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

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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. 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.

2. 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).

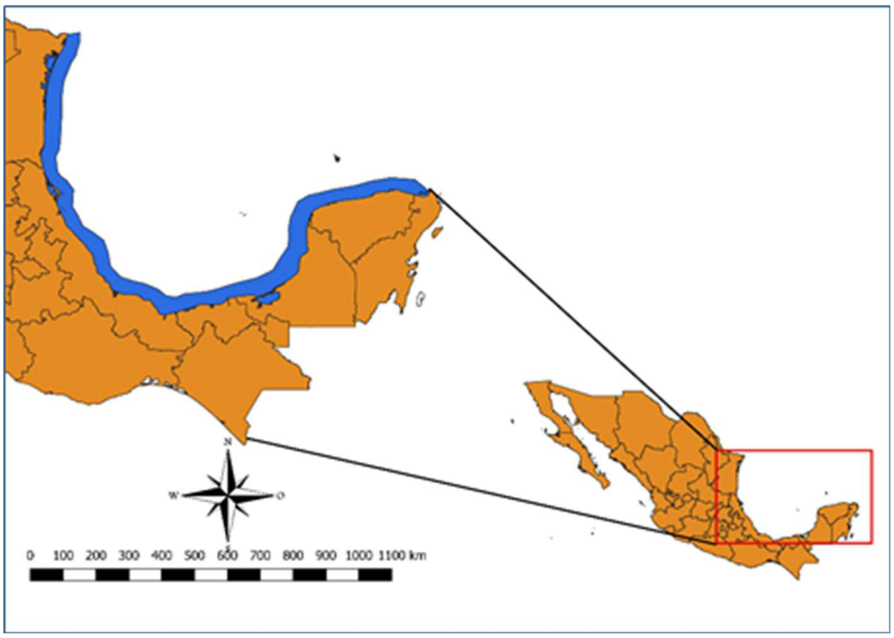

Figure 1. Study area for *C. sapidus* in the Mexican Gulf of Mexico

3. 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).

<u>Catch and Effort Trends</u>

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 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

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

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:

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

and the biomass of the following years as:

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

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).

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

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:

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

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

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

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.

4. 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 F_{MSY} 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}).

5. 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.