Update to 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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BACKGROUND:

During the fall of 2020, upon request from Sustainable Fisheries Partnership and the "Mexico Gulf of California swimming crab-pot/trap/ring net" FIP participants, the Evaluation and estimation of reference points for the crab stocks (Callinectes spp.) from the Gulf of California and the west coast of Baja California Sur, Mexico, was conducted. Its report was made public in February 2021 and a scientific report based on this report was accepted for its publication in the INAPESCA's *peer reviewed* journal "Ciencia Pesquera" in March 2022.

In the summer of 2022, the Mexican fisheries authorities published the 2020 fisheries yearbook that reports 2019 and 2020 fisheries production records, including the crab species analyzed in this report.

These new data were used to develop the first biannual update to the stock assessment report, using the exact same methodology of 2020 and taking into account different comments to the first report, including and adjustment to the time series to include only the 2000-2020 since it is in 2000 the fishery scientific evaluations started to be published in the (Carta Nacional Pesquera 2000), and the implementation in 2006 of the Mexican Official Standard for the crab fishery and the publications of the first stock assessment in 2006.

This document, that includes the 2021 fisheries yearbook and the 2022 fisheries production records, recently published by the fisheries authorities, constitutes the second biannual update to the stock assessment report published in 2021.

This biannual update includes updated results of the C-MSY and Schaefer models, annual surplus production and biomass estimate for consecutive years, C-MSY method for management purposes based on Monte Carlo assessment and Kobe plots.

Figure 1 shows the capture time series for the Gulf of California crab populations (WC_GC and CC_GC), while Figure 2 shows those for the Baja California west coast crab population. For the stocks in the Gulf of California, it can be seen that the catches of the last two years that are incorporated for this update (2021-2022) show a decrease in value, otherwise for the stock on the west coast of California. Baja California Sur, which observes an increase.

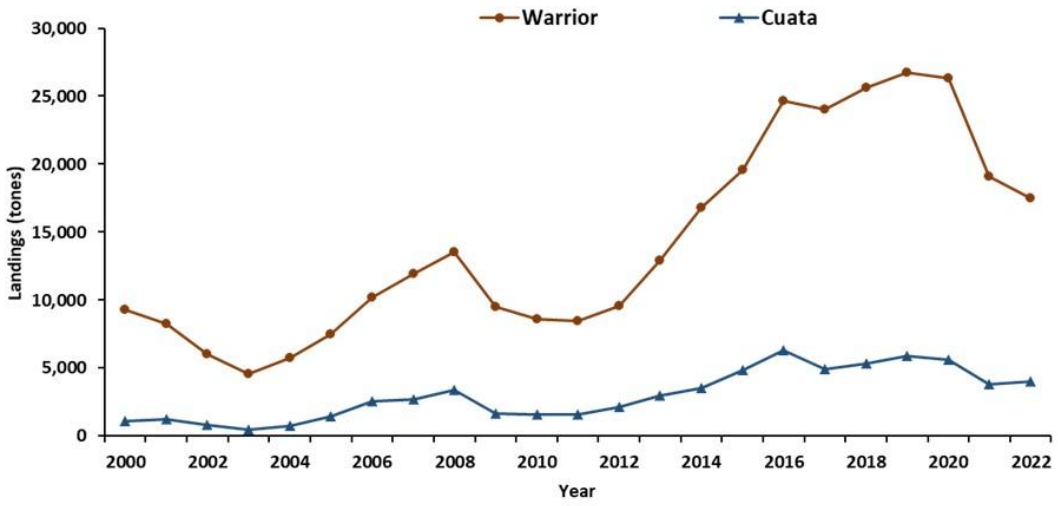

Figure 1.- Total landings of swimcrabs in Gulf of California (GC), as well as species-specific (warrior and cuata swimcrabs) landings from the Gulf of California.

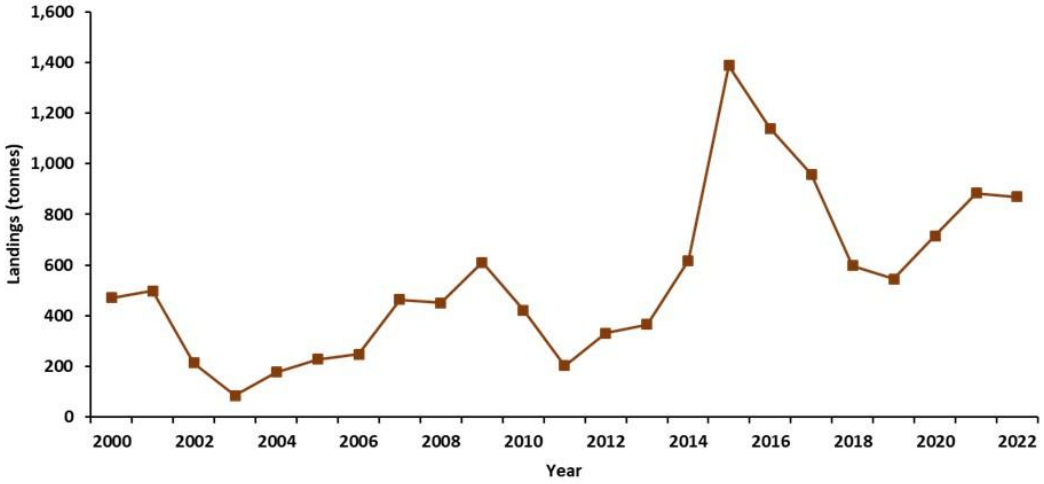

Figure 2.- Landings of warrior swimcrab (*C. bellicosus*) from the west coast of Baja California.

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 news catches and the previous input assumptions, are presented in Figures 3, 4 and 5, respectively. In the figures, Panel a) shows the most viable *r*-k pair values. The model yielded for each of the three examined populations, 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 stock size 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 0.582 k and 0.578 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 0.596 k. Panel c) shows the exploitation rate of the stock. In the last year for the stock of WC_GC the exploitation rate was 0.569, for CC_GC it was 0.608 and for WC_WC it was 0.826.

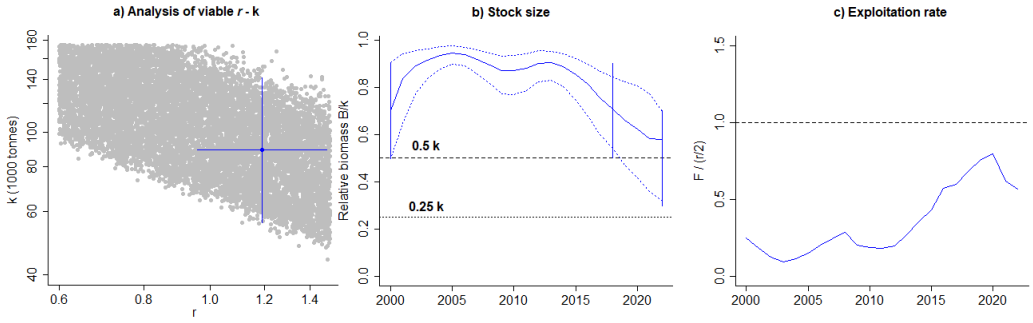

Figure 3. - Results of the C-MSY method for the warrior swimcrab stock in the Gulf of California (WC_GC). a) Analysis of the most probable combinations of r and k. The viable r-k pairs that fulfilled conditions are show in grey. The blue cross,

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.

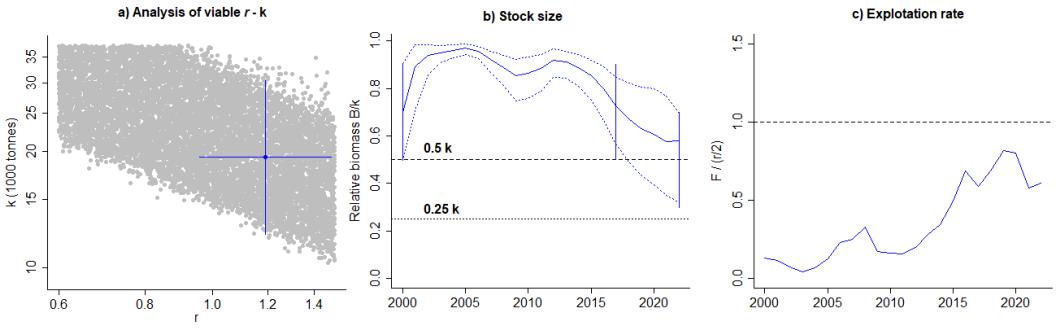

Figure 4. - Results of the C-MSY method for the cuata swimcrab stock in the Gulf of California (CC_GC). a) Analysis of the most probable combinations of r and k. The viable r-k pairs that fulfilled conditions are show in grey. The blue cross, with approximate 95% confidence limits, marks the most probable *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.

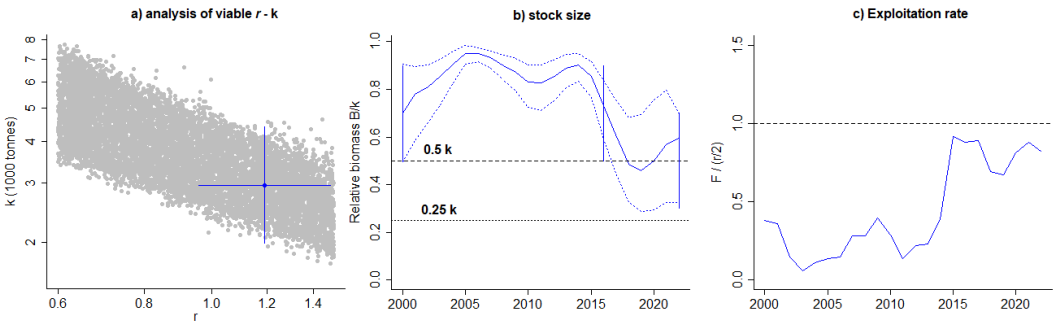

Figure 5.- Results of the C-MSY method for the warrior swimcrab stock off the west coast of Baja California (WC_BC). a) Analysis of the most probable combinations of r and k. The viable r-k pairs that fulfilled conditions are show in grey. The blue cross, with approximate 95% confidence limits, marks 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.

Figure 6 shows the equilibrium curves of the Schaefer model of C-MSY. 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 < 0.8).

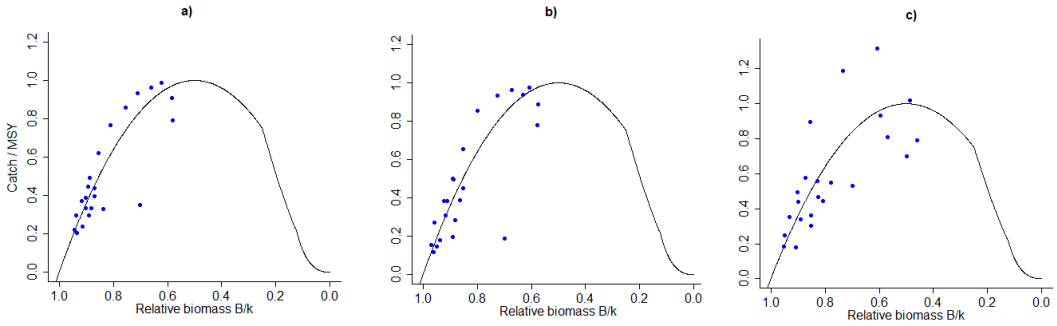

Figure 6.- Equilibrium curve of the Schaefer model (Equation 3) to explain reduced recruitment at low stock sizes. Panel a) WC_GC stock, panel b) CC_GC stock and panel c) WC_BC stock. The dots indicate values of catch relative to MSY and biomass relative to k.

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 1 .

Table 1. Estimated reference points 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	26,494 (16,364 – 42,893)	44,480 (27,959 – 70,765)	0.596	44,480	22,240	0.596
CC_GC	5,745 (3,614 – 9,132)	9,645 (6,119 – 15,202)		9,645	4,822	
WC_BC	883 (619 – 1,258)	1,482 (994 – 2,209)		1,482	741	

Gulf of California warrior swimcrab (WC_GC)

The MSY estimated by the C-MSY method for the WC_GC was 26,494 t. For this stock, for most of the time the catches were kept below the lower confidence interval (CI) of MSY with increasing trend towards MSY (Figure 9 a), until 2019 when the catches exceeded MSY and the last year the catch value show a decrease. The biomass associated with the maximum sustainable yield, or TRP_{BMSY}, was 44,480 t. During most of the period analyzed the biomass trajectory remained fairly constant and well above the TRP_{BMSY}, but a drastic decrease to levels close to the TRP_{BMSY} can be observed beginning in 2014 (Figure 9 b), the biomass in the last year relative to TRP_{BMS} was 1.16 (B_{2022}/TRP_{BMS}); Figure 9 c 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 2020 of 0.475, located below the LRP_{FMSY}; the exploitation rate for that year was 0.797, and the last year the exploitation rate was 0.569.

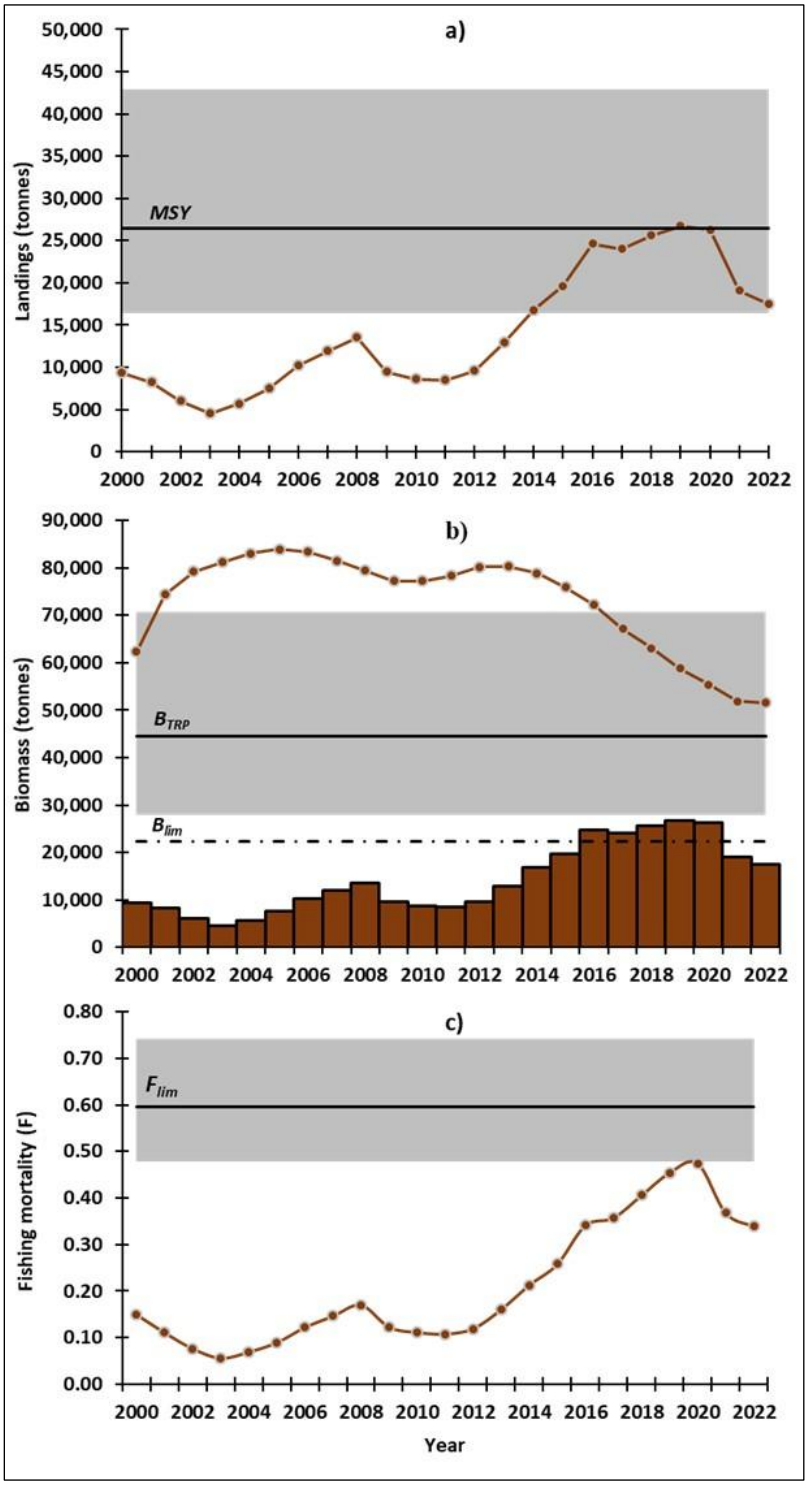

Figure 7. Results of the C-MSY method for management purposes based on Monte Carlo assessment for the stock of warrior swimcrab (*Callinectes bellicosus*) in the Gulf of California (WC_GC). a) Landings, MSY with 95% confidence interval (gray area) b) Biomass trajectory, TRP_{BMSY} with 95% confidence 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 5,745 t. The catches of this stock until 2013 were kept below the lower CI of MSY varying between 450 t and 3,211 t, showing a trajectory of increase in catches towards MSY until 2015, when the catches were above MSY (Figure 10 a) and the catch values of the last three years of the time series are located below the MRS. The TRP_{BMSY} was 9,645 t. Until 2014, the biomass trajectory (Figure 10 b) varied but remained at or above the upper CI of TRP_{BMSY}, after which the biomass shows a drastic decrease to near levels of TRP_{BMSY}; the biomass in the last year relative to TRP_{BMS} was 1.16 (B_{2022}/TRP_{BMS}). Figure 10 c shows the fishing mortality (F) throughout the time series compared to the LRP_{FMSY} of 0.596. The annual fishing mortality throughout the time series is below of LRP_{FMSY}, but as of 2012 these increased markedly, reaching their maximum value in the 2019 (F_{2019}) of 0.486, below the LRP_{FMSY} and with an exploitation rate for that year of 0.817; The last year the exploitation rate was 0.608.

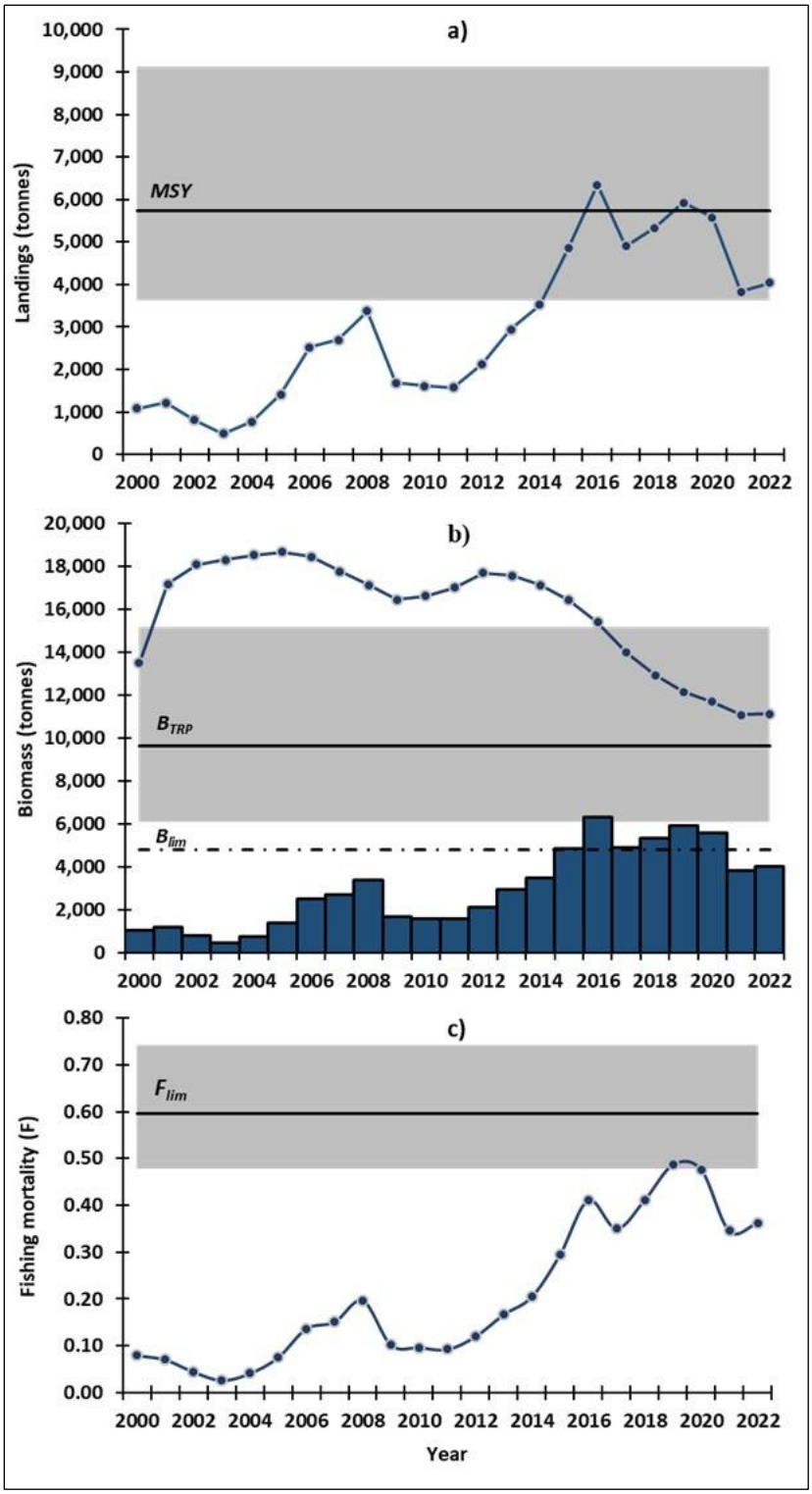

Figure 8.- Results of the C-MSY method for management purposes based on Monte Carlo assessment for the cuata swimcrab (*Callinectes arcuatus*) stock from the Gulf of California (CC_GC): a) landings, MSY with 95% confidence interval (gray area) b) Biomass trajectory, TRP_{BMSY} with 95% confidence interval (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 883 t. For this stock most of the catches show a large oscillation that remains below the lower CI of MSY until 2011 when catches increased to locate above for MSY in 2015 (Figure 11a), to later show a decrease and in the last year the catch value increased to levels close to the MSY. The TRP_{BMSY} was 1,482 t. The trajectory of biomass (Figure 11b) was located at or above the upper limit of the TRP_{BMSY} confidence interval until 2015, then demonstrated a drastic decrease to levels below the TRP_{BMSY} (2018-2019) and the last year's show and increased with values located above the $TRP_{BMSY.}$ The biomass value in the last year relative to TRP_{BMS} was 1.19 (B_{2022}/TRP_{BMS}). Figure 11 c shows the fishing mortality (F) throughout the time series compared to the LRP_{FMSY} of 0.596. 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 reaching their maximum value in the 2015 (F_{2015}= 0.547) locate above of lower CI of LRP_{FMSY}., with an exploitation rate for that year of 0.918. Last year the value of fishing mortality (F_{2022}) was 0.492 with an exploitation rate for that year of 0.826.

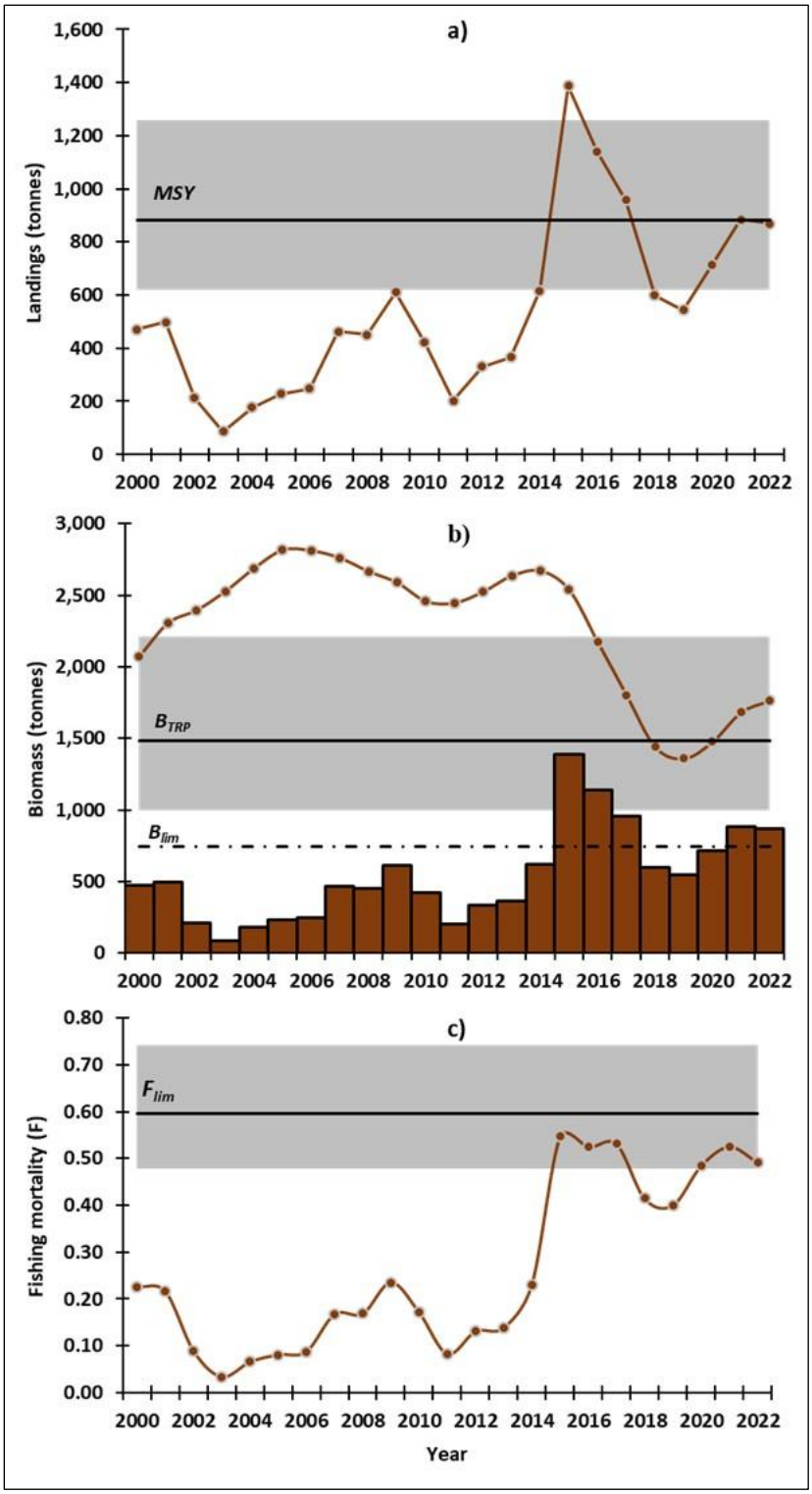

Figure 9.- Results of the C-MSY method for management purposes based on Monte Carlo assessment for the warrior swimcrab (*Callinectes bellicosus*) stock from west coast of Baja California, México (WC_BC): a) landings, MSY with 95% confidence interval (gray area) b) Biomass trajectory, TRP_{BMSY} with 95% confidence interval (gray area) and LRP_{BMSY} (dotted line) c) Fishing mortality and LRP_{FMSY} with 95% confidence intervals (gray area).

Figure 12, 13 and 14 are Kobe plots for the WC_GC, CC_GC and WC_WC swimcrabs fisheries in the Gulf of California, which show the evolution of fishery exploitation over time. The trajectory of the different points shows that these fisheries remained at healthy levels of exploitation (green quadrant). There is an 80 % probability that the current status of the WC_GC and CC_GC fishery is in the green quadrant, 78.3 % probability that the current status of the CC_GC fishery is in the green quadrant and 68.3 % that the current status of the WC_WC fishery is in the green quadrant.

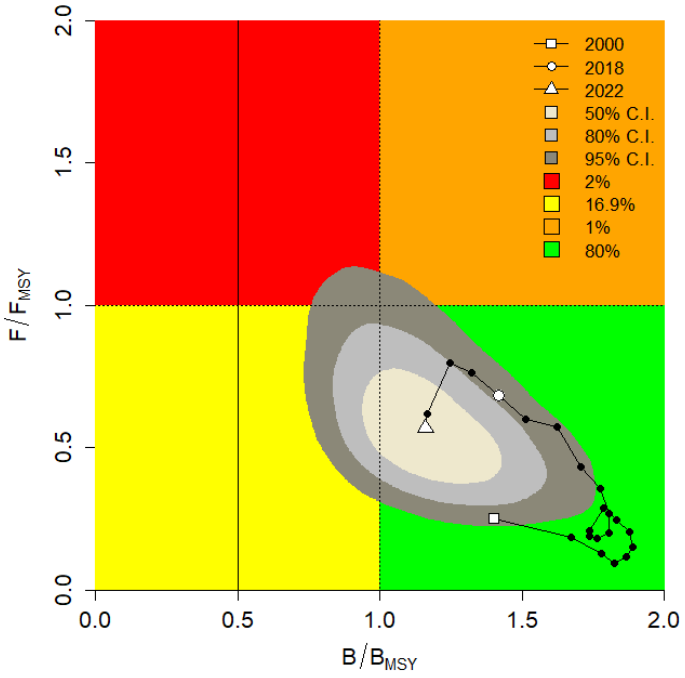

Figure 10.- Kobe plot for the warrior swimcrab fishery (WC_GC) in the Gulf of California, Mexico. Gray areas indicate iso-probabilities.

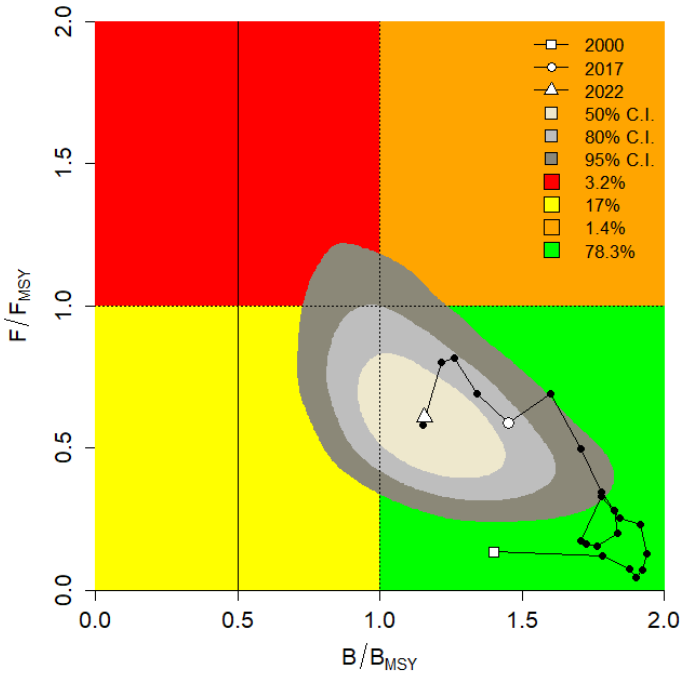

Figure 11.- Kobe plot for the cuata swimcrab fishery (CC_GC) in the Gulf of California, Mexico. Gray areas indicate iso-probabilities.

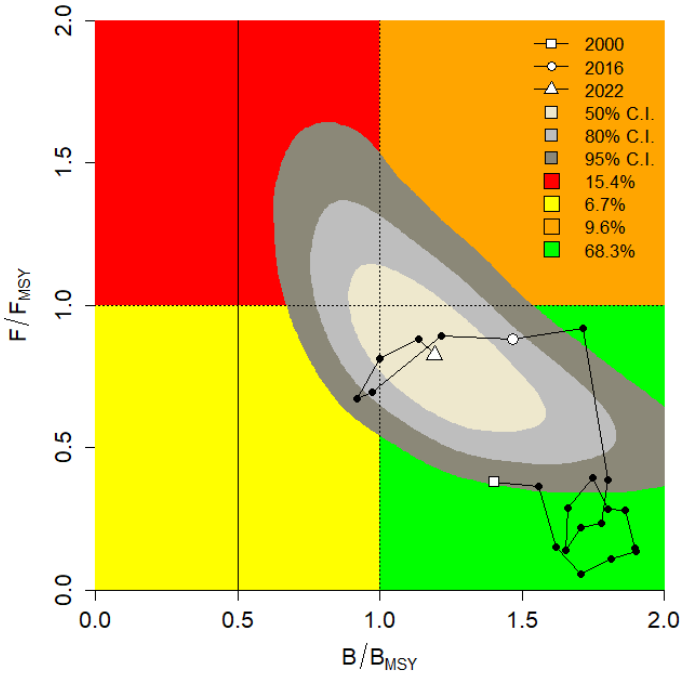

Figure 12.- Kobe plot for the warrior swimcrab fishery (WC_BC) of the west coast of Baja California. The gray areas indicate the iso-probabilities.

CONCLUSIONS

While the Gulf of California stocks present a decrease in the 2021-2022 period, the West coast one shows the oposit. Results of this update show, for the las year, an increase in the population related to the carrying capacity (B/k) for the three stocks of swim crabs analyzed; while the exploitation rate for the Gulf of California Stocks dimishnished and increased for the West coast of Baja California strock.

With regards to the updated MSY and Biomass values, these present an increment fore the Gulf of California stocks and a reduction for the West Coast of Baja California Stock.

While the stocks status, according to the Kobe diagrams remains in healthy conditions, the West Coast of Baja California one diminished its probabilities to remain in healthy conditions and the Gulf of California ones increased those probabilities.