EVALUATION AND ESTIMATION OF REFERENCE POINTS FOR THE CRAB STOCKS (*Callinectes spp.*) FROM THE GULF OF CALIFORNIA AND WEST COAST OF BAJA CALIFORNIA SUR, MEXICO

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SUMMARY
In the Mexican Pacific, particularly the northwest region, the crab fishery has gained importance among the nearshore fisheries, occupying the second place in production volumes, after the shrimp fishery. 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 required to develop such estimates is often more difficult to obtain. Biological reference points to inform management are usually derived from models that are difficult to understand and often require 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), the biomass associated with MSY (B_{MSY}) and the fishing mortality associated with maximum sustainable yield (F_{MSY}), using limited data. A 1980-2018 official landings series was used, to determine the level of exploitation of the warrior (*Callinectes bellicosus*) and cuata (*C. arcuatus*) swimcrab resources for the Mexican Pacific northwest region (Gulf of California and west coast of the Baja California). For the Gulf of California, the warrior swimcrab the MSY and B_{MSY} found by the C-MSY method were 19,272 t and 32,356 t, respectively. For the Gulf of California cuata swimcrab the values of MSY and B_{MSY} were estimated at 4,479 t and 7,520 t, respectively, and, for the west coast of the Baja California warrior swimcrab, the values of MSY and B_{MSY} were estimated at 736 t and 1,236 t, respectively. The F_{MSY} value was 0.596 for the three stocks. The results indicate that the Gulf of California crab fishery is at maximum exploitation levels and is experiencing overfishing, while for the crab stock on the west coast of the Baja California peninsula, the estimated biomass for the last year of the series is below the B_{MSY}, potentially approaching an overfished state, and with the fishing mortality above the F_{MSY}, thus experiencing overfishing. To maintain the Gulf of California swimcrab species biomass at sustainable levels its recommended to establish and enforce annual Total Allowable Catches (TAC) around 17,345 t (0.9 MSY) for warrior crab fishery and 4,031 t (0.9 MSY) for cuata crab fishery or for both species fishing mortality limits at 0.9 F_{MSY}. For the Baja California Sur warrior crab fishery it is recommended, to establish and enforce annual TAC equal or below of 589 t (0.8 MSY) or fishing mortality limits at 0.9 F_{MSY}.

1. Introduction

Crabs of the genus *Callinectes* are benthic crustaceans of the Portunidae family that are characterized by their flattened dorso-ventral shape. As adults, they live in environments with soft substrates at depths of up to 40 m on the sea shore and in coastal lagoons. In the Pacific Ocean, *C. arcuatus* (Ordway, 1863) and *C. bellicosus* (Stimpson, 1859) are distributed from southern California, USA to Peru. Both are meroplanktonic species, with differential ontogenetic distributions: a pelagic larval phase and benthic phase in coastal lagoons and estuaries, where they grow and reproduce (Hendrickx 1984, Hernández & Arreola-Lizárraga 2007, Ramos-Cruz 2008). These species are exploited all along the Pacific coast of Mexico.

The marine, coastal lagoon and estuarine crab populations of support fisheries of great economic and social importance in the Gulf of California, if we consider the size of the catches and their wide geographic distribution (Fischer and Wolff, 2006). In the Mexican Pacific, this genus is represented by several species, though warrior and cuata swimcrab account for almost all the commercial catches.

The development of the crab fishery in the Gulf of California followed the collapse of the blue crab (*C. sapidus*) fishery in the US, which has been associated with overexploitation and deterioration of its habitat (Huato-Soberanis *et al* 2006). In the Gulf of California, mainly in Sonora and Sinaloa, the crab fishery began in the early 1980s and was fully developed by 1992, by which time it was an important fishery, equivalent to the shrimp fisheries in the bays and coastal lagoons of southern Sinaloa (Cisneros et. al. 2014a).

Within the Gulf of California, the warrior swimcrab is the most important, representing 81% of landings. In Sonora, warrior swimcrab represents more than 95% of the commercial landings and cuata swimcrab 5%. In Sinaloa, warrior swimcrab contributes 66% of the commercial landings, cuata swimcrab 30% and the rest is giant swimcrab (*C. toxotes*). In Baja California (primarily the eastern coast) and Baja California Sur (primarily the western coast), warrior swimcrab constitutes 100% of the landings. These four states contribute 80% of Mexican crab landings recorded in the Pacific. (CNP 2018; DOF 2018).

Fisheries management generally involves making decisions regarding fishing effort based on a population size assessment and population dynamics, in order to maintain desired levels of exploitable biomass over time (Anderson and Seijo, 201; 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 often 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, with a technical and scientific basis, is the legal instrument that serves as a reference for the Federal Government to establish the condition of the fisheries in the country, and from there to formulate actions for the administration of the fisheries.

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

In the section on regulations and instruments of fisheries policy and management, the Pacific swimcrab fishery profile contained in the National Fisheries Chart 2017 (DOF 2018) mentions as management instruments:

- (i) the Mexican Official Standard that establishes the conditions for its use NOM-039-PESC-2003 (DOF: 07/26/2006);
- (ii) the existence of a fishery management plan for swimcrabs in Sonora and Sinaloa (DOF: 07/15/2014);
- (iii) minimum legal sizes for the different species;
- (iv) establishes management strategies, such as a variable harvest rate;
- (v) establishes management tactics, including the control of fishing effort, minimum capture size, fixed temporal closures, refuge areas, and the release of egg bearing females.

However, no relevant management reference points to guide the exploitation of the resources are established, and there is no evaluation of the risks and best management options, as raised 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.

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 1996 in Sonora, before the establishment of the Mexican Official Standard (NOM), a committee comprised of capture sector representatives, with INAPESCA as the technical advisor, proposed a set of management measures in order to establish some basic limitations on harvest. These measures aimed to establish a temporary fishing ban, a minimum catch size, and a limit of 70 traps per boat (Molina-Ocampo 2000). However, these measures were not respected by all users as they were voluntary.

In 2003, INAPESCA, in coordination with CONAPESCA, considered it pertinent to integrate and analyze the results of investigations and monitoring on the swimcrab fishery and to propose the NOM that today regulates its capture. In July 2006, the Mexican Official Standard (NOM-039-PESC-2003) for responsible fishing of Pacific swimcrab was published, which also contains specifications for its use. In May 2012, the notice was published by which, for the first time, an official closure was decreed for swimcrab fishing in Sonora and Sinaloa, from May to August, starting in 2013. In 2014 and 2015, a fishery closure was again implemented during the summer, but shortening the fishing period only for females by three weeks.

The only population genetics study carried out in the Mexican Pacific indicated that in the northwestern part there is genetic flow between warrior swimcrabs from different localities (Pfeiler *et al*. 2005). However, the gene flow rates between swimcrabs in different areas are not known, nor have detailed studies been performed to test the similarities/differences between phenotypic parameters of swimcrabs found in different locations along the Pacific coast. Therefore, the stock structures of these crab species remain uncertain.

The first investigations about the swimcrab resources in the Pacific were carried out by INAPESCA through the Regional Fisheries Research Centers (CRIP) of Guaymas, Sonora, and Mazatlán, Sinaloa, in 1997, when the fishery was already five years old and fully developed, which was described in the "Libro Rojo" Sustentabilidad y Pesca Responsable en México (Molina-Ocampo *et al.* 2006).

As of July 2011, INAPESCA, through Guaymas CRIP and the INAPESCA office in Mazatlán, began the development of a management plan for the crab fisheries in Sonora and Sinaloa. Vision, Objectives, Lines of Action and Goals were defined in a series of workshops. This plan was published in 2014.

In Sonora, the first investigations carried out were aimed at recording information from landings on the beach, in the factory and onboard commercial fishing vessels to document lengths and weights of the organisms and their sex-ratios, as well as the macroscopic categorization of gonadic maturity (Molina-Ocampo and Montemayor-López, 1998). Hernández and Arreola-Lizárraga (2007) provided information on the size-structure and growth parameters of warrior and cuata swimcrabs in Las Guásimas coastal lagoon. In both species the width-weight relation showed that males are bigger than females, with an isometric growth tendency being observed. Rodríguez-Domínguez *et al*. (2012), using a multi-model inference (MMI) approach for both sexes, found significant differences in the asymptotic carapace width between males and females of warrior swimcrab, due to the fact that females present a terminal molting process when they reach maturity age.

Balmori-Ramírez *et al.* (2009 a and b), carried out studies evaluating the retention of crab in traps with different sizes of escape windows.

Among the studies carried out in lagoons and estuaries along the Pacific coast of Mexico are those of Williams (1974), Paul (1982 a, b) and Rodríguez-Domínguez *et al*. (2012). In particular, for the Sonora coast, the researches of Montemayor-López (2001), Arreola-Lizárraga *et al*. (2003) and Nevárez-Martínez *et al.* (2003). Reproduction studies are essential for fisheries management to understand the basic population dynamics. The estimation of age and size at first sexual maturity is essential to determine an appropriate size at first catch, which is intended to protect juveniles and ensure that individuals participate in at least one reproductive event before entering the fishery and thus avoid compromising future recruitment. The warrior swimcrab is a resource with high fishing potential, for this reason, it is necessary to expand the knowledge about its biological aspects to strengthen the strategies for its management (Rodríguez-Félix *et al*. 2015).

Studies on swimcrabs feeding have been carried out in Baja California Sur (Rodríguez-Rojero 2004). In Magdalena Bay, the warrior swimcrab reproduces from July to August, which is related to the higher sea temperatures, although a second reproductive pulse has been detected in March-April (Sánchez-Ortíz and Gómez-Gutiérrez, 1992). Recent studies indicate that the warrior swimcrab fishery in Magdalena Bay is aimed at larger males; this activity takes place in April through August (Castañeda-Fernández de Lara *et al*. 2015).

Huato-Soberanis *et al*. (2006) for Sinaloa and Sonora, suggests that the fishery reached, and possibly surpassed, its optimum development since the 1990s, the annual biomass values show a decreasing trend. This work estimates for Sinaloa a maximum biomass of all the species of swimcrab (warrior, cuata, and giant) of between 10,800 and 21,200 t, and concludes that the combined catches of these species should not exceed the range of 3,180 to 4,995 t annually. In the case of Sonora, the estimated maximum biomass of the warrior swimcrab stock was between 8,800 and 21,600 t and that the annual yield should be between 3,240 and 3,960 t.

In 2006, Molina-Ocampo and collaborators conducted an evaluation of the fisheries in Sinaloa and Sonora and found that, in 2002, the warrior swimcrab stock was fully exploited. In Sonora an analysis indicated that the decreasing trend of biomass stabilized and from 2008 it increased slightly (Cisneros-Mata *et al.* 2013).

Estimates of swimcrab abundance have been made in some of the areas fished. For Baja California Sur, González-Ramírez *et al*. (1990), through the analysis of monthly logs of the daily catch of swimcrab fishermen in Bahía Magdalena-Almejas, estimates of the average monthly abundance per trap indicated that the highest relative abundance of the warrior swimcrab was registered in June and July. These abundance values are associated with localities with seagrass and macroalgae.

For Sinaloa, Ramírez-Félix *et al*. 2003, in the localities of Ceuta (2001), Santa María (1999), Topolobampo (1999), Navachiste (2000), Ensenada del Pabellón-Altata (2000) and Santa María-La Reforma (2000), by the transect and count method, and using traps and pots as a sampling unit, estimated the abundance in number of crabs and total biomass of warrior and cuata swimcrabs. The total biomass for these localities was 5,260 t for cuata swimcrab and 12,347 t for warrior swimcrab. Cisneros-Mata *et al* 2014 b, estimated abundance for the warrior swimcrab using a tag, release and recapture method.

Rodríguez-Domínguez *et al.* 2014, applying the method of Martel and Froese, 2012, for the *Callinectes spp* swimcrabs fishery for the state of Sinaloa and Sonora, with official landings records until 2012, concluded that the fishery was at the maximum sustainable level. Ortega-Lizarraga *et al*. 2020, with a landings history from 1993 to 2012, applying the same method, determined a maximum sustainable yield (MSY) for the state of Sinaloa, Mexico of 7,895 t and estimated the then current (2012) biomass to be below B_{MSY} (i.e. the biomass was less than that which would yield MSY), concluding that catches for that area should be reduced.

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, a fully factorial simulation testing framework was developed 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 populations in these areas and estimate candidate reference points for these fisheries.

3. Objectives

- To determine the stock status of the swimcrab stocks in the coast of the Gulf of California and the west coast of Baja California.
- To estimate appropriate candidate reference points for these different stocks of swimcrabs.

4. Study Area

The study area includes the coast of the Gulf of California and the west coast of the Baja California Sur state (Figures 1 and 2).

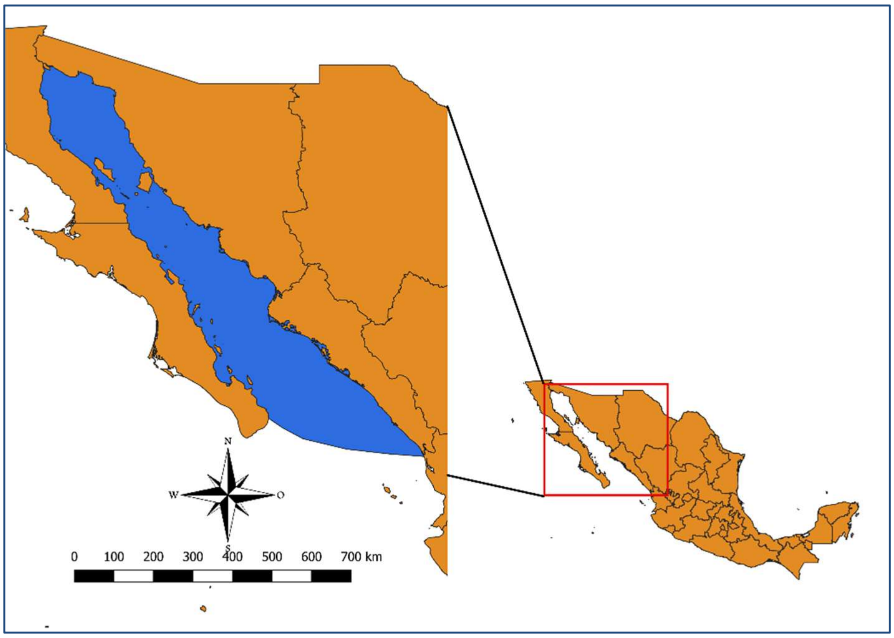

Figure 1. Study area for *C. bellicosus* and *C. arcuatus* in the Gulf of California

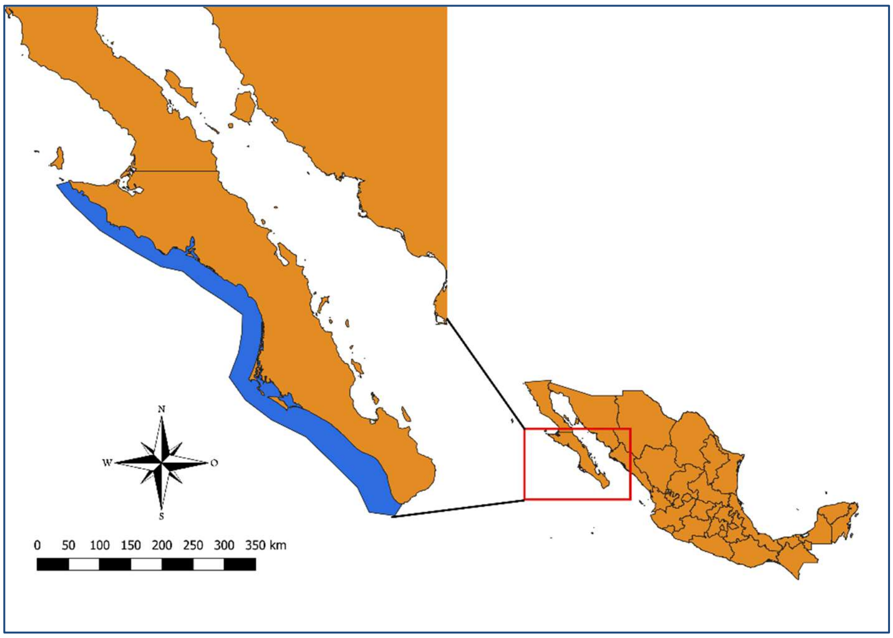

Figure 2. Study area for *C. bellicosus* on the west coast of Baja California Sur.

6. 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 Catch-MSY (C-MSY) method described by Froese *et al.* 2017.

<u>Catch Trends by Stock</u>

The information on the live weight catches was taken from official crab catch records from the Statistical Fishing Yearbooks for the 1980 to 2018[1] period. In this base, all the species of the *Callinectes* family that bear the common name crab were grouped and later they were disaggregated by species, according to the participation percentages described in the National Fisheries Chart 2018.

<u>Stock Assessment, Limit Reference Point (LRP), Target Reference Point (TRP) Fishing Mortality (F)-based Reference Points</u>

For the purposes of this study the warrior swimcrab fishery in the Gulf of California was considered to fish on a single stock (WC_GC), according to Pfeiler *et al*. 2005. The warrior swimcrab from the West coast of the Baja California Sur, was also considered a separate, single stock (WC_BC). Similarly, the cuata swimcrab from the Gulf of California was evaluated as a single stock (CC_GC).

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}). This method requires the estimation of 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 stock-based 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.

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

Part of the C-MSY package is a spatial implementation of the Bayesian state 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:

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

Where:

B_t = Biomass at time t

B_{t+1} = Biomass one time-step after t

C_t = Capture at time t, and

exp (vt) = 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 (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 swimcrab stocks for the three fisheries varied between 50% and 90% ($B/k = \lambda_{i1}, \lambda_{i2}$) of their respective carrying capacities (k), and in the last year, between 30% and 70% ($B/k = \lambda_{f1}, \lambda_{f2}$) for the warrior (WC_GC) and cuata (CC_GC) swimcrab stocks in the Gulf of California and between 30% and 40% for the west coast of Baja California stock (WC_BC). The biological plausible range for r for species with high resilience ($0.6 < r < 1.5$ Froese *et al.* 2017) was considered appropriate for all the crab stocks.

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

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

$$B_{MSY} = 0.5\,k, \qquad \text{Eqn 5}$$

$$F_{MSY} = 0.5\,r, \qquad \text{Eqn 6}$$

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

$$F_{MSY} = 0.5\,r\,4\,B/k. \qquad \text{Eqn 7}$$

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

By means of the equilibrium curve graph (Equation3), the relation of the relative biomass of the population (B_t/k) vs 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 (SP) in a period of time t of a population subject to fishing is defined as (Anderson and Seijo, 2010, Seijo *et al.* 1997):

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

Where *r* is the intrinsic rate of population growth and k is the carrying capacity of the population.

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

$$B_{t+1} = B_t e^{\rho_t - F_t} \qquad \text{Eqn 9}$$

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_t) as follows (Jacobson *et al.* 2001):

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

Units are by time and measure the instantaneous population growth rate resultant from 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. The 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 of 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 MSY, the lower confidence interval of 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}.

7. Results

a) Fishery Indicators

Capture Behavior

With the data from the fishing statistical yearbooks (1980-2018), Figure 3 was elaborated. This shows the time-series of landings of swimcrabs in waters of the Gulf of California. During this period of time annual landings have averaged 9,200 t, with a general increase in volumes throughout the series, including periods of ups and downs, reaching a maximum value of 31,000 t in the last year of the period analyzed. Of these landings volumes, the warrior swimcrab represents 82% of the total volume. The WC_GC annual landings trend shows an increase over time but with great variability. The average annual value during the time series was 7,505 t, the lowest catch was 49 t (in 1984), reaching the highest catch value (25,602 t) in the last year of the period analyzed. The CC_GC landings show a trend similar to that of the WC_GC, with some oscillation. The average annual value was 1,595 t and the lowest catch was obtained in 1984 with 6.7 t, reaching the historical maximum in 2016 with 6,336 t. The average annual landings for both stocks of the last 5 years (2014 to 2018) was 22,140 t for the WC_GC swimcrab, and for the CC_GC swimcrab the average was 5,394 t.

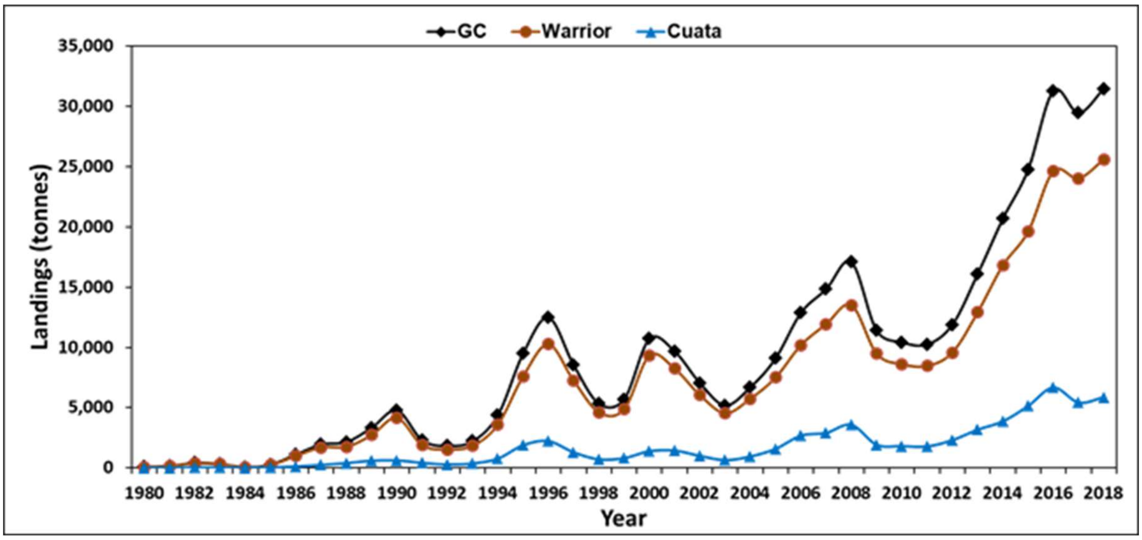

Figure 3.- Total landings of swimcrabs in Gulf of California (GC), as well as species-specific (warrior and cuata swimcrabs) landings from the Gulf of California.

With regard to the crab fishery in the west coast of Baja California, the only species captured is warrior (WC_BC) swimcrab, with catches first recorded in 1983 and where 75% of the catches are from the lagoon complex of Magdalena Bay-Almejas. The average annual landings on the west coast of Baja California during this period was 398 t. Figure 4 shows the WC_BC landings during the time series from 1983 to 2018, with a fluctuating pattern with no trend over most of the period but with a marked rise in landings beginning in 2014. The maximum annual landings of 1,387 t was taken in 2015. In the last 5 years of the time series the annual landing average was 940 t.

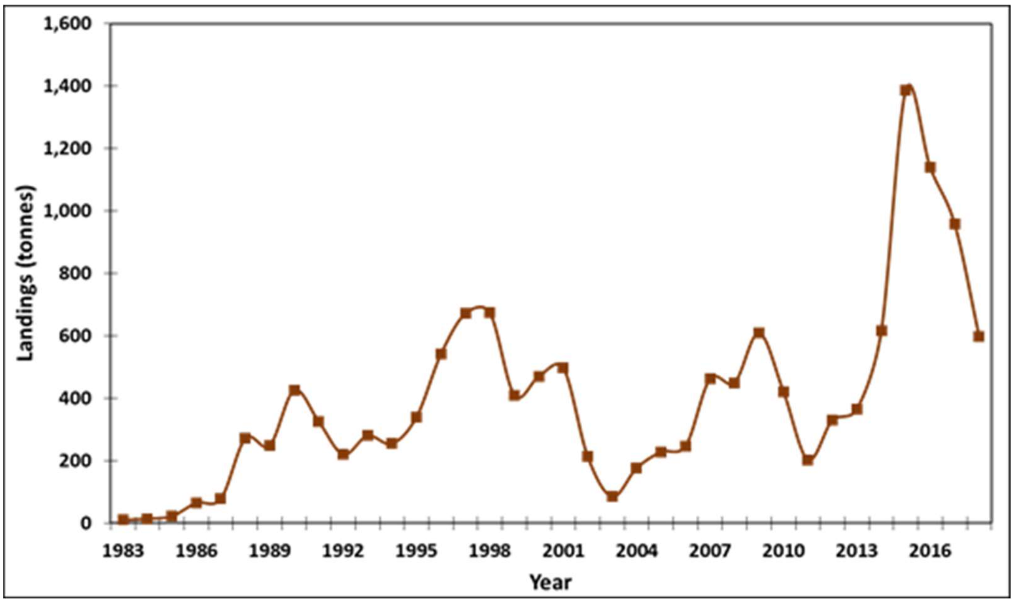

Figure 4.- Landings of warrior swimcrab (*C. bellicosus*) from the west coast of Baja California.

Effort

According to official data (National Fisheries Chart) in 2011, the fishery had 330 permit holders, 1,694 vessels and 3,384 fishermen in the Pacific coast of Mexico. Most of the permit holders were from Sinaloa (162), Sonora (78) and Baja California Sur (66), with 874, 461 and 169 vessels, respectively (Cisneros-Mata *et al.* 2014 a). The 2018 National Fisheries Charter mentions that there are 2,700 smaller vessels, of which 79% are in the Gulf of California. There are 8,000 traps in Baja California Sur; 43,600 traps in Sonora and 70,800 traps in Sinaloa. The number of boats in the Gulf of California participating in the swimcrab fishery increased by 42% in the 2011-2017 period.

b) Stock Assessment and Status

The results of the C-MSY method for the estimation of *r* and k, of the stocks of WC_GC, CC_GC and WC_BC through the Monte Carlo method, with the information of the catches and the previous input assumptions, are presented in Table 1 and Figures 5, 6 and 7, respectively. In the figures, Panel a) shows the most viable *r*-k pair values. The model yielded for each of the three examined populations, through the underlying principle that defines *r* as the maximum rate of increase for the examined population, among the highest viable *r* values, a value of maximum net productivity of r equal to 1.190 with confidence intervals of 0.957 to 1.480. Panel b) shows the biomass relative to the carrying capacity (k) of the population in the time analyzed. The biomass relative to k in the last year of the time series was 0.567 k and 0.536 k for the stocks of WC_GC and CC_GC, respectively, the WC_BC stock presented a relative biomass to k in the last year of 0.350 k. Panel c) shows the exploitation rate of the stock. In the last year for the stock of WC_GC the exploitation rate was 1.17, for CC_GC it was 1.11 and for WC_BC it was 1.16.

Table 1. – Assumed parameter and output results C-MSY method for the different stocks of swimcrab.

<table>
<tr><th rowspan="2">Stock</th><th colspan="4">Prior range values</th><th colspan="2">Carrying capacity
Median
(CI = 95 %)</th></tr>
<tr><th>Initial biomass relative λ_{i1} - λ_{i2}</th><th>Final biomass relative λ_{f1} - λ_{f2}</th><th>r</th><th>ki
(tonnes)</th><th>r</th><th>k
(tonnes)</th></tr>
<tr><td>WC_GC</td><td>0.5 - 0.9</td><td>0.3 - 0.7</td><td rowspan="3">0.6 - 1.5</td><td>16,505 - 165,050</td><td rowspan="3">1.190
(0.957 - 1.480)</td><td>64,713
(41,953 - 99,820)</td></tr>
<tr><td>CC_GC</td><td>0.5 - 0.9</td><td>0.3 - 0.7</td><td>3,683 - 36,828</td><td>15,039
(8,995 - 25,144)</td></tr>
<tr><td>WC_BC</td><td>0.5 - 0.9</td><td>0.3 - 0.4</td><td>774 - 7,743</td><td>2,471
(1,683 - 3,629)</td></tr>
</table>

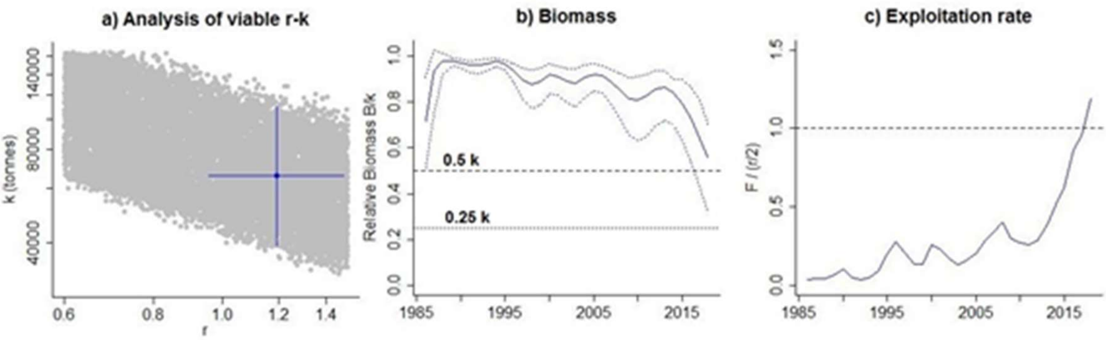

Figure 5. - Results of the C-MSY method for the warrior swimcrab stock in the Gulf of California (WC_GC). a) Analysis of the most probable combinations of r and k. The viable r-k pairs that fulfilled conditions are show in grey. The blue cross, with approximate 95% confidence limits, marks the most probable *r*-k pair. b) Stock status, biomass relative to the size of the population carrying capacity in the time analyzed with 2.5 and 97.5 percentiles. c) Exploitation rate of the stock.

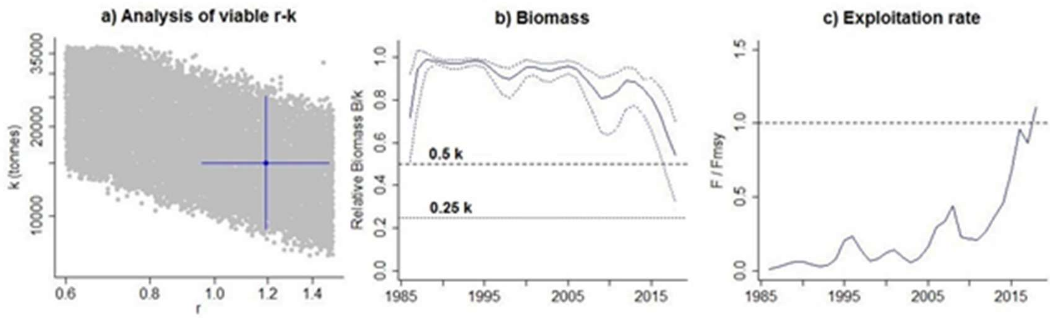

Figure 6. - Results of the C-MSY method for the cuata swimcrab stock in the Gulf of California (CC_GC). a) Analysis of the most probable combinations of r and k. The viable r-k pairs that fulfilled conditions are show in grey. The blue cross, with approximate 95% confidence limits, marks the most probable *r*-k pair. b) Biomass relative to the size of the population carrying capacity in the time analyzed with 2.5 and 97.5 percentiles. c) Exploitation rate of the stock.

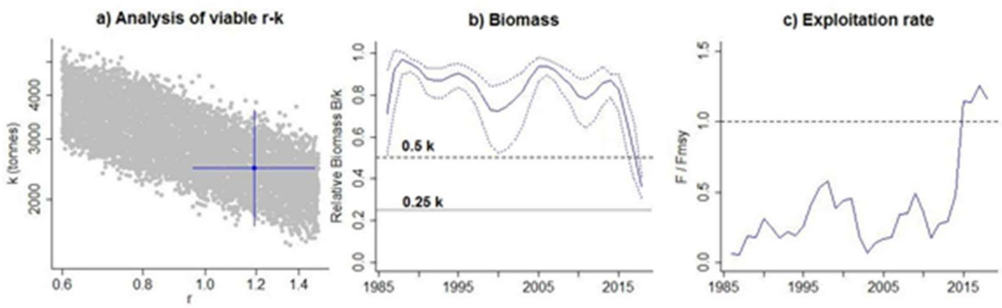

Figure 7.- Results of the C-MSY method for the warrior swimcrab stock off the west coast of Baja California (WC_BC). a) Analysis of the most probable combinations of r and k. The viable r-k pairs that fulfilled conditions are show in grey. The blue cross, with approximate 95% confidence limits, marks the most probable *r*-k pair. b) Biomass relative to the size of the population carrying capacity in the time analyzed with 2.5 and 97.5 percentiles. c) Exploitation rate of the stock.

It is worth noting that the steep rises in the estimated exploitation rates seen in Figures 5, 6 and 7 are entirely consistent with the timing of the rapid rise in landings presented in Figures 3 and 4 for each assessed stock.

Figure 8 shows the equilibrium curves (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). The equilibrium curves show the three stocks with a decreasing biomass, including phases of decline, increase, and equilibrium, as shown by the location of the points below, above, and near the equilibrium curve (blue dots). For the three stocks it is observed that during almost the entire period, these were kept around the equilibrium curve with relative biomass values higher than 0.5 B/k indicating catches that will maintain the corresponding biomass (Catch/MSY < 0.7). In recent years, the last four point values can be observed above and away from the equilibrium curve, suggesting a biomass decrease. For the stock of WC_BC (Figure 8c), the value of the last year is at levels close to the indentation of B/k < 0.25.

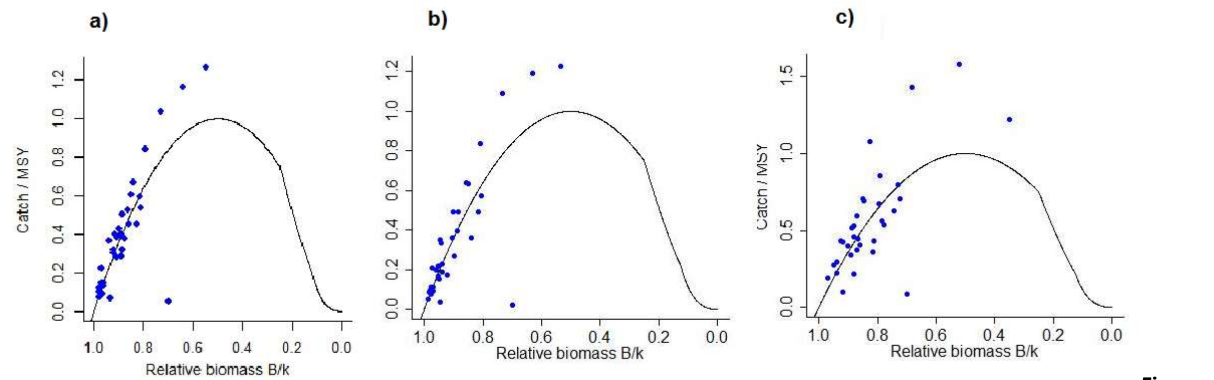

Figure 8.- Equilibrium curve of the Schaefer model (Equation 3) to explain reduced recruitment at low stock sizes. Panel a) WC_GC stock, panel b) CC_GC stock and panel c) WC_BC stock. The dots indicate values of catch relative to MSY and biomass relative to k.

<u>Surplus Production and Instantaneous Rate of Population Growth</u>

The surplus production (SP) (Equation 8) of swimcrab for the different stocks varied, with the lowest values for the stock of WC_BC which varied between 83 t and 734 t (Figure 9). The stock of WC_GC gave the highest values which varied between 1,555 t and 18,907 t, while for CC_GC the values varied between

208 t and 4,450 t. In Figure 9, the a) panels for each of the three populations shows the annual SP and its corresponding biomass for consecutive years. The initial SP value is located at the beginning of the period with the maximum biomass value and, as time progresses, the annual SP values tend to approach values close to B_{MSY}. In the particular case of the WC_BC population, the value of SP of the last year is below and to the left the B_{MSY}.

In Figure 9 the b) panes show the instantaneous rate of population growth (Equation 11) for each of the three populations. The instantaneous rate of population growth of WC_GC varied between 0.02 year^{-1} and 0.42 year^{-1}, while the WC_BC varied between 0.03 year^{-1} and 0.57 year^{-1}. For the CC_GC, the instantaneous rate of population growth varies between 0.01 year^{-1} and 0.44 year^{-1}. There is a rapid increase in instantaneous rate for all stocks in the last years of the period analyzed.

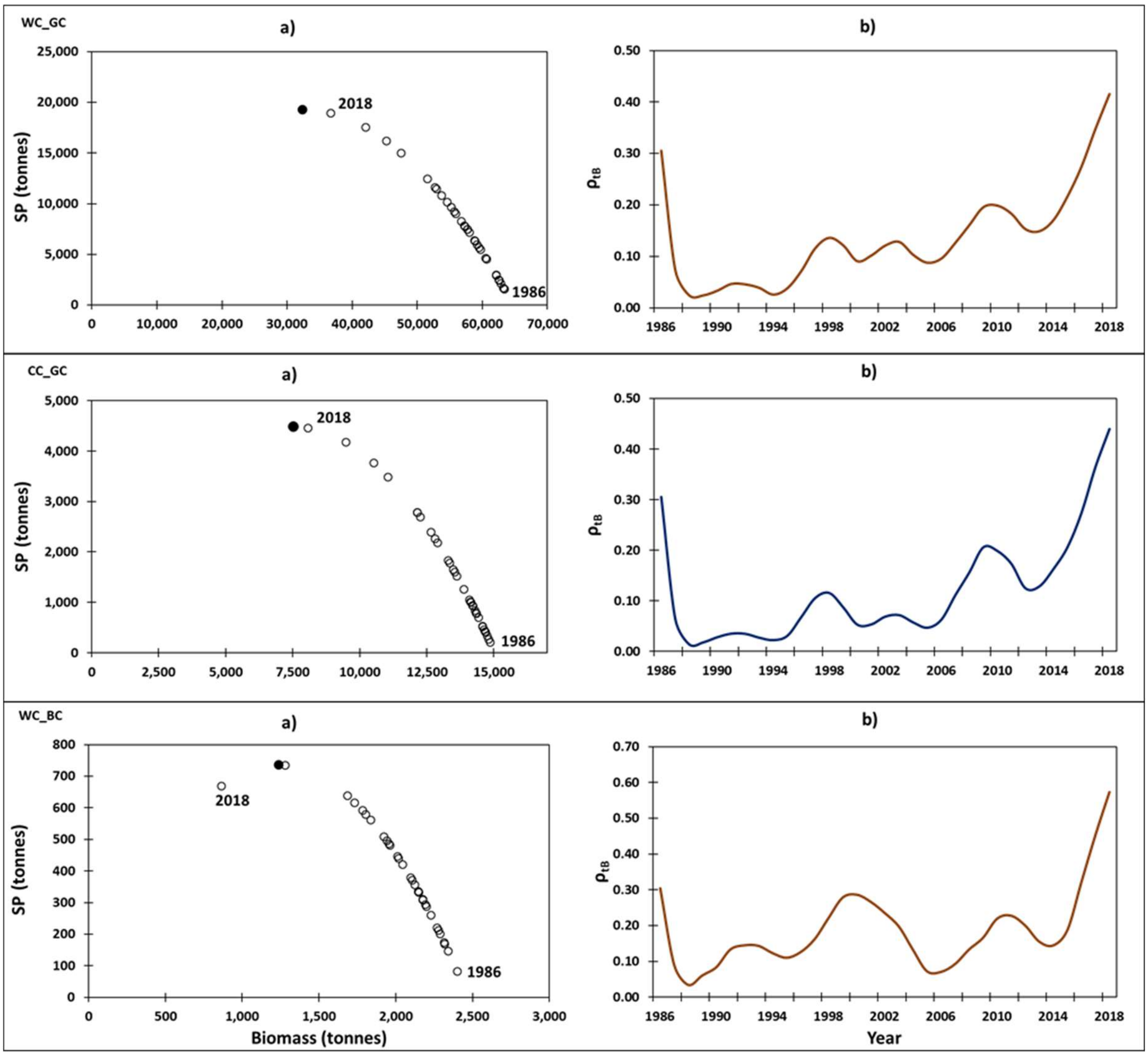

Figure 9.- a) Annual surplus production and biomass estimate for consecutive years of the different stocks of swimcrabs in the Gulf of California (GC) and the west coast of Baja California (BC) (the black point shows the TRP_{BMSY} value). b) Annual instantaneous rate of population growth.

At the end of the time series (2013-2018), an increase in the values of SP is observed for the WC_GC and CC_GC stocks (Figure 10a and 10b), while for the WC_BC stock, the values of SP show an increase and then a decline (Figure 10c). For all three stocks, the biomass shows a decrease and the landings values are above the surplus production, except for the WC_BC stock for which the landings value of last year is below the value of SP (Figure 10c).

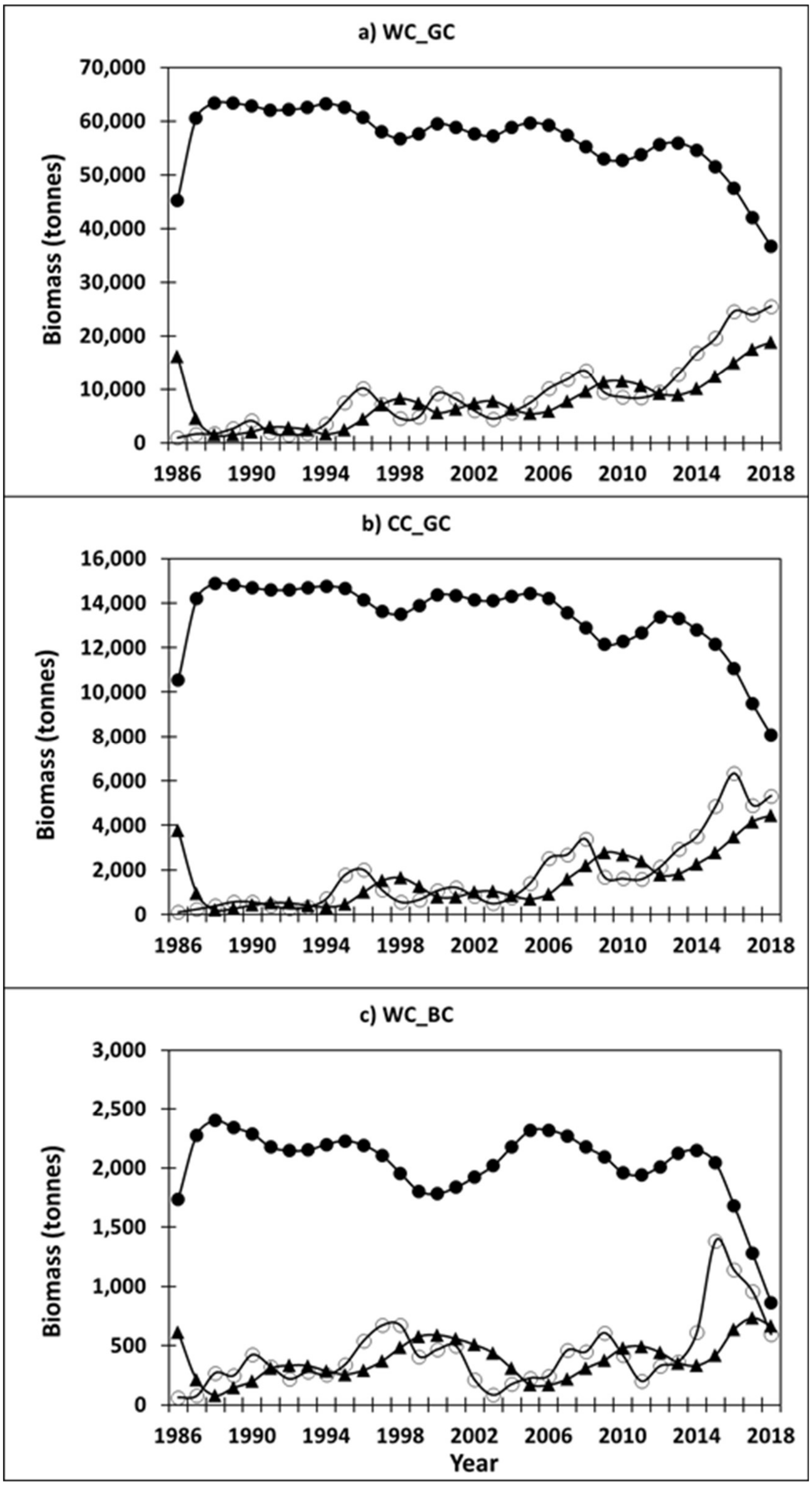

Figure 10. Annual Surplus production (solid triangles), landings (open circles) and biomass (solid circles) of the different stocks of swimcrabs in the Gulf of California (panel a warrior swimcrab and panel b cuata swimcrab) and the west coast of Baja California Sur (panel c warrior swimcrab).

Estimation of Candidate Target and Limit Reference Points for Management

The reference points (RPs) estimated by the C-MSY (MSY, B_{MSY} and F_{MSY}) for the three swimcrab stocks, and the candidate reference points associated with these 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 different stocks of the swimcrab fishery in the Gulf of California and the west coast of Baja California, Mexico.

Stock	Reference Points Estimated by C-MSY method			Candidate Reference Points for Management		
	Median (CI = 95 %)			Target	Limit	
	MSY	B_{MSY}	F_{MSY}	B_{MSY}	0.5 B_{MSY}	F_{MSY}
	Tonnes			Tonnes		
WC_GC	19,272 (12,647 - 29,367)	32,356 (20,977 - 49,910)	0.596 (0.479 - 0.741)	32,356	16,178	0.596
CC_GC	4,479 (2,510 - 7,992)	7,520 (4,498 - 12,572)		7,520	3,760	
WC_BC	736 (532 - 1,018)	1,236 (842 - 1,814)		1,236	618	

Gulf of California Warrior Swimcrab (WC_GC)

The MSY estimated by the C-MSY method for the WC_GC was 19,272 t. For this stock, for most of the time the catches were below the lower confidence interval (CI) of MSY with an increasing trend towards MSY (Figure 11a), until 2015 when the catches exceeded MSY and with an increasing trend to levels close to the upper limit of the MSY confidence interval. The biomass associated with the maximum sustainable yield, or TRP_{BMSY}, was 32,356 t. During most of the period analyzed the biomass trajectory (Figure 11b) remained fairly constant and well above the TRP_{BMSY}, but a drastic decrease to a level close to the TRP_{BMSY} can be observed beginning in 2015; Figure 11c shows the fishing mortality (F) throughout the time series compared to the LRP_{FMSY} of 0.596. The annual fishing mortality throughout most the time series is below half of the LRP_{FMSY} value, but from 2012 fishing mortality increased markedly, reaching a maximum value in the last year (F_{2018}) of 0.697, located above the LRP_{FMSY}; the exploitation rate for that year was 1.171.

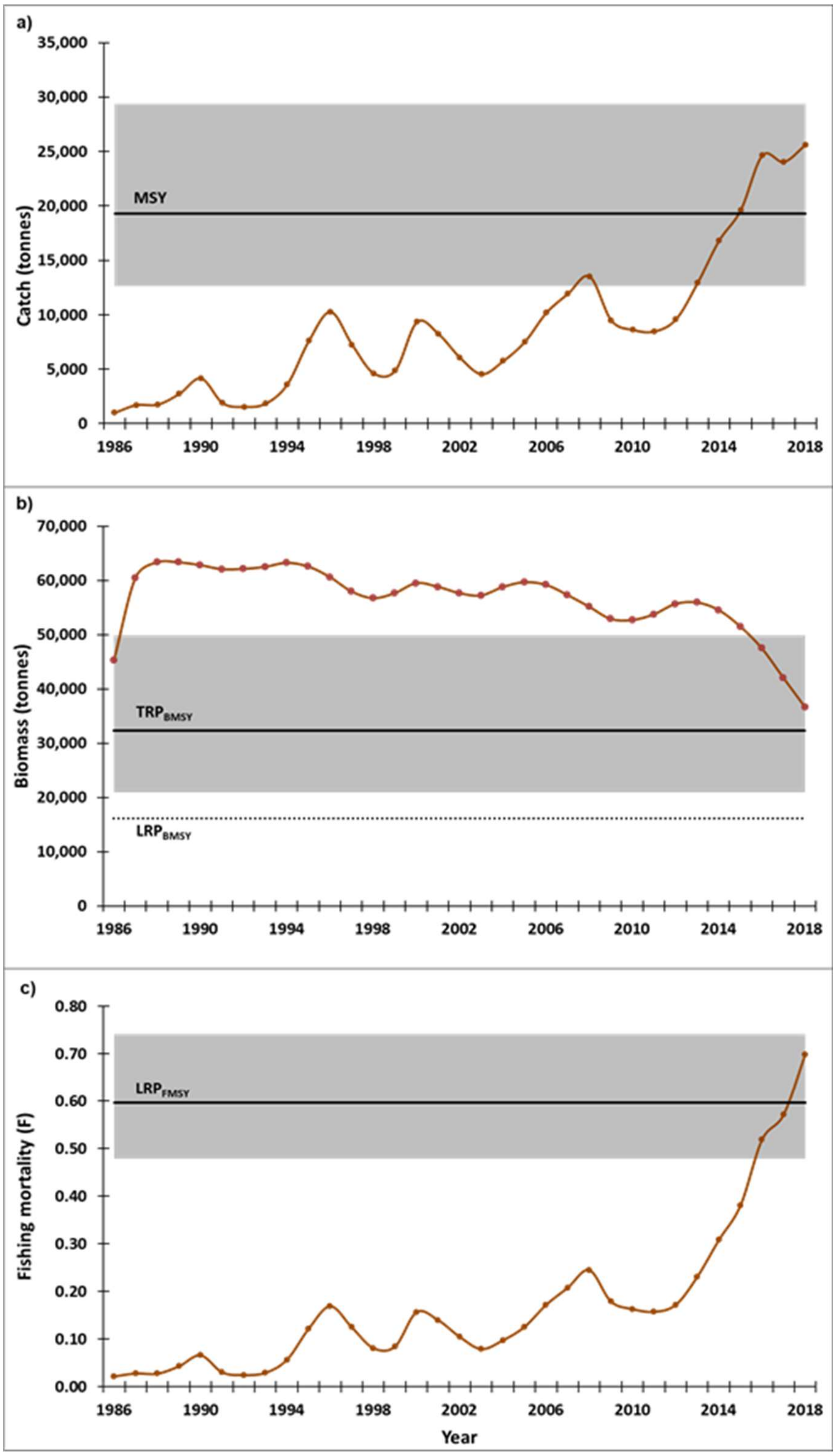

Figure 11. Results of the C-MSY method for management purposes based on Monte Carlo assessment for the stock of warrior swimcrab (*Callinectes bellicosus*) in the Gulf of California (WC_GC). a) Landings, MSY with 95% confidence

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).

Gulf of California Cuata Swimcrab (CC_GC)

The MSY estimated by the model for the CC_GC was 4,479 t. The landings from this stock were below the lower CI of MSY until 2005, varying between 500 t and 2,000 t and showing a trajectory of increase in landings towards MSY until 2015, when the landings were above MSY (Figure 12a). The biomass associated with the maximum sustainable yield, or TRP_{BMSY}, was 7,520 t. Until 2006, the biomass trajectory (Figure 12b) varied but remained at or above the upper CI of TRP_{BMSY} until 2015, after which the biomass shows a steep decrease to near the TRP_{BMSY}. Figure 12c shows the fishing mortality (F) throughout the time series compared to the LRP_{FMSY} of 0.590. The annual fishing mortality throughout the time series is below half of LRP_{FMSY}, but as of 2012 these increased markedly, reaching their maximum value in the last year (F_{2018}) of 0.660, above the LRP_{FMSY} and with an exploitation rate for that year of 1.110.

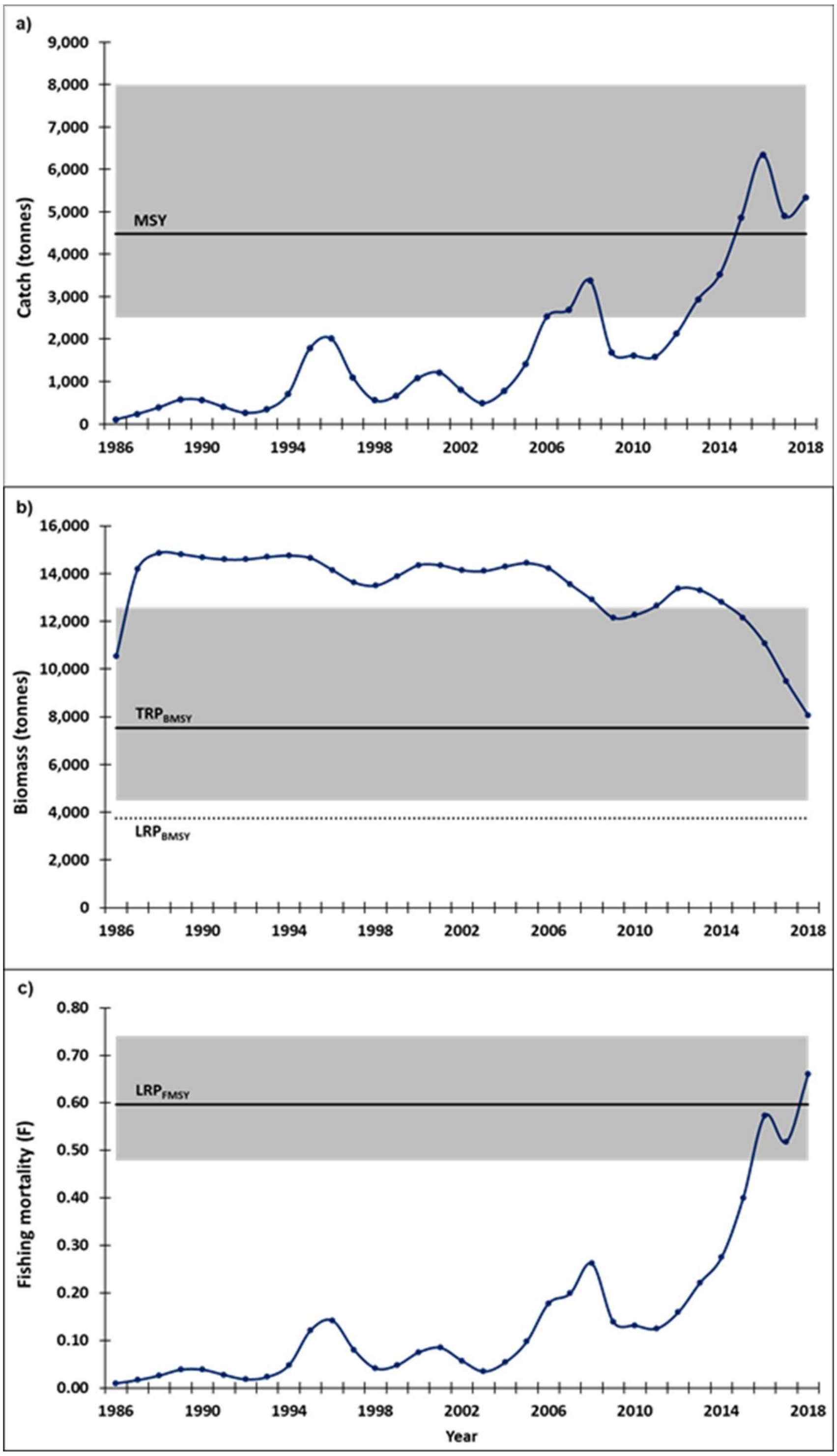

Figure 12.- Results of the C-MSY method for management purposes based on Monte Carlo assessment for the cuata swimcrab (*Callinectes arcuatus*) stock from the Gulf of California (CC_GC): a) landings, MSY with 95%

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).

Warrior swimcrab From the West Coast of Baja California (WC_BC)

The MSY estimated by the model for the WC_BC was 736 t. For this stock most of the landings show a large oscillation that remains below MSY until 2015 (Figure 13a), when landings increased above the upper CI for MSY. In the last year, the landings decrease to levels close to the lower limit of the CI. The biomass associated with the maximum sustainable yield, or TRP_{BMSY}, was 1,236 t. The trajectory of biomass (Figure 13b) was located at or above the upper limit of the TRP_{BMSY} confidence interval until 2015, then showed a steep decrease with the last year being located below the TRP_{BMSY}, and near the lower limit of its confidence interval, though not yet below the LRP_{BMSY}. Figure 13c shows the fishing mortality (F) throughout the time series compared to the LRP_{FMSY} of 0.590. The annual fishing mortality throughout the time series is below half of the LRP_{FMSY} value, but as of 2012 fishing mortality increased very markedly, with the last four years of the series time above LRP_{FMSY}. The highest fishing mortality (F) was 0.747 in 2017, with an exploitation rate for that year of 1.25. In the last year, the value of F_{2018} was 0.692.

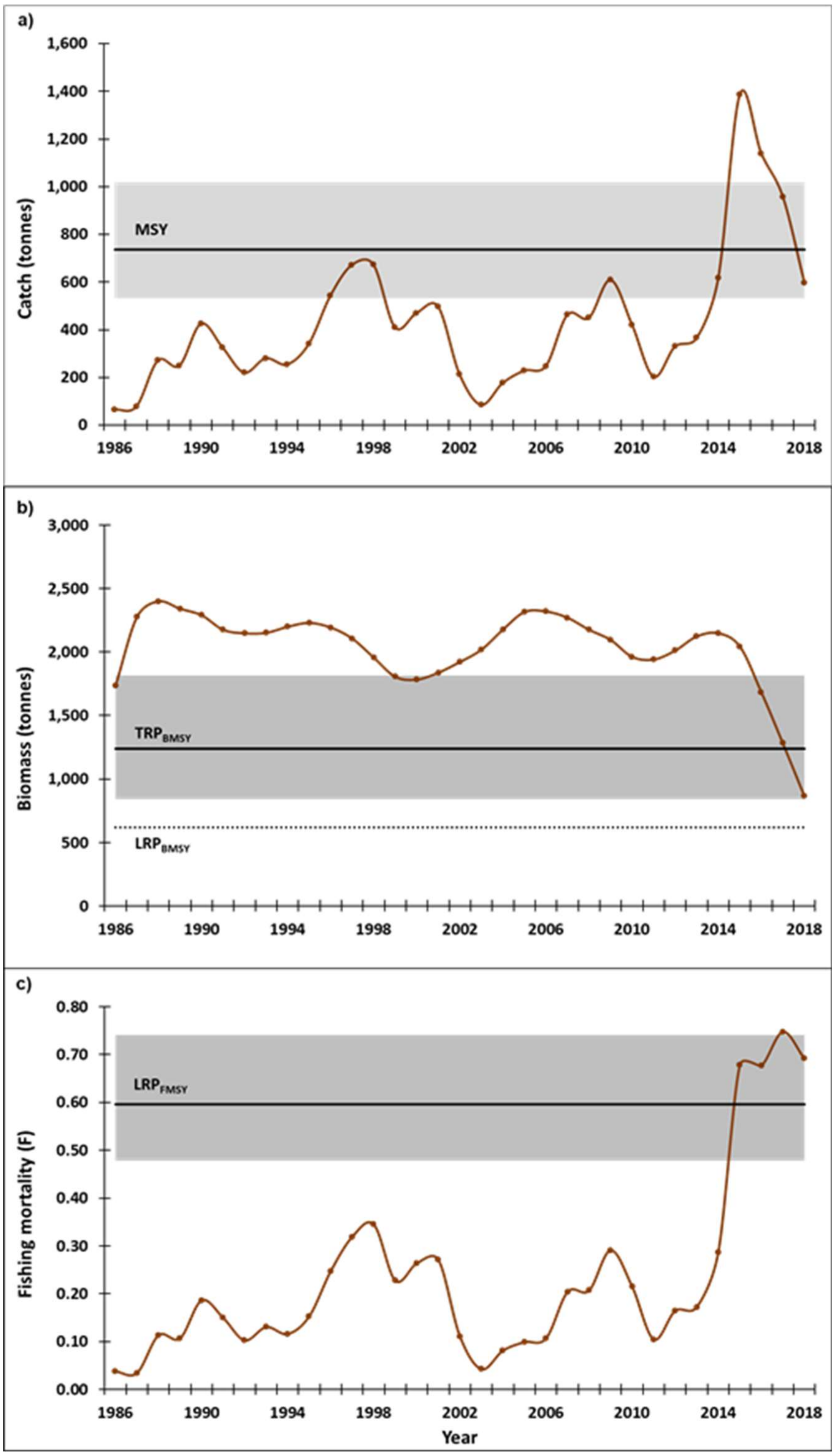

Figure 13.- Results of the C-MSY method for management purposes based on Monte Carlo assessment for the warrior swimcrab (*Callinectes bellicosus*) stock from west coast of Baja California, México (WC_BC): a) landings, MSY with 95% confidence interval (gray area) b) Biomass trajectory, TRP_{BMSY} with 95% confidence interval (gray area) and LRP_{BMSY} (dotted line) c) Fishing mortality and LRP_{FMSY} with 95% confidence intervals (gray area).

Figure 14 and 15 are Kobe plots for the WC_GC and CC_GC swimcrabs fisheries in the Gulf of California, which show the evolution of fishery exploitation over time. The trajectory of the different values shows that these fisheries remained at healthy levels of exploitation (green quadrant) for most of the time series, but with increasing fishing mortality rates and decreasing relative biomass values from 2014. At the end of the assessed period, the end points lie in the upper right (orange quadrant) indicating healthy populations that are experiencing overfishing, but with some uncertainty. There is a 67.7% probability that the current status of the WC_GC fishery is in the orange quadrant (not overfished but experiencing overfishing), and a 40.2% probability that the current status of the CC_GC fishery is in the same state.

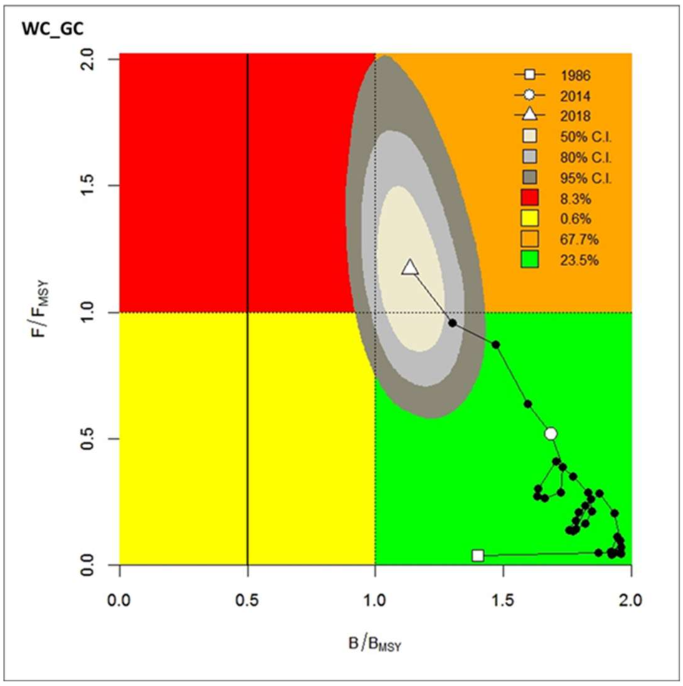

Figure 14.- Kobe plot for the warrior swimcrab fishery (WC_GC) in the Gulf of California, Mexico. Gray areas indicate iso-probabilities.

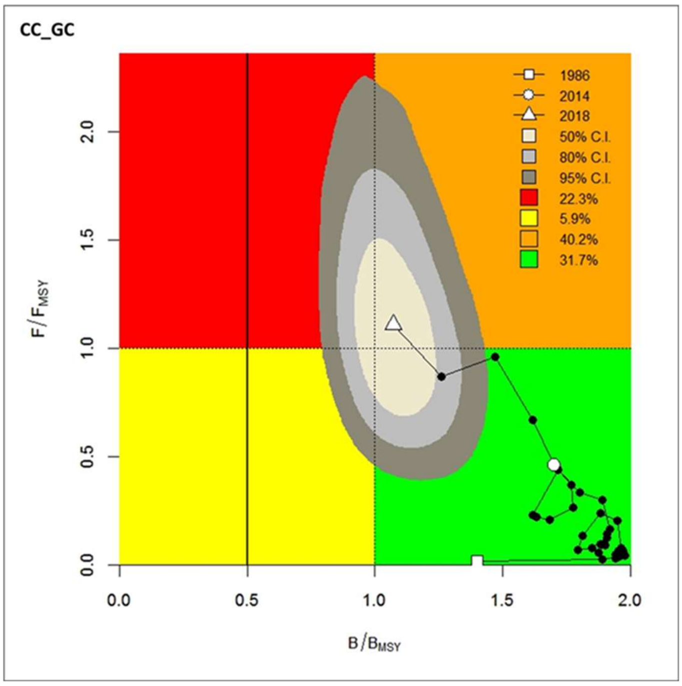

Figure 15.- Kobe plot for the cuata swimcrab fishery (CC_GC) in the Gulf of California, Mexico. Gray areas indicate iso-probabilities.

For the WC_BC swimcrab fishery, the Kobe plot (Figure 16) shows the trajectory of the different points and how this fishery has evolved in the period analyzed, remaining until 2014 at healthy levels of exploitation (green quadrant), moving to a precautionary area with overfishing occurring (orange quadrant) and in the last year being located in the red quadrant (overfished stock experiencing overfishing) with a high probability (78.1%).

It is of note that, for all three fisheries, stock status remained in good condition for many years but rapidly changed over the last four years to move into less favorable status.

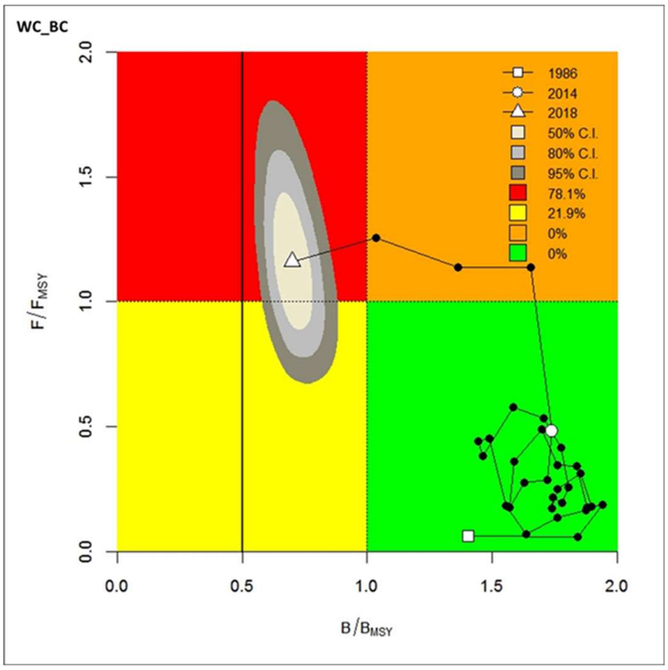

Figure 16.- Kobe plot for the warrior swimcrab fishery (WC_BC) of the west coast of Baja California. The gray areas indicate the iso-probabilities.

Management Strategies

Figures 17 and 18 shows the projected biomass stock trajectory to 2025 for the swimcrab fisheries with the application of the Schaefer model (constant catch and constant fishing mortality) to evaluate the effect of the establishment of different reference values expressed as a percentage of the MSY and F_{MSY}. With a catch equal to the MSY (Table 3) of each population as a harvest strategy, for the WC_GC and CC_GC populations the biomass presents a value below the TRP_{BMSY} and stabilizing at that value (Figure

17a and 17b), while the biomass value of the WC_BC stock decreases to low levels of biomass (Figure 17c), probably that the catches of the recent years have exceeded the upper CI of MSY was using surplus production (biomass available) and potentially reduced recruitment with value of B/k (Figure 8c) of the last year is at levels close to the indentation of $B/k < 0.25$, resulting in recent biomass below the level that can produce MSY. With values of 0.9 MSY, the WC_GC and CC_GC swimcrab fisheries soon reach biomass levels higher than TRP_{BMSY}, and WC_BC swimcrab fishery reaches levels equal to TRP_{BMSY} by 2025 (Table 3). With values of 0.8 MSY, all three populations soon reach biomass levels close to the upper limit of the B_{MSY} confidence interval. With a harvest value equal to the lower confidence interval of MSY the biomass value increases rapidly and by 2025 it is located at or above the upper limit of the B_{MSY} confidence interval for all three populations. Note that the projected catch values are long-term average values and do not reflect real-world annual variability and do not capture expected levels of uncertainty.

Considering the limitation of fishing mortality as a second strategy, in Figure 18 we observe that establishing the fishing mortality at F_{MSY} allows the populations to recover to a level equal to TRP_{BMSY} by 2025. With fishing mortality limited to 0.9 F_{MSY} as a harvest strategy, the biomass for 2025 reaches values above the TRP_{BMSY} for the three populations (Table 3).

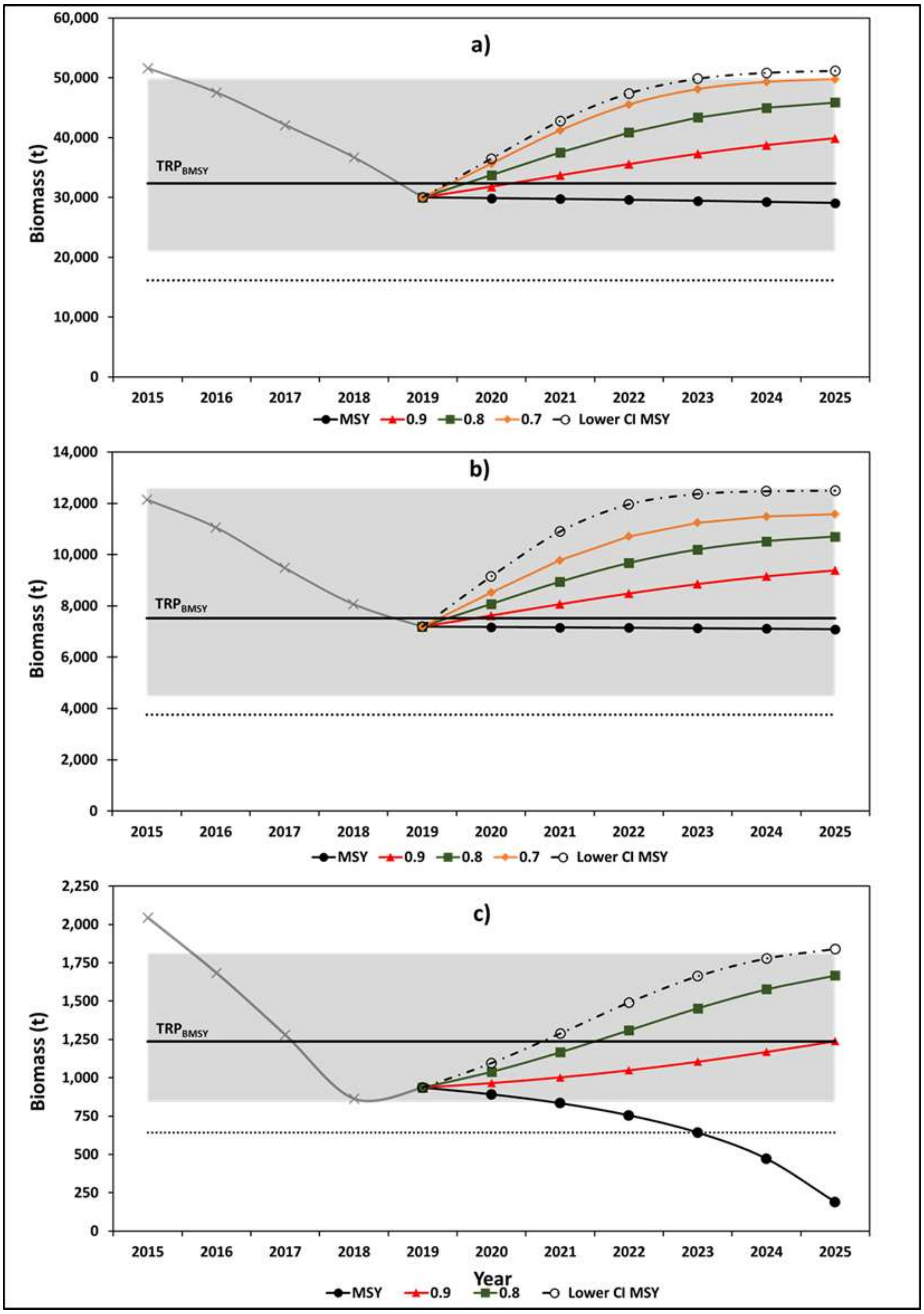

Figure 17.- Standard management scenarios projected to 2025 for the swimcrabs stocks, using harvest value as the management parameter, including the MSY and lower confidence interval of MSY as well as values in between. a) WC_GC, b) CC_GC and c) WC_BC. The solid lines show TRP_{BMSY}. The dotted lines show LRP_{Bmsy} . The gray area show confidence intervals of B_{MSY}. Refer to Figures 11b, 12b and 13b respectively to view the historic biomass trajectory (gray line).

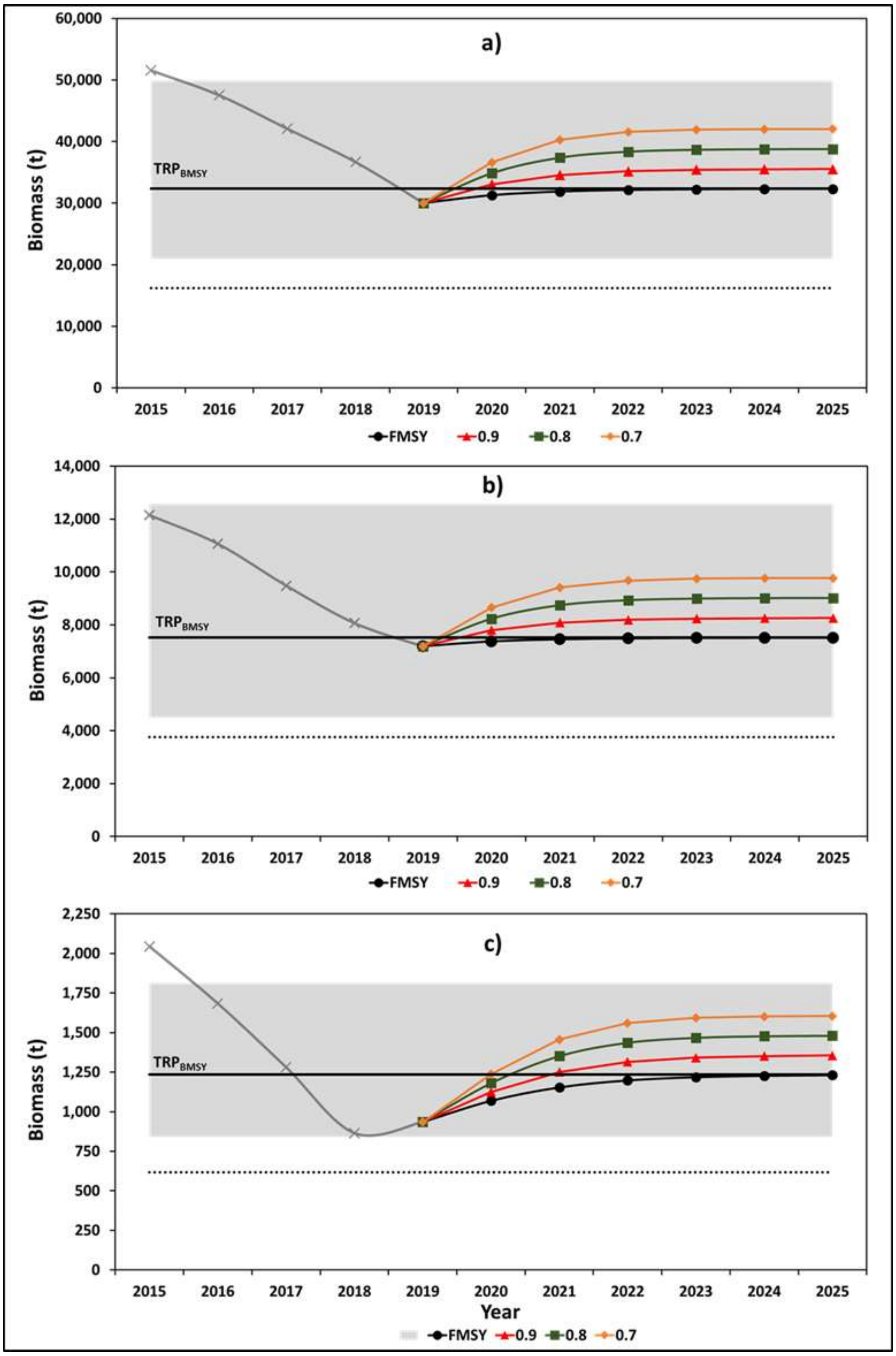

Figure 18- Standard management scenarios projected to 2025 for the swimcrabs stocks, using fishing mortality as the management parameter, including LRP_{FMSY} and three lesser F values. a) WC_GC, b) CC_GC and c) WC_BC. The solid lines show TRP_{BMSY}. The dotted lines show LRP_{Bmsy} . The gray area show confidence intervals of B_{MSY}. Refer to Figures 11b, 12b and 13b respectively to view the historic biomass trajectory (gray line).

Table 3. Results of the Schaefer model (constant catches and constant fishing mortalities) for the establishment 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	0.8	0.7	Lower CI MSY	F_{MSY}	0.9	0.8	0.7
WC_GC	Catch (t)	25,602	19,272	17,345	15,418	13,490	12,647	19,245	19,057	18,487	17,531
	F	0.698	0.663	0.435	0.336	0.271	0.247	0.596	0.536	0.477	0.417
	B/B_{MSY}	1.130	0.898	1.233	1.418	1.539	1.581	0.998	1.098	1.198	1.299
	F/F_{MSY}	1.170	1.113	0.729	0.564	0.455	0.415	1.000	0.900	0.800	0.700
CC_GC	Catch (t)	5,328	4,479	4,031	3,583	3,135	2,510	4,473	4,429	4,297	4,074
	F	0.661	0.631	0.429	0.335	0.271	0.201	0.596	0.536	0.477	0.417
	B/B_{MSY}	1.070	0.943	1.248	1.423	1.540	1.662	0.998	1.098	1.198	1.299
	F/F_{MSY}	1.110	1.060	0.721	0.562	0.454	0.337	1.000	0.900	0.800	0.700
WC_BC	Catch (t)	598	736	662	589	515*	532	734	727	706	669
	F	0.692	3.917	0.535	0.353		0.289	0.596	0.536	0.477	0.417
	B/B_{MSY}	0.700	0.152	1.003	1.349		1.488	0.996	1.096	1.197	1.298
	F/F_{MSY}	1.160	6.572	0.897	0.593		0.485	1.000	0.900	0.800	0.700

* Catch value below lower confidence interval of MSY

8. 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. For the warrior and cuata swimcrab fisheries of the Gulf of California and the west coast of Baja California Sur, 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 the uncertainties inherent in this approach. For a data limited fishery, such as this one, the C-MSY method provides a valuable scientific perspective from which to develop scientific advice to managers. This advice can provide the basis on

which to take interim fishery management decisions such as choices of harvest strategies and harvest control rules, to be refined when more robust data and associated advice become available.
The C-MSY model yielded a value of *r,* which indicates the maximum net productivity 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 (Froese *et al.* 2017). The estimated value of *r* is within the high resilience range proposed by Froese *et al.* 2017.
The highest k values were for the WC_GC and the CC_GC stocks with a relative biomass in the last year of 0.567 k and 0.536 k, respectively. The WC_BC stock presented a relative biomass in the last year of 0.350 k. Exploitation rates of the three stocks were above the F_{MSY} (0.596), with values in the last year of 1.17 for the WC_GC, 1.11 for the CC_GC and 1.16 for the WC_BC.
The equilibrium curve shows stocks with high resilience and with a decreasing biomass as catches increase, including the phases of decrease, increase and equilibrium, as shown by the position of the points below, above and near the equilibrium curve (Figure 8).

The catch at maximum sustainable yield (MSY) estimated by the C-MSY method was 19,272 t for the WC_GC, 4,479 t for the CC_GC and 736 t for the WC_BC. For all stocks evaluated the catches of the last four years were greater than MSY, except for the WC_BC stock, for which the catch of the final year (2018) declined below the MSY.

The Gulf of California and west coast Baja California stocks of warrior and cuata swimcrabs evaluated in this research showed, during the last five years of the analyzed period, an average catch higher than the overall time-series average and exceeding the estimated MSY. This may have played a large role in the commensurate decreases in the population biomass of stocks, which have declined to levels approaching the candidate TRP_{BMSY} for the Gulf of California stocks, and below the candidate TRP_{BMSY} and nearing the candidate LRP_{BMSY} for the western Baja California stock.
For the WC_BC stock, an increase in fishing pressure or a combination of fishing and poor recruitment could have generated the observed decrease in biomass. The relative biomass in the last year analyzed was close to the $B/K < 0.25$ which indicates that the stock is, or is likely to be in the immediate future, experiencing stock-size related reduced recruitment. In addition, changes in the marine environment, such as El Niño, La Niña, and climate change, can play important roles in the recruitment success of these species.
The exploitation rates from 2010 showed a constant increase, and in the last year of the period, the fishing mortality was above F_{MSY}, defined here as the candidate limit reference point for fishing mortality, or

LRP_{FMSY}; for the particular case of the WC_BC, the fishing mortality of the last four years exceeded the LRP_{FMSY}, indicating that fishing mortality needs to be reduced in this fishery.
The estimated biomass, for the cases of the WC_GC and CC_GC, is found throughout the recorded period above the B_{MSY} (defined here as the candidate target reference point for biomass, TRP_{BMSY}), though decreasing in recent years, while the biomass of the stock of WC_BC, in the last years of the analyzed period, is below the TRP_{BMSY}. The fact that the catches have exceeded the MSY in recent years indicates that the applied fishing effort was using the available biomass, causing it to decrease. None of the stocks have 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, biomass decreases are pronounced when the captures exceed the surplus production for a 5-year period or more (Figure 10). Surplus production was exceeded for each of the three stocks considered here, but only at the end of the time series, particularly for the WC_BC stock that shows a decrease in biomass, catches and surplus production.

The Kobe plots place the WC_GC and CC_GC stocks in the last year in an overfishing zone (orange color). The uncertainty indicators indicate that in the case of the WC_GC there is 67.7% probability that the status is in the orange quadrant, a 23.5% probability of it being located in the green quadrant (an area of greater sustainability) and 8.3% probability of it being located in the red quadrant (an overfished stock also experiencing overfishing). For the CC_GC the uncertainty indicators show that there is a 40.2% probability that the status is in the orange quadrant, with a 31% probability of it being located in the green quadrant, and a 22.3% probability of it being located in the red quadrant.
For the WC_BC, the Kobe plot places this stock in the overfished and experiencing overfishing zone in the last year, and the probability indicators show that there is 78% probability to remain the same and 22% to be located in the yellow quadrant.
It is of note that, for all three fisheries, stock status remained in good condition for many years but rapidly changed over the last four years to move into less favorable status. This is important from a management perspective as it demonstrates the speed needed by managers to respond to changes in the fishery and stock in order to keep the stock status in good condition. The number of boats in the Gulf of California participating in the swimcrab fishery increased by 42% in the 2011-2017 period and with exploitation rates in recent years above the LRP_{FMSY}. For the WC_BC stock, it is not clear if the status change in this short period of time is solely due the fishing effort increasing or a combination of increased fishing effort and reduced recruitment, a situation that should be further explored.

Projecting stock status forward over the next five years allowed testing of catch limits and fishing mortality limits as alternative management strategies. In order for the warrior and cuata swimcrab stocks of the Gulf of California to be in a status of good health with no overexploitation by 2025 would require a catch level less than or equal to 0.9 MSY. For the warrior swimcrab stock off the coast of Baja California Sur to be in a status of good health with no overexploitation by 2025 would require a catch level less than or equal to 0.8 MSY. This strategy would allow biomass to reach levels higher than TRP_{BMSY} and the fishing mortality to decreases to values below the F_{MSY}.

Considering the limitation of fishing mortality as a second strategy, all tested values of F equal to or less than F_{MSY} allowed biomass to increase to levels at or above B_{MSY} by 2025.

Based on the foregoing, we consider that the warrior and cuata crab stocks in the Gulf of California are not overfished, with biomass above the candidate TRP_{BMSY}, but are experiencing overfishing with fishing mortality values above the candidate limit reference point associated with F (F_{MSY}). The warrior crab fishery off the west coast of Baja California Sur is not overfished, though the biomass is between the candidate TRP_{BMSY} and LRP_{BMSY}, but it is experiencing overfishing with fishing mortality values above the candidate limit reference point associated with F (F_{MSY}).

9. Recommendations

- Fishery scientists and managers of the Gulf of California and Baja California Sur swimcrab fisheries should formally adopt the C-MSY methodology described here to enable on-going evaluation of stock status and provision of scientific advice to managers.
- Managers of the Gulf of California and Baja California Sur swimcrab fisheries should formally adopt the candidate reference points (at least as interim RPs) and use these in managing the fisheries.
- To maintain the biomass of each stock of the Gulf of California swimcrab at sustainable levels (i.e. around B_{MSY}), its recommended to establish and enforce annual Total Allowable Catches (TACs) of 17,345 t for WC_GC and 4,041 t for CC_GC fisheries, (around 0.9 MSY) or fishing mortality limits at or below 0.9 F_{MSY}.

- Based on this analysis, the Baja California Sur warrior swimcrab is experiencing overexploitation and is nearing an overfished state. It is therefore recommended to establish a TAC that will return the stock to B_{MSY} is a short period. This analysis shows that 588 t (0.8 MSY) would do this by 2025.
- To improve the swimcrab stock assessment, it is recommended to establish a comprehensive biological monitoring program, including catch, landings, size frequency, weight-at-size, and sex data, among others, for each species and stock.
- It is recommended to establish a periodic swimcrab stock assessment program to routinely evaluate the fishery performance and management outcomes for each stock.
- 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.

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