pair of r-k that corresponds to the estimated biomass trajectory that is compatible with the observed catches and, from there, estimates the relative biomass ranges for the beginning and end of the respective time series and the respective reference points. In general, the confidence intervals indicate that the possible true value is within that range, and in the blue crab fishery of the Mexican Gulf of Mexico the confidence intervals were wide for all the estimated parameters. With more robust fishery and fishery-independent data, different models could be applied, which could reduce these uncertainties. For a data limited fishery, such as this one, the C-MSY method provides a basis for the provision of scientific advice on which to base interim fishery management decisions such as a the harvest strategy and harvest control rules, to be refined when more robust data become available.

The C-MSY model yielded a value of *r*, which indicates the maximum net productivity is equal to 1.190 with confidence intervals of 0.957 to 1.480, that could be explained by a wide range of large stock sizes and low productivity (high resilience), or by a narrow range of small stock sizes and high productivity. The estimated value of *r* is within the high resilience range proposed by Froese *et al.* (2017), indicating a high recovery capacity of these species in the event of a possible diminution of the stock due to fishing pressure.

The equilibrium curve shows us a stock with high resilience (typical of these species) and with a decreasing biomass pattern with increasing effort, including the phases of decrease, increase and equilibrium, as shown by the position of the points below, above and near the equilibrium curve, respectively.

The C-MSY model yielded an estimate of MSY of 16,491 t, a B_{MSY} of 27,687 (the candidate TRP_{BMSY}), and an estimate of F_{MSY} of 0.596 (candidate LRP_{FMSY}). During the last five years of the analyzed period the Mexican crab fishery in the Gulf of Mexico has shown an increase in its catch volumes, the average catches in that period was one and a half times higher than the general average, with catches exceeding MSY in the last three years. This may have played a large role in the commensurate decrease in the population biomass, which has declined to a level approaching the candidate TRP_{BMSY}. The exploitation rates from 2012 showed a constant increase, reaching levels very close to the candidate LRP_{FMSY} in the last year, which represents a precautionary situation.

The fact that the catches have exceeded MSY in recent years indicates that the applied fishing effort was using more than the available surplus biomass, causing it to decrease. Fortunately, this stock has not yet decreased below the candidate limit reference point for biomass (LRP_{BMSY}) or $0.5B_{MSY}$.

Jacobson *et al*. (2001) mentions that, for stocks with long time series, the biomass decreases are pronounced when the captures exceed the surplus production for a 5-year period or more.

The Kobe plot shows that the trajectory of the size and evolution of the blue crab stock over the time series remained in good condition (green quadrant), with a healthy population that is not experiencing overfishing. The management indicators in the Kobe plot show the uncertainty of the results, and indicate that there is 0.644 probability that the status is in the green quadrant, and a 0.259 probability that the status is in the orange quadrant (healthy population but overfishing occurring), a 0.034 probability that the status is in the yellow quadrant (overfished population, but not experiencing overfishing), and a 0.063 probability that the status is in the red quadrant (overfished population with overfishing occurring).

Projecting stock status forward for five years to 2025, allowed evaluation of different constant catch limits and different constant fishing mortality limits as alternative management strategies. Assuming the starting point biomass estimate in 2015 is robust, these results show that, for the blue crab stock to retain good status in 2025 (i.e. $B_{2025} \geq B_{MSY}$) with no overexploitation, a maximum catch level less than MSY or fishing mortality no greater than FMSY would be required (Figure 10 and Table 3). This also can be seen from the management outcome projections to 2025 (Figure 12 and Table 4) which show that if a constant catch limit equal to MSY is applied, there is a 0.51 probability that the biomass will remain above the TRP_{BMSY}, and there is a 0.39 probability that the biomass will be below the LRP_{BMSY}. A constant catch limit equal to or less than 0.9 MSY increases the probability that the biomass will be above the TRP_{BMSY} in 2025 to 0.60, and decreases the probability that the biomass will be below LRP_{BMSY} to 0.30.

Based on the foregoing, it is considered that the crab fishery in the Mexican Gulf of Mexico is not overfished, with the current biomass above the candidate TRP_{BMSY}, and is not experiencing overfishing, with fishing mortality values below the candidate limit reference point associated with F (F_{MSY}). However, due to the uncertainties inherent in a data-poor fishery, and a need to implement a precautionary approach, we recommend that catches be limited to no more than 0.9 MSY (or fishing mortality to 0.9 F_{MSY}).

8. Recommendations

- Fishery scientists and managers of the Gulf of Mexico blue crab fishery should formally adopt the C-MSY methodology and candidate reference points, described here, to enable on-going evaluation of stock status and provision of scientific advice to managers.
- Managers of the Gulf of Mexico blue crab fishery should formally adopt the candidate reference points (at least as interim RPs) and use these in managing the fisheries.
- To better understand the blue crab stock genetic structure and distribution in the Gulf of Mexico, it is recommended to expand the genetic studies to cover the distributional range of blue crab in the Gulf of Mexico.
- To maintain the biomass of the Mexican blue crab stock in the Gulf of Mexico at a sustainable level (i.e. around B_{MSY}), it is recommended to establish and enforce, as a precautionary management strategy, an annual Total Allowable Catch (TAC) of around 0.9 MSY of 14,842 t (or fishing mortality limits at or below 0.9 F_{MSY}).
- To strengthen the sustainability of the Mexican blue crab fishery in the Gulf of Mexico and fully adopt a precautionary approach, it is recommended to harmonize the regulatory framework through the development of Mexican Official Standard that regulates the Gulf of Mexico blue crab fishery, including minimum legal size, protection of egg bearing females, management strategies to protect reproduction and recruitment, and fishing access and effort controls.
- To improve the stock assessment, it is recommended to establish a comprehensive biological monitoring program, including at least, catch and landings, size frequency, weight-at-size, and sex data.
- It is recommended to establish an annual blue crab stock assessment program to routinely evaluate the fishery performance and management outcomes for this stock. This should include early investigation of approaches to reduce the risk of breaching the LRP.
- In order to ensure scientific advice from the stock assessment program is appropriately developed and used to inform management, it is also recommended to establish a clear advisory and decision-making process to manage the fishery. This process would enable management based on the appropriate use of TACs, effort limitation, closed areas, closed periods, minimum landing sizes and using the accepted and periodically updated limit and

target reference points. This process should be open, transparent and inclusive, with some level of peer-review of the science, and with full and timely publication of assessments and management decisions.

9. References

Aires-da-Silva, A. y M.N. Maunder. 2011. Status of bigeye tuna in the eastern Pacific Ocean in 2009 and outlook for the future. Inter-Amer. Trop. Tuna Comm., Stock Asses. Rep. 11: 17-156.

Anderson Lee G. y J. C. Seijo. 2010. Bioeconomics of Fisheries Management. First ed. John Wiley & Sons, Ltd., Publication. 319 pp

Arreguín-Sánchez, F., L. Beléndez Moreno, I. Méndez Gómez-Humarán, R. Solana Sansores & C. Rangel Dávalos (Eds.). 2006. Sustentabilidad y Pesca Responsable en México: Evaluación y Manejo. Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Instituto Nacional de la Pesca. México. 544p.

Arreguín-Sánchez, F. y E. Arcos-Huitrón. 2011. La pesca en México: estado de la explotación y uso de los ecosistemas. Hidrobiológica 21(3): 431-462.

Barrowman, N.J. and Myers, R.A. (2000) Still more spawner–recruitment curves: the hockey stick and its generalizations. Canadian Journal of Fisheries and Aquatic Sciences 57, 665–676.

Beverton, R.J.H. and Holt, S.J. (1957) On the Dynamics of Exploited Fish Populations. Great Britain Ministry of Agriculture, Fisheries and Food, London.

Caddy J.F. & Mahon R. 1995. Reference points for fisheries management. FAO Fish. Tech. Pap. 347, Rome, 83 pp.

Chávez-L R, Rocha-R A, Vázquez-L H. 2019. Aspectos ecológicos de los estadios juveniles de *Callinectes sapidus* (Crustacea: Portunidae) en un estuario ciego del Golfo de México. Caldasia 41(2):422–432. doi: https://dx.doi.org/10.15446/caldasia.v41n2.70500.

Carruthers, T.R., Punt, A.E., Walters, C.J. et al. (2014) Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research 153, 48–68.

Díaz-de-León A., J. I. Fernández, P. Álvarez-Torres, O. Ramírez-Flores y L. G. López-Lemus. 2004. La sustentabilidad de las pesquerías del Golfo de México In: Margarita Caso, Irene Pisanty y Exequiel Escurra (Compiladores). Diagnóstico ambiental del Golfo de México. SEMARNAT. Instituto Nacional de Ecología. Instituto de Ecología. HRIGMS. Vol. 2. 727-756.

DAWE (2018). Commonwealth Fisheries Harvest Strategy Policy and Guidelines. Australian Government, Department of Agriculture, Fisheries and Forestry, 28p and 80p. https://www.agriculture.gov.au/fisheries/domestic/harvest_strategy_policy#:~:text=The%20harvest%20strategy%20policy%20provides,maintaining%20stocks%20at%20sustainable%20levels.

Froese, R., Demirel, N. and Sampang, A. (2015) An overall indicator for the good environmental status of marine waters based on commercially exploited species. Marine Policy 51, 230–237.

Froese, Rainer, Demirel, Nazli, Gianpaolo, Coro, Kleisner, Kristin M. and Winker, Henning. 2017. Estimating Fisheries Reference Points from Catch and Resilience. Fish and Fisheries, 18 (3). pp. 506-526. DOI 10.1111/faf.12190.

Gabriel W. L. and Mace, P. M. 1999. A review of biological reference points in the context of the precautionary approach. Proceedings, 5th NMFS NSAW. 1999. NOAA Tech. Memo. NMFS-F/SPO-40.

Guerra-Jiménez. L. A., R, E. Lara-Mendoza y A. G. Díaz-Álvarez. 2018. Estimación del máximo rendimiento sostenible para la pesquería de jaiba (Callinectes spp) en el Sur de Campeche. Mem. IX Foro Científico de Pesca Ribereña. Mazatlán, Sin. Octubre 16-18.

Gulf data, assessment, and review GDAR 01 (2013) Stock Assessment Report: Gulf of Mexico Blue Crab https://www.gsmfc.org/publications/GSMFC%20Number%20215.pdf

Haddon, M., Klaer, N., Smith, D.C., Dichmont, C.D. and Smith, A.D.M. (2012) Technical Reviews for the Commonwealth Harvest Strategy Policy. FRDC 2012/225. CSIRO. Hobart. 69 p.

Hilborn R. & Walters C. 1992. Quantitative Fisheries Stock Assessment. Choice, Dynamics and Uncertainty. Chapman & Hall, New York, 570 pp.

ICES. 2014. Report of the Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE IV), 27–31 October 2014, Lisbon, Portugal. ICES CM 2014/ACOM:54. 223 pp.

Jacobson, L.D, J.A.A. De Oliveira, M. Barange, M.A. Cisneros-Mata, R. Félix-Uraga, J.R. Hunter, J.Y. Kim, Y. Matsuura, M. Ñiquen, C. Porteiro, B. Rothschild, R.P. Sánchez, R. Serra, A. Uriarte y T. Wada. 2001. Surplus production, variability, and climate change in the great sardine and anchovy fisheries. Can. J. Fish. Aquat. Sci. 58:1891-1903.

Jul-Larsen, E., J. Kolding, R. Overå, J.R. Nielsen y P.A.M. Zwieten. 2003. Management, co-management or no management? Major dilemmas in southern African freshwater fisheries. 1. Synthesis report. FAO Fisheries Technical Paper. No. 426/1. Roma, FAO. 127 pp.

Laurence T. Kell, Josetxu Ortiz de Urbina and Paul De Bruyn. 2014. Kobe II strategy matrices for north atlantic swordfish based on catch, fishing mortality and harvest control rules. Collect. Vol. Sci. Pap. ICCAT, 70(4): 2009-2016.

Leo-Peredo A. S. y Enrique-Conde. 2014. Talla de primera madurez en jaiba azul (*Callinectes sapidus*) en Tamaulipas (2009-2013). Mem. VII Foro Científico de Pesca Ribereña. Mazatlán, Sin. Agosto 26-28.

Macedo D, Caballero I, Mateos M, Leblois R, McCay S, Hurtado LA. 2019. Population genetics and historical demographic inferences of the blue crab *Callinectes sapidus* in the US based on microsatellites. PeerJ 7:e7780 DOI 10.7717/peerj.7780.

Martell, S. y R. Froese. 2012. A simple method for estimating MSY from catch and resilience. Fish and Fisheries 14 (4): 504-514.

MFNZ (2008) Harvest Strategy Standard for New Zealand Fisheries. Ministry of Fisheries, Wellington, New Zealand, 27 p. https://fs.fish.govt.nz/Page.aspx?pk=113&dk=16543

Palacios-Fest, M. R., L. Domínguez-Trejo, C. E. Cotero-Altamirano y E. Arzate-Aguilar. 2000. Jaiba del Golfo de México y Mar Caribe. En: M. A. Cisneros-Mata, L. F. Belendez-Moreno, E. Zarate-Becerra, M. T. Gaspar-Dillanes, L. C. López-González, C. Saucedo-Ruiz y J. Tovar Ávila (eds.) Sustentabilidad y pesca responsable en México. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. pp 745-772.

Pesca Responsable y Comercio Justo. 2020. Pers. Comm. Interview on capture and landings composition for the Mexican Gulf of Mexico blue crab fishery.

Pescando Datos. 2021. Crab fishery fishing licenses for the Mexican Gulf of Mexico. Available at: https://pescandodatos.org/permisos#estado-actual-permisos

Ramírez, M.S. y Hernández, I. 1988. Investigación biológico pesquera para la obtención de la jaiba suave Callinectes spp. en la Laguna de Alvarado, Veracruz. ENEP Iztacala, Tesis. UNAM. 97 pp.

Ricker, W.E. (1975) Computation and Interpretation of Biological Statistics of fish Populations. Bulletin of the Fisheries Research Board of Canada 191, Ottawa, Canada, 382 pp.

Rodríguez-Castro, J. H.; A. Correa-Sandoval, J. A. Ramírez-de-León y J. A. Adame-Garza. 2017. Modelling the catch and development phases of the blue crab fishery (*Callinectes sapidus*) in the Laguna Madre, Tamaulipas, Mexico. CienciaUAT; Tamaulipas. Tomo 12, No. 1: 96-113. DOI:10.29059/cienciauat.v12i1.775.

Rodríguez-Castro J. H., J. A. Ramírez, G. Velázquez-de-la-Cruz & A. Correa-Sandoval. 2016. Evaluación del crecimiento de *Callinectes sapidus* (Decapoda: Portunidae) con métodos basados en talla, Tamaulipas, México. Rev. Biol. Trop. (Int. J. Trop. Biol. ISSN-0034-7744) Vol. 64 (2): 821-836.

Rosas-Correa, C. O y A. de Jesús-Navarrete. 2008. Parámetros poblacionales de la jaiba azul Callinectes sapidus (Rathbun, 1896) en la bahía de Chetumal, Quintana Roo, México. Biología Marina y Oceanografía 43(2): 247-253.

Rosenberg, A.A., Fogarty, M.J., Cooper, A.B., Dickey-Collas, M., Fulton, E.A., Gutiérrez, N.L., Hyde, K.J.W., Kleisner, K.M., Kristiansen, T., Longo, C., Minte-Vera, C., Minto, C., Mosqueira, I., Chato Osio, G., Ovando, D., Selig, E.R., Thorson, J.T. & Ye, Y. 2014. Developing new approaches to global stock status assessment and fishery production potential of the seas. FAO Fisheries and Aquaculture Circular No. 1086. Rome, FAO. 175 pp.

SAGARPA 2012. Anuario Estadístico de Pesca.

SAGARPA 2013. Anuario Estadístico de Pesca.

Schirripa, M.J. 2016. Projections, Kobe plots, and maximum sustainable yields for Atlantic bigeye tuna. Collect. Vol. Sci. Pap. ICCAT 72(2): 564-576.

Schnute, J.T. and Richards, L.J. (2002) Surplus production models. In: Handbook of Fish Biology and Fisheries, Vol. 2. (eds P.J.B. Hart and J.D. Reynolds). Blackwell Publishing, Oxford, UK, pp. 105–126.

Seijo, J.C.; Defeo, 0.; Salas, S. 1998. Fisheries bioeconomics. Theory, modelling and management. FA0 Fisheries Technical Paper. No. 368. Rome, FAO. 1998.108p.

Soto, L.A. 1979. Fishery aspects and ecology. Decapod crustacean shelf-fauna of the Campeche Bank. Gulf Caribb. Fish. Inst. Proc. 32th Ann. Sess. P. 66-81.

Villasmil, L.; y L. Mendoza. 2001. La pesquería del cangrejo *Callinectes sapidus* (Decapoda: Brachyura) en el Lago de Maracaibo, Venezuela. Interciencia. 26(7): 301-306.

Villegas-Hernandez, H, G. R. Poot-López, J. A. López-Rocha, C. González-Salas and S. Guillen-Hernández, 2017. Abundance and catchability estimates of the Atlantic blue crab *Callinectes sapidus* based on mark-recapture data from the northern Yucatan Peninsula. Journal of the Marine Biological Association of the United Kingdom, p 1 – 9.

Williams A. B. 1974. The swimming crabs of the genus Callinectes (Decapoda: Portunidae). Fishery Bulletin us 72(3): 685–798.