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# CATCH–MAXIMUM SUSTAINABLE YIELD METHOD APPLIED TO THE CRAB FISHERY (*CALLINECTES* SPP.) IN THE GULF OF CALIFORNIA

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***ABSTRACT*** The objective of this study was to determine the maximum sustainable yield (MSY) of the crab fishery in the Gulf of California by applying the catch-MSY method. This fishery occurs in two states—Sonora and Sinaloa, along the mainland coast of the Gulf of California—and involves two species: *Callinectes bellicosus* and *Callinectes arcuatus*. The main species supporting the fishery in both states is *C. bellicosus*, whereas *C. arcuatus* accounts for 5% of crab catches in Sonora and 20%–30% in Sinaloa. The catch-MSY method uses a set of viable r–k combinations to approximate MSY. The *r–k* combinations are the carrying capacity *k* and the maximum rate of population increase *r* for a given stock in a given ecosystem, which are required in most production models, such as the Schaefer model, to estimate MSY. Prior carrying capacity in this study was set arbitrarily from the maximum catches in a series evaluated to 100 times the maximum catch. This range ensures the real carrying capacity could be determined if catches were at MSY sometime during the period evaluated. Maximum potential could have been realized since 2006 for the Sinaloa stock and since 1996 for the Sonora stock. The evidence for these facts is that the catch per unit of effort decreased, and reductions were observed in the mean size of individuals; these changes occurred in the Sinaloa crab fishery. All methods devoted to management procedures of fisheries stocks entail a number of criticisms, and estimations of carrying capacity and stock biomass are costly; however, because sustainable fisheries are desired and data-poor stocks are common, a simple method like catch-MSY has proved be useful in the management of the crab fishery in the Gulf of California.

***KEY WORDS:*** maximum sustainable yield model, Gulf of California, fisheries, *Callinectes*, crab

## INTRODUCTION

Effective management of fisheries that sustain viable fishing communities require knowledge to maintain exploited populations of marine organisms at levels that can produce the maximum sustainable yield (MSY) (Martell & Froese 2012). The scarcity of biological and fisheries information for many stocks means that researchers have to consider the use of many different methods. Siddeek et al. (2004) uses reference points to assess the status of a stock for management purposes. However, even reference points are defined in terms of the fishing mortality of stock biomass; thus, reference points are evaluated from limited quantitative analyses or are assigned arbitrary values from fisheries of similar stocks. In other cases, stock assessments, or estimates of abundances, rely on catch-per-unit-effort data provided by commercial fishers. Despite the large quantities and long time series of such data, their inherent biases, inaccuracies, and imprecision mean that fishery-independent surveys are often required to corroborate stock assessments (Kennelly & Scandol 2002).

With this in mind, Martell and Froese (2012) presented a simple method that uses catch data plus readily available additional information to approximate MSY within error margins. The method uses a set of viable *r–k* combinations to approximate MSY. Here, *k* refers to the carrying capacity and *r* refers to the maximum rate of population increase for a given stock in a given ecosystem. These values are required in most production models, such as the Schaefer model, to estimate MSY. Use of this model is advocated because, although estimates of subtractions (catches) are available for most stocks, abundance estimates are difficult to make, costly to obtain, and often unavailable. Martell and Froese (2012) demonstrated the use of *r–k* combinations to approximate MSY in 146 stocks. The results from the *r–k* combination method were compared with independent MSY estimates available from a previous study for 48 stocks from the Northeast Atlantic and MSY estimates for 98 global stocks.

Although most of the stocks analyzed were finfish, we believe this novel method can be used in the crab fishery from the Gulf of California. This fishery occurs in two states—Sonora and Sinaloa, along the mainland coast of the Gulf of California—and includes two species: *Callinectes bellicosus* (Stimpson, 1859) and *Callinectes arcuatus* (Ordway, 1863). Independent stocks of *C. bellicosus* support the fishery in both states, whereas *C. arcuatus* accounts for 5% of crab catches in Sonora and 20%–30% in Sinaloa. In Sonora, the crab fishery operates in open ocean waters, whereas in Sinaloa, the crab fishery operates in coastal lagoons. This fishery has become an important commercial fishery in Mexico, especially in the eastern Gulf of California, where a small-scale fishery for these crabs was established in 1982 (Rodríguez-Domínguez at al. 2012a). However, scientific knowledge of many aspects of the biology of these species is limited. A literature review found only five peer-reviewed publications focusing on *C. bellicosus*, with additional information contained primarily in government publications. All the peer-reviewed papers reported research conducted in estuarine lagoons along the Pacific coast (Paul 1982, Arreola-Lizárraga et al. 2003, Hernández & Arreola-Lizárraga 2007, Rodríguez-Domínguez at al. 2012a, Rodríguez-Domínguez at al. 2012b). We believe that

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the crab fishery from the Gulf of California is affected by many of the same precepts that motivated Martell and Froese (2012) to propose the use of $r$–$k$ combinations to approximate MSY. For example, no previous biomass studies have been conducted for this fishery, yet estimating the abundances of individuals in exploited populations is an obvious prerequisite for the sustainable management of commercial marine fisheries. Thus, the purpose of this investigation is to determine the MSY of the crab fishery in the Gulf of California by applying the catch-MSY method proposed by Martell and Froese (2012).

## MATERIALS AND METHODS

The catch-MSY method (Martell & Froese 2012) was used to assess the crab fishery in the Gulf of California in coastal zones of the states Sinaloa and Sonora, México (Fig. 1). No specific catch statistics exist for either state; therefore, this assessment of the crab fishery represents a first approximation for both species. We also applied the same method to crab catch data from Bahía Santa María La Reforma (BSMR), a coastal lagoon in the central part of the state of Sinaloa, because specific catch information exists for *Callinectes bellicosus* in this region. The information required for implementation of the method includes time–catch series $C_t$, initial ($\lambda_{01}$, $\lambda_{02}$) and final ($\lambda_1$, $\lambda_2$) biomass of the stock as a proportion of the carrying capacity ($k$), and a set of $r$ (the maximum rate of population increase) and $k$ pairs selected by a random process with a uniform distribution in the range of each parameter. Annual biomass estimates were realized using the Schaefer production model, and a Bernoulli distribution was used as the likelihood function for accepting each $r$–$k$ pair that never collapsed the stock or exceeded the carrying capacity. The result of these calculations was a final relative biomass estimate that fell within the assumed range of depletion. Process error was added with a Schaefer model × antilog of error with a normal distribution (0, $\sigma$(v t)). When $\sigma$(v t) = 0, the observation error was assumed.

For the Sinaloa and Sonora crab stock assessment, we used a range of initial proportional biomass $\lambda_{01}$, $\lambda_{02}$ of 0.8–1.0,

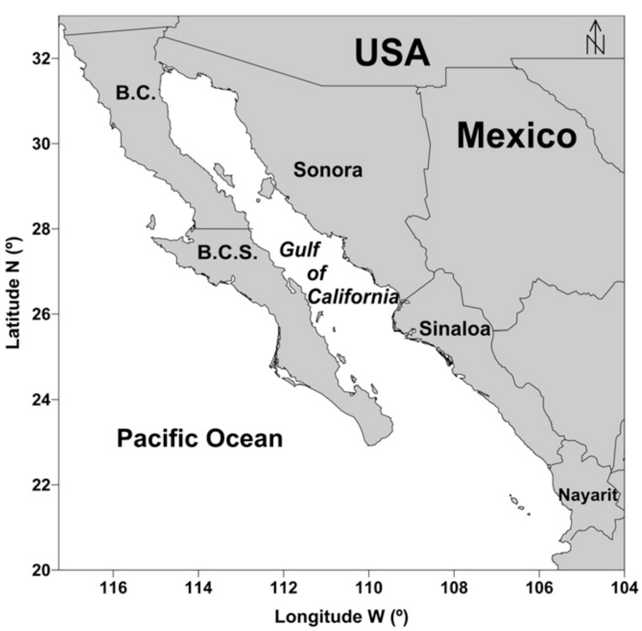


**Figure 1. Location of the fishery zone.**

because both time series catches began when stocks were virgin. For BSMR, we used $\lambda_{01}$, $\lambda_{02}$ of 0.5–0.9, which are default ranges proposed by Martell and Froese (2012). For the Sinaloa crab stock, we used the default values for final biomass proposed by Martell and Froese (2012). Catch for the final time series/maximum catch was less than 0.5; therefore, we used a range of depletion: $\lambda_1 = 0.01$, $\lambda_2 = 0.5$. However, an alternative range of $\lambda_1 = 0.01$, $\lambda_2 = 0.7$ was used to explore whether the assumed range for the final biomass influenced the model outputs. Observation error was assumed, but process error was evaluated using the first range of depletion values and $\sigma$(v t) = 0.05. For the Sonora and BSMR stocks, the final catch/maximum catch was greater than 0.5, and a depletion interval of $\lambda_1 = 0.3$, $\lambda_2 = 0.7$ was selected; observation error was only assumed.

An $r$ interval for highly resilient species of 0.6–1.5 was assumed for the first iteration; $r$ values from 0.65–0.91 were reported for a related species, *Callinectes sapidus* (Murphy et al. 2007, Sutton & Wagner 2007). The $k$ interval for the first iteration was defined as (maximum catch, 100 × maximum catch). The initial biomass for the time series was calculated as $B_0 = \lambda_0 k \times \exp(vt)$ and biomass at time $t + 1$ as

$$B_{t+1} = \left[B_t + rB_t \times \left(1 - \frac{B_t}{k}\right) - C_t\right] \times \exp(vt).$$

This calculation was performed with 100,000 randomly generated $r$–$k$ pairs with independent probabilities:

$$P(r) \sim \exp\{\text{uniform}[Ln(lr), Ln(ur)]\}$$

$$P(rk) \sim \exp\{\text{uniform}[Ln(lk), Ln(ul)]\}.$$

The model calculations were repeated for each $\lambda_0$ over the interval 0.8–1.0 in 0.05 steps. Therefore, 500,000 $r$–$k$ pairs were evaluated with a Bernoulli distribution. In cases when combinations of ($r$, $k$) led to the population going extinct or overshooting $k$ before the end of the time series, we simply assigned a 0 for that parameter combination. For combinations of ($r$, $k$) that resulted in final stock sizes between $\lambda_1$ and $\lambda_2$, we assigned a value of 1. Cases in which the likelihood was 1 were selected for the second iteration, and new bounds for $r$ and $k$ were defined. The smallest $k1$ near the initial lower bound of $r1$ was selected as the maximum $k2$, and the minimum $k2$ was defined as 0.9 × the minimum $k1$. The maximum $r2$ was 1.2 × maximum $r1$, and the minimum $r1$ was set equal to the minimum $r2$. The analysis was repeated with the new bounds for $r2$ and $k2$. Management quantities were estimated using values for $r2$ and $k2$ pairs from cases from the second iteration with a likelihood of 1:

$$\text{MSY} = \frac{rk}{4}$$

$$B_{\text{MSY}} = \frac{k}{2}$$

$$F_{\text{MSY}} = \frac{r}{2}$$

Geometric means were calculated for $r$, $k$, MSY, $B_{\text{MSY}}$, $F_{\text{MSY}}$, and biomass ($Bt$) over all time series. As a measure of uncertainty, we used two times the SD of the logarithmic mean. This implies that, with a roughly log-normal distribution, approximately 95% of the parameters, management quantities, and *Bt* estimates would fall within this range.

## RESULTS

Posterior density distributions of *r*, *k*, and MSY for the Sinaloa crab stock are shown in Figure 2. Regardless of the different assumptions on the initial and final biomass, and observation or process error, the posterior density distributions were very similar.

The *r* values were between 0.98 and 1.08, *k* estimates were between 27,629 mt and 28,436 mt, mean MSY was between 7,025 mt and 7,585 mt, $B_{MSY}$ was between 13,814 mt and 14,218 mt, and $F_{MSY}$ was between 0.494 and 0.543. There was a side overlap of 95% confidence intervals (CIs) for all estimations, regardless of differences in assumptions (Table 1).

Posterior density distributions for *r*, *k*, and MSY for the Sonora crab stock are shown in Figure 2. The posterior density was similar to that of the Sinaloa crab stock; however, the geometric mean of *r* (1.11) was greater than that of the Sinaloa crab stock, although the 95% CIs overlapped (Table 1). Geometric means of *k*, MSY, and $B_{MSY}$ were significantly less than those of the Sinaloa crab stock (i.e., the upper 95% CIs were less than the geometric means of the Sinaloa crab stock). The geometric mean of $F_{MSY}$ (0.557) was greater than that of the Sinaloa crab stock, but no statistically significant differences were found (the Sonora $F_{MSY}$ 95% CI includes the geometric mean of the Sinaloa $F_{MSY}$).

Posterior density distributions for *r*, *k*, and *MSY* for the *Callinectes bellicosus* stock of BSMR are shown in Figure 3. No statistically significant differences were found between *r* values of Santa María La Reforma and the Sinaloa or Sonora stocks. *k*, *MSY*, and $B_{MSY}$ estimates were 19%–20% of the Sinaloa crab stock (Table 1); these percentages represent catches from the past 6 y from Santa María with respect to all catches from Sinaloa.

Trends in biomass estimates were similar regardless of the different assumptions considered for the Sinaloa crab stock (Fig. 4). In 1996, when the catch overshot MSY, the biomass declined but then recovered during the subsequent years as a result of a decrease of catches to less than MSY. From 2006 to 2008, the catch far exceeded MSY, and biomass declined again to a level less than $B_{MSY}$, where it remained until 2011.

In the Sonora crab stock, catches increased exponentially from 1992 to a maximum near MSY in 1996 and 1997. In response, stock biomass decreased from 1996 to 1998, but never

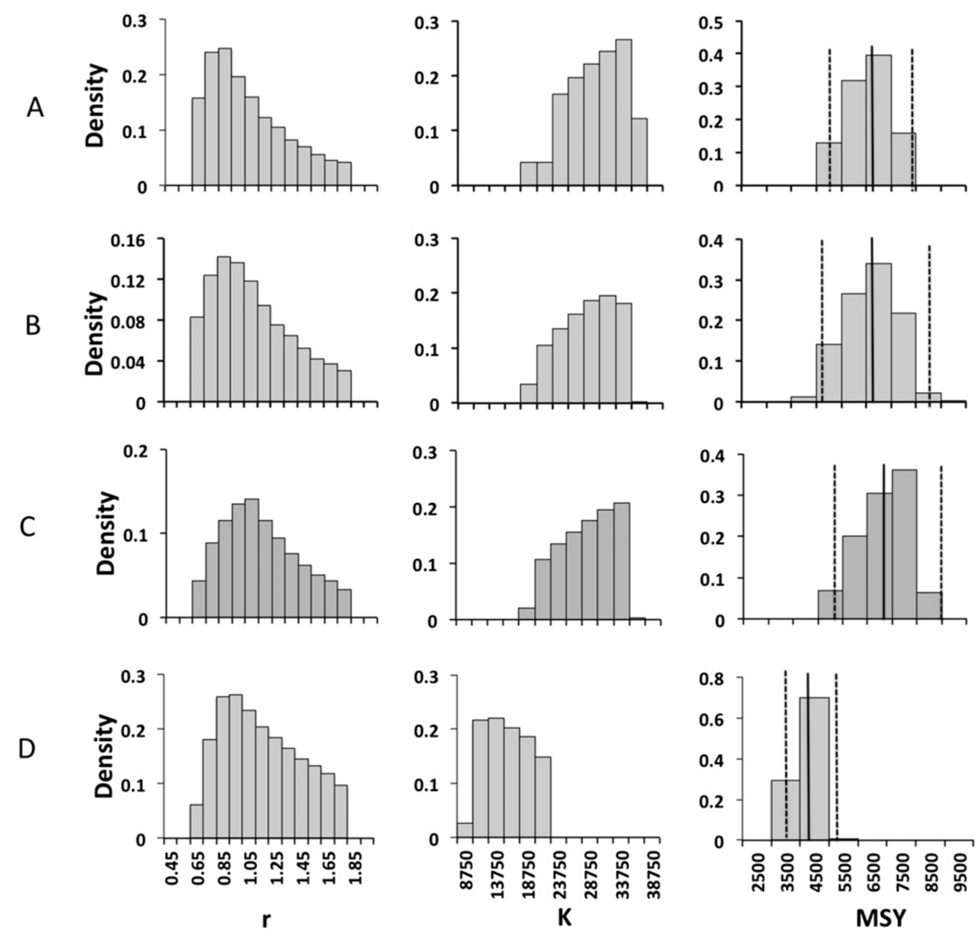


**Figure 2. (A–D) Posterior density of *r–k* pairs and maximum sustainable yield (MSY) for Sinaloa (A, B, C) and Sonora (D) crab stocks after using the catch-MSY method. (A) Outputs with an assumed depletion range of $\lambda_1 = 0.01$, $\lambda_2 = 0.5$, and $\sigma(v\ t) = 0$. (B) Same as view A, but $\sigma(v\ t) = 0.05$. (C) Outputs with an assumed depletion range of $\lambda_1 = 0.01$, $\lambda_2 = 0.7$, and $\sigma(v\ t) = 0$. (D) Outputs with an assumed depletion range of $\lambda_1 = 0.3$, $\lambda_2 = 0.7$, and $\sigma(v\ t) = 0$.**

**TABLE 1.**

**Summary of assumed parameters and outputs of the catch–maximum sustainable yield (MSY) method applied to the Sinaloa and Sonora crab stocks.**

| Crab stock | $\lambda_{01}$–$\lambda_{02}$ | $\lambda_1$–$\lambda_2$ | $\sigma(v\ t)$ | Second iterations | | Geometric mean (95% CI) of outputs using the catch-MSY method | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $r_1$ | $k_1$ | $r$ | $k$ | MSY | $B_{MSY}$ | $F_{MSY}$ |
| Sinaloa | 0.8–1.0 | 0.01–0.5 | 0 | 0.6–1.8 | 18,802–36,354 | 0.98 (0.57–1.71) | 28,436 (20,197–40,036) | 7,025 (5,505–8,965) | 14,218 (10,098–20,018) | 0.49 (0.28–0.86) |
| Sinaloa | 0.8–1.0 | 0.01–0.5 | 0.05 | 0.6–1.8 | 15,851–35,024 | 1.03 (0.59–1.78) | 27,629 (19,996–38,175) | 7,098 (5,259–9,579) | 13,814 (9,998–19,087) | 0.51 (0.30–0.89) |
| Sinaloa | 0.8–1.0 | 0.01–0.7 | 0 | 0.6–1.8 | 18,914–35,048 | 1.09 (0.65–1.81) | 27,922 (20,303–38,400) | 7,585 (5,795–9,928) | 13,961 (10,151–19,200) | 0.54 (0.33–0.91) |
| Sonora | 0.8–1.0 | 0.3–0.7 | 0 | 0.6–1.8 | 9,338–22,144 | 1.12 (0.66–1.89) | 15,231 (9,595–24,177) | 4,246 (3,517–5,126) | 7,615 (4,797–12,088) | 0.56 (0.33–0.95) |
| Santa María La Reforma | 0.5–0.9 | 0.3–0.7 | 0 | 0.6–1.9 | 3,602–7,105 | 1.11 (0.66–1.88) | 5,468 (3,848–7,769) | 1,528 (1,171–1,993) | 2,734 (1,924–3,884) | 0.56 (0.32–0.94) |

to less than $B_{MSY}$. In 2000 and 2001, catches exceeded MSY, and biomass decreased again to $B_{MSY}$, where it remained until 2011 with catches around MSY (Fig. 4).

Trends in biomass estimates were similar to the Sinaloa stock (Fig. 4). Beginning in 2006, biomass declined, with greater declines observed after 2008, when the catch exceeded $MSY$ estimates. However, biomass decreased to $B_{MSY}$, unlike the Sinaloa stock, which decreased to less than the estimated values of $B_{MSY}$.

## DISCUSSION

A key assumption of the catch-MSY approach, as explained here, is the ability to define a reasonable prior range for the parameters of the Schaefer model. In our case studies, prior values of $r$ were between 0.6 and 1.5, which are default values suggested by Martell and Froese (2012) for highly resilient species. Although no estimates of $r$ for *Callinectes bellicosus* or *Callinectes arcuatus* exist, some reported life history parameters, such as age at 50% maturity ($tm_{50\%}$) and growth rate ($K_{vb}$) from a von Bertalanffy model, are consistent with those of a resilient species. FishBase classifies highly resilient fishes as those with a $K_{vb}$ value greater than 0.3/y and $tm_{50\%}$ less than 1 y. This classification could also be applied to crabs. A $K_{vb}$ value greater than $0.5/y^1$ and $tm_{50\%}$ less than 1 y have been reported for *C. arcuatus* (Fischer & Wolff 2006, Hernández & Arreola-Lizárraga 2007, Ramos Cruz 2008) and *C. bellicosus* (Hernández & Arreola-Lizárraga 2007, Rodríguez-Domínguez et al. 2012a, Rodríguez-Domínguez et al. 2012b). Some $r$ values for a related species, *Callinectes sapidus*, were calculated as being between 0.60 and 0.91 (Murphy et al. 2007, Sutton & Wagner 2007).

Prior carrying capacity was set arbitrarily from maximum catches over the evaluated series to 100 times the maximum catch. This range ensures that the real carrying capacity could be found if catches were at MSY sometime during the period evaluated. Maximum potential could have been realized since 2006 for the Sinaloa stock and since 1996 for the Sonora stock, as evidenced by the decrease in catch per unit effort and reduction in individual mean size observed in the Sinaloa crab fishery.

Another key assumption was the stated range of depletion used to accept or reject the sets of $r$–$k$ pairs of parameters. The lower depletion limit defines the lower boundary of the resulting MSY distribution, and the upper depletion limit and the range of values for $k$ determine the upper bound of MSY. We assumed the default range of depletion values proposed by Martell and Froese (2012) based on the final catch/maximum catch rate. For the Sinaloa stock, the default range of depletion was from 0.01–0.5; however, a range of 0.01–0.7 was used to explore the effect of depletion on MSY estimates. The final range includes assumptions for actually depleted, full, and subfished crab fisheries. Outputs of MSY from models containing the maximum limits of depletion, prior and posterior ranges, and observation and process error, were not statistically significant, indicating that MSY estimates from the catch-MSY method are reliable. Martell and Froese (2012) found that MSY estimates from the catch-MSY method were comparable with MSY estimates from full stock assessment of 130 stocks of fishes.

Surplus production models (SPMs) are applied when there is insufficient information to evaluate more complex models

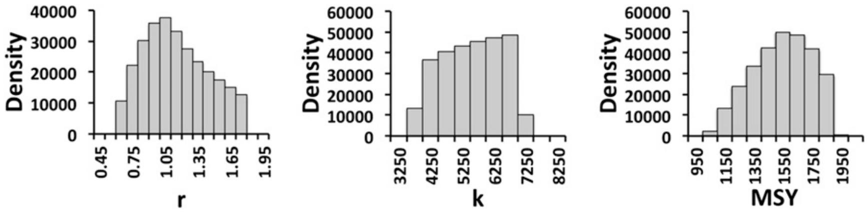


**Figure 3. The posterior density of *r–k* pairs and maximum sustainable yield (MSY) for the *Callinectes bellicosus* stock at Santa María La Reforma using the catch-MSY method.**

(Hilborn & Walters 2001). However, Miller et al. (2011) found that MSY estimates from SPMs applied to a crab fishery within Chesapeake Bay were comparable with those from a more complex, sex-specific catch multiple survey model. However, these authors observed that SPMs overestimated abundance reference points, whereas Martell and Froese (2012) found that the catch-MSY method overestimated carrying capacity and related biomass reference points for about 10% of stocks. Here, we could have overestimated stock biomass and $B_{MSY}$; however, because both values were compared for the evaluated status of the stocks, systematic biases were not deemed to be important.

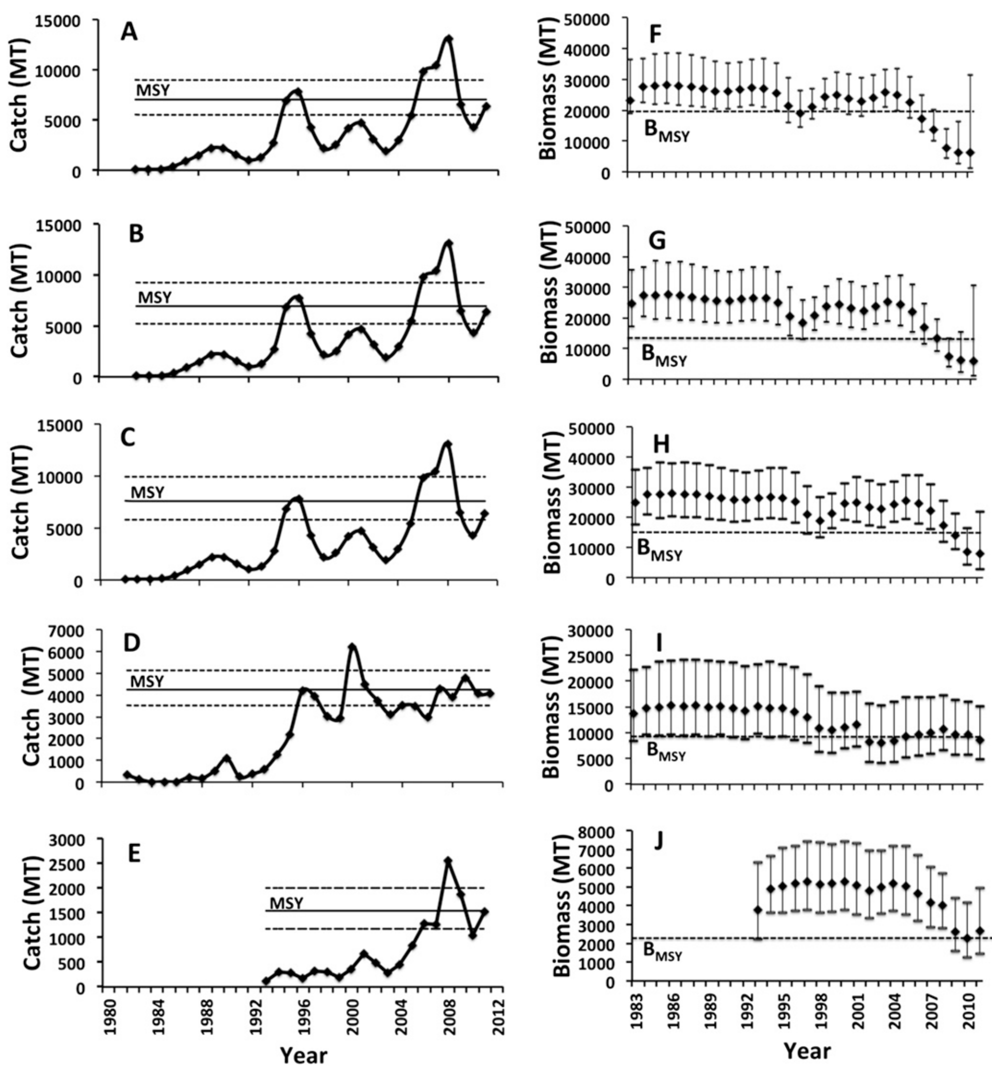


**Figure 4. (A–J) Catch–time series (measured in metric tons) with maximum sustainable yield (MSY) mean and 95% CIs (A–C), and biomass estimations with 95% CIs and line of $B_{MSY}$ overlaid (F–H) for Sinaloa crab stock using the catch-MSY method. (A, F) Outputs with an assumed depletion range of $\lambda_1 = 0.01$, $\lambda_2 = 0.5$, and $\sigma(v\ t) = 0$. (B, G) Same that views A and D, but $\sigma(v\ t) = 0.05$. (C, H) Outputs with an assumed depletion range of $\lambda_1 = 0.01$, $\lambda_2 = 0.7$, and $\sigma(v\ t) = 0$. (D, I) Outputs for Sonora crab stock. (E, J) Outputs for Santa María La Reforma crab stock. Depletion ranges assumed for Sonora and Santa Maria La Reforma were $\lambda_1 = 0.3$, $\lambda_2 = 0.7$, and $\sigma(v\ t) = 0$.**

A caveat of our study is that the catch data were aggregated for the 2 study species. However, MSY estimates from SPMs applied to aggregated data have been shown to have only minor deviations from the MSY estimates for individuals species within those aggregates (Mueter & Megrey 2006, Fogarty et al. 2012, Link et al. 2012). Our MSY estimates could be less than individual estimates of MSY for each species, and thus could lead to more precautionary management strategies. Martell and Froese (2012) recommend a lower limit of the 95% CI of MSY as the target for management. Thus, a catch quota of 5,500 t would be recommended for the fishery in Sinaloa; however, because the stock biomass is less than $B_{MSY}$, a smaller quota should be used until the stock is replenished. Precautionary catch quotas of 3,500 t and 1,171 t are recommended for the Sonoran stock and for BSMR, respectively. If the recommended catch quota for the Sinaloa stock is divided by zones based on how catches from the past 6 y contributed to the overall production of the state, a catch quota of 1,100 t would correspond to BSMR, similar to that obtained in the stock assessment for BSMR separately. Similar $r$ values and proportional (20%) $k$, MSY, and $B_{\mathrm{MSY}}$ estimates suggest that SPMs, such as the catch-MSY method, work well for subdivisions of stocks. Fluctuations in catches and $r$ values of Sonora and Sinaloa were similar, and crabs within these regions could be managed as 1 stock. Genetic analyses of these species revealed a high level of gene flow over a wide geographical area in the Gulf of California, including Sonora and Baja California (Pfeiler et al. 2005); however, a widely distributed subclade (clade II) embedded cryptically at low frequency in the main (clade I) population was also identified.

Maximum sustainable yield estimates by region, as presented here, are relevant to management, and trends in biomass suggest some differences between the Sinaloa and Sonora stocks. To prevent overexploitation, knowledge of population biology is fundamental. The contribution of our results tend to support the conservation of the species under study. It is important to recall that in organisms with a short life cycle that are subject to high fishing pressure, biological process that occurs in a particular year define the stock's abundance in the same years. Crabs of the Portunidae family from the Gulf of California comprise this principle. Since 1982, the brown crab *Callinectes bellicosus* has become the focus of an important commercial fishery in Mexico, especially in the eastern Gulf of California, where a small-scale fishery for these crabs has been established (Rodríguez-Domínguez et al. 2012a, Rodríguez-Domínguez et al. 2012b). The most effective strategy to reduce the risks of adverse economic and social effects in this fishery would be the continued gathering of biological study results such as from the surveys presented here, which provided an approximation to the $MSY$. Such calculations are derived because scientific knowledge of many aspects of the biology of *C. bellicosus* is limited. There are only two formal papers on growth. Rodríguez-Domínguez et al. (2012a) found the asymptotic carapace width of *C. bellicosus* to be 155.38 ± 5.19 mm in males by averaging the results of 4 models. The same method yielded an estimate of 125.53 ± 6.62 mm for females. The other study carried out, by Hernández and Arreola-Lizárraga (2007), reported the asymptotic carapace width of 169 mm from the Guasimas coastal lagoon in the central Gulf of California. It should be recognized that the growth study by Hernández and Arreola-Lizárraga (2007) combined data from males and females.

The other species under study, *Callinectes arcuatus*, has been the subject of three formal articles addressing the growth of Pacific coastal populations (Paul 1982, Fischer & Wolff 2006, Hernández & Arreola-Lizárraga 2007). In addition, two reports have furnished information on laboratory-reared animals (Dittel & Epifanio 1984, Vega-Villasante et al. 2007). In wild populations, Fischer and Wolff (2006) reported an asymptotic carapace width of 142 mm for males. Hernández and Arreola-Lizárraga (2007) reported an asymptotic carapace width of 140 mm for both sexes combined.

A central topic in fisheries ecology is the study of individual growth because it offers insights into the population dynamics of species. Such studies shed light on mortality rates and other parameters that are commonly used to conduct stock assessments. After the literature research, we support the use of the catch-MSY method proposed by Martell and Froese (2012) because of the scarcity of biological data for a strong biomass analysis.

All methods devoted to management of fisheries stocks have several shortcomings, and estimations of carrying capacity and stock biomass are costly; however, because the sustainability of fisheries is desired and data-poor stocks are common, a simple method such as the catch-MSY method proposed by Martell and Froese (2012) is useful for the management of crab fisheries in the Gulf of California.

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## LITERATURE CITED

Arreola-Lizárraga, J. A., L. G. Hernández-Moreno, S. Hernández-Vázquez, F. J. Flores-Verdugo, C. Lechuga-Devezé & A. Ortega-Rubio. 2003. Ecology of *Callinectes arcuatus* and *C. bellicosus* (Decapoda: Portunidae) in a coastal lagoon of Northwest Mexico. *Crustaceana* 76:651–664.

Dittel, A. I. & C. E. Epifanio. 1984. Growth and development of the portunid crab *Callinectes arcuatus* Ordway: zoeae, megalopae and juveniles. *J. Crustac. Biol.* 4:491–494.

Fischer, S. & M. Wolff. 2006. Fisheries assessment of *Callinectes arcuatus* (Brachyura, Portunidae) in the Gulf of Nicoya, Costa Rica. *Fish. Res.* 77:301–311.

Fogarty, M. J., W. J. Overholtz & J. S. Link. 2012. Aggregate surplus production models for demersal fishery resources of the Gulf of Maine. *Mar. Ecol. Prog. Ser.* 459:247–258.

Hernández, L. & J. A. Arreola-Lizárraga. 2007. Estructura de tallas y crecimiento de los cangrejos *Callinectes arcuatus* and *C. bellicosus* (Decapoda: Portunidae) en la laguna costera Las Guásimas, México. *Int. J. Trop. Biol.* 55:225–233.

Hilborn, R. & C. J. Walters. 2001. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Norwell, MA: Kluwer Academic Publishers. 570 pp.

Kennelly, S. J. & J. P. Scandol. 2002. Using a fishery-independent survey to assess the status of a spanner crab *Ranina ranina* fishery: univariate analyses and biomass modeling. *Crustaceana* 75:13–39.

Link J. S., S. Gaichas, T. J. Miller, T. Essington, A. Bundy, J. Boldt, K. F. Drinkwater & E. Moksness. 2012. Synthesizing lessons learned from comparing fisheries production in 13 northern hemisphere ecosystems: emergent fundamental features. *Mar. Ecol. Prog. Ser.* 459:293–302.

Martell, S. & R. Froese. 2012. A simple method for estimating MSY from catch and resilience. *Fish Fish.* DOI: 10.1111/j.1467-2979.2012.00485.x.

Miller, T. J., M. J. Wilberg, A. R. Colton, G. R. Davis, A. Sharov, R. N. Lipcius, G. M. Ralph, E. G. Johnson & A. G. Kaufman. 2011. Stock assessment of blue crab in Chesapeake Bay 2011, final assessment report. Technical report series no. TS-614-11. Solomons, MD: University of Maryland Center for Environmental Science. 203 pp.

Mueter, F. J. & B. A. Megrey. 2006. Using multi-species surplus production models to estimate ecosystem-level maximum sustainable yields. *Fish. Res.* 81:189–201.

Murphy, M. D., A. L. McMillen-Jackson & B. Mahmoudi. 2007. A stock assessment for blue crab, *Callinectes sapidus,* in Florida waters. Report to the Florida Fish and Wildlife Commission Division of Marine Fisheries Management. In-house report 2007-006. St. Petersburg, FL: Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute. 90 pp.

Paul, R. K. G. 1982. Observation on the ecology and distribution of swimming crabs of the genus *Callinectes* (Decapoda: Brachyura: Portunidae) in the Gulf of California, Mexico. *Crustaceana* 42:96–100.

Pfeiler, E., L. A. Hurtado, L. L. Knowles, J. Torre-Cosío, L. Bourillón-Moreno, J. F. Márquez-Farías & G. Montemayor-López. 2005. Population genetics of the swimming crab *Callinectes bellicosus* (Brachyura: Portunidae) from the eastern Pacific Ocean. *Mar. Biol.* 146:559–569.

Ramos Cruz S. 2008. Estructura y parámetros poblacionales de *Callinectes arcuatus* Ordway, 1863 (Decapoda: Portunidae), en el sistema lagunar La Joya-Buenavista, Chiapas, México: Julio a Diciembre de 2001. *Pan-American J. Aquat. Sci.* 3:259–268.

Rodríguez-Domínguez, G., S. Castillo-Vargas-Machuca, R. Pérez-González & E. A. Aragón-Noriega. 2012a. Estimation of the individual growth parameters of the brown crab *Callinectes bellicosus* (Brachyura, Portunidae) using a multi-model approach. *Crustaceana* 85:55–69.

Rodríguez-Domínguez, G., S. G. Castillo-Vargasmachuca, R. Pérez-González & E. A. Aragón-Noriega. 2012b. The size at maturity of the brown crab *Callinectes bellicosus* (Decapoda, Portunidae) in the Gulf of California. *Crustaceana* 85:1513–1523.

Siddeek, M. S. M., B. Sainte-Marie, J. Boitillier & G. Bishop. 2004. Comparison of reference point estimated using a side-based method for two high-latitude crab species in the United States and Canada. *Can. J. Fish. Aquat. Sci.* 61:1404–1430.

Sutton, G. & T. Wagner. 2007. Stock assessment of blue crab (Callinectes *sapidus*) in Texas coastal waters. Management data series no. 249. Austin, TX: Texas Parks and Wildlife. 53 pp.

Vega-Villasante, F., E. Cortés-Jacinto & M. García-Guerrero. 2007. Contribution to the knowledge of moulting and growth of *Callinectes arcuatus* Ordway, 1863 (Brachyura, Portunidae) in Baja California Sur, Mexico. *Crustaceana* 80:769–778.